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Spatial Modeling of Coastline Change for Two Decades (1994-2014) in Pangandaran, West Java - Indonesia

Syawaludin A. Harahap*, Isni Nurruhwati, Noir P. Purba, Mecha Gamma

Faculty of Fisheries and Marine Science, Universitas Padjadjaran,
Jalan Raya Bandung-Sumedang KM. 21, Jatinangor 45363, Indonesia

*E-mail address: syawaludin.alisyahbana@unpad.ac.id

ABSTRACT

Coastal areas are very vulnerable to various pressures, developments, and changes. In the last three decades, due to the process of abrasion and accretion, there have been changes in coastlines in various coastal areas in Indonesia. Coastal abrasion and accretion are major concerns in coastal management. Morphological changes have had a major impact on land use and the socio-economic development of communities in coastal areas. In connection with this issue, it is necessary to conduct a study that aims to determine the rate and location of coastline changes in Pangandaran Regency. Considering that Pangandaran Regency is one of the southern regions of Java which is directly facing the Indian Ocean it has high coastal dynamics. In addition, Pangandaran beach is a beach tourism destination that is quite well known and has the potential to be developed, but in some locations, there are indications of a significant decline in the coastline. In this study, Landsat satellite images in time series (1994-2014) were analyzed using remote sensing technology and GIS approaches. Analysis of coastline change was carried out using the DSAS program. The results of the study show that the coastline change in Pangandran is dominated by abrasion at a rate of about -2.5 to -0.1 meters/year. The rate of change of the Pangandaran coastline which experienced the highest abrasion was -4.7 meters/year and the lowest was -0.1 meters/year, while the highest accretion rate was 40.1 meters/year and the lowest was 0.1 meters/year. Maximum abrasion is located at Sukaresik village (Sidamulih Sub-district) at the mouth of the Karang Tirta River. The minimum abrasion is located at Pananjung village. Meanwhile, accretion occurred in several villages such as Pananjung Village, Wonoharjo Village (Pangandaran Sub-district), Balogo Village (Kalipucang Sub-district), Kerta Mukti Village (Cimerak Sub-district), and Cikambulan Village (Sidamulih Sub-district). Minimum accretion is located at Pananjung village and maximum accretion is located at Bagolo village near the estuary of Citanduy River.

***Keywords*:** Abrasion, accretion, coastal area, estuary, shoreline, sedimentation

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1. INTRODUCTION

Coastal areas face various pressures, developments, and changes. In the last three decades, coastal erosion and abrasion have led to the deterioration of coastline in various coastal areas in Indonesia [1]. Coastal erosion and sedimentation are the major concern in coastal management. Changes in morphology have caused a major impact on land use and socio-economic development in coastal areas [2]. The issue of land change in the coastal area has received enough attention from various stakeholders, one of which is related to coastline changes. The coastline may change at any time because it is very dynamic [3]. Coastline change also comes about due to the disruption of the coastal area and its ecosystems. Naturally, coastline changes can be caused by hydrodynamic aspects such as currents, waves, tides, wind, and sedimentation [4–7].

Changes in the coastline are also strongly influenced by human activities, for example, the burden of developing residential areas, industrial areas, and all supporting facilities and infrastructure [8–10]. They are coming under increased pressure from land reclamation, anthropogenic impact, climate change, and sea-level rises [11–13] such as buildings and the manufacture of embankments and canals that are located around the beach. The problem in planning the coastal environment is to determine the pattern of changes in the coastline that have occurred or will occur in a certain period. By knowing the patterns that occur, coastal environment development planning can succeed optimally [14].

Pangandaran, which is part of the southern coastal area of West Java Province which is directly opposite the Indian Ocean has the potential to experience changes in coastline due to the considerable hydrodynamic energy hitting the coast. In addition, the Pangandaran coast is one of the most popular tourist attractions for local and foreign tourists because it is known to have beautiful beaches and is commonly used for water recreation activities. From 2013 to 2014 such as on the west coast and Batukaras coast, there were indications of a significant decline in the coastline. This is certainly very worrying considering that the area is a location that has a lot of tourist activities. According to [15], the consequence of the continued growth of development activities, population growth, urbanization, and a movement towards the coast especially. If these activities are not well ordered, then, of course, it will reduce the carrying capacity and also increase vulnerability in the coastal areas [16].

Besides, this area is very wide and many are in remote areas. So doing so requires an effective, efficient approach and acceptable accuracy. Researchers and experts have tried a variety of approaches to study the dynamics of change that occur in coastal areas both by modeling and direct observation. However, with this approach, it is felt that it is still lacking to conduct monitoring quickly and in real-time while still considering a high level of accuracy. Coastline change is a phenomenon that occurs through natural processes in coastal areas that can be recognized from remote sensing data image processing analysis. One of the remote sensing data that can be used to see this phenomenon is data from satellites. With this data, mapping, inventory, monitoring, and evaluation of environmental damage can be carried out quickly to assist in the prevention, management, and future planning of the coastal area [17].

Although the coast of Pangandaran Regency is dominated by a low level of vulnerability, which is equal to 50.02% [18], however, information on coastline change by time-series trend constitutes an essential and vital input in any coastal management plan so that areas of potential loss to erosion can be identified and appropriate land use planning adopted [19, 20]. Unfortunately, in Pangandaran, such information about coastline change is lacking and, where present, often of doubtful reliability. Based on the reasons that have been explained, it is necessary to do a study to know the rate and location of coastline change in Pangandaran. The result of this study is expected to provide valuable information on the latest conditions of coastal areas in Pangandaran. It can be used as a basis for land use management and future mitigation of the coastal areas [21, 32-53].

2. MATERIALS AND METHODS

2. 1. Scope of the study area

The study area covers the coast of Pangandaran along the coastline that extends outward from east to west with a coastline length of approximately ± 91.09 km. Administratively, Pangandaran is part of West Java Province which consists of ten Sub-districts namely Kalipucang, Pangandaran, Sidamulih, Parigi, Cijulang, Cimerak. These five Sub-districts are areas that have a coastline and are directly facing the Indian Ocean.

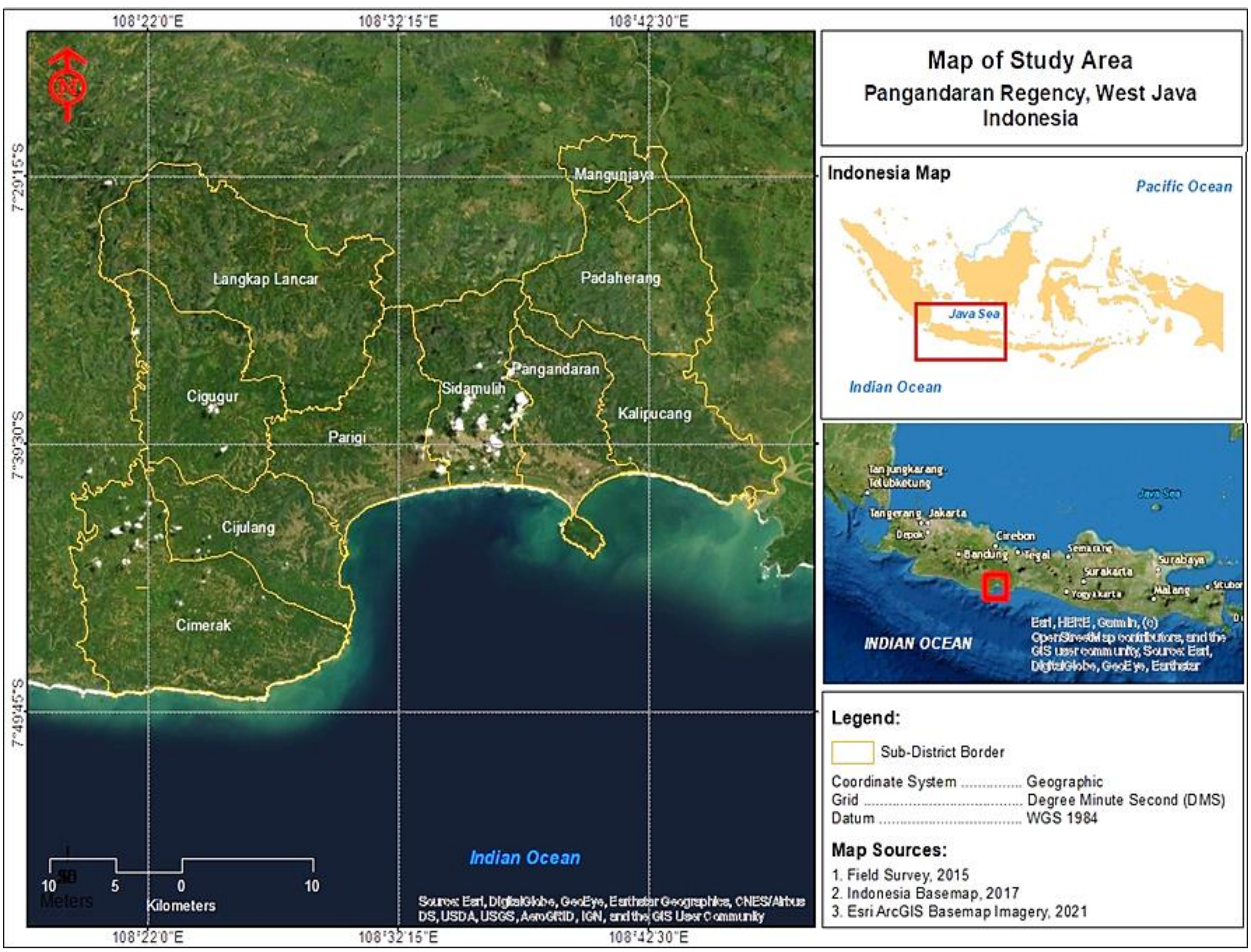


Figure 1. Map of the study area in the Pangandaran Regency, West Java, Indonesia

Next up are the Cigugur, Langkaplancar, Mangunjaya, and Padaherang Sub-districts (can be seen in **Figure 1**.) Geographically, Pangandaran is in the coordinates of 108°8'0" - 108°50'0" East and 7°24'0" - 7°54'20" South with administrative boundaries as follows: (1) Northern, bordering with Ciamis and Tasikmalaya Regency; (2) southern, bordering the Indian Ocean; (3) Western, bordering Tasikmalaya Regency; and (4) Eastern side, bordering Cilacap Regency, Central Java Province.

2. 2. Tools

The tools used in conducting this research consist of several hardware and software devices, for the name of the tool, the specifications of the tool, and the usefulness of the tool used in this study can be seen in **Table 1**.

Table 1. Research equipment for data processing, data analysis, and performing ground checks.

No.	Hardware & Software	Specification	Utilities
1.	Personal Computer (PC)	Intel Core i3, 4 GB RAM with VGA 2 GB with OS Windows 7 or 10	Data processing and reports
2.	GPS	Garmin 60csx	Marking and tracking the coordinates of the field survey location.
4.	ArcGIS	ArcGIS 10.4	Digitizing coastlines, geomorphological maps, and visualizing maps.
5.	Digital Shoreline Analysis System (DSAS)	DSAS 5.0	Processing & Analysis of coastline changes using Net Shoreline Movement (NSM) & End Point Rate (EPR).

2. 3. Data

In this study, the configuration of changes in coastline was determined using imagery data of Landsat TM/ETM+ satellite by downloading from the USGS Data Center (http://earthexplorer.usgs.gov/). There are 20 imageries data collected for the path 121/row 65 have 30 meters spatial resolution that is cloud-free in the Pangandaran study area during the period from 1994 to 2014.

Figure 2 is a cross-section of Landsat imagery that has been downloaded to represent 1994 image data that is free of clouds in the study area.

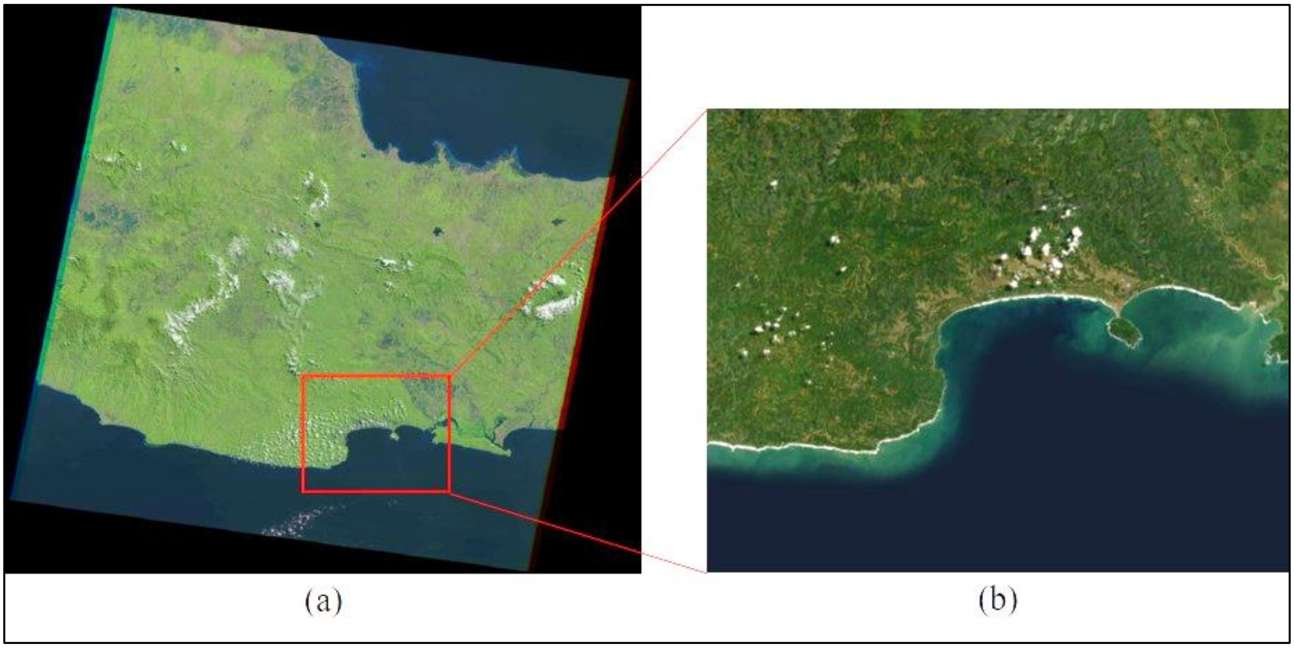


Figure 2. The sample of display of Landsat TM imagery year 1994 path 121/row 65, (a) with inset red box as the scope of the study area and (b) subset/cropping of the study area.

2. 4. Data Processing

After determining the study area, equipment and data used, then to implement this study, the steps in processing and further data analysis were arranged. In connection with this study, the implementation of the study consists of three stages, namely data collection, data processing, and analysis. Briefly, this stage can be seen in the following **Figure 3**.

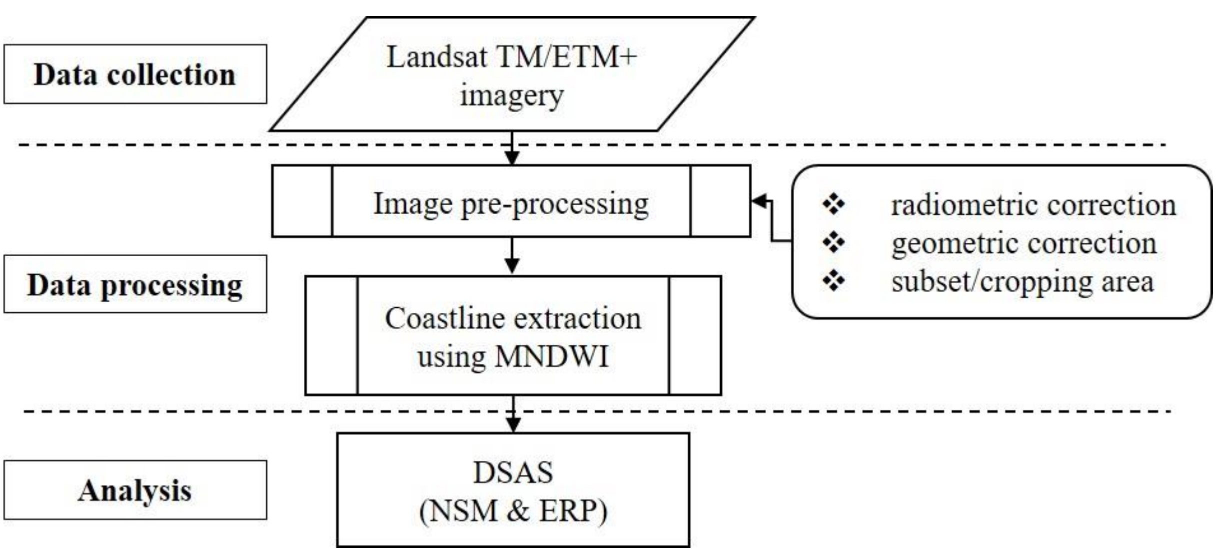


Figure 3. Diagram Alir Pengolahan Data

Specifically related to satellite image data, sometimes corrections must be made to the quality of the satellite imagery that has been collected. This correction consists of radiometric and geometric corrections. Radiometric correction is a process to eliminate noise that occurs due to atmospheric influences or due to systematic image recording. Meanwhile, geometric correction aims to improve the position or location of the object so that its coordinates are by geographic coordinates (actual position on the earth's surface).

After the image correction process is carried out, then image cropping is performed. Image cropping is done to reduce areas that are not studied so that the area to be studied is clearer and the analysis process can be faster. The next step is to carry out coastline extraction, where the processing uses the MNDWI (Modification of Normalized Difference Water Index) method [22]. The MNDWI can delineate water bodies and can find the area of individual water bodies, and finally convert the reclassified image into a vector format.

2. 5. Analysis

The data was analyzed using the observation method with comparative descriptive analysis. The observation was done with a remote sensing approach. Many studies detect coastline changes using satellite imagery that have been conducted previously e.g [23, 24]. The implementation of calculations for coastline changes is based on the distance between the coastline vectors in each year so that the total movement of the coastline is known. This calculation uses transects as a reference for coastline changes (**Figure 4**). In this study, each transect is spaced 30 meters apart, adjusting to the spatial resolution of the image data with the assumption that one transect will represent each pixel of the Landsat image. This measurement uses a geographic information system (GIS) approach using the digital shoreline analysis system (DSAS) program based on the NSM (net shoreline movements) method and also the EPR (end point rate) method [25].

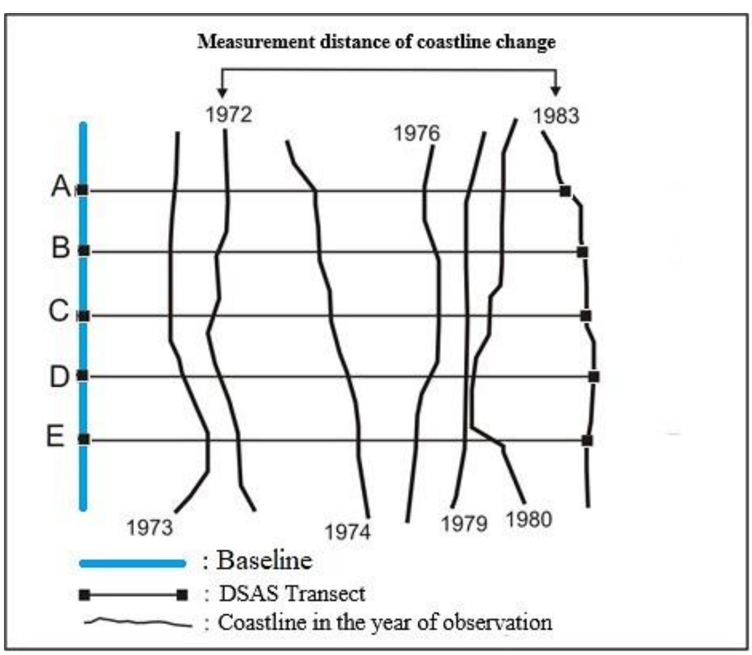


Figure 4. Illustration of calculating coastline changes using DSAS (modified from [26])

NSM is a statistical method used to measure coastlines in the DSAS program by linking two coastlines based on the oldest time with the newest time. Transects for observations were selected that showed changes in coastlines that were farthest (maximum transect) and closest (minimum transect). Meanwhile, EPR is a statistical method that is also part of the DSAS program. It is useful for observing the rate of change by dividing the coastline movement that occurs by the time distance from the coastline of the oldest year to the coastline of the latest year. The equations of NSM and EPR can be seen respectively in **Equation 1** and **Equation 2**.

$$\boldsymbol{NSM = the\ former\ coastline - the\ new\ coastline}$$ .... **Equation 1**

$$\boldsymbol{EPR = \frac{the\ former\ coastline - the\ new\ coastline}{time\ interval\ (year)}}$$ .... **Equation 2**

3. RESULTS AND DISCUSSION

3. 1. Rate of coastline change

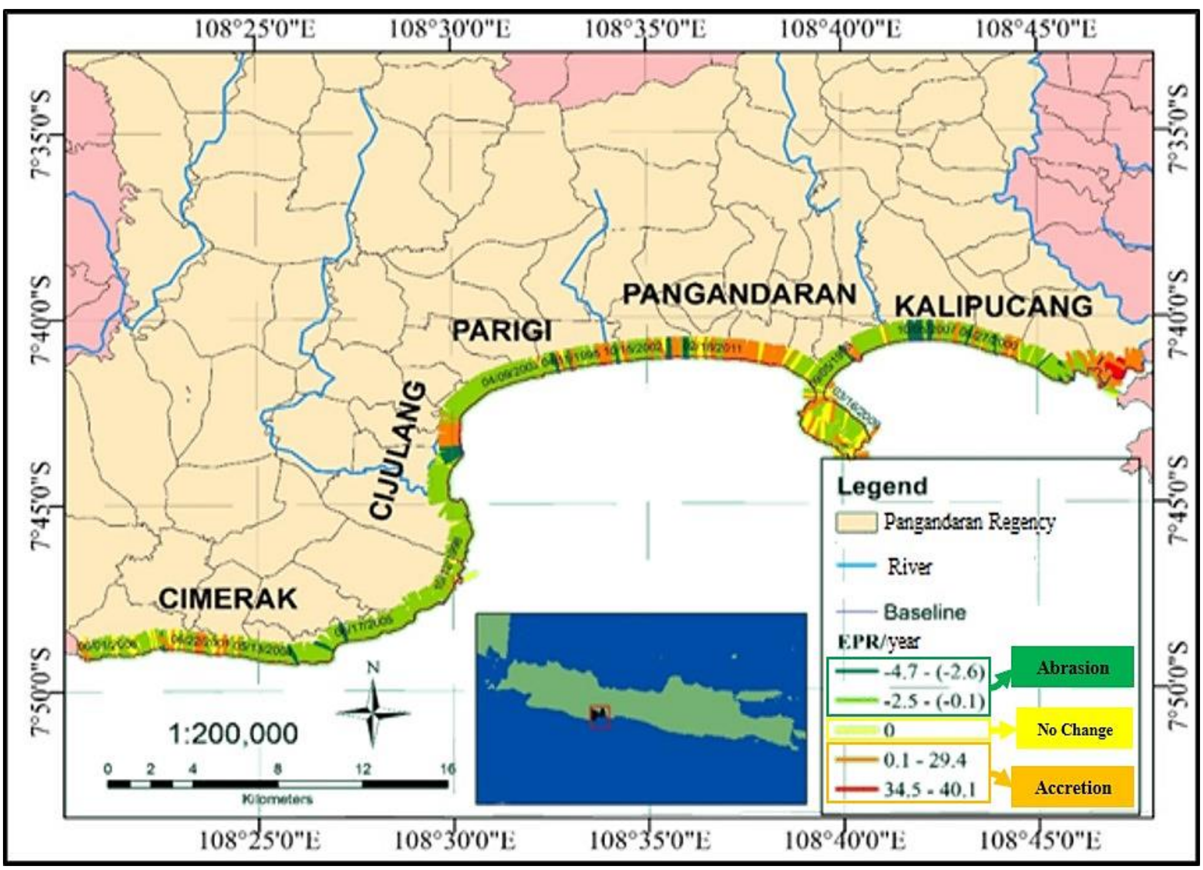


Figure 5. Reta of coastline change in Pangandaran Regency.

The results of DSAS processing using NSM show that there are significant changes in the coastline in Pangandaran Regency, these changes are due to accretion and abrasion.

The changes that have occurred can be seen in **Figure 5**, by depicting the rate of change of coastline per year from 1994 to 2014. A negative EPR value indicates a coastline decline (abrasion) and a positive EPR value indicates coastline progress (accretion). The rate of change of the Pangandaran coastline which experienced the highest abrasion was -4.7 meters/year and the lowest was -0.1 meters/year, while the rate of change of the Pangandaran coastline which experienced the highest accretion was 40.1 meters/year and the lowest was 0.1 meters/year.

The coastline change di Pangandaran is dominated by abrasion at a rate of about -2.5 to -0.1 meters/year. In contrast to the northern region of Java, where the coastline changes that occur are more dominated by the accretion process (sedimentation), as an example has been studied by [27, 28]. The results showed that the dynamics of the Pangandaran coastline are strongly influenced by the hydro-oceanographic and coastal morphology aspects. The coastline of an area is always changing due to the movement of seawater towards the coast or leaving the coast. The shape of the change is in the form of a forward and backward coastline. The results of the analysis and imaging process from Landsat satellite data show that the Pangandaran coastline between 1994 and 2014 experienced a significant shift in the coastline in several places.

In general, the coastline that is advancing or retreating in Pangandaran can be indicated as a result of abrasion and accretion processes, so that the coastline becomes forward or backward from the old coastline. Abrasion and accretion that has occurred on the coast lately tend to increase in various regions [11]. Abrasion and accretion are indicators of changes in coastline and have become one of the important problems in coastal areas.

3. 2. Coastline abrasion

The change in the coastline of Pangandaran Regency is dominated by the occurrence of abrasion which is indicated by **Figure 6**. The dominance of abrasion on the coast of Pangandaran Regency occurs because of the type of beach owned by Pangandaran Regency. The type of beach found in Pangandaran Regency is dominated by sandy beaches with fine to very fine sand which is commonly called sand dunes. [29]. This type of beach is more prone to abrasion because it is easily eroded by natural factors such as waves, currents, tides, and wind.

In **Figure 7** it can be seen the locations where the abrasion process occurs, both maximum and minimum abrasion. Maximum abrasion occurred in Sukaresik Village, Sidamulih Sub-district. This area experienced a coastline decline of about 98.65 m from 1994 to 2014. This location is the estuary of the Karang Tirta River. The decline of the coastline in this area is caused by changes in the shape of the estuary so that there is a decline in the coastline. Significant changes in the shape of the estuary occurred at the transect A location when compared to the position of the coastline in the early years from 1994 to the end of the coastline in 2014. Changes in the shape of the estuary occurred four times, namely in 1996, 2001, 2003, and the last in 2005 when viewed from the results of processing Landsat satellite imagery.

The abrasion process occurs due to ocean currents and ocean waves that continuously hit the coastline. According to [30], abrasion caused by seawater in West Java Province is the most serious. Coastal abrasion by seawater can cause a reduction in land area. To prevent abrasion, prevention efforts need to be carried out, for example through reforestation programs in coastal areas, by planting coastal vegetation, and reducing upstream land use to reduce land clearing. This needs to be done considering the results of research showing that from 1999 to 2013, the condition of coastal forests along the Pangandaran coast experienced a drastic reduction of approximately 40% [29].

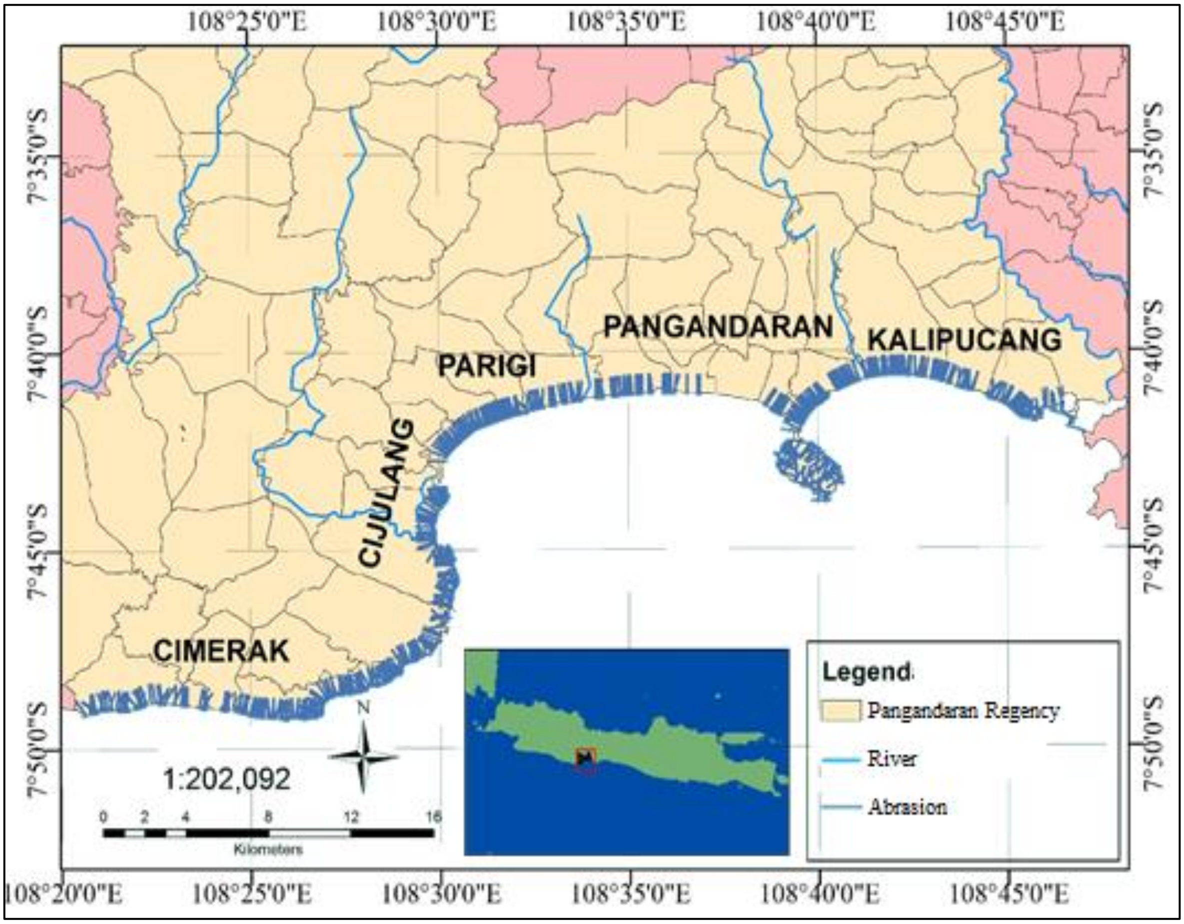
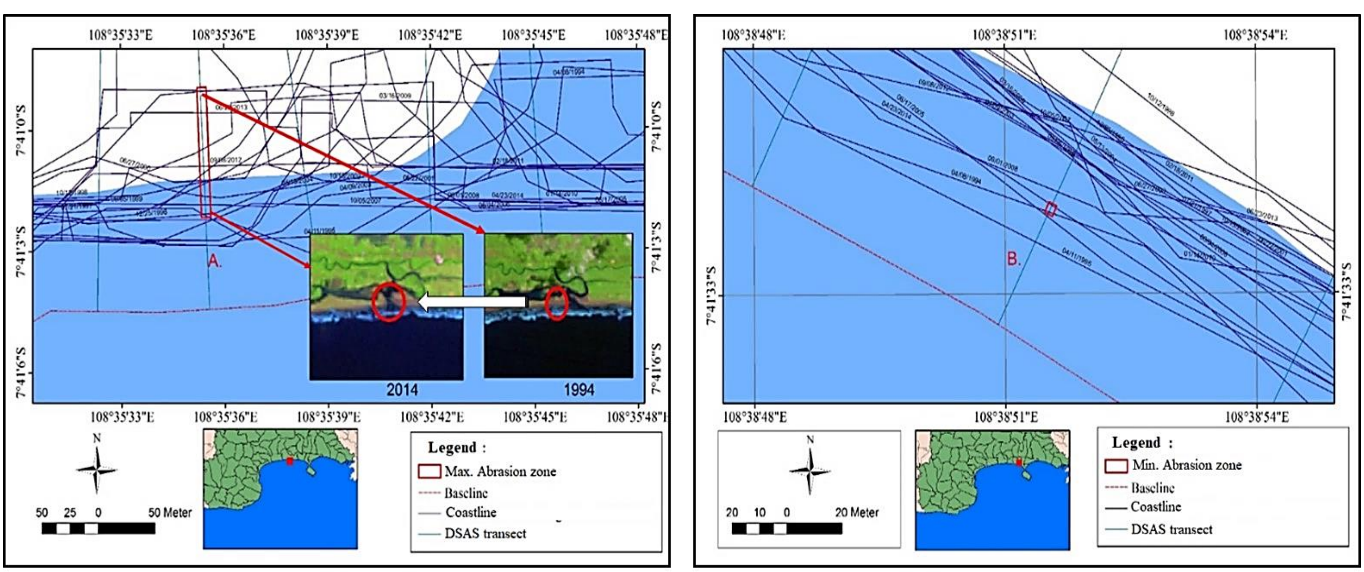


Figure 6. Coastline change by abrasion.



(a) Transect (A) max. abrasion

(b) Transect (B) min. abrasion

Figure 7. The samples of abrasion location, (a) Maximum abrasion located at Sukaresik village with the estuary of the Karang Tirta River; and (b) Minimum abrasion located at Pananjung village.

3. 3. Coastline accretion

Accretion of coastline changes can be seen in **Figure 8**. Accretion on the coastline of Pangandaran Regency only occurs in a few villages such as Pananjung Village, Wonoharjo Village (Pangandaran Sub-district), Balogo Village (Kalipucang Sub-district), Kerta Mukti Village (Cimerak Sub-district), and Cikambulan Village (Sidamulih Sub-district). Accretion is caused by the accumulation of sediment originating from land that is deposited on the coast, especially through river mouths. In **Figure 9**, the location of the minimum and maximum accretion events can be seen. Minimum accretion occurs on the west coast of Pangandaran, which is located in Pananjung Village, Pangandaran Sub-district. This area progressed about 2.28 m from 1994 to 2014.

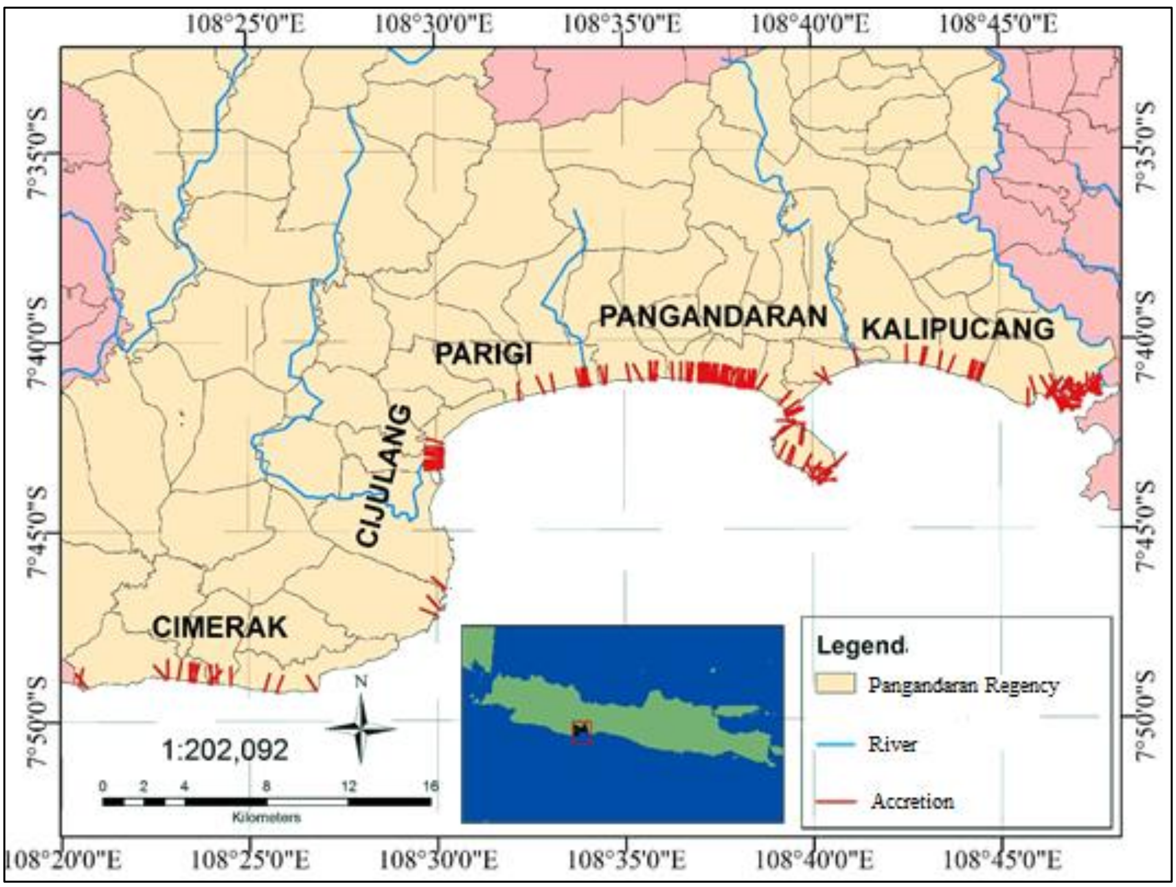
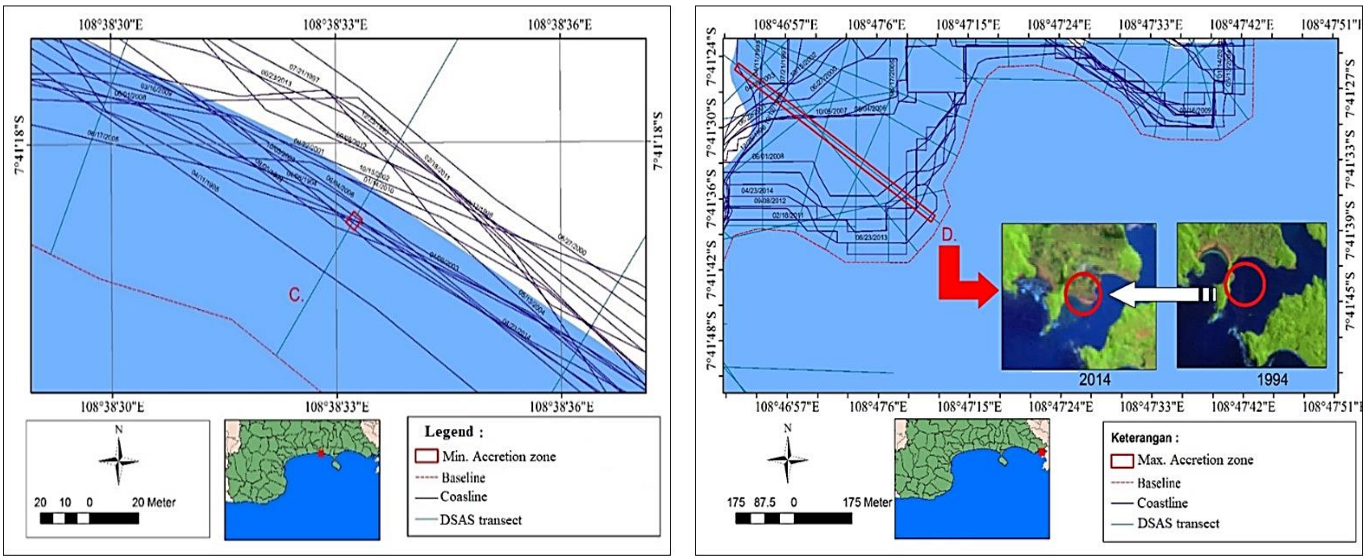


Figure 8. Coastline changes by accretion

Meanwhile, the maximum accretion occurred in Bagolo Village, Kalipucang Sub-district as indicated by transect D. At this location, the coastline progressed by about 842.31 m from 1994 to 2014. This area is known as the Palatar Agung. The Palatar Agung area was previously covered by seawater and underwent a process of sedimentation that occurred for years from mud deposits carried by the Citanduy river, then carried by sea and settled to form land. The appearance of land as a result of sedimentation carried by the Citanduy river flow that occurred in this area began in 2000 and the sediment in the area continues to expand towards the sea as the years increase until 2014. Accretion is usually caused by the presence of rivers that empties into the sea. around the beach. Water from watersheds carries onshore sediments and is deposited in coastal areas [31].



(a) Transect (C) min. accretion

(b) Transect (D) max. accretion

Figure 9. The samples of accretion location, (a) Minimum accretion located at Pananjung village; and (b) Maximum accretion located at Bagolo village near to the estuary of Citandui River.

4. CONCLUSIONS

Changes in the coastline for two decades between 1994 and 2014 in Pangandaran have been identified using Landsat satellite imagery. The results of the study show that the coastline change in Pangandran is dominated by abrasion at a rate of about -2.5 to -0.1 meters/year. The rate of change of the Pangandaran coastline which experienced the highest abrasion was -4.7 meters/year and the lowest was -0.1 meters/year, while the highest accretion rate was 40.1 meters/year and the lowest was 0.1 meters/year.

Maximum abrasion located at Sukaresik village (Sidamulih Sub-district) with the estuary of the Karang Tirta River coastline retreat of about 98.65 m and significant changes occurred in 1996, 2001, 2003, and 2005. The minimum abrasion is located at Pananjung village with a coastline retreat of about 2.44 meters. Meanwhile, accretion occurred in several villages such as Pananjung Village, Wonoharjo Village (Pangandaran Sub-district), Balogo Village (Kalipucang Sub-district), Kerta Mukti Village (Cimerak Sub-district), and Cikambulan Village (Sidamulih Sub-district). Minimum accretion located at Pananjung village with coastline move onward about 2.28 m and Maximum accretion located at Bagolo village near to the estuary of Citanduy River with coastline move onward about 842.31 m.

The results of the study reveal that natural factors have played an important role in changing the coastline in Pangandaran during the two decades. However, a series of other factors that drive coastline changes certainly contribute. For this reason, it is necessary to carry out a more detailed field investigation and a simulation approach is also needed to determine the right and dominant driving variable. This study can certainly provide basic information for coastal management and ecological conservation along the coastline and can also provide some efficient guidelines for future studies in assessing the dynamic mechanism of coastal change that occurs on the southern coast of Java, especially Pangandaran Regency.

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