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Monitoring Total Suspended Solid Concentration and Shoreline Dynamics Using Sentinel-2 Imagery in 2015-2021

Lia Novianti Ni'amah[1], Nurhadi Bashit[1], LM Sabri[1], Abdi Sukmono[1], Farouki Dinda Rassarandi[2]

[1]*Department of Geodetic Engineering, Diponegoro University, Jl. Prof Sudarto, SH, Tembalang, Semarang, Indonesia*
[2]*Department of Informatics Engineering – Politeknik Negeri Batam, Jl. Ahmad Yani, Tlk. Tering, Kec. Batam Kota, Kota Batam, Kepulauan Riau 29461*

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Corresponding author:
Nurhadi Bashit
Email:
nurhadi.bashit@live.undip.ac.id

ABSTRACT

Human activities in the Juwana Estuary impact increasing sedimentation, including industry, fish processing, ponds, and settlements. Increased sedimentation every year can lead to the formation of new land. In the long term, sedimentation will impact shoreline changes due to the formation of new land. This study aims to determine changes in Total Suspended Solid (TSS) concentration and shoreline values in the Juwana River Estuary. Increased sedimentation can be indicated based on water turbidity and TSS values—an effective method for observing TSS and coastline using remote sensing. The data for this study uses Sentinel-2 imagery. The TSS processing algorithm uses Laili, Liu, and C2RCC. TSS results using the C2RCC algorithm show the best regression results between image TSS and in situ TSS with an R^2 of 0.721 compared to other algorithms. In 2015-2018 the average TSS value decreased by 2.303 mg/l. Processing results show the largest TSS reduction value of 12.466 mg/l on the Juwana Coast. The TSS value in 2018-2021 shows an average decrease of 4.447 mg/l; the largest decrease, with a value of 19.3 mg/l, is in the Batangan Coast. The coastline is extracted from image data using the Normalized Difference Water Index (NDWI) algorithm. In 2015-2018 changes in the coastline were dominated by abrasion, covering an area of 35.2348 ha with a maximum distance of 143.78 m. In 2018-2021 changes in the coastline were dominated by abrasion, covering an area of 10.28224 ha with a maximum distance of 53.23 m. It can be interpreted that a decrease in TSS indicates a decrease in sedimentation, causing increased abrasion around the coastline.

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1. INTRODUCTION

River estuaries have an important role as shipping lanes connecting rivers and seas which are areas of water bodies where seawater and river water merge (Purnawan et al., 2012). The accumulation of natural processes and human activities causes the sedimentation process to change the coastline (Paena, 2008). The estuary of the Juwana River is one of the river mouths where there are various human activities. The Juwana River estuary is used by residents through ponds, settlements, fish processing industries, shipping lanes, and fishing activities (Indriananingrum et al., 2016). This land use has high economic value but affects the aquatic environment because of the area's high activity. Periodic observations are important for observing environmental problems in the waters of the Juwana Estuary.

The waters of the Juwana River have problems regarding sedimentation (Tantiyana & Khakhim, 2016). This problem will certainly have an impact on the estuary area of the river. High sedimentation can form new land at river mouths in the long term (accretion) (Mulerli, 2007). One indication of sedimentation can be seen from the Total Suspended Solid (henceforth called TSS) water turbidity. Turbidity and TSS are interrelated parameters indicating sedimentation (Shodiqin, 2016). The TSS value will be directly proportional to the increase in the sedimentation rate because it is affected by ocean currents (Roswaty et al., 2014). Increasing sedimentation rates can have the effect of adding land to the coastline. Therefore, it is necessary to monitor changes in TSS which can result in changes to the coastline. Remote sensing techniques can be used to monitor changes in the beach profile due to sedimentation in the Saddang River estuary so that it can be concluded that the beach profile continues to change following the sedimentation rate (Paena, 2008).

TSS monitoring and shoreline changes can be carried out using remote sensing methods because this method is considered effective in terms of time, cost, and coverage of the observation area using satellite imagery (Alikas & Kratzer, 2017). Sentinel-2 data can be utilized for TSS modeling using channel 7 (Visible and Near Infrared/VNIR) (Liu et al., 2017). TSS value on the East Coast of Surabaya using Landsat 8 image data with the Laili algorithm obtains a correlation coefficient of 82.6%, so the relationship between the image TSS value and In-Situ data is very strong (Hariyanto et al., 2018). Therefore, this study aims to determine changes in TSS concentration and shoreline values in the Juwana River Estuary. The data in this study used sentinel-2 imagery, tidal data from Tuban Station, DEMNAS, and TSS in-situ data. This study uses the Laili, Liu, and C2RCC algorithms. Determination of the coastline based on satellite imagery extraction uses a combination of green channels and Near Infrared (NIR) if the beach conditions are muddy and vegetated, while if the beaches are sandy and rocky, use a combination of green channels and Shortwave Infrared (SWIR) (Winarso, 2001). The Juwana River estuary is a muddy beach with mangrove forests (Prahesti et al., 2020).

Analysis of shoreline changes was carried out to determine abrasion and accretion at the mouth of the Juwana River due to sedimentation. Sentinel-2 image acquisition time adjusts the availability of tide data so that the satellite image recording time is the same as the tide data time. It aims to be able to know the shoreline changes accurately. This study aims to provide an overview of changes in the coastline at Muara Juwana and changes in TSS values so that it can be seen whether there is an increase in sedimentation along the coast.

2. METHOD

2.1. Study Location

The estuary of the Juwana River is located along the coast of Juwana District and Batangan District, Pati Regency. This study is located at 6°38'47"S to 6°40'28" S and 111°09'40"E to 111°12'24" E with a coastline length of 12.2 km which can be seen in Figure 1.

2.2. Data

This study uses Sentinel-2A Level 1C imagery data in 2015, 2018, and 2021, tidal data at the Tuban station in 2015, 2018, and 2021 and DEM Nasional (DEMNAS) data on sheet number 1509-13. This study determines the time of image acquisition, and the tides are determined based on data availability. In-situ TSS data is secondary data from Astuti (2018), as many as 30 points with the acquisition of May 4 and June 2, 2018.

2.3. Total Suspended Solid Algorithm

2.3.1. Laili's Algorithm

TSS concentration estimation uses Sentinel-2 data by applying the algorithm from Laili et al. (2015) at the mouth of the Porong River and the Java Sea with better results than Landsat-8 because it has higher spatial resolution and high visit time (Bioresita et al., 2018). Laili modeled the TSS algorithm using Landsat 8 imagery data and in situ data from TSS in 2015. The research was conducted in Poteran Island waters, Sumenep district. The in situ data used comes from nine stations with the same acquisition as the image data on April 22, 2015, and is then modeled to obtain a coefficient of determination of 0.709 (Laili et al., 2015). The following is the 2015 Laili's Algorithm in Equation 1.

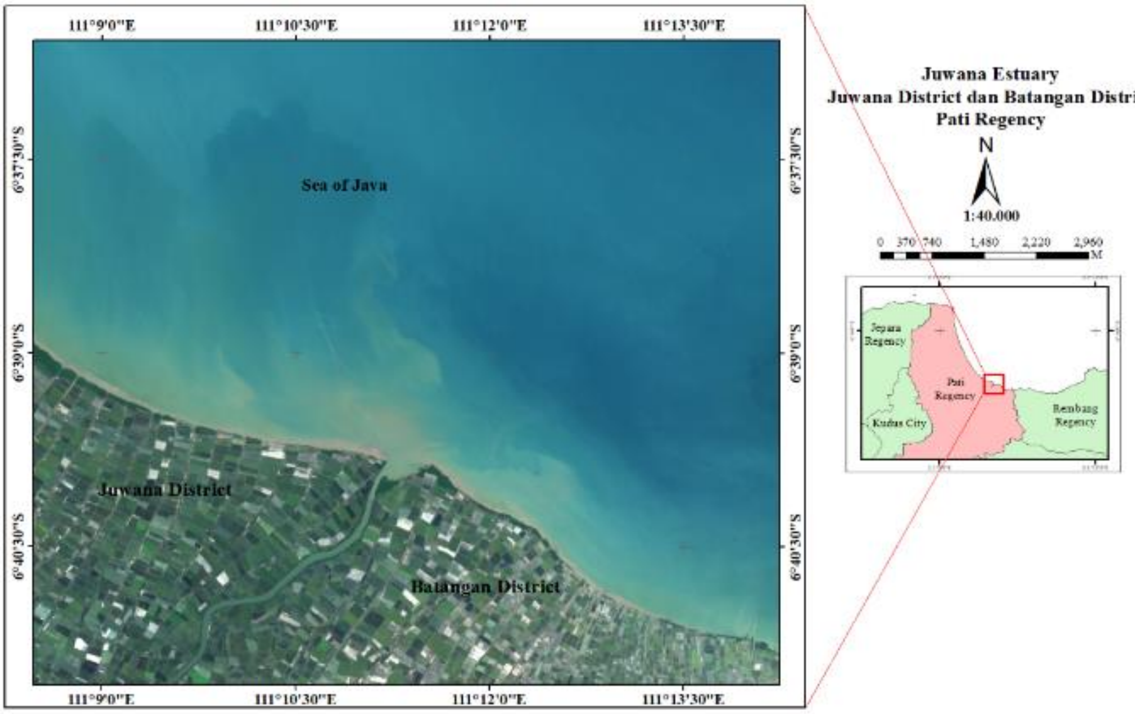


Figure 1. Research location

$$\text{TSS}\left(\frac{\text{mg}}{\text{L}}\right) = 31{,}420 \times \left(\frac{\log \lambda 2}{\log \lambda 4}\right) - 12{,}71 \quad (1)$$

where: $\boldsymbol{\lambda}2$ is reflectance band 2; $\boldsymbol{\lambda}4$ is reflectance band 4.

2.3.2. Liu's Algorithm

Huizeng Liu's TSS research 2017 modeled the TSS using Sentinel-2 Imagery data located at Lake Poyang (Liu et al., 2017). This study models nine algorithms from bands 1 to 8a. The modeling results show that band 7 (Visible and Near Infrared/VNIR) has the highest value compared to the other bands, with a coefficient of determination of 0.93 (Liu et al., 2017). The following is Liu's Algorithm in 2017 in Equation 2.

$$\text{TSS}\left(\frac{\text{mg}}{\text{L}}\right) = 2950 \times \lambda 7^{1{,}357} \quad (2)$$

where: $\boldsymbol{\lambda}7$ is reflectance band 7

2.3.3. C2RCC Algorithm

The Case 2 Regional Coast Color (C2RCC) is an AC processor made available through ESA's Sentinel Toolbox Sentinel Application Platform (SNAP) (Neves et al., 2021). C2RCC is a Neural Network (NNT) based correction algorithm created by Doerffer and Schiller. C2RCC uses a large radiative transfer simulation database of reflected water radiance (water signals) and top-of-atmosphere radiance (satellite signals) in imagery. C2RCC is a good algorithm for Case 2 waters, and special neural nets, such as C2X-Nets, are trained for extreme IOP ranges (Brockmann et al., 2016). The following is the C2RCC Algorithm in Equation 3.

$$\text{TSS}\left(\frac{\text{mg}}{\text{L}}\right) = \text{btot}_{\text{annl}} \times 1{,}7 \quad (3)$$

where: $\text{btot}_{\text{annl}}$ is scattering by band 8 particles

2.4. Shoreline

Law of the Republic of Indonesia No. 4 of 2011 concerning Geospatial Information states that the Indonesian Coastal Environment Map and the National Marine Environment Map determine the coastline based on the Lowest Low Water Level (LLWL) position line. The shoreline has changed due to natural conditions, such as increased sedimentation (Darmiati et al., 2020).

Shoreline changes can occur due to various natural processes on the coast, including sediment dynamics, coastal currents, sea wave movements, and continuous land use (Darmiati et al., 2020). The shape of the shoreline change can be characterized by abrasion or accretion. Abrasion is the process of eroding the coast, which usually follows an avalanche (collapse) of massive material, causing the position of the coastline to retreat from its original position (towards the land) (Istijono, 2013). Meanwhile, coastal accretion is the addition of land due to sedimentation around the coast so that the coastline shifts to the sea.

2.5. Shoreline Extraction

Water bodies can be detected on satellite imagery using the green channel and NIR because the wavelength of the green channel has the advantage of better identifying the characteristics of the waters. In contrast, the NIR channel has a low reflectivity to water but a high reflectivity to vegetation and soil (McFeeters, 1996). Therefore, the combination of the two channels can be seen in Equation 4.

$$NDWI = \frac{\lambda 3 - \lambda 8}{\lambda 3 + \lambda 8} \quad (4)$$

where: $\boldsymbol{\lambda}3$ is reflectance band green; $\boldsymbol{\lambda}8$ is reflectance band NIR

2.6. Shoreline Corrections

Tidal conditions are influenced by the time of sea waves, so the coastline's determination using imagery must be adjusted to the time data of the tide recording (Winarso, 2001). The area's topography also influences the position of the coastline from the extraction of satellite image data. Therefore, the magnitude of the shoreline shift due to tides needs to pay attention to topography by using DEM (Digital Elevation Model). Data DEM (Digital Elevation Model)data is used to determine the slope angle of the beach itself (Suhana et al., 2017). The distance of the shoreline shift resulting from the correction to the LLWL is then calculated using Equation 5.

$$a = h \times \tan^{-1}\alpha \quad (5)$$

where: a is the distance shift of the shoreline correction (m); h is the value LLWL (m); α is the beach slope (°).

3. RESULTS AND DISCUSSION

3.1. Analysis of Total Suspended Solids

The TSS value results in a significant difference in the values of the three algorithms. The TSS value of the Laili algorithm produces an average value of 22.201 mg/l. Meanwhile, the TSS value of Liu's algorithm produces an average value of 51.425 mg/l. Also, the TSS value of the C2RCC algorithm produces an average value of 32.186 mg/l. The results of the TSS value are calculated by linear regression and correlation test between the in-situ TSS value and the TSS value resulting from algorithm processing on the image. The relationship between In-situ TSS and image-processing TSS can be seen in Table 1.

The linear regression results of the three TSS algorithm models show that the C2RCC algorithm has the highest coefficient of determination, so in this study, the C2RCC algorithm was used in TSS image processing. Changes in TSS values can be seen from the difference in values per sample point in 2015, 2018, and 2021. TSS values from 2015 to 2018 decreased by an average of 2.303 mg/l. The highest decrease in val ue was at sample point 41, with a value of 12.466 mg/l found in the coastal area of Juwana. The TSS value from 2018 to 2021 is also dominated by a decrease, with an average value of 4.447 mg/l. The highest reduction value of 19.3 mg/l was at sample point 44, which is in the coastal area of Batangan.

Table 1. Linear regression calculation

Algorithm	Linear Regression	R^2	r
Laili	y = 24.869x + 360.09	0.6118	0.782
Liu	y = 4.5415x + 41.519	0.6198	0.787
C2RCC	y = 5.0059x + 27.753	0.7216	0.849

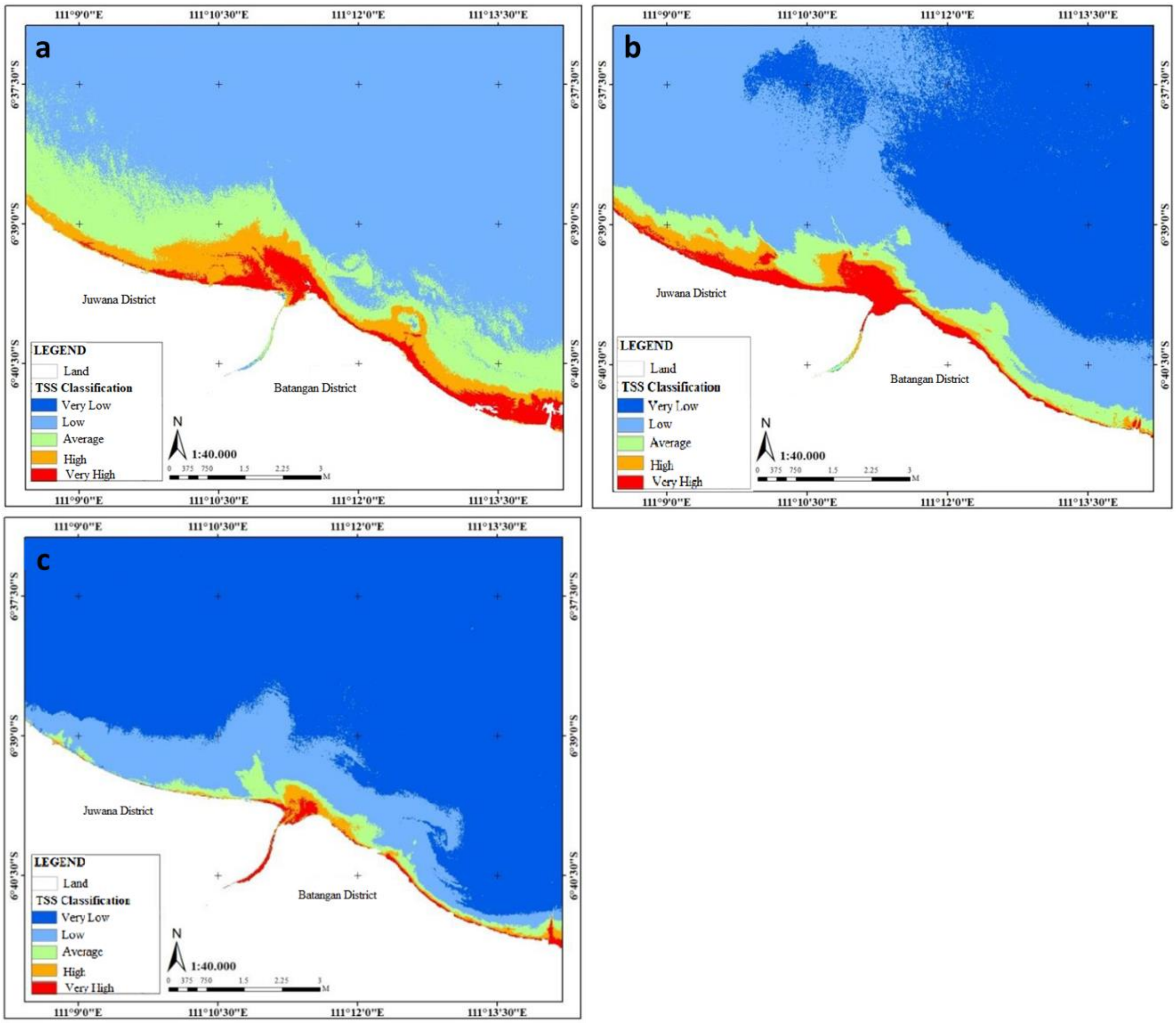
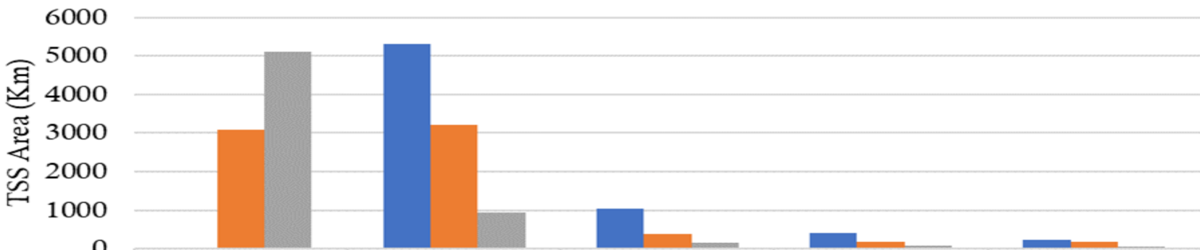


Figure 2. Classification of TSS; (a) 2015, (b) 2018, and (c) 2021

Roswaty et al. (2014) concluded that there is a strong correlation between the sedimentation rate and the TSS value. In this case, several points are defined as having no value (not null) and are defined as land. The land is formed due to increased sedimentation characterized by high TSS values. TSS values are classified into five classes, including very low (0-8 mg/l), low (8-16 mg/l), moderate (16-24 mg/l), high (24-32 mg/l), and very high (>32 mg/l) are seen in Figure 2. This is done to facilitate the analysis of TSS changes every year. Changes in TSS values from 2015 to 2018 and 2021 are seen in Figure 3. Changes in TSS in 2015, 2018, and 2021 showed a decrease for low class (8-16 mg/l), medium class (16-24 mg/l), high class high (24-32 mg/l), and very high class (>32 mg/l). Th e very low class (0-8 mg/l) experienced a significant increase in area.



	Very Low	Low	Average	High	Very High
2015	0.504	5311.613	1049.669	398.297	228.238
2018	3083.109	3216.572	394.749	189.407	191.169
2021	5106.016	936.493	161.464	77.928	45.694

TSS Classification

Figure 3. Changes in the TSS area in 2015, 2018, and 2021

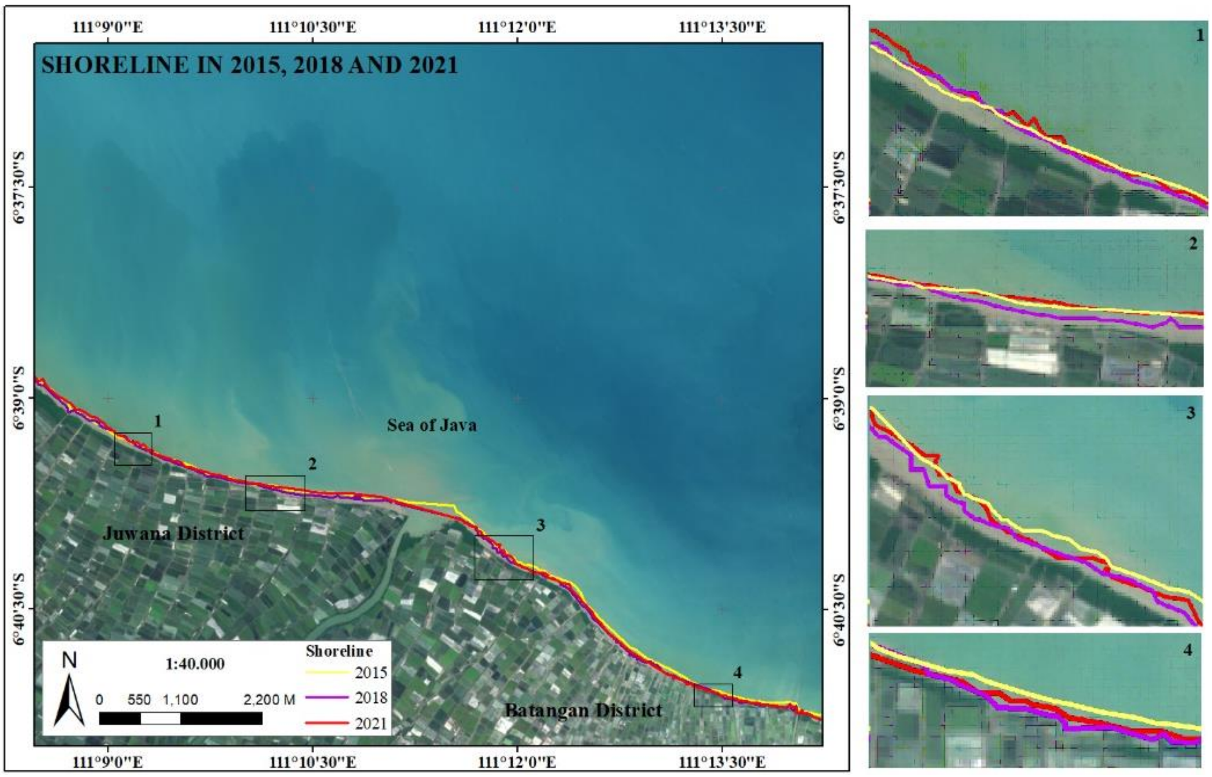


Figure 4. Shoreline extraction

The TSS value from 2015 to 2021 experienced a very high-grade decrease in 2015 along 228,238 km to 45,694 km in 2021, indicating reduced sedimentation at the mouth of the Juwana River. This causes abrasion around the coastline. The TSS value in the very low class increased significantly because, in 2015, it was 0.504 km long to 5,106.016 km in 2021. Changes in the TSS value from 2015 to 2018 caused a change in the coastline at the mouth of the Juwana River. Shoreline changes are caused by the continuous accumulation of material from the sedimentation process, causing accretion (Paena, 2008). Suspended solids, turbidity, and brightness are three interrelated parameters. The increase in suspended solids levels is in line with the turbidity level and is reversed with the level of brightness (Shodiqin, 2016).

3.2. Analysis of Shoreline Change

Shorelines are generated from image extraction using the NDWI algorithm. The NDWI value ranges from -1 to 1, which assumes that the higher the spectral value of the NDWI calculation, the wetter the object, which means water and vice versa. The shoreline extraction results can be seen in Figure 4. Image extraction using the NDWI algorithm obtains a coastline which is then corrected for the topographical conditions of the study area. Meanwhile, tides cause the position of the coastline recorded at the time of image acquisition to be different from the actual one. Therefore, this study carried out shoreline corrections by shifting the coastline to eliminate tidal effects during image recording so that the coastline is in the LLWL position as well as the topographical slope of the study area. The visualization of the 2021 coastline correction can be seen in Figure 5.

The results of the shoreline correction need to be validated to determine the accuracy of the data processing results that distinguish between land and sea. This study conducted field validation by taking the coordinates of 30 points in the field. Validation was carried out using GPS tracking of 30 points. The shoreline validation results from field data are compared with the processing results from satellite imagery data. The validation results show the compatibility between the field and the image, with the number of points corresponding to 29 out of 30 points in the field with a percentage of 96.6%. Calculation of shoreline changes from the 2015 baseline to 2018 resulted in 1213 transects. The results of the calculation of changes in the 2015-2018 coastline can be seen in Table 2. The percentage of the entire transect shows that the abrasion value is higher, namely 53.83%, compared to the accretion of 46.17%. Changes in the coastline in 2015-2018 see Figure 6.

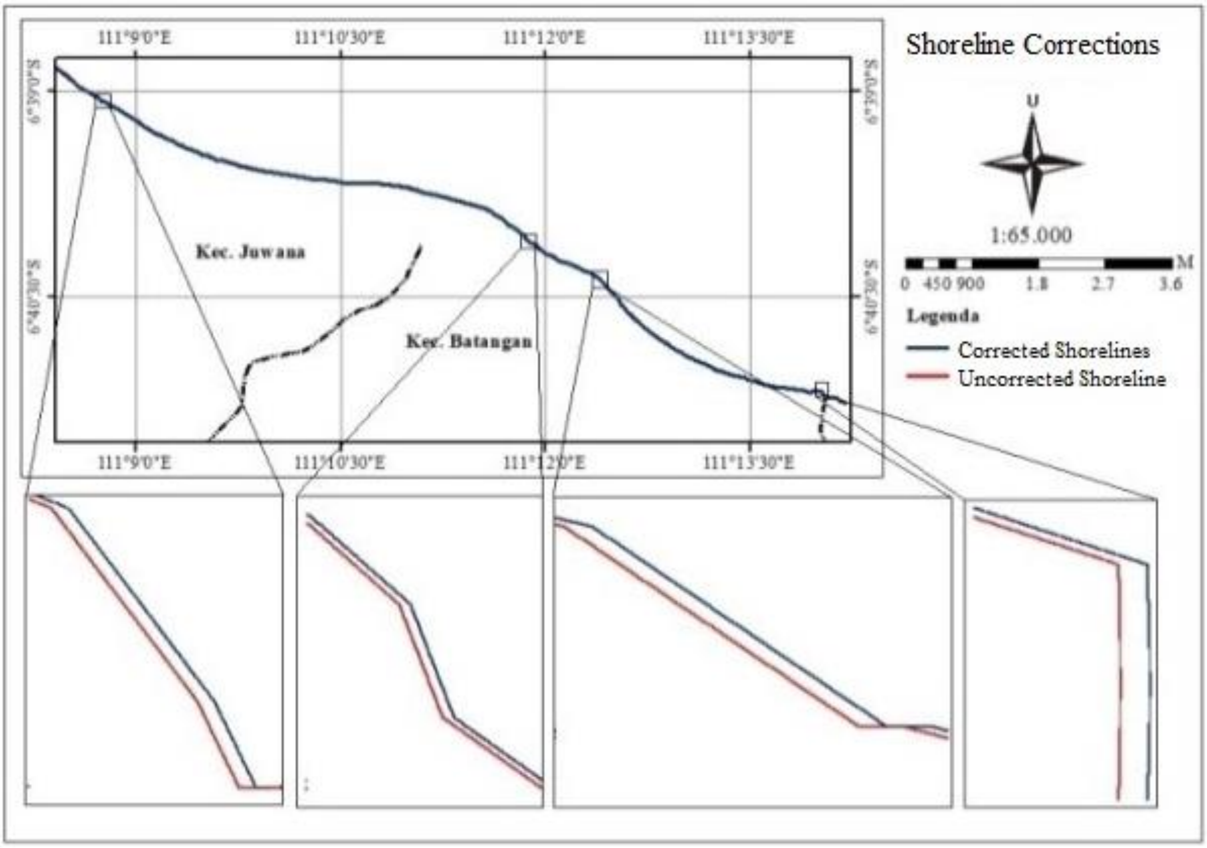


Figure 5. Shoreline correction

The results of the overall transect percentage show that shoreline changes in 2015-2018 were dominated by abrasion. Based on Figure 5, it can be seen that there are two zones with significant changes in abrasion and accretion. Zone 1 in Juwana waters occurs where accretion with the maximum distance also occurs in that zone. Based on image interpretation, zone 1 contains several tributary estuaries. These tributaries carry a lot of solid material so that additional land can occur. Changes in the coastline in the image in Zone 1 can be seen in Figure 7. Zone 2 is the area in the form of waters around the mouth of the river where abrasion occurs and where the abrasion with the maximum distance also occurs. Based on image interpretation, the coastal land area 2015 was very wide and reduced in 2018. Changes in the coastline in the image in zone 2 can be seen in Figure 8. From 2018 to 2021, calculating shoreline changes resulted in 1204 transects. The results of calculating the change in the 2018-2021 coastline can be seen in Table 3. The percentage of the entire transect shows that the abrasion value is higher, namely 59.55% compared to 40.45% abrasion. Changes in the coastline for 2018-2021 can be seen in Figure 9.

The study area shows that there has been a change in the coastline from 2018 to 2021, which is dominated by abrasion. Based on Figure 9, it can be seen that there are two zones with significant changes in abrasion and accretion. Zone 1 in Juwana waters also occurs where accretion with the maximum distance also occurs in that zone. Sentinel-2 imagery was performed using a band combination using the Near Infrared, Shortwave Infrared, and Blue bands to distinguish the appearance of vegetation, mainly mangroves. Mangrove forests have increased from 2018 to 2018, so there seems to be an addition of land or accretion. Changes in the image in zone 1 can be seen in Figure 10. Figure 10 displays the image as a false-color composite to see changes in mangrove density more clearly.

Table 2. Shoreline changes in 2015-2018

Shoreline change	The length of the shoreline changes (m)
Maximum Accretion	69.55
Average Accretion	21.53
Maximum Abrasion	119.61
Average Abrasion	22.89

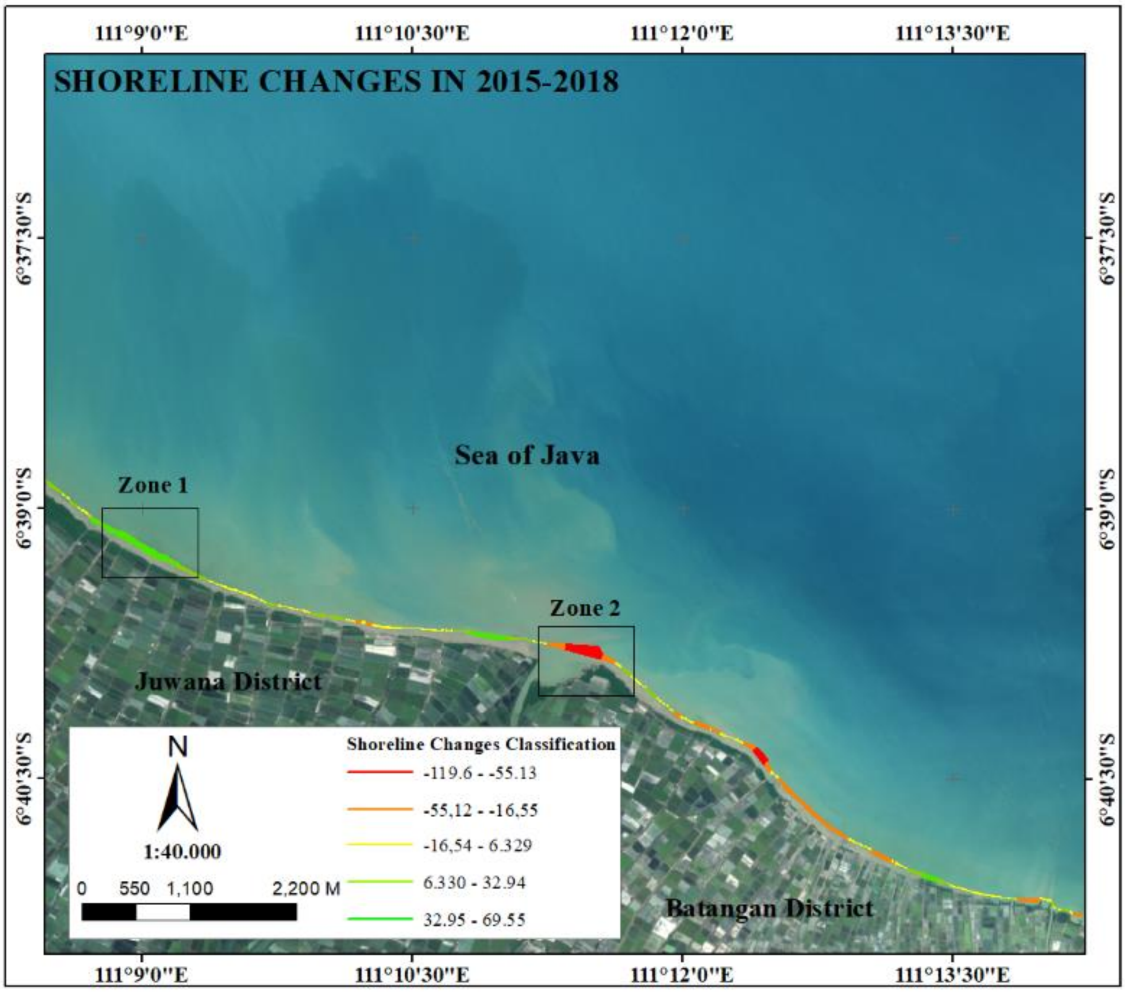


Figure 6. Shoreline Changes in 2015-2018

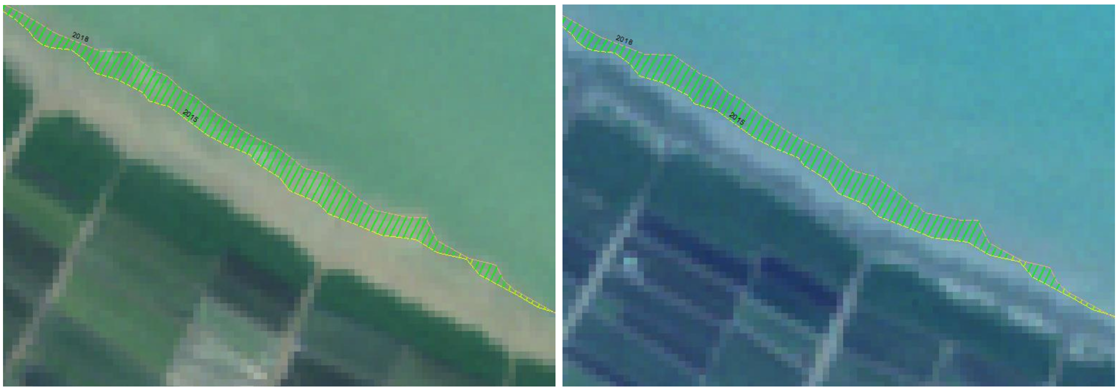


Figure 7. Zone 1 changes in 2015-2018

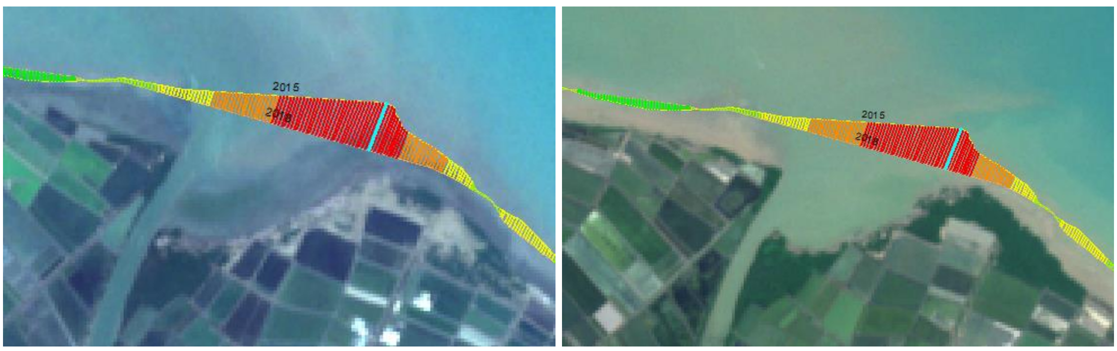


Figure 8. Zone 2 changes in 2015-2018

Table 3. Shoreline Changes in 2018-2021

Shoreline change	The length of the shoreline changes (m)
Maximum Accretion	57.74
Average Accretion	18.14
Maximum Abrasion	53.23
Average Abrasion	14.82

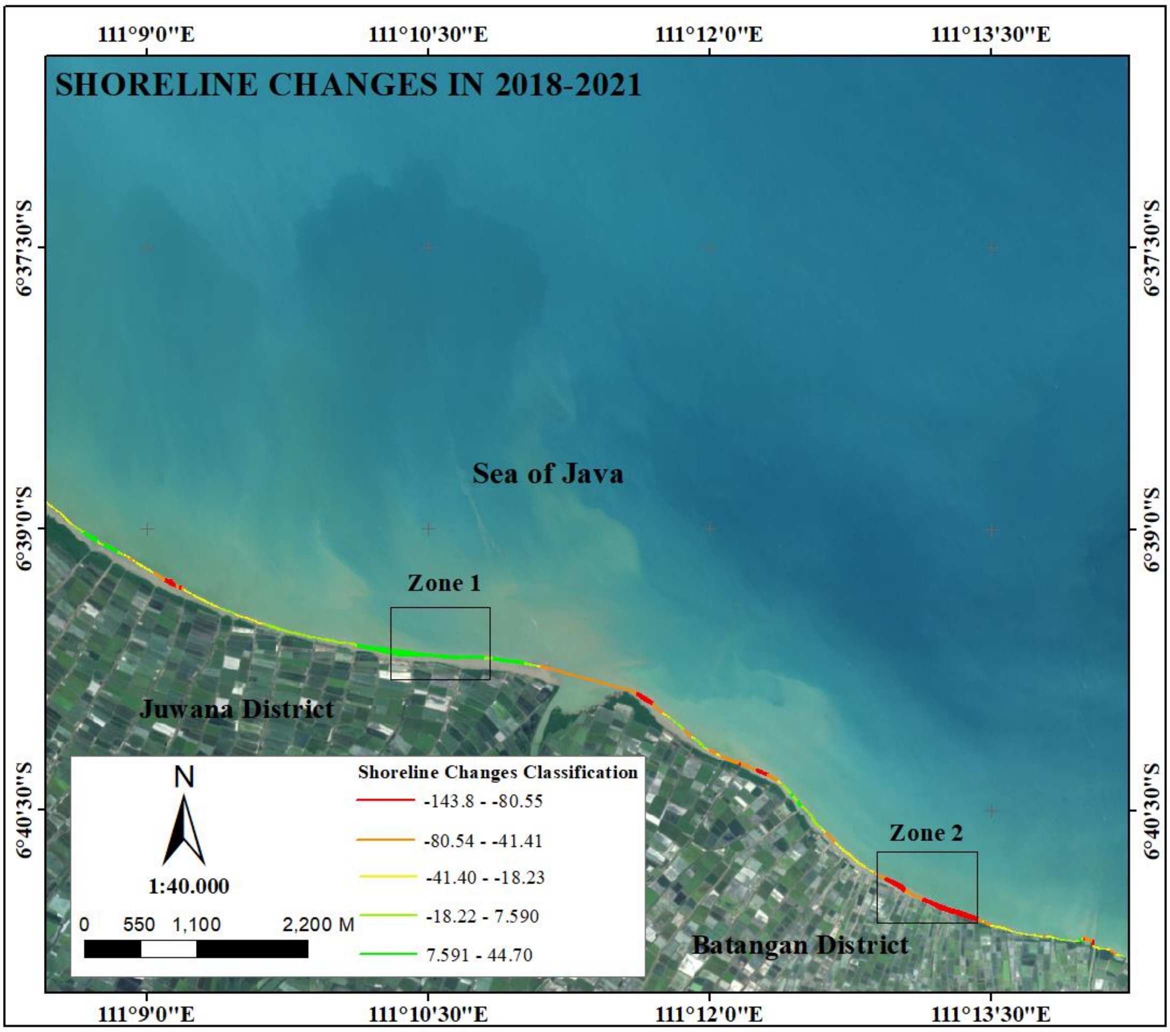


Figure 9. Shoreline changes in 2018-2021

The location of zone 2 in Batangan waters has the longest abrasion, causing damage to the coastline. Based on image interpretation, the coastal area in 2018 and 2021 identified no mangroves or breakwater structures to reduce the danger of erosion. Prahesti (2020), in his research, stated that changes in mangrove density to changes in coastline have a strong correlation relationship so that reduced or no increase in mangrove plant density causes reduced coastal land or abrasion. Changes in the image in zone 2 can be seen in Figure 11.

Figure 12 shows the area's high abrasion value from 2015 to 2018 decreased. The abrasion area of 14,162 ha has decreased to 10,282 ha from 2018 to 2021. Abrasion events dominated changes in the coastline in 2015-2018. The low accretion value in 2015-2018 also experienced a decrease in the area from 11,762 ha to 8,651 ha in 2018-2021, but the abrasion value is still higher than the accretion value. This shows that changes in the 2018-2021 coastline are also dominated by abrasion.

The beach of Pati Regency has the characteristics of a muddy beach with a sloping beach topography (lowland beach) (Solihuddin et al., 2020). A sloping beach has the characteristics of a muddy substrate or muddy sand to increase the potential for waves and currents that cause beach abrasion, increasing turbidity in coastal areas (Siswanto & Nugraha, 2016).

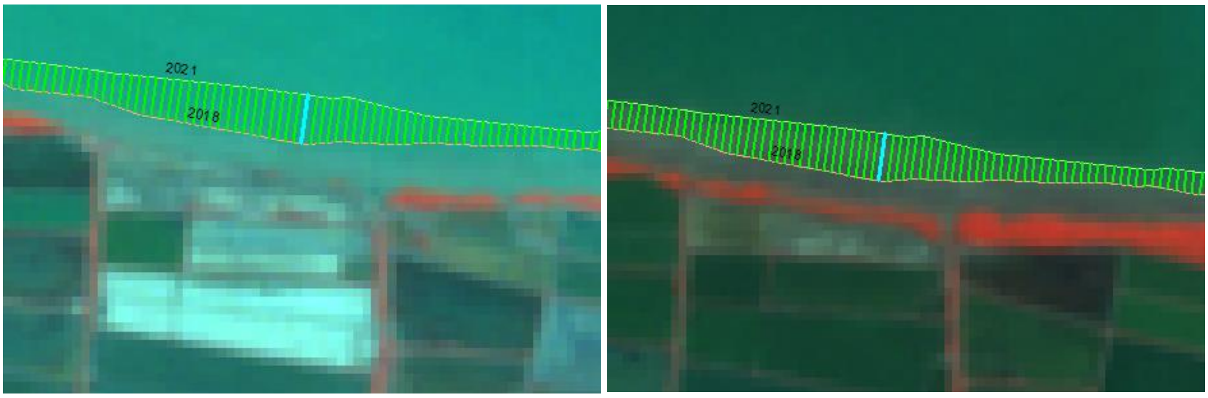


Figure 10. Zone 1 changes for 2018-2021

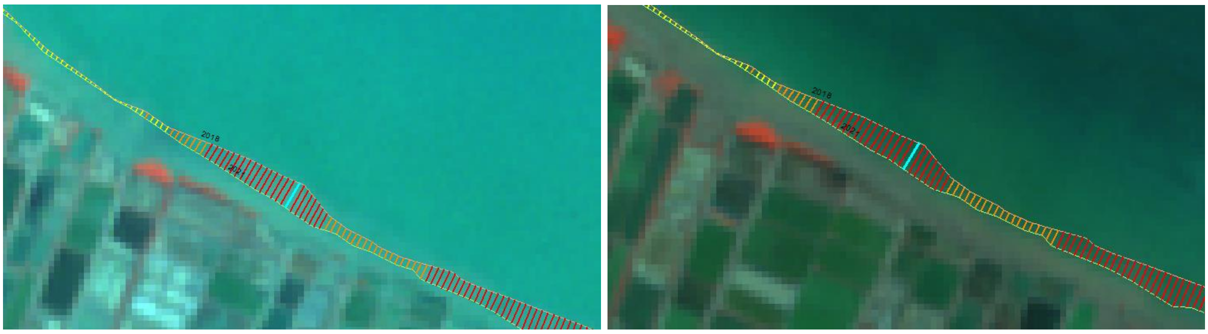
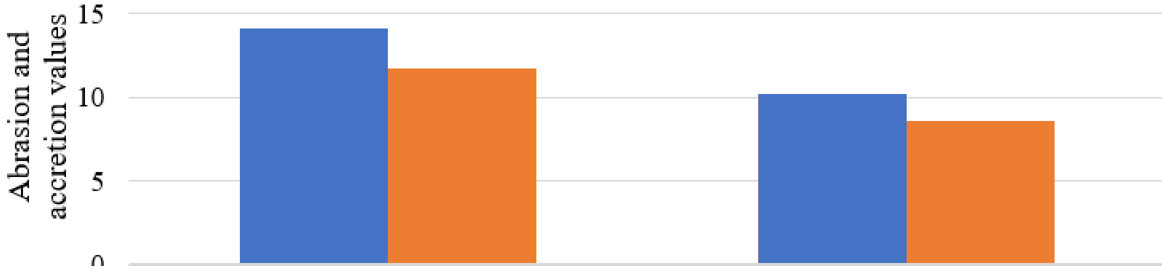


Figure 11. Zone 2 changes for 2018-2021



	Abrasion (ha)	Accretion (ha)
2015-2018	14.162	10.282
2018-2021	11.726	8.651

Figure 12. The extent of the change in the coastline in 2015-2018 and 2018-2021

4. CONCLUSIONS

Based on the processing and interpretation of TSS data and shoreline processing results using Sentinel-2 imagery in 2015, 2018, and 2021, it can be concluded that: TSS in 2015-2018 experienced a decrease with an average decrease value of 2,303 mg/l where the largest decrease with a value 12,466 mg/l is in the Juwana Coastal area. Meanwhile, changes in the coastline in 2015-2018 were dominated by abrasion covering an area of 14,162 ha with a maximum distance of 119.61 m in the Muara Juwana area. Based on the study's results, it can be concluded that a decrease in TSS concentration indicates a decrease in sedimentation due to eroding of coastal areas, which causes abrasion. In contrast, areas with increased concentrations of TSS indicate an increase in sedimentation, which causes accretion.

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