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OPAK AND BOGOWONTO COASTAL INLET SAND SPIT MORPHODYNAMICS USING LANDSAT AND SENTINEL SATELLITE IMAGES

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ABSTRACT

Sand spits are elongated sand deposits on the beach that often form at the inlet or the headland's tip. The hydrodynamics of the river flow, waves, storm surge, and tide affect the sand spit formation, which was created by the longshore transport along the coast. Bogowonto and Opak inlets are located in southern coastal Java facing directly to the Indian ocean where micro-tidal, waves, and river flow affecting both inlets, are chosen for this case study. Morphodynamics analysis of sand spit using Landsat 7 and 8, Sentinel 2 image from 2000 to 2020, coastline identification using Modified Normalized Different Water Index (mNDWI). In November 2007 and October 2013, Opak Inlet migratory routes were detected, and closures related to the east season occurred at both of them. Inlet tend to close occur on east season during July until November.

Keywords: sand spit, mNDWI, Opak, Bogowonto, closure, inlet.

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INTRODUCTION

The coast is a dynamic environment, with morphology being a sensitive environment due to human activity and climate change (Roca *et al*., 2022) (roca. and co , 2022)(roca. and co , 2022). Changes in form are caused by the dynamics of the coast, which are influenced by weather, hydrology, geology, and oceanography. The process of shoreline fluctuation over the long term, up to decades, must be understood in order to understand the coastal dynamics. Analysis of the dynamics of coastal morphology, in particular barrier island sand (sandy barrier island) or tongue sand (sand spit), analyzed alongside the shape of the beach, with the orientation of the beach being carefully regarded.

A section of beach created by expanding sand deposits is called a “sand spit,” and it has one end that is connected to the land and one that is open (Lu *et al*., 2020). Sand spit is typically found on capes, river estuaries, and lagoons and has a generally narrow and extended shape. Movement of sediment along the coast produced by coastal processes, particularly waves that transport sediment and deposit at the end of the sand spit so that the spit grows (Saengsupavanich, 2021).

Seasonal sediment flow creating sand spit along river mouths throughout the Southern Java Island coast. Waves, which actively participate in nearshore processes, are followed by micro tidal ranges and river discharges, which are affected by the season, in strengthening this situation (Chrysanti *et al*., 2019).

The buildup of sediment transported by longshore currents causes sand spits to accumulate in coastal inlets, which can block the inlet and create issues with river navigation, drainage systems, and flood control (Anh, *et al*., 2020a). Growing sand spits, however, might aid in reducing ocean encroachment. In most cases, sand spits are created naturally and are affected by natural forces. Hydrodynamic forces, bed materials, and long-term sediment transport all have an impact on the morphodynamics of the sand spit (Anh *et al*., 2020b).

Sand spit growth data limitations are removed by obtaining the morphodynamics of spit using satellite imaginary data. On a worldwide scale, coastline detection and mapping using reliable remote sensing methods is possible (Konlechner *et al*., 2020). Combining Landsat and Sentinel satellite imaging data, this study intends to investigate the morphodynamics of the sand spit and the closure of the Opak and Bogowonto inlet spatially and temporally for 21 years from 2000 to 2020.

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METHODOLOGY

The estuary of the Opak and Bogowonto rivers, which is situated on the coast of southern Java Island, served as the subject location for this investigation. The estuaries face the Indian Ocean directly, which has

Figure 1. Sand spit morphodynamics identification area.

Table 1. Field observation results

Satellite	Time Observa-tion	Temporal resolu-tion	Pixel size

an impact on shoreline alterations brought on by coastal processes that are impacted by waves, currents, tides, sedimentation, and river flow. Figure 1 depicts the research area used in this study.

The data used in this study include top-of-atmosphere (TOA) reflectance image data from Sentinel-2, Landsat 7 (ETM+), and Landsat 8 (OLI), covering a period of 21 years (2000–2020) (Table 1). The image's data were collected using the Python package's toolkit and coastsat functions(Vos *et al*., 2019). With the help of image data processing, Google Earth Engine (GEE), a Python API module, makes it possible to retrieve satellite photos and automatically identify coastlines (Vos *et al*., 2019).

The pre-processing of TOA images involves downsampling, panchromatic image pansharpening, and cloud masking. With the assistance of cloud masking, picture data from the study area can be selected so that clouds that are present in image pixel units don't impact its utilization.

Panchromatic image pansharpening and down sampling are used to make the image stronger and more suitable for shoreline detection. Using the bilinear interpolation technique, Landsat 7 and Landsat 8 images have the highest resolution in the panchromatic band with a resolution of 15 m, whereas Sentinel-2 imagery has a resolution of 10 m.

The shoreline are identified during picture acquisition as the line separating the land from the water and is determined in two processes. (1) Image categorization into four groups (2) Subpixel boundary segmentation of sand, water, foam, and other features are used as class labels in neural networks for image classification. Using the Modified Normalized Difference Water Index (mNDWI) approach, the subpixel scale border is segmented to provide water and land boundaries. According to Xu (2006), mNDWI is calculated using the formula:

$$mNDWI = \frac{SWIR - G}{SWIR + G} \quad \text{.............................. 1)}$$

where SWIR and G represent the pixel intensities in short-wave infrared band and green band respectively. mNDWI's range of values is from -1 to 1, and it generates positive values for land and negative values for water or the ocean. The similarity of the coastline's contour values will be modified to reflect the sea/land border.

The length of the spit at the river mouth was measured in this study in order to use the sand spit growth method. With a constant sand spit width and movement that corresponds to the passage of time, it is assumed that longshore sediment transport has an impact on the sand spit's growth. The process for determining the sand tongue's length is depicted in Figure 2.

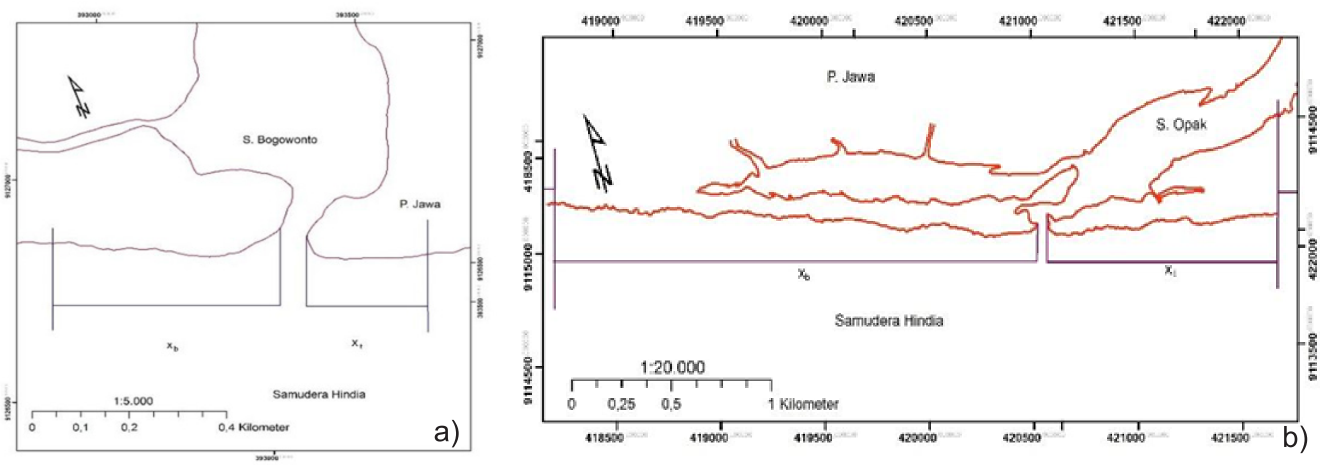

Figure 2. Schematic diagram of feature of sand spit morphodynamics, (a) Bogowonto inlet, (b) Opak inlet.

RESULTS AND DISCUSSION

The movement of the sand spit at the Opak river estuary is depicted in Figure 3 by the coastline created by processing data from the coastsat toolkit. The red line delineating the coastline represents the changes in the morphology of the sand spit that were discovered after 21 years of picture data processing. In 2000, the sand spit on the east side of the Opak river estuary measured 813 m in length. The sand spit's expansion from east to west, measured 1.353 m in length in 2002. The 635 m long sand spit expanded, increasing its length to 1.988 m in 2004. The sand spit reached 2.393 m in 2006, increasing at a rate of 202 m/year from 2005 to 2006.

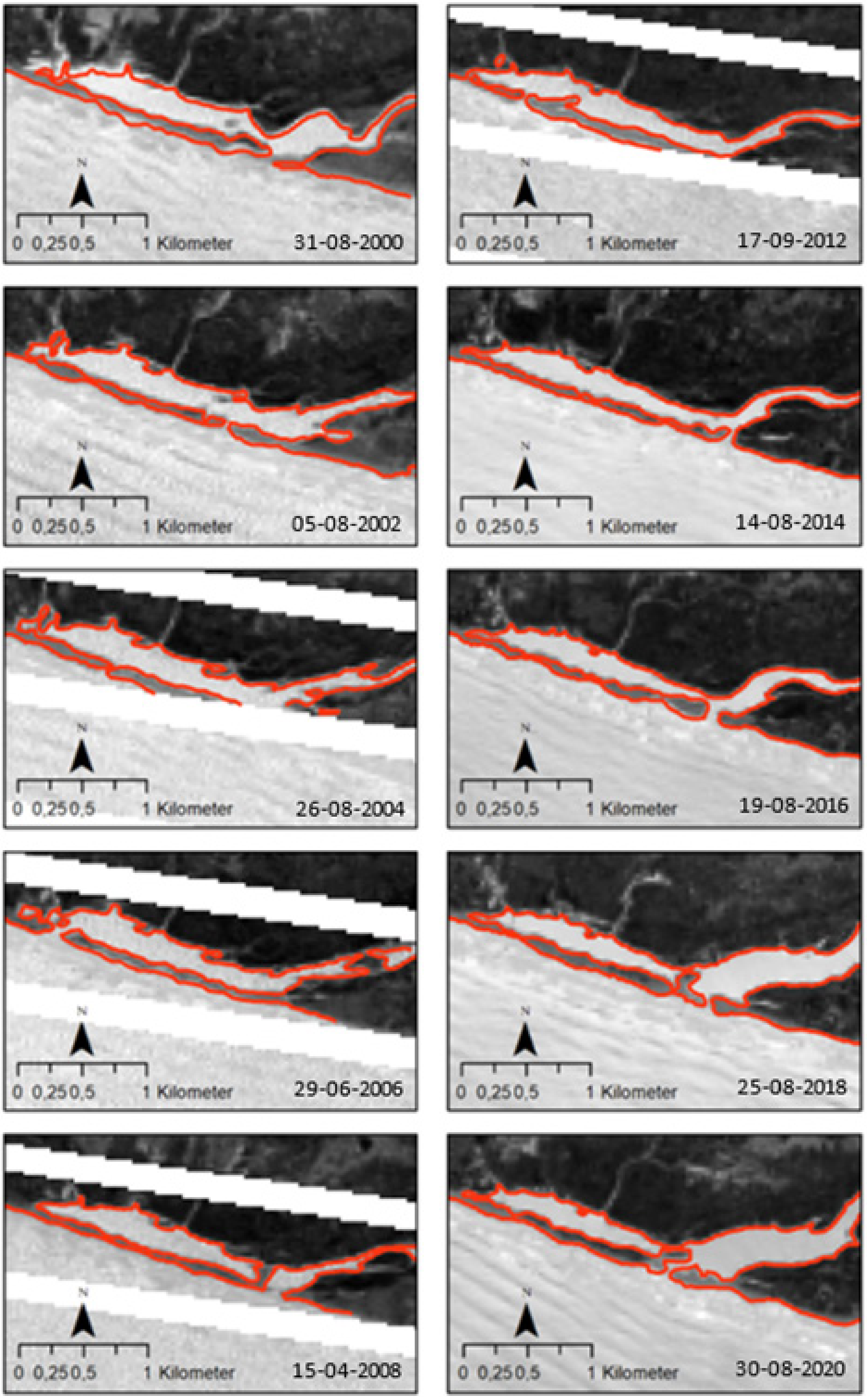

Figure 3. Sand spit morphodynamics at the Opak inlet.

Sand length decreased significantly from 2.799 m to 967 m as a result of the initial breaching in January 2008. After the first breach, the length of the sand spit increased until it reached 2.377 m in September 2012. The sand spit increased in size until it reached 3.042 m in October 2013, and during that time there was a second breakout. The length of the sand spit was reduced by 747 m by the second break, which happened in October 2013. After the second break, the sand spit's length actually decreased to 669 m in August 2014.

The length of the sand spit has increased steadily from 196 m to 865 m since the discovery of the second sand spit and shortening of the sand spit in 2014. In August 2018, the sand spit reached a length of 1206 m.

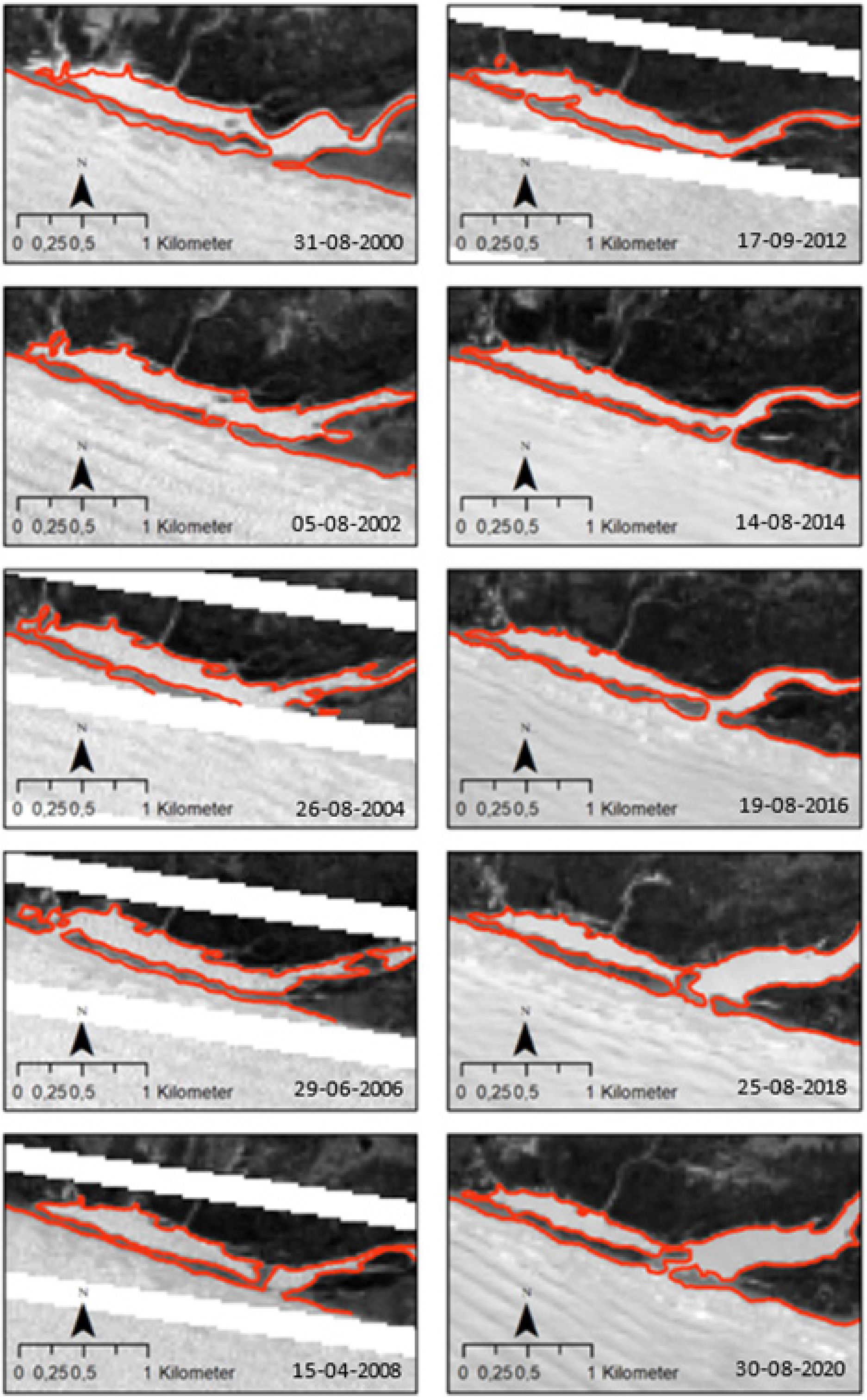

Figure 4. Sand spit morphodynamics at the Opak inlet.

After that, it shrank by 1074 m, but the reduction was not significant. Between 2000 and 2013, there was a pause in the sand spit's expansion, resulting in an 1832 m reduction in length.

The Bogowonto sand spit movement from 2000 to 2020 is depicted in Figure 4. The Bogowonto river mouth sand spit is 412 m long, measuring from its eastern boundary to its tip on the east side of the estuary. The Bogowonto inlet was closed in November 2002 and reopened in 2003 with a 332 m long sand spit. After the river mouth was closed in October 2004, the length of the sand spit on the east side of the river mouth was 332 m in November 2004.

The Bogowonto inlet was closed in August 2008, and compared to November 2002, the width of the sand spit was narrower. The Bogowonto inlet was opened in 2010 with a 240 m sand spit from the east side. By December 2012, the sand spit length had increased to 268 m. With a length of 260 m in November 2014, the sand spit's length tended to be steady. The Bogowonto River's mouth was closed between August and November of 2015, and it was subsequently opened with a large, 241m sand spit.

The inlet was once again closed in September 2017, even though the sand spit length in September 2016 was 223 m. The Bogowonto inlet reopened with an average sand spit length of 258 m before closing once more from July to September 2018. The Bogowonto inlet was shut down in 2019 from July to September. The Bogowonto river mouth was closed in 2020 from September through October, then in November it was opened with a 242 m spit.

Based on Landsat image data (blue circle) and Sentinel image data (red triangle), length of the sand spit at the Opak and Bogowonto inlet are varied. A red line (Landsat) and a black line (Sentinel) indicate the inlet closure. Due to variations in the image resolution that was employed, the observations imply various values for the length of the sand spit from each set of image data.

When compared to the mouth of the Bogwonoto, the morphodynamics of the sand tongue near the mouth of the Opak have different characteristics. The pattern of sand spit movement is influenced by the estuary morphology and the features of the river. According to Bhakty *et al*. (2021), the Opak river flows under the medium discharge category, meaning that its mouth will close periodically, particularly during the east monsoon. In contrast, the Bogowonto River flows under the low discharge category, meaning that its mouth will close quickly during the east monsoon. River flow and wave conditions led to longshore sediment transport, which grew until it fully blocked the two river mouths. This caused the closure of the two river mouths.

Two sand spit breaching occurred in the Opak river estuary sand spit, causing it to dramatically shorten in 2008 and 2013 (Figure 5). After the river mouth was breached, the Opak river estuary sand spit continued to expand until 2020, with growth rates of 65.78 m per year, 415 m per year, and 127.79 m per year. With a growth rate of 67 m/year, the sand spit at the mouth of the Bogowonto River is expanding at a comparatively constant rate (Figure 6).

A geographic information system can be used to evaluate the process of accretion and erosion that leads to changes in shorelines by calculating the distance between the past and the present (Lawson *et al*., 2021). Optical image data offers a wide coverage area, a medium resolution, and a quick coverage time scale.

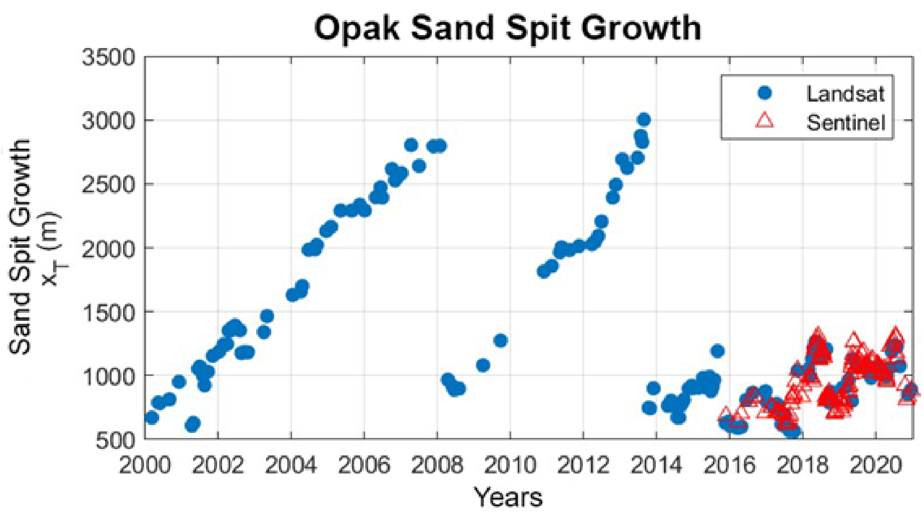

Figure 4. Sand spit growth on Opak inlet.

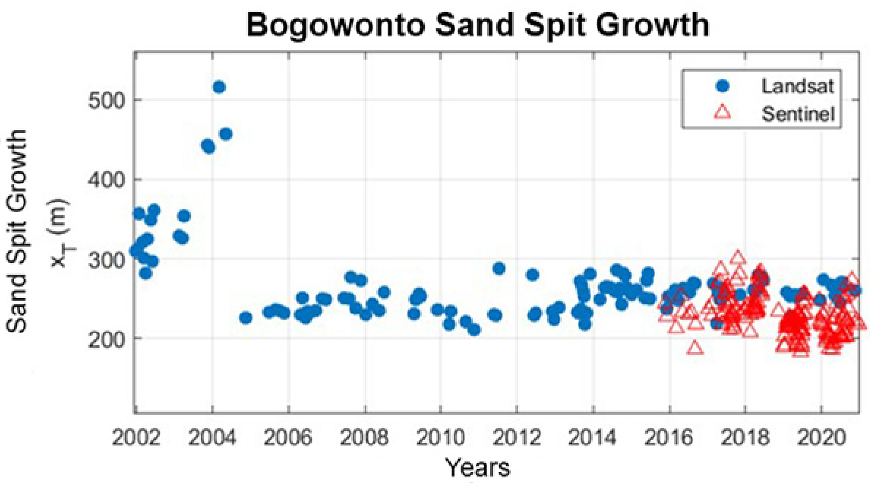

Figure 6. Sand spit growth on Bogowonto inlet.

The ability to explore shoreline alterations in remote places is a benefit of satellite image data (Garca-Rubio *et al*., 2015). On the same day that Landsat image data was acquired, the shoreline at both river mouths was verified using SPOT satellite image data. For the accuracy of shoreline identification, a comparison between Landsat and SPOT image data is used; the two data are compared to identify the same earthly features (Wang, 1980).

Figure 7 shows the variation in coordinates (x, y) between the test sites on the Landsat image data and the SPOT image data used as a reference in determining the accuracy of the coordinates. Calculate the coordinates (x, y) for the Landsat image using SPOT to perform a coordinate accuracy test using RMSE (Root Mean Square Error). In Figure 7, it is depicted how the coordinate points from the Landsat and SPOT imagery differ. The Opak River Estuary's coordinate deviation is 28.9 m on the x-axis and 29.6 m on the y-axis, with a maximum radius of up to 33.9 m from the center point coordinate. At a distance of 20 m from the center point 0, the 50% distribution of the coordinate deviation radius of Landsat and SPOT image data is located.

The Bogowonto Estuary coordinate deviation is 65 m on the x-axis and 70,65 m on the y-axis, resulting in a maximum residual of 76,7 m from the center point. With a value of 36% of the total data, the radius of the largest deviation distribution of Landsat and SPOT image coordinates is 20 m. This coordinate divergence can happen because Landsat imagery data has one pixel measuring 225 m2, but SPOT imagery data has one representing an area of 25 to 100 m2. The RMSE at the Bogowonto Estuary is 7,685 m, while it is 6,883 m at the Opak River Estuary.

Considering the Landsat image data with an image resolution of 30 m x 30 m and a coverage area of 900 m2, the RMSE value of the Bogowonto River Estuary is still at a suitable level, thus an accuracy error of 30 m can still be considered to be good.

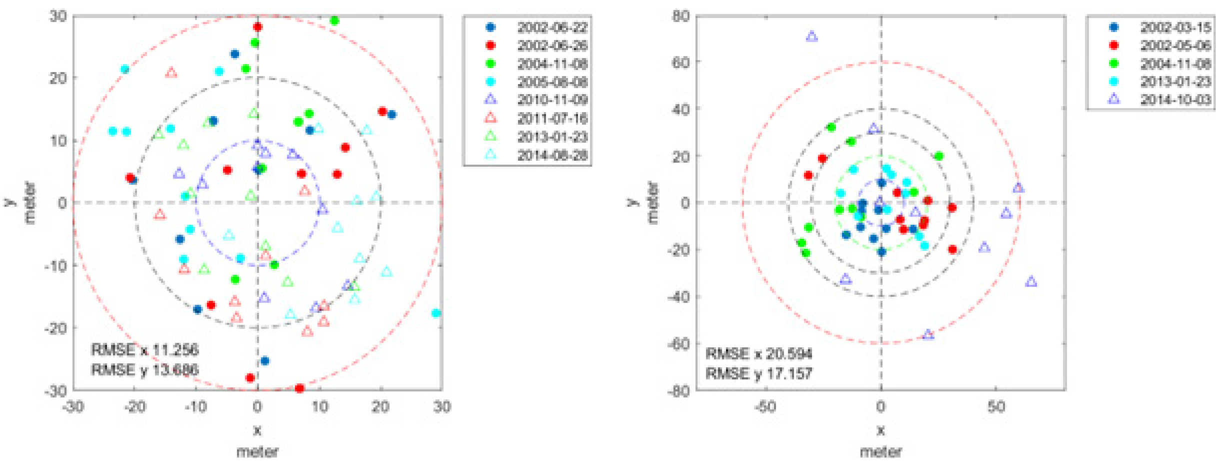

Figure 6. Coordinate point differences between the Landsat and SPOT imagery data at (a) the Opak River estuary and (b) the Bogowonto River estuary.

CONCLUSION

The utilized shoreline detection technique is simple enough to be used in other monitoring scenarios. Continuous data and essential long-term information are provided by satellite data images, and coastal area correspondence is provided by land-sea mapping analysis. Using satellite imaging analysis, the findings revealed changes in the morphology of the sand spit near the mouths of the Opak and Bogowonto rivers. Sand spit englongation rate at Opak inlet is unstable about 65,78 m/year to 127,79 m/year. Whereas, the sand spit rate in Bogowonto inlet is a stable rate about 67 m/year. The Opak sand spit was breach twice on 2008 and 2003 during the early west monsoon. Both inlet are closed during east monsoon depend on phenomenon at the nearshore process were varying corresponding to each different season. With values found in the Landsat image data subpixels with a resolution of up to 30 x 30 m, the accuracy of the image data used in this study reached 7,685 m. The findings of this study provide the local coastal authorities with valuable data that will help them choose the appropriate management strategy or plans going forward.

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REFFERENCE

Anh, N.Q.D., Tanaka, H., Tam, H.S., Tinh, N.X., Tung, T.T., & Viet, N.T. (2020). Comprehensive study of the sand spit evolution at tidal inlets in the central coast of Vietnam. *Journal of Marine Science and Engineering, 8*(9). https://doi.org/10.3390/JMSE8090722

Anh, N.Q.D., Tanaka, H., Tinh, N.X., & Viet, N.T. (2020). Sand spit morphological evolution at tidal inlets by using satellite images analysis: Two case studies in Vietnam. *Journal of Science and Technology in Civil Engineering (STCE) - NUCE, 14*(2), 17–27. https://doi.org/10.31814/stce.nuce2020-14(2)-02

Bhakty, T.E., Swasono, A.H., Yuwono, N., Ghalizhan, A.F., & Widyasari, T. (2021). Determination of the length of Bogowonto double jetty as the river mouth stabilization. *IOP Conference Series: Earth and Environmental Science, 930*(1). https://doi.org/10.1088/1755-1315/930/1/012027

Chrysanti, A., Bagus Adityawan, M., Widyaningtyas, Pramono Yakti, B., Nugroho, J., Zain, K., Haryanto, I., Sulaiman, M., Kurniawan, A., & Tanaka, H. (2019). Prediction of shoreline change using a numerical model: case of the Kulon Progo Coast, Central Java. *MATEC Web of Conferences, 270*, 04023. https://doi.org/10.1051/matecconf/201927004023

Escudero, M., Silva, R., Hesp, P.A., & Mendoza, E. (2019). Morphological evolution of the sandspit at Tortugueros Beach, Mexico. *Marine Geology, 407*, 16–31. https://doi.org/10.1016/j.margeo.2018.10.002

García-Rubio, G., Huntley, D., & Russell, P. (2015). Evaluating shoreline identification using optical satellite images. *Marine Geology, 359*, 96–105. https://doi.org/10.1016/j.margeo.2014.11.002

Konlechner, T. M., Kennedy, D. M., O'Grady, J. J., Leach, C., Ranasinghe, R., Carvalho, R. C., Luijendijk, A. P., McInnes, K. L., & Ierodiaconou, D. (2020). Mapping spatial variability in shoreline change hotspots from satellite data; a case study in southeast Australia. Estuarine. *Coastal and Shelf Science, 246*. https://doi.org/10.1016/j.ecss.2020.107018

Lawson, S. K., Tanaka, H., Udo, K., Hiep, N. T., & Tinh, N. X. (2021). Morphodynamics and evolution of estuarine sandspits along the bight of benin coast, West Africa. *Water (Switzerland), 13*(21). https://doi.org/10.3390/w13212977

Lu, J., Han, G., Xia, C., Chen, Z., Tong, C., Song, Z., Teng, Y., & Qiao, F. (2020). Sediment dynamics near a sandy spit with wave-induced coastal currents. *Continental Shelf Research, 193*. https://doi.org/10.1016/j.csr.2019.104033

Roca, M., Navarro, G., García-Sanabria, J., & Caballero, I. (2022). Monitoring Sand Spit Variability Using Sentinel-2 and Google Earth Engine in a Mediterranean Estuary. *Remote Sensing, 14*(10). https://doi.org/10.3390/rs14102345

Saengsupavanich, C. (2021). Morphological Evolution of Sand Spits in Thailand. *Marine Geodesy, 44*(5), 432–453. https://doi.org/10.1080/01490419.2021.1893873

Vos, K., Harley, M. D., Splinter, K. D., Simmons, J. A., & Turner, I. L. (2019). Sub-annual to multi-decadal shoreline variability from publicly available satellite imagery. *Coastal Engineering, 150*, 160–174. https://doi.org/10.1016/j.coastaleng.2019.04.004

Wang, Y.-H. (1980). SATELLITE APPLICATIONS ON A COASTAL INLET STABILITY STUDY. Coastal Engineering.

Xu, H. (2006). Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery. *International Journal of Remote Sensing, 27*(14), 3025–3033. https://doi.org/10.1080/01431160600589179