Jurnal Ilmu Kelautan
SPERMONDE (2023) 9(2): 39-46

P-ISSN: 2460-0156
E-ISSN: 2614-5049

ANALYSIS OF COASTLINE CHANGES IN GORONTALO CITY USING REMOTE SENSING TECHNOLOGY

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Submitted: August 22, 2023 Accepted: September 10, 2023

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ABSTRACT

Coastal areas are important for economic activities, but are also vulnerable to environmental changes caused by human activities. The use of remote sensing technology can assist in efficient and accurate monitoring of coastline changes related to the spatial-temporal dynamics of coastlines in local areas, which is needed in the development of effective coastal management strategies. By applying the Modified Normalized Difference Water Index (MNDWI) method for coastline extraction, the research results show that the addition of coastal areas (accretion) as a dominant process in coastal stability in almost all coastal areas of Gorontalo City during the period 2000−2022, has experienced the significantly accelerated trend during the 2015−2022 period with an increase in the accretion rate of 60.15%. The rate of accretion in this period has caused an increase in the land area of coastal areas by 425.44% compared to the accretion that occurred during the 2000−2015 period. The findings of this research can be used as a basis for further research regarding the impact of human activities on coastal ecosystems and the effectiveness of Gorontalo City's coastal management strategies.

Keywords: Coastal abrasion/accretion, Google earth engine, coastal stability, satellite image, MNDWI.

INTRODUCTION

Information on coastlines plays an important role in planning activities in coastal areas, especially for Indonesia as an archipelagic country (Ginting & Faristyawan, 2020). The coastline is an imaginary line as the boundary between a body of seawater and land, marking the lowest tide and low tide lines, the highest tide line, and the average water level line which is influenced by the tides. Determining the location of the coastline is very important for exploring and mapping coastal areas, coral reefs and islands. Where, it plays a very important role in planning and protecting coastal areas, ensuring community safety, extracting islands and coral reefs, and improving navigation (Kasim & Salam, 2015; Ding et al., 2021). The research shows the importance of monitoring and detailed study of the spatial-temporal dynamics of coastlines for local areas, considering the dynamic nature of coastlines which caused by processes and factors from land and ocean, such as waves, tidal currents, sea level rise, subsidence. land surface, human activities, and many other factors (Kasim & Siregar, 2012).

Exploitation of coastal resources and migration as well as changes in the lifestyle of coastal communities have a significant impact on the environment and the stability of balance processes in coastal areas. According to Wicaksono & Darmawan (2021), development activities in coastal areas, especially in big cities in Indonesia, tend to neglect the carrying capacity of the environment, especially in coastal border areas. Land use activities in the form of reclamation for settlements, as well as industrial and tourism needs and others are examples that can put pressure on changes in border areas and coastlines which threaten the existence of coastal cities and countries (Hidayah & Apriyanti, 2020; Karlina & Viana, 2020 ; Isdianto et al., 2020).

Since 2000, the coastal area of Gorontalo City has experienced a rapid increase in development activities. This happened in line with changes in the administrative area of Gorontalo. Initially Gorontalo was one of the regions of North Sulawesi Province. Then, the province expanded so that Gorontalo City became the capital of Gorontalo Province. This development condition has an impact on increasing exploration and exploitation of land resources in Gorontalo City area, including the coastal border area, considering that this area is one of the important economic activity centers of Gorontalo City with the presence of a sea port and fishing port, as well as a fish landing site (TPI). Based on this reason, monitoring is needed to obtain an understanding of changes in coastlines in the coastal areas of Gorontalo City to assist effective sustainable development planning in this area.

Remote sensing technology, which is available in various types of data and spatial-temporal resolution (Auliya et al., 2017; Julianto & Anggara, 2021), will make it easier to identify changes in coastlines in coastal areas efficiently in a relatively fast and accurate results (Kurniadin & Fadlin, 2021). The use of remote sensing data is widely used in extracting and detecting coastlines, changing previous traditional methods of data collection thereby providing convenience for large-scale coastline studies to monitor spatial and temporal changes in coastlines (Ding et al., 2021).

This research was aimed to determine changes in the coastline in Gorontalo City from 2000 to 2022 by utilizing remote sensing technology, and the level of accuracy of the results of mapping coastline changes. It is hoped that the data obtained can provide information for the government in determining coastal area management policies for management and development plans for the coastal areas of Gorontalo City.

MATERIALS AND METHODS

The research was conducted from February to April 2023. The research locations were in four sub-districts in the coastal area of Gorontalo City, namely North Leato, South Leato, Pohe and Tanjung Kramat Subdistricts.

The data collected in this research consisted of a selection of image data collections and field data collection through surveys. The two types of data were collected purposively, as follows; 1) The criteria determined in collecting multi-temporal satellite image data are availability for 2000, 2015 and 2022, having a cloud cover percentage of 20%, and having been corrected atmospherically and radiometrically (Table 1). For convenience reasons, this data requirement was collected using the big data cloud platform available on Google Earth Engine. 2) The field data collection survey refers to Kasim & Salam (2015), namely at each location of the extracted feature class required for accuracy test steps, tied-points and other data.

The Modified Normalized Difference Water Index (MNDWI) algorithm method is used to process land and sea boundary delineation data to detect changes in coastlines. MNDWI is an image index calculated from multiband imagery and emphasizes water features while reducing the effects of built-up areas, which are often correlated with water in other indices. The MNDWI formula uses a wavelength range of 0.5-0.6 μm (green band) and the shortwave infrared (SWIR) band with a wavelength of 0.55-1.75 μm., where this index formula is calculated as (Green - SWIR) / (Green + SWIR) (Xu, 2006).

This research used different types of imagery (Table 1), based on a decision on the need for analysis of the type of image data that meets the purposive requirements of cloud cover criteria and its spatial-temporal availability (study area and observation time). The application of these image band types in calculating the MNDWI formula is presented in Table 2.

Table 1. Type of Image Dataset

	Image Data Type	Year	Resolution (m)
1	Landsat 5 TM, *Collection* 2 Tier 1 TOA *Reflectance*	2000	30
2	Landsat 8 Landsat *Collection* 2 Tier 1 TOA *Reflectance*	2015	30
3	*Harmonized* Sentinel-2 MSI: *Multi Spectral Instrument*, Level-2A	2022	10

Table 2. Type of Use of Image Dataset Bands and Application of the MNDWI Formula

No	Image Data Type	MNDWI Formula
1	Landsat-5 Imagery	$\mathrm{MNDWI} = \frac{\text{band 2} - \text{band 5}}{\text{band 2} + \text{band 5}}$ (Xu, 2006)
2	Landsat-8 Imagery	$\mathrm{MNDWI} = \frac{\text{band 3} - \text{band 6}}{\text{band} + \text{band 6}}$ (Hasan et al., 2020)
3	Sentinel-2A Imagery	$\mathrm{MNDWI} = \frac{\text{Band 11} - \text{Band 3}}{\text{Band 11} + \text{Band 3}}$ (Wijayah et al., 2021)

The transformation results of each image dataset produce a MNDWI image map which has a pixel value range of -1 to 1. Positive values indicate the presence of water or puddles and clouds, while negative values indicate the presence of land and built-up areas. The masking step determines the threshold value at the land-water boundary, which can be done through the MNDWI pixel value. The threshold value used in this research is 0.0 to produce a binary image or masking of land against water. Google earth engine makes it possible to export processed datasets for analysis on other platforms.

Related to this condition, the steps for processing image datasets to extract coastlines using the Google Earth Engine platform consist of the stages; selection of datasets according to criteria, temporal and spatial filtering, application of the MNDWI and Otsu threshold methods. The processed dataset in the form of a binary raster (tiff) is exported for further processing in the form of an overlay and confusion matrix for accuracy testing using QGIS software through the raster to vector conversion step. In this study, accuracy tests were carried out on image data interpreted as a result of 2022, following the statement of Lubis et al (2018) that accuracy test calculations can be carried out using image data recorded in the year closest to the year of image data processing.

RESULTS AND DISCUSSION

The results of applying the MNDWI method with an otsu threshold of 0.0 in the form of a land-water binary image are presented in Figure 1.

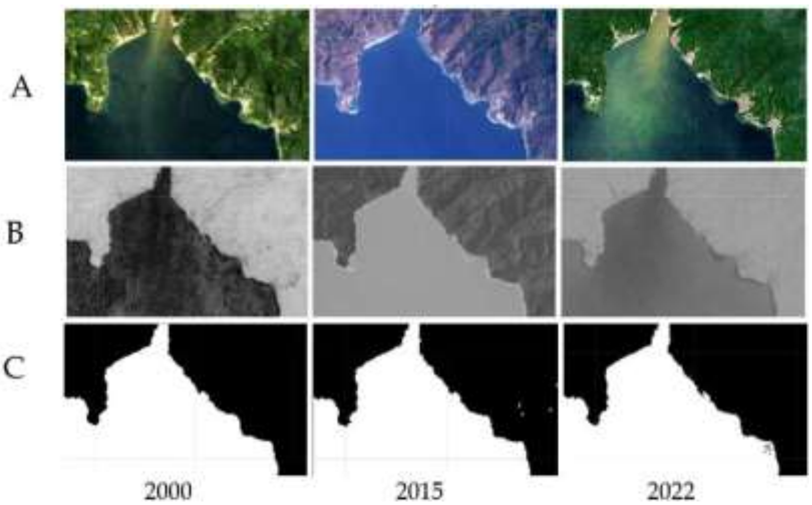

Figure 1. Map of Binary Image Dataset 2000, 2015, 2022 Results of the Transformation of the Application of the Otsu Thershold Alogarithm (Information: A= Composite True Color RGB, B= MNDWI Imagery, C= Binary Image

Coastline features

The coastline feature is the result of masking land against the sea or vice versa, showing a clear display of the boundary differences between land and water as represented by the MNDWI map. Land pixel values tend to be <0 while water bodies have pixel values >0 (Hasan et al., 2020). The application of the Otsu threshold algorithm produces binary image data that groups MNDWI values into two pixel values, namely value 1 as land and pixel value 0 as water bodies (Figure 1). The results of the overlay analysis of the area (polygon) and length of the coastline (polyline) of the coastline in 2000, 2015 and 2022 of the coastal area of Gorontalo City, obtained from the export of binarized raster results as presented in Figure 2.

Coastline Changes

Analysis of changes in beach length and area respectively is presented in Table 3 and Table 4. Based on the results of the analysis, it shows that the accretion process is the dominant process compared to abrasion in each coastal area of Gorontalo City sub-district. Observation of changes in line length and area area features shows this trend of change which is in line with previous reports based on observations for the 2000–2015 time period, for changes in the Dumbo Raya District area (Kasim & Salam, 2015). Further analysis to see the comparison of the rate of change in coastline length, shows a significant rate of change in coastline length over the last 7 years (2015–2022 period) compared to the previous change period of 15 years (2000–2015), with differences in the rate of change in coastline length amounting to 6468.52% (Table 3). A similar comparative trend was also found in the analysis of the rate of change in the area of abrasion and accretion in both observation periods. The abrasion process was reduced from 0.51 ha/year during the 2000–2015 period to 0.49 ha/year in the 2015–2022 period, or a reduction in the abrasion rate of -3.90%. A

Figure 2. Map of Shoreline Changes of Gorontalo City in 2000–2022

different thing is the increase in area caused by the accretion rate, namely 1.37 ha/year in the 2000–2015 period to 2.19 ha/year in the 2015–2022 period or an increase of 60.15% in the accretion rate in both periods. Where, the comparison of the rate of change in coastal area in these two periods was 425.44% (Table 4).

Table 3. Changes in the Feature Length of the Shoreline in the City of Gorontalo

Coast of Gorontalo City	Length of Shoreline (km)			Changes			
	2000	2015	2022	2000–2015	Rate (m/yr)	2015–2022	Rate (m/yr)
North Leato	1.175	1.167	1.438	-0.008	0.53	0.27	38.71
South Leato	3.403	3.413	4.216	0.01	0.67	0.8	114.71
Pohe	1.37	1.398	1.811	0.028	1.87	0.41	59
Tanjung Kramat	2.435	2.464	2.758	0.029	1.93	0.29	42
Total length (km)	8.383	8.442	10.223	0.059	3.93	1.78	254.43

Table 4. Area of Abrasion and Accretion of Polygon Feature in Gorontalo City

Coast of Gorontalo City	2000–2015				2015–2022			
	Area (Ha)		Process	Rate	Area (Ha)		Process	Rate
	Abrasion	Accretion	Dominant	(m^2/yr)	Abrasion	Accretion	Dominan	(m^2/yr)
North Leato	0.54	0.21	Abrasion	-0.02	0.12	1.17	Accretion	0.15
South Leato	0.65	3.04	Accretion	0.16	1.53	2.47	Accretion	0.13
Pohe	0.13	0.64	Accretion	0.03	0	2.53	Accretion	0.36
Tanjung Kramat	0.73	1.58	Accretion	0.06	0.32	2.59	Accretion	0.32
Total area (ha)	2.05	5.47	Accretion		1.97	8.76	Accretion	
Rate of area change (ha/yr)				0.23				0.97
Average rate of change (ha/yr)	0.51	1.37			0.49	2.19		

The causes of coastal accretion in Indonesia are influenced by several causal factors, namely: beach reclamation (Mutaqqin et al., 2021), as well as the presence of artificial buildings such as groynes, jetties, breakwaters and harbors (Munandar & Kusumawati, 2017). Apart from that, the existence of large rivers, such as those found on the East coast of Sumatra and Kalimantan, can also be a cause of coastal accretion because they supply sediment which can change the coastline (Yulius et al., 2020). The conditions of these various factors, except reclamation, can be found in the coastal conditions of the Gorontalo City area. However, further hydro-oceanographic research is needed to determine the dominant factors contributing to accretion due to the contribution of sedimentation originating from river estuaries in the study area. This research is important, considering previous information which states the implications of sediment load in the dominant accretion in the coastal area of Gorontalo City based on geomorphological conditions, namely the confluence area of the Bolango River and the Tamalate River flowing into the city area as well as the downstream part of the Bolango river basin (DAS) thereby providing negative impacts around the river estuary area. This is influenced by activities in upstream areas (upland areas in the form of flows of sediment and other materials. Likewise, there is an increase in basic infrastructure development activities and economic growth and has an impact on increasing densely populated residential areas in coastal areas both along the Bone River estuary and the borders coast (Husain et al., 2019). Our findings show that the alleged implications of the contribution of sedimentation and infrastructure growth to the beach accretion process in the coastal area of Gorontalo City has accelerated over the last 7 years (2015– 2022 period).

Coastline map accuracy

Coastline mapping has varying accuracy based on each determination technique. Several known methods for making coastline maps are field surveys, mapping via aerial and drone photos, and satellite image data. The difference in map accuracy resulting from the delineation of coastline features from other earth surface features is related to the dynamic nature of the sea surface in coastal areas related to the uncertainty in the position of the coastline feature lines extracted according to the datum conditions related to the tides of each mapped location (Kasim, 2011; Oktaviani et al., 2021). Based on the type of coastline determination, the best accuracy of coastline maps is of course through direct surveys in the field.

For coastline position delineation using aerial photography data and satellite image data, accuracy regarding the uncertainty of the datum position during image acquisition will be largely determined by image resolution, slope and tidal range area, as well as the position of the water level in each datum condition (Kasim, 2011). However, our research does not include the tidal correction stage in analyzing the coastline feature delineation results. Several things to consider are that in general the coastline of Gorontalo City has the topographic characteristics of a steep beach type with a narrow tidal range area, as well as the absence of datum data that represents the position of water surface pools during High Astronomical Tide (HAT) tide conditions in the form of higher high-water levels. (HHWL) and high-water level (HWL), as well as the low tide position of the Lowest Astronomic Tide (LAT) which consists of low water height (LLWH), and low water height (LWH) as well as the Coastal Environment Map (LPI) which is a reference for the mean sea level (MSL).

In the absence of tidal correction steps, the coastline delineation results for 2000, 2015, and 2022, the accuracy of the coastline map and the uncertainty of changes in this research refer entirely to the image dataset processing steps calculated using the confusion matrix method on the resulting map. The accuracy test value for the confusion matrix of binary image data resulting from MNDWI masking processing on the Sentinel 2022 dataset in this study was 96.4%, showing very good results as presented in Table 5.

The level of accuracy of our research's coastline extraction results using the MNDWI method on the Sentinel-2 dataset is in accordance with other reports which state that the application of the MNDWI algorithm method is one of the best methods for clearly separating water and land bodies, with an accuracy level of around 99.85% (Abrar, 2022; Hasan et al., 2020).

Table 5. Confusion matrix of Accuracy test result

Classification	Field Data		Total
	Water body	Land	
Water body	28	0	28
Land	2	26	28
Total	30	28	56
Producers accuracy	0,92%		
Consumers accuracy	0,93%		
Kappa accuracy	0,92%		
Overall accuracy	96,4%		

Where, when compared with NDWI, MNDWI often produces greater water surface values because water has the property of absorbing electromagnetic waves more strongly in the SWIR band than in the NIR band (Tuan et al, 2019).

Our research also does not look at comparisons of water index transformation methods in analyzing coastline change trends. However, in addition, there are several things that determine the level of accuracy of the type of water index transformation in delineating the coastline. Such as the selection value of the threshold value, the condition of the original image dataset used to apply index transformation, the choice of index formula used, the presence of mixed pixels, as well as atmospheric disturbances in the form of cloud and fog coverage. Likewise, there is no single water index that provides good coastline retrievals for all types of land cover classes, especially at a scale of 1:100,000 (Wicaksono & Wicaksono, 2019; Sasmito et al., 2021; Cholidah, 2022).

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CONCLUSION

This research shows that the use of remote sensing technology, especially the MNDWI water index method, has helped monitor coastline changes efficiently and accurately. With this technology, detailed information on the stability of both coastline features and the area of the coastal area of Gorontalo City is known to experience an accretion trend throughout 2000-2022. The findings of this research highlight the accretion trend which caused an increase in coastline of 0.059 km during 2000-2025 and 1.78 km in 2015-2022, which means an acceleration of accretion of 6468.52% between the two periods. The same trend was also found in changes in area area, where although abrasion and accretion took place throughout the region, the predominant rate of accretion has accelerated by 60.15% compared to abrasion which experienced a reduction in acceleration of -3.90% in the 2015-2022 period. The comparison of abrasion/accretion rates has resulted in an increase in beach area of 425.44% between the two periods. From these results, this study recommends the importance of efforts to develop effective coastal management strategies to reduce the negative impacts of human activities on ecosystems in the coastal areas of Gorontalo City.

ACKNOWLEDGMENT

The author would like to thank the Faculty of Fisheries and Marine Sciences, Gorontalo State University as the sponsor in financing collaborative research between students and lecturers.

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