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Research Article

Morphological Evolution of the Binahaan River, Palo, Leyte, 6501, Philippines

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ABSTRACT

Using Landsat satellite images, this study evaluated the morphological evolution of the Binahaan River, Palo from 2000-2020. It focuses on quantifying the morphological changes in terms of river planform parameters namely channel width, channel length, channel area, and sinuosity, as well as erosion and accretion rates. Multi-temporal satellite images were collected and analyzed to recognize the quinquennial and seasonal alterations. With the quantification of the spatial extent and rates of bank-line alterations by means of remote sensing, the purpose is to better understand the erosion and accretion processes of the Binahaan River from the perspective of its planform parameters. Throughout the study period, the river experienced significant morphological changes in planform; however, no consistent trend was found due to the dynamic nature of the river. The seasonal and quinquennial erosion and accretion rates of the river were also analyzed. It was found that the right bank line was more susceptible to erosion and accretion. Seasonally, the river was more prone to sediment accumulation which led to the narrowing of channel widths and decreasing channel area. In the quinquennial comparison during the dry seasons, the river was mostly dominated by erosion, while during wet seasons, the river was more prone to accretion. In terms of change in the area, whether by loss or gain of land, the river consistently displayed increasing change from 2000 to 2020. The results of this study could be utilized to develop an integrated strategy for its management and restore the fundamental processes that shape and maintain the river.

Keywords: River, remote sensing, morphological changes

INTRODUCTION

River morphology and channelization are attributed to sediment flow, deposit characteristics, river discharge patterns, and erosion-accretion processes occurring in spatial and temporal scales. In addition to natural interferences, human constructions such as the building of bank protection structures, channel width widening, bridges, artificial cutoffs, dams, and land use adjustments also modify the physical configuration and fluvial processes of these river systems (Credit Valley Conservation, 2012; Dar, Mir, & Romshoo, 2019).

The unpredictable character of seasonal rain during monsoons in the Philippines encourages diverse behavior in river flow, which can alter channel characteristics and result in floods, changes in drainage patterns, and sediment deposition (Asio & Cagasan, 2014). These morphological alterations may aggravate erosion, accretion, and channel instability, inducing environmental problems such as flooding, debris flows, and water quality degradation (Baki & Gan, 2012; Hossain et al., 2013). Consequently, these directly influence the riverine and riparian coenoses because these provide the setting for the ecological processes and the habitats of the flora and fauna of the river (Elosegi, Díez, & Mutz, 2010; Gran et al., 2015; Michal & Gran, 2014).

The Binahaan River is one of the biggest rivers in the province of Leyte, Philippines. It supplies the Leyte Metropolitan Water District (LMWD) with potable water for the city and several towns of the province (Figure 1). However, due to varying natural occurrences such as moderate to heavy flooding, exacerbated by human activities and urban development, it is perceptible that the primeval condition of the river and topography has been altered.

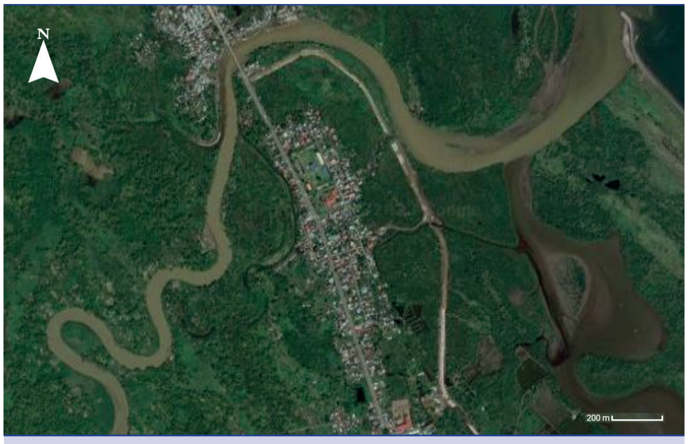

Figure 1. Binahaan River study area taken from Google Map images.

As watersheds within the Philippines are characteristically prone to flooding, debris flows, liquefaction, storm surge, and soil erosion, the Binahaan River is likewise predictably prone to these naturally-occurring geological alterations. In fact, for the past eight years, the Department of Environment and Natural Resources (DENR) discussed significant laws concerning environmental protection and preservation of the river. Further, according to the Philippine Information Agency (2011), there has been extensive destruction of the Binahaan Watershed mainly due to illegal or unmonitored activities being conducted in the past years.

As mentioned, the Binahaan River in the Philippines is an important source of water, but there has been little research done on its features. Obbus et al. (2021) aimed to develop a model to classify the river's geomorphic typologies and identified 12 types based on parameters such as sinuosity, entrenchment ratio, and channel material. They found that Typology B5c was dominant and sand was the most common channel material. More importantly, sand mining has disturbed the river and reduced the recovery potential of the river. The identified typologies of the Binahaan River will be significant components for future research focusing on biodiversity and its relationship with the river's geomorphology. Other than sand mining, channel interventions, such as riparian land use, bank line infrastructures, and sand extraction areas for construction purposes, were also present. Locals were also found to fish and mine in the river based on ocular surveillance.

Hence, to mitigate the risk of flooding and debris flows due to the mentioned natural and anthropogenic activities and contribute to improving the ecological conditions of the river, it is necessary to analyze the seasonal morphological evolution and the sediment transport dynamics and river flow of the Binahaan River (Department of Environment and Natural Resource, n.d.). In this regard, this present study assessed the seasonal and quinquennial morphological changes of the Binahaan River.

Data from assessing the morphological changes of the Binahaan River using satellite images provided important information on the river's geomorphology. Using Landsat satellite images, this study assessed and quantified the morphological changes of the Binahaan River throughout the years 2000 - 2020. Seasonal data was acquired through the recommendation of the Philippine Atmospheric, Geophysical and Astronomical Services Administration (Retrieved May 20, 2023). Using temperature and rainfall as bases, the wet season was defined from June to November while the dry season was defined from December to May. However, the unavailability of higher-resolution images, as well as the sporadic capture of imagery in the area of interest and cloud cover reduced optical data and limited the potential outcomes of the study.

By assessing the morphological evolution of the Binahaan River in Palo, the study described the probable impacts on the river and its geomorphology, proving to be helpful in developing an integrated strategy to enhance the management, if not restore, the fundamental processes that shape and maintain the river. This could additionally contribute to drafting policies for its maintenance and flood management, without compromising the socio-economic aspect of this river system, assisting concerned government bodies in planning for effective and sustainable flood risk and land use management, river restoration projects, and agricultural land management practices.

MATERIAL AND METHODS

Satellite data collection

Multitemporal Landsat Collection 2 Level 1 image products from Landsat 7 and 8 were collected through USGS Earth Explorer and were used as data sources. Landsat images with a spatial resolution of 30 x 30 m^2 were collected from 2000 - 2020. These images were geometrically matched and projected onto the same map coordinates (Table 1).

Satellite image processing

Satellite images were processed and analyzed using the QGIS software. These images were subjected to two correction procedures before the final image processing. The radiometric correction involved the conversion of the measured multispectral brightness values to top-of-atmosphere (TOA) reflectance units to eliminate discrepancies between images as a result of sensor differences, Earth-sun distance, and solar zenith angle caused by the different scene dates, overpass time, and latitude distances (Table 2). The images were subjected to pansharpening and merging with high-resolution panchromatic images. A Modified Normalized Difference Water Index (MNDWI) was calculated through Eq. 1:

Table 1. List of satellite data used in the study.

Satellite Data	Acquisition Date	Spatial Resolution (m)	Band Number
Landsat-ETM	May 26, 2000 December 04, 2000 April 19, 2004 November 13, 2004 April 07, 2011 October 16, 2011	30	2, 5, 8
Landsat-OLI	May 28, 2015 November 20, 2015 May 25, 2020 November 17, 2020	30	3, 6, 8

Table 2. Satellite data specifications for MNDWI calculation.

Landsat	Green	MIR	Panchromatic	Final Spatial Resolution (m)
Landsat 7	Band 2	Band 5	Band 8	15
Landsat 8	Band 3	Band 6	Band 8	15

$$MNDWI = \frac{Green - MR\ (Mid\ Infrared)}{Green - MIR\ (Mid\ Infrared)} \quad (1)$$

Satellite data analysis

Delineating the bank lines in the processed satellite images is a principal step in the assessment of the collective impact of geomorphic processes and anthropogenic activities on the morphological evolution of the river. A bank line is defined as the feature that separates the outer margin of a river channel from the floodplain (Hossain et al., 2013). Four river planform parameters were selected in accordance with the topographic and geographical characteristics of the river – channel width, area, length, and sinuosity.

Spatial analysis and parameter value calculation were conducted, wherein the channel area was the instantaneous water surface area of the river, the channel width was calculated as a range, the left bank length was defined as the left side along the river flow direction, the right bank length was defined as the right side along the river flow direction, and the sinuosity index was calculated through Eq. 2:

$$Sinuosity\ Index = \frac{CL}{SL} \quad (2)$$

wherein CL = Channel length and SL = Straight line distance between start and endpoints (García, 2015).

Policy assessment and recommendation

Current policies of the Local Government Unit were reviewed and assessed to determine the current state of the environmental protection and management of the river. Policy recommendations based on the outcome of the study will be drafted at a later date. For a comprehensive assessment of the morphological evolution of the Binahaan River, Palo, seasonal changes within a year, as well as quinquennial changes, were evaluated. The results of the morphological changes of the river are discussed below.

RESULTS AND DISCUSSION

Ideally, the best approach to accurately detect the morphological changes of a river body is by analyzing multiple satellite data over a consistent time interval. However, sporadic capture of imagery of the area of interest as well as cloud cover, which impedes optical data, restricted the availability of satellite images appropriate for the study. Gathering a continuous time series of data with a consistent interval proved to be unachievable. As such, the researchers employed satellite images from neighboring years on periods with no available data. In this study, Landsat satellite images from 2000, 2004, 2011, 2015, and 2020 were acquired. The 30 × 30 m^2 spatial resolution of Landsat data limited the extent of the precision of the monitoring of morphological changes. Even with the application of higher-resolution panchromatic images, assessments of changes in erosion and accretion along the river banks were approximate and subject to an order of accuracy comparable to the spatial resolution of the satellite images.

River planform parameters

Changes in the river channel of the Binahaan River, Palo were estimated in terms of channel width, channel length, channel area, and sinuosity (Figure 2).

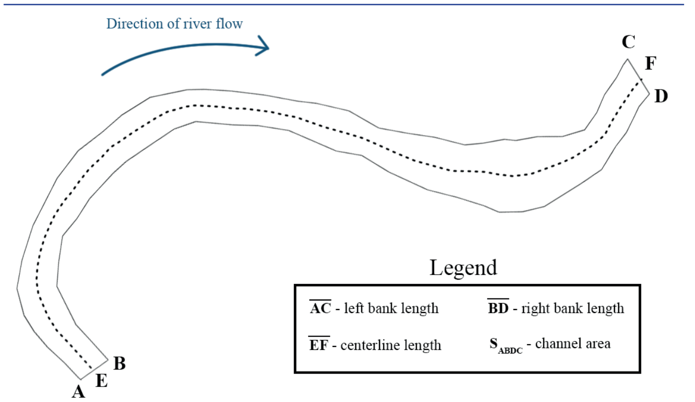

Figure 2. Illustration of river planform parameters Illustration of river planform parameters.

Channel width

Based on the results found in Table 1, the channel width of the river ranged from 19.348 m to 135.633 m, both found in the wet seasons of 2004 and 2015. Typically, the area within the first to third meander from the river source measured the smallest width (Figure 3), while the area near the river mouth measured the greatest width (Figure 4). This phenomenon is reasonable for several factors, such as the increase in the volume of water as well as the velocity downstream, changes in the landscape, channel patterns, and human activities. All these contribute to the changes in the river width as these lead to erosion and accretion or lateral movement in both banks (Mohammadi et al., 2008).

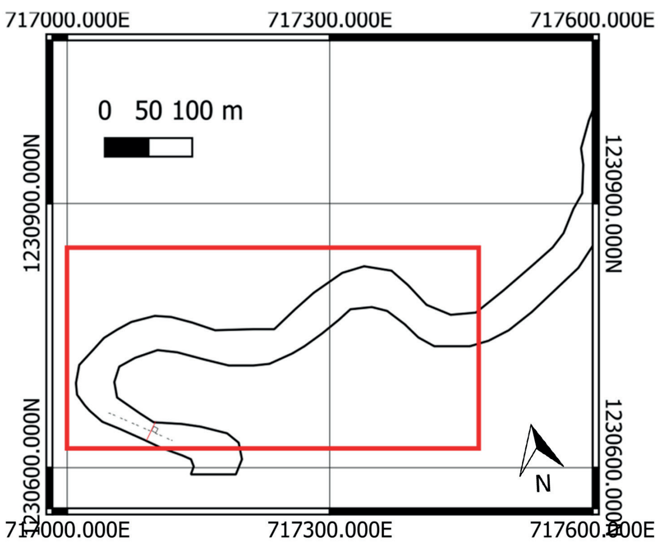

Figure 3. Area of the river where least channel width is usually observed.

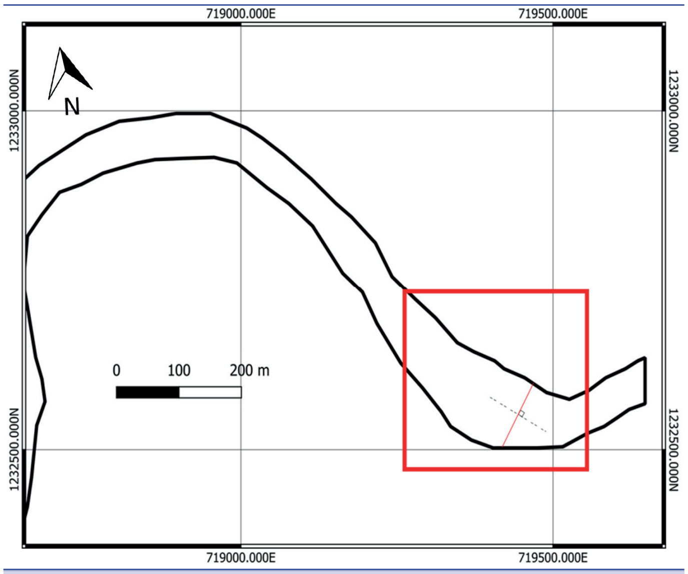

Figure 4. Area of the river where greatest channel width is usually observed.

There was no uniform pattern in the changes in maximum and minimum widths between the two seasons (Figure 5). In 2000, the maximum width increased while the minimum width decreased from the dry to the wet season of the year, so the range difference between the two increased by about 24 m. This change was identified to be the greatest throughout the study period. Such an event was similar for 2004 and 2015 but with a slight increase and decrease in the maximum and minimum width within the seasons of the said years. However, an opposite pattern was seen in the year 2011 between its dry and wet seasons when the maximum width decreased while the minimum width increased. This resulted in the lowering of the width range between seasons with a range difference of 13 m. From the dry to wet seasons of the year 2020, both the maximum and the minimum widths decreased. As for the quinquennial change, the average maximum and minimum width alteration were graphed in Figure 6. Only a minimal change was detected, except from 2000 to 2004 when a more noticeable increase in the maximum channel width could be recognized. On the other hand, the average minimum width showed an increasing pattern of data starting from the year 2000 to 2015, but a decreasing one from 2015 to 2020. On average, the maximum channel width, minimum channel width, and width range resulted in 126.613 m, 24.341 m, and 102.272 m, respectively.

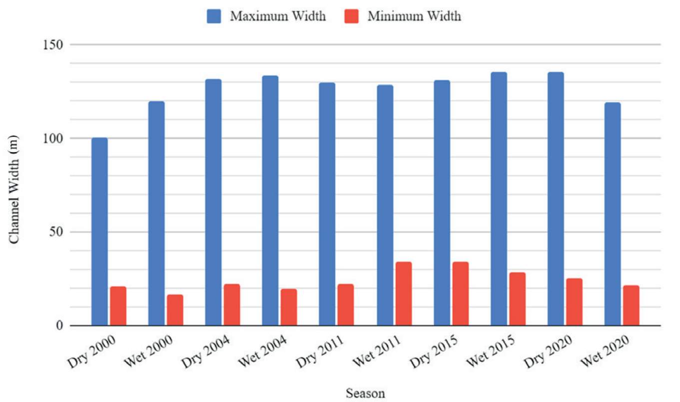

Figure 5. Seasonal changes in channel width.

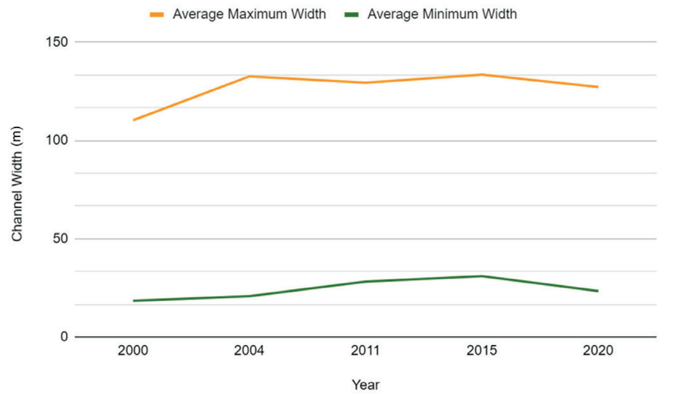

Figure 6. Quinquennial changes in channel width.

Channel length

Minimal changes were observed between the dry and wet seasons for both the left and the right bank lines of the river (Figure 7) apart from 2004 which measured length differences of about 369 m and 230 m, respectively. Within a year, 2011 had the least change of length in the left bank line with a measure of approximately 11 m, as well as in the right banking with a length difference of about 30 m.

Starting from 2011 to 2020, an increasing pattern can be recognized for the left and right bank lines of the river as represented by Figure 8. It is different, however, from 2000 to 2004 as there was a decrease in length for both of the bank lines. Generally, the average channel length of the left and right bank lines measured higher in 2020 than in 2000 with a calculated difference of about 118 m and 206 m, respectively. Moreover, there was only a slight change in channel length for the different sides of the river during the time period of the study.

Channel area

In the years 2004, 2015, and 2020, the channel area was greater during the dry season than the wet season with a difference of 6,450.662 m^2, 43,597.662 m^2, and 19,997.125 m^2, respectively (Table 3). On the contrary, in the years 2000 and 2011, the values of

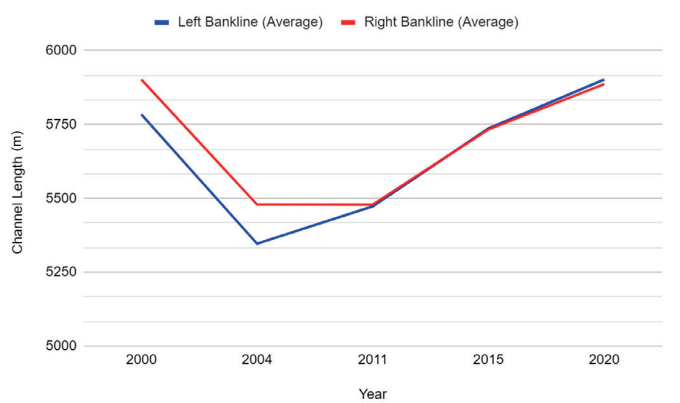

Figure 7. Seasonal changes in channel length.

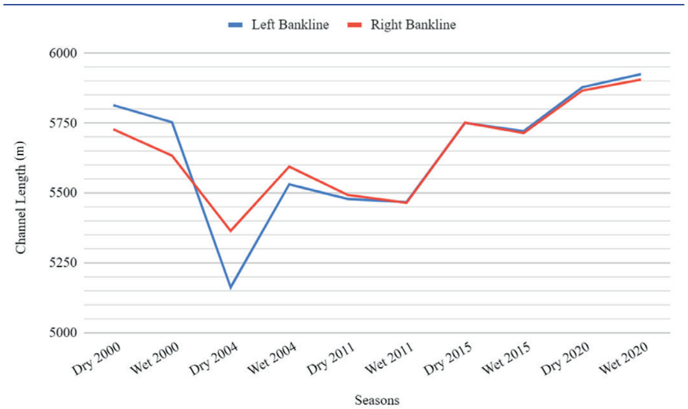

Figure 8. Quinquennial change in channel length.

Table 3. Changes in channel width.

Year	Season	Channel Width (m)	
		Maximum	Minimum
2000	Dry	100.564	20.736
	Wet	120.055	16.174
2004	Dry	131.513	22.323
	Wet	133.784	19.348
2011	Dry	130.109	22.275
	Wet	128.653	22.275
2015	Dry	131.395	33.759
	Wet	135.633	28.131
2020	Dry	135.219	25.373
	Wet	119.204	21.320

the channel area were greater during the rainy season than in the dry season. The wet seasons of 2000 and 2011 had a channel area greater by 28,220.716 m^2 and 20,917.073 m^2. Overall, there was no consistent trend between the channel areas of the processed river segments with regard to seasonality. The area of the river segment approximated 265,511.301 m^2 by 2000 but slightly decreased to 259,355.595 m^2 by 2004. As seen in Figure 9, the average channel area continued to increase throughout 2011 and was successively maximized by 2015, particularly during the dry season, with a value of 311,691.882 m^2. Afterwards, the channel area fell substantially during the year 2020 with around 48,907.667 m^2 less in value.

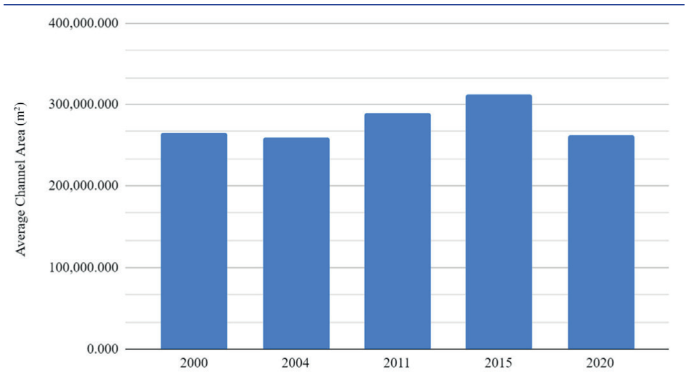

Figure 9. Quinquennial changes in average channel area.

Sinuosity

The sinuosity of the river is regarded as a measure deviation of a river from its ideal path movement. However, as a straight-line path is nearly impossible to achieve due to several geomorphic factors, the sinuosity index was used to highlight irregularities in the channel path instead. In Table 4, the sinuosity indices of the river are enumerated. In accordance with the river sinuosity classification, the Binahaan River, Palo was characterized as a sinuous river with an average sinuosity of 1.778 in the span of two decades (Table 5). The right bank consistently measured greater sinuosity than the left bank, suggesting that the right bank is more susceptible to erosion and accretion. Furthermore, the sinuosity of the centerline of the river follows the sinuosity of the left

Table 4. Changes in channel area.

Year	Channel Area (m²)	
	Dry	Wet
2000	251,400.943	279,621.659
2004	262,580.926	256,130.264
2011	278,783.067	299,700.140
2015	333,490.768	289,892.996
2020	272, 782.778	252, 785.653

Table 5. Changes in sinuosity.

Year	Season	Bank lines		
		Left	Right	Centerline
2000	Dry	1.785	1.822	1.784
	Wet	1.767	1.780	1.751
2004	Dry	1.593	1.711	1.637
	Wet	1.711	1.777	1.720
2011	Dry	1.721	1.789	1.739
	Wet	1.716	1.789	1.732
2015	Dry	1.807	1.886	1.823
	Wet	1.798	1.868	1.843
2020	Dry	1.841	1.917	1.863
	Wet	1.869	1.928	1.885

bank line more closely than the right bank. No consistent pattern in sinuosity was recognized between the dry and wet seasons of the same year. However, average quinquennial changes revealed a more consistent trend. A decreasing sinuosity index was observed only in the period between 2000 and 2004 because of the straightening of the channel path that led to the loss of a meandering section of the river between the two time periods. Apart from that, the general trend showed that the sinuosity gradually increased, with an increase of 0.195 in the centerline sinuosity between 2004 and 2020 which implies the presence of shifting of the channel and bank lines. The increase in sinuosity of a river is related to an increase in bank erosion as it causes a decrease in streamflow velocity (Hossain et al., 2013).

Erosion and accretion

Seasonal erosion and accretion

The largest eroded bank area was recorded in the year 2000, while the smallest was recorded in 2015. On the other hand, the year 2015 recorded the largest accreted area, while the year 2011 recorded the smallest accreted area. On average, the river seasonally eroded 40,905.634 m² and accreted 45,300.617 m² for a seasonal net gain of 4,394.983 m² of land. With this, it can be inferred that the river is more prone to accretion, which may lead to the narrowing of the channel width and a decrease in the channel area from dry to wet seasons, as seen in Figure 10.

Quinquennial erosion and accretion during dry seasons

The river consistently lost land from 2000 to 2015. To be specific, the river lost 11,179.920 m² from 2000 to 2004, 16,202.162 m² from 2004 to 2011, and 54,707.774 m² from 2011 to 2015 (Table 6).

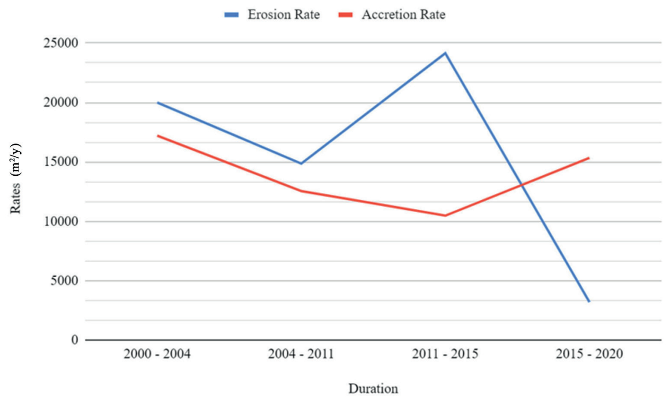

Figure 10. Quinquennial erosion and accretion rates during dry seasons.

Table 6. Quinquennial eroded and accreted areas during dry seasons.

Year	Area (m²)	
	Eroded	Accreted
2000 - 2004	79,990.204	68,810.284
2004 - 2011	103,975.412	87,773.25
2011 - 2015	96,604.862	41,897.088
2015 - 2020	15,994.3958	76,702.442

This continuous erosion contributed to the widening of the channel width and an increase in the channel area. However, during the recent time period from 2015 to 2020, the Binahaan river exhibited decreasing erosion and increasing accretion with a net gain of 60,708.047 m². In terms of change in the area whether by loss or gain of land, the river consistently displayed increasing change from 2000 to 2020. As observed in Figure 11, the river was mostly dominated by erosion throughout the period covered by the study with an estimated average annual erosion rate of 15, 550.319 m² and an average annual accretion rate of 13, 889.092 m² for an average annual net loss of 1, 661.227 m². The river recorded the fastest rate of erosion of 24,151.216 m²/yr. between 2011 and 2015 while the slowest rate of erosion of 3,198.879 m²/yr. between 2015 and 2020. Meanwhile, the river recorded the fastest rate of accretion of 17,202.571 m²/yr. between 2000 and 2004 and the slowest rate of accretion of 10,474.272 m²/yr. between 2011 and 2015.

Quinquennial erosion and accretion during wet seasons

In the three consecutive time intervals, the river exhibited an alternating pattern between land gain and land loss with a net gain of 23, 491.496 m² from 2000 to 2004, a net loss of 43,569.847 m² from 2004 to 2011, and a net gain of 13,300.136 m² from 2011 to 2015. It was only from 2011 to 2020 that the river followed a consistent trend of land gain while the period from 2015 to 2020 followed the previous interval's trend with a net gain of 33,615.345 m². Overall, it can be observed in Figure 12 that only during the period between 2004 to 2011 did the river have a greater erosion rate than accretion while the others exhibited an inverse phe-

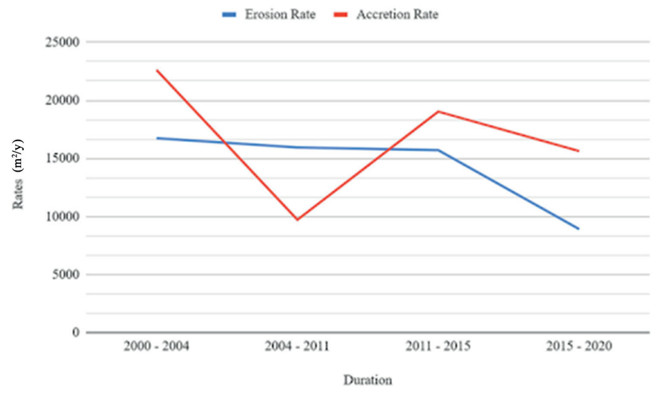

Figure 11. Quinquennial erosion and accretion rates during dry seasons.

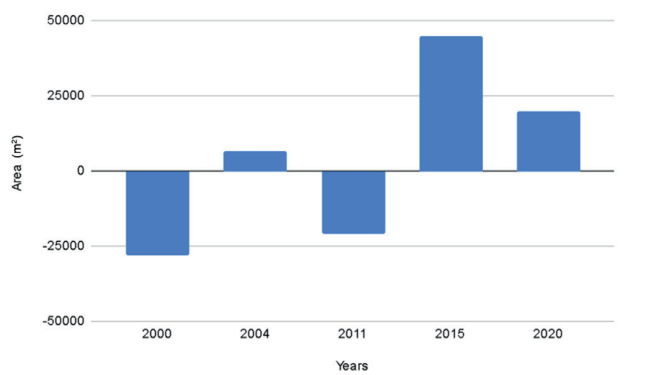

Figure 12. Seasonal eroded and accreted areas.

nomenon, indicating that the river is more prone to accretion with an estimated average annual erosion rate of 14,321.949 m^2 and average annual accretion of 16,746.077 m^2 for an annual net gain of 2,424.128 m^2. The river recorded the fastest rate of erosion of 16,737.000 m^2/yr. between 2000 and 2004 while the slowest rate of erosion of 8,906.666 m^2/yr. between 2015 and 2020. Meanwhile, the river recorded the fastest rate of accretion of 22,609.874 m^2/yr. between 2000 and 2004 and the slowest rate of accretion of 9,713.865 m^2/yr. between 2004 and 2011 (Table 7).

Impact of natural phenomena

In a study by Marteleira (2019) about the impacts of climate change on some rivers, the Binahaan River was found to have an insufficient flow, making it one of the water bodies to be categorized as not a resilient water source and river basin based on the hydrological model QSWAT. With that, it could be said that such a river system is prone to deformation and change.

As stated on the Modified Corona's Climate Classification, the Binahaan River, Palo is characterized by fair rainfall distribution for the entire year and is also categorized under tropical wet climate having significant rainfall even amidst dry seasons. As high amounts of water flow in streams or rivers, such water bodies experience flooding. According to the College of Forestry and Natural Resources, the Binahaan River, Palo, is susceptible to flooding. For the municipality of Palo, with an area of 65.34 sq. km., it is identified that 53.26% will be able to encounter flood levels of less than 0.20 m, 11.10% of the area will experience flood levels of 0.21 to 0.50 m, while 2.25%, 0.27%, and 0.097% of the area will experience flood depths of 0.51 to 1 m, 1.01 to 2 m, and more than 2 m, respectively. Apart from that, the said river also has the largest area with serious incidents of erosion comprising about 1,387 ha. among the principal river basins and minor watersheds of Cluster 5 (College Forestry and Natural Resources, n.d.). These climate trends and natural hazards paved the way for some morphological changes to occur in the Binahaan River, Palo.

Table 7. Quinquennial eroded and accreted areas during wet seasons.

Year	Area (m^2)	
	Eroded	Accreted
2000 - 2004	66,947.998	90,439.494
2004 - 2011	111,566.904	67,997.057
2011 - 2015	62,824.000	76,124.136
2015 - 2020	44,533.3268	78,147.671

Impact of human activities

Anthropogenic influences are thought to exacerbate erosion and sedimentation in the Binahaan River, Palo. In the Binahaan River, Palo, black sand mining is an essential livelihood for the households residing near the river and a source of sediment for local construction. Black sand mining activities are particularly prominent near the mouth of the river, wherein machinery like grapple trucks excavate the area. However, locals also individually mine points along the river by manually scooping up sand from the riverbed. This method of mining alters the planforms and composition of the river. Although black sand mining is an important element in local commerce, it disturbs the riverine ecosystem and makes the river more susceptible to erosion and as a result, other associated geohazards. It not only increases erosion by directly removing sand but also by disrupting the riverbed sediment distribution (Chaussad & Kerosky, 2016). As such, erosion may continue to affect adjacent areas even decades after the mining activity.

CONCLUSION

Several morphological changes were observed over the course of two decades. The river exhibited significant changes in channel width and area; however, no consistent trend of increase or decrease was found due to the dynamic nature of the river. The right bank consistently measured greater sinuosity than the left bank line, suggesting that the right bank is more susceptible to erosion and accretion. Furthermore, a steady increase in sinuosity can be observed during recent years that contribute to the lengthening of the bank lines. The channel shifting and lengthening bank lines indicate an increase in the amount of land erosion and accretion that the river has been experiencing. This was supported by the erosion and accretion rates of the river. Seasonally, the river is more prone to accretion which led to the narrowing of channel widths and decreasing channel areas between dry and wet seasons. In the quinquennial comparison during the dry seasons, the river was mostly dominated by erosion. On the other hand, in the quinquennial comparison during wet seasons, the river was more prone to accretion. In terms of change in the area whether by loss or gain of land, the river consistently displayed increasing change from 2000 to 2020.

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