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Assessment on Coastal Changes at Kuching Wetland National Park, Sarawak

[1]Ainul Husna Abdul Rahman
[2] Mohamad Zaid Sapii
[3]Sarah Rozalia Sai'aulil'lah

[1,2,3] Faculty of Defence and Science Technology, Kuala Lumpur, Malaysia

Ainul Husna Abdul Rahman

Abstract - The Kuching Wetlands National Park, designated as a Ramsar Wetland Site, holds significant ecological importance and biodiversity. It provides mutual benefits with marshes in sustaining aquatic ecosystems. Despite their crucial role, mangrove forests face alarming destruction, often due to the oversight of their non-market environmental values in developmental decisions. This study investigates shoreline change and coastal erosion dynamics in the Kuching Wetlands National Park from 2019 to 2023. Utilizing remote sensing and GIS techniques, coastlines were demarcated and extracted from Landsat images to facilitate DSAS-based change detection. The results reveal significant erosion rates, particularly along the park's western boundary. Anthropogenic activities emerge as primary contributors to this erosion, with about 62.77% of the coastal area experiencing erosion and rates reaching up to 12.46 meters per year. Monitoring and addressing shoreline dynamics is crucial to safeguarding coastal environments and communities from the adverse effects of erosion and accretion.

Keywords: Coastal changes, DSAS, Landsat, Kuching Wetlands National Park

[INTRODUCTION]

Background

Wetlands, particularly the Kuching Wetland National Park in Sarawak, play a vital role in mitigating the increasing hazard risks in the region (J.K, 2019). The rapid urbanization in Kuching, Sarawak, driven by population growth and the consequent demand for land, has heightened the threats to these wetlands (Jones, M. P., Ozga-Hess, J. E., & Shen, 2020). These threats are further intensified by the high incidence of hazards such as urban floods, coastal floods, and landslides (Brown, G., 2018) which pose significant risks to human populations and infrastructure. The degradation and loss of wetlands due to urbanization exacerbate these hazards (Leal and Spalding, 2022) increasing the vulnerability of coastal communities and worsening the impacts of hazard events (Chen *et al.*, 2019). Therefore, conserving and managing wetlands like the Kuching Wetland National Park is crucial not only for preserving biodiversity and ecosystem services but also for enhancing resilience against the rising hazard risks in the region (Omar, Misman and Linggok, 2018).

Recent statistics underscore a concerning trend, revealing a 50% increase in mangrove habitat loss due to floods over the past decade (Leal and Spalding, 2022). Coastal zones are experiencing significant alterations resulting from both natural and anthropogenic impacts. The physical environment of shorelines is being affected by processes of erosion and accretion. In coastal regions, where natural processes and human activities are the primary drivers of shoreline changes, these changes are recognized as significant dynamic shifts.

Mohd Azhar (2018) investigated shoreline alterations caused by natural processes, focusing on the interplay of waves, currents, tides, and river flow, which often result in coastal erosion. Unplanned development and increasing population in coastal areas contribute to human-induced changes. Coastal accretion and erosion are inevitable processes due to the continuous movement of sediments by tides, currents, winds, and waves. Routine activities such as harbor construction and sand dredging disrupt sediment continuity, accelerating coastal erosion (Azhar et al., 2018). Rising sea levels, climate change, and storm surges further complicate coastal erosion. (Ehsan et al., 2019) agreed that sea level rise due to global climate change sign. Therefore, understanding shoreline changes over time is crucial for identifying patterns of impact in specific areas.

The study of shoreline dynamics has been facilitated by recent technological advancements (Selamat et al., 2017). Traditional methods of field surveys and observation are both time-consuming and costly. Considering this, there is a need for time-efficient and cost-effective approaches to mangrove mapping, which can be achieved through remote sensing technologies (Maurya et al., 2021).

Geographic Information Systems (GIS) integrate geographic location data with attribute information. The historical rate of change can be determined using GIS and remote sensing technology. Aerial photographs, bathymetric surveys, beach profiles, historical maps, and topographical data can all be utilized to analyse spatial and temporal changes in coastal environments both qualitatively and quantitatively. To calculate erosion and deposition in coastal regions, GIS relies on inputs such as aerial photographs and satellite images. The latest GIS and remote sensing technologies can effectively extract and identify coastline changes from satellite imagery (Maurya et al., 2021).

Therefore, this project utilizes remote sensing and GIS techniques to comprehensively analyse the changes experienced in the Kuching Wetland National Park (KWNP) coastal areas from year 2019 to 2023.

Study Area

The coastline of Sarawak, approximately 1035 km in length, encompasses diverse coastal marine environments, including rocky coasts, mudflats, and sandy beaches. Mangrove forests are predominant along this coastline, constituting about 60% of the area. Additionally, the northeast and southwest regions of Sarawak host distinct reef systems. The coastline features rocky shorelines with smaller rocky outcrops and boulder formations. There are three main tidal levels on these rocky coasts: high tide, mid tide, and low tide

The focus of this study is the Kuching Wetlands National Park (KWNP) (refer to Figure 1), located in Kuching, a city in Sarawak. The study area extends from Checkpoint A (Latitude: 1°41'8.46"N, Longitude: 110°12'27.98"E) to Checkpoint B (Latitude: 1°39'33.80"N, Longitude: 110°14'55.27"E), covering approximately 8.15 km along the coast (refer to Figure 2). Two significant rivers, Sungai Sibu Laut to the west and Sungai Semariang to the east, along with various channels and creeks, contribute to the water flow within the park. KWNP, recognized as a Ramsar Wetland, contains a rich mangrove ecosystem crucial for environmental stability and protection against coastal erosion.

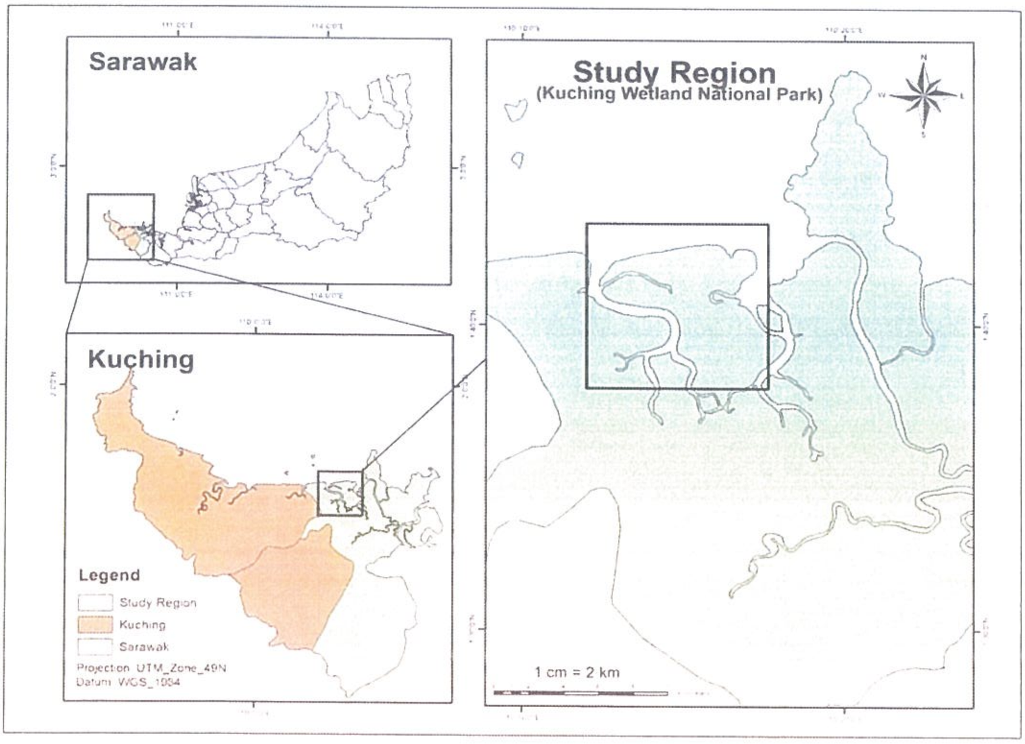


Figure 1: The illustration map of study region's location.

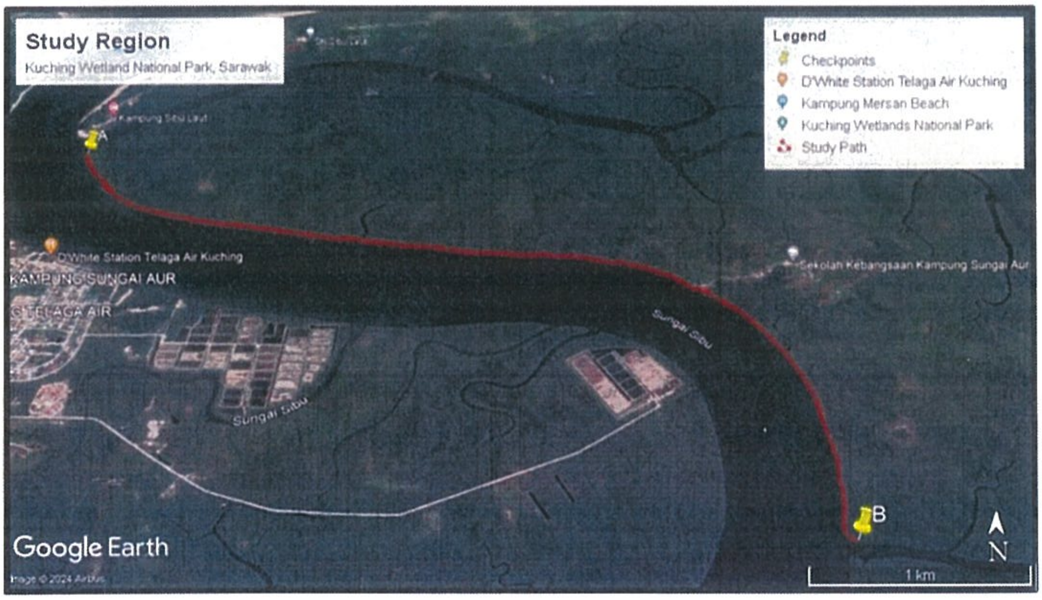


Figure 2. The location of the study area

[METHODS AND MATERIALS]

Landsat Data

The USGS Landsat data, website (https://earthexplorer.usgs.gov) offers historical shoreline anomalies that are crucial for understanding long-term shoreline changes and their impacts on coastal environments. Overall, USGS Landsat data is the optimal choice for processing shoreline changes in any analysis software due to its consistent archive, no-cost policy, diverse data products, online tools, and support for historical shoreline anomalies.

The KWNP area satellite images are downloaded from Landsat for pre-processing purpose. Both images used the same path/row (121/059) and are georeferenced to the World Geodetic System (WGS) of 1984. Images with cloud coverage below 20% were selected and averaged into a single image to minimize the impacts of clouds and shadows and to reduce noise. Parameters of the data as per in Table 1.

Table 1. Datasets downloaded from Landsat

No.	Data	Year of Acquisition	Resolution (Pixel Size) (m)	UTM Zone
1	Landsat 8	2019	30	49N
2	Landsat 8	2023	30	49N

DSAS V5.1 Software

Digital Shoreline Analysis Software (DSAS) version 5.1 is a plugin tool in the ArcGIS software which it is used for analysing shoreline changes by integrating Normalized Difference Water Index (NDWI), an analysis tool used to determine of water content in a feature. Numerous studies have validated the accuracy of NDWI in detecting shoreline changes, indicating its effectiveness in delineating accurate shorelines. NDWI spatial analysis tool is effectively separating land and water features, thereby facilitating precise shoreline delineation and change detection within DSAS-based coastal studies.

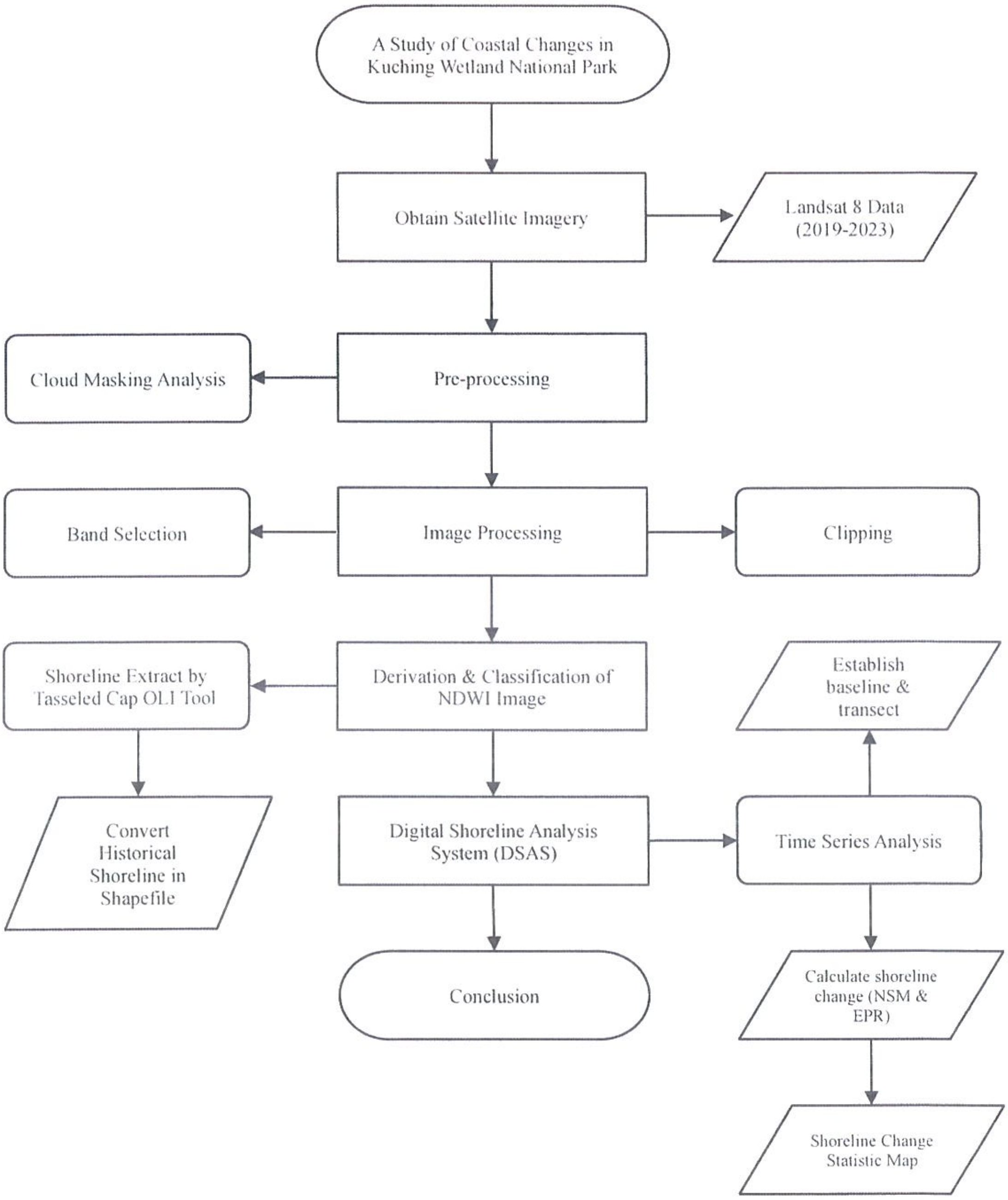
The purpose of utilizing the DSAS is due to the efficiency of the tool to calculate for shoreline changes using Net Shoreline Movement (NSM) and End Point Rate (EPR). These two are key parameters in analysing shoreline changes, indicating erosion and accretion dynamics along coastlines. NSM quantifies the total length of shoreline change over a specified period, while EPR represents the average rate of change per unit distance along the coastline. DSAS tool provides output and statistical data, thus researchers can compute NSM and EPR, enabling comprehensive analysis of shoreline dynamics. NSM is calculated through the formula (1) while EPR is determined using (2)

$$NSM = D_{t2} - D_{t1} \text{ .... } (1)$$

$$\text{EPR} = \frac{D_1 - D_2}{t_1 - t_0} \text{ ....} (2)$$

where D is the distance of shoreline and t is the time lapse.

Research Design



[RESULT AND DISCUSSION]

Classification using NDWI

The classification of satellite images for both year 2019 (Figure 3) and 2023 (Figure 4) is conducted using spatial analysis, NDWI to separate between land and water areas for shoreline extraction (Figure 5). NDWI effectively distinguishes water bodies from surrounding soil and vegetation, thereby aiding in the shoreline detection. The mean NDWI value is in between -1 to 1 and the higher mean NDWI value signifies increased water content, while a lower mean NDWI value suggests a decrease in water content. While the mean NDWI value alone may not fully encapsulate all aspects of shoreline changes, it complements other metrics such as NSM and EPR, contributing to a comprehensive understanding of shoreline dynamics and their determinants. In Figure 3, the NDWI values indicate higher water content, ranging from 0.51 to 0.63, whereas in Figure 4, the values range from 0.07 to 0.41. This suggests that the shoreline area experienced significant water extraction between 2019 and 2023.

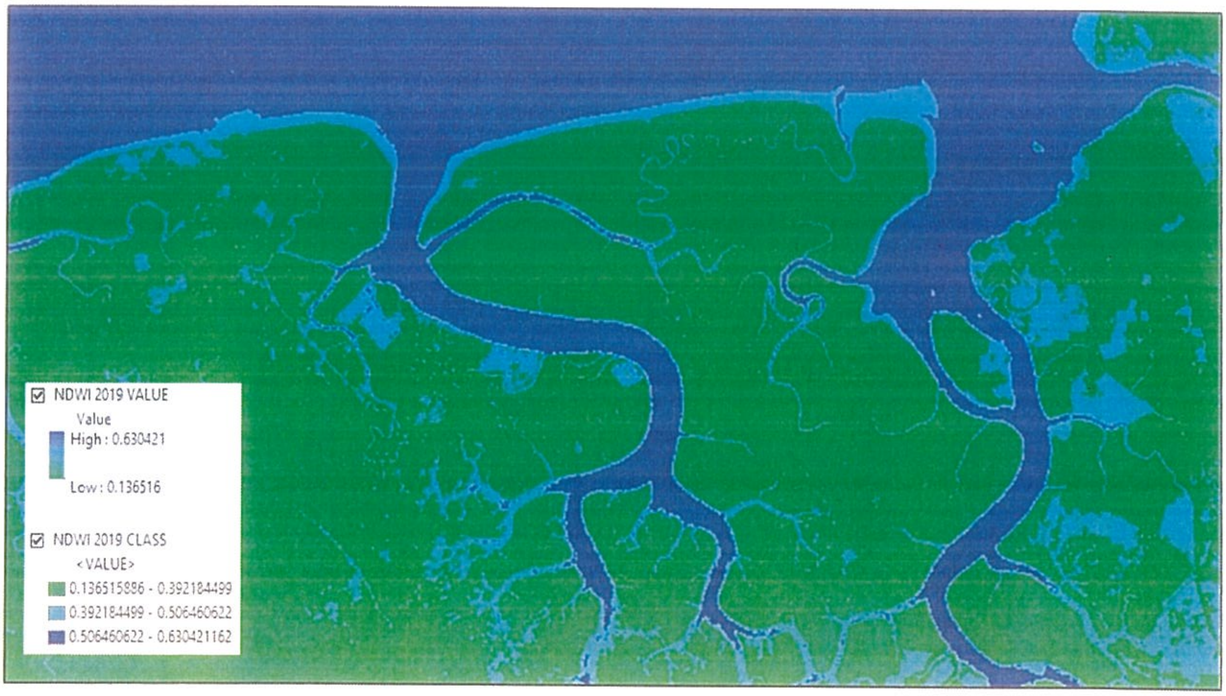


Figure 3. NDWI value year 2019

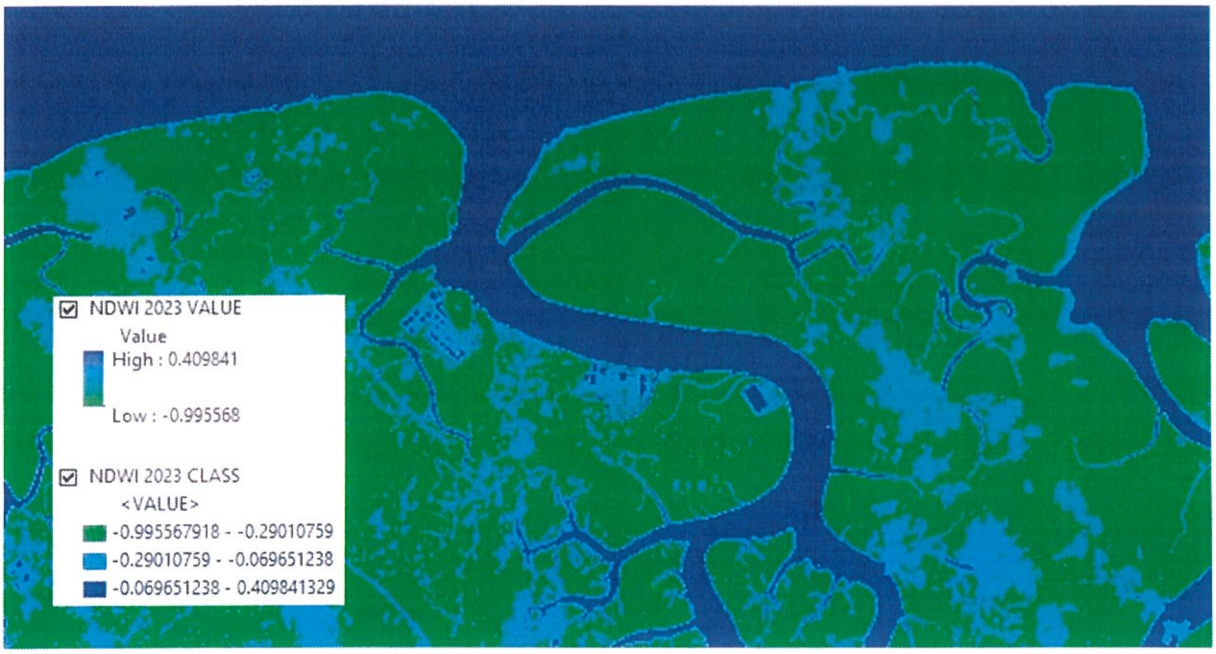


Figure 4. NDWI value year 2023

Shoreline Extraction

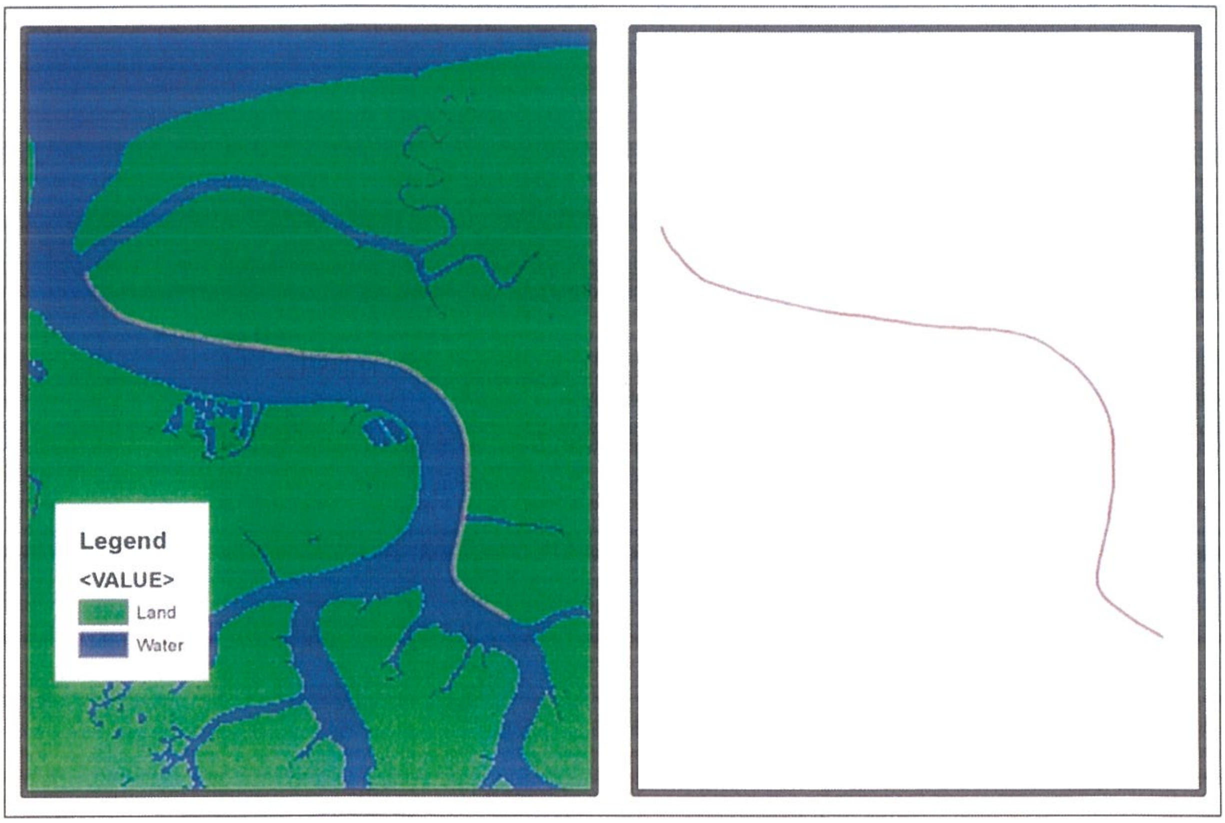
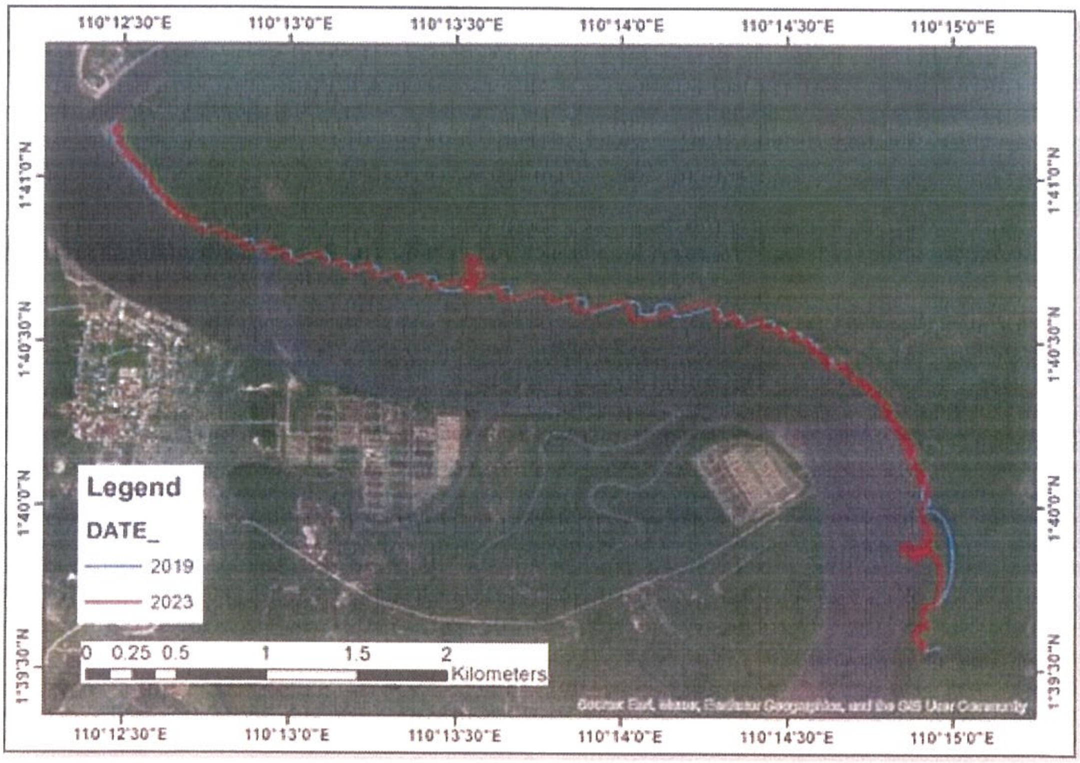


Figure 5. Extracted shoreline using Tasseled Cap

Shoreline Changes

188 number of transects are used to evaluate the NSM (Figure 7) and EPR (Figure 8). NSM is calculated to evaluate the total length of shoreline change over a specified period at the study area while EPR is used to calculate the average rate of change per unit distance along the coastline. These analyses used historical lines to determine the anomalies of changes experienced by the shoreline.

Figure 6 depicts the visual shoreline variation between the years 2019 and 2023. Several alterations are evident, particularly in regions where the red line (shoreline in 2023) moves inward towards the land compared to the blue line (shoreline in 2019). This inward movement indirectly suggests that the KWNP experienced significant erosion during this four-year period. While overall the area experienced significant changes, some sections showed minimal change, highlighting variability in the erosion patterns. These observations underscore the importance of targeted coastal management practices to address the areas most affected by erosion while monitoring and preserving sections that remain stable.



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

Figure 6. Shoreline change detection at KWNP.

The overall variations of NSM can be seen at Figure 7, which depicts throughout the 4 years period, the study area experienced significant erosion at most transects. Figure 8 illustrates the EPR variations within the study area. For each transect, the distance between the oldest and most recent shoreline positions was determined using the NSM, as well as two prior shoreline positions, as depicted in Figure 8.

The analysis was conducted simultaneously across all study areas. The transect lines were automatically generated, resulting in a total of 188 transects, each spaced at 30-meter intervals. Among the five statistical operations performed by the DSAS, only NSM was employed in this investigation. Utilizing these statistical methods allows for the computation of change rates over a specified timeframe of shoreline positions, providing valuable insights in various contexts. These metrics facilitate a more precise examination of shoreline dynamics and change patterns.

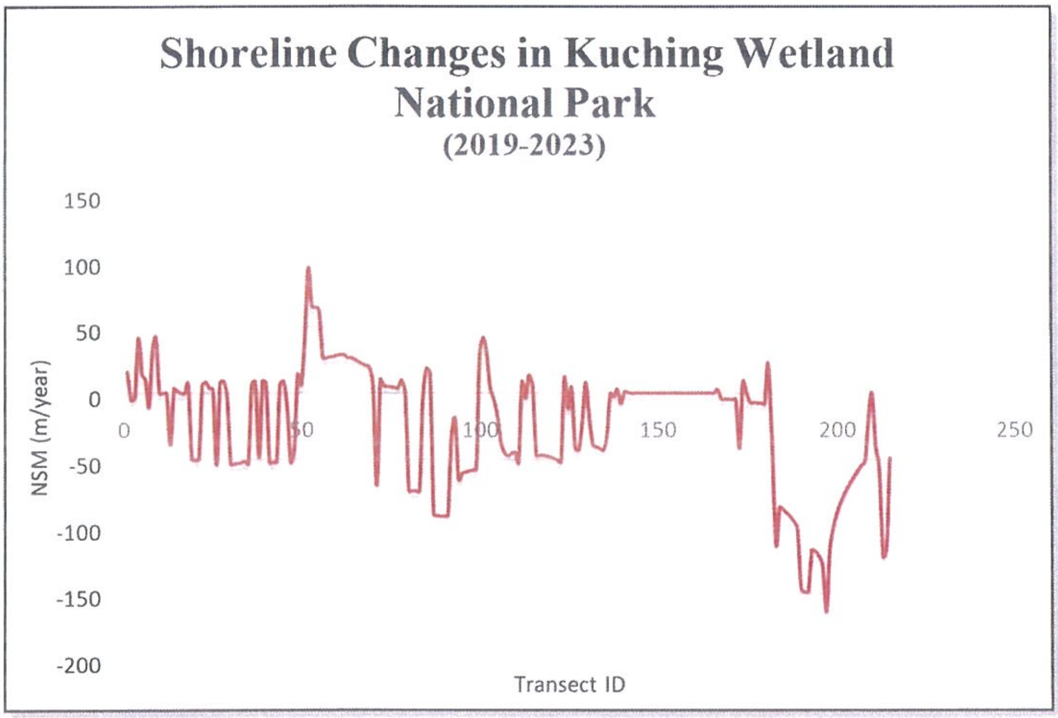


Figure 7. NSM from year 2019 to 2023

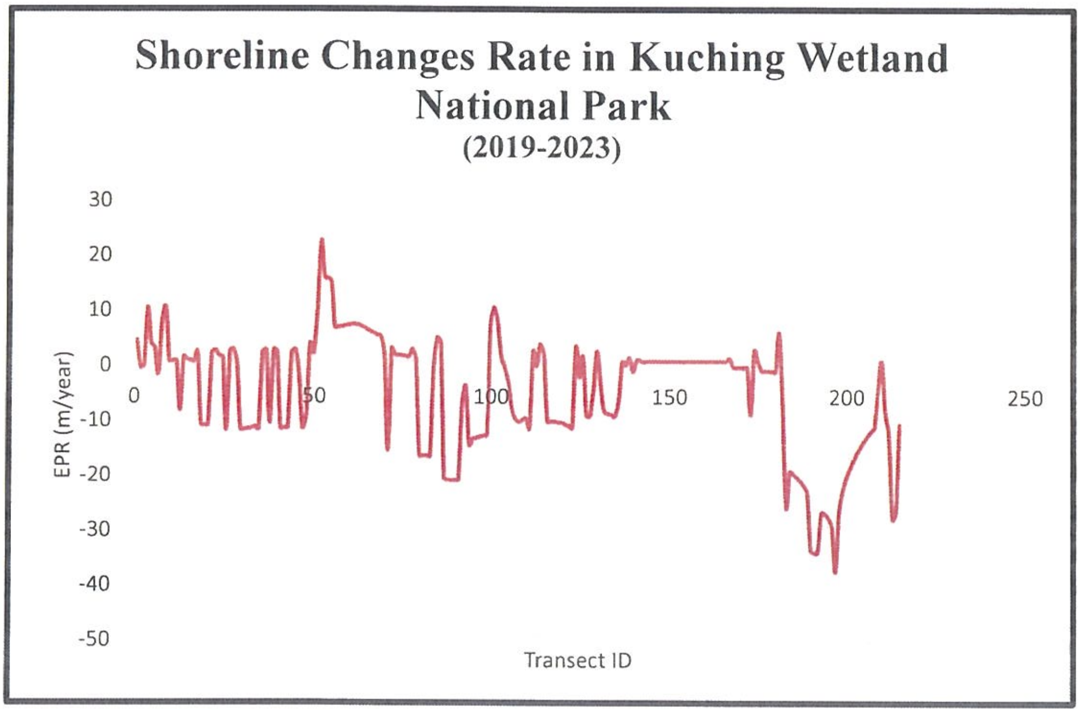


Figure 8. EPR from year 2019 to 2023

188 transect lines was set up along the 8.15-kilometer stretch of the KWNP's Coast. The resulting DSAS calculation that obtained from DSAS Summary of the generated transects, reflecting shoreline changes, is detailed in Table 1:

Table 2. Rate of erosion at KWNP between year 2019 until 2023

Region	Shoreline Changes Rate	KWNP Coastline
Transect Spacing (m)	-	30
Transect Length (m)	-	1000
Number of transects	-	188
Number of Accretional Transects	EPR	70
Number of Erosional Transects	EPR	118
Average Accretion (m/year)	EPR	4.09
Average Erosion (m/year)	EPR	12.46
Average Percentage Accretion	EPR	37.23%
Average Percentage Erosion	EPR	62.77%

According to the analysis of erosion and accretion percentages at each location over the 2019–2023 research period, 62.77% of the study area experiences erosion. The coastal line of KWNP exhibited significant erosion during this period, with erosion rates reaching up to 12.46 meters annually. Despite accretion occurring in only a few areas, the study area is notable for its rapid average growth rate of 4.09 meters per year. The data presented indicate varied patterns with significant implications for coastal communities, infrastructure, and ecosystems.

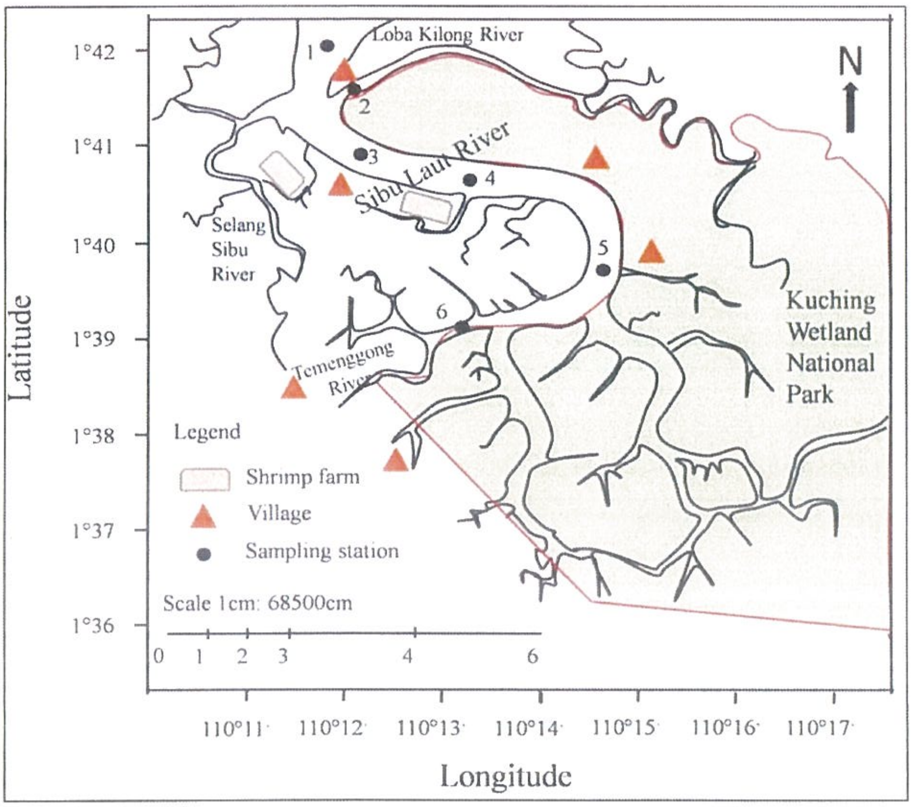


Figure 9. Map of KWNP

Accretion is notably concentrated near three shrimp farms in the upper area of KWNP as in Figure 9, affecting both accretion and erosion along the mangrove coastal line. Nutrient-rich effluents enhance primary productivity, potentially fortifying accretion by accumulating organic matter and sediments nearby. However, the infrastructure of shrimp farms alters hydrological dynamics, leading to localized sedimentation and accretion. These changes may disrupt the natural sediment equilibrium, inducing erosion downstream or in adjacent mangrove ecosystems. The conversion of mangrove forests into shrimp ponds further increases vulnerability to erosion.

While shrimp farms may promote localized accretion, broader impacts such as modified hydrology and mangrove degradation can exacerbate erosion along the coastal line. This underscores the necessity for integrated coastal management to mitigate adverse effects and maintain ecological integrity.

Additionally, ongoing sand dredging activities within the Sg. Sibu Laut, marking the western boundary of the Kuching Wetland National Park (KWNP), have substantial impacts on coastal and mangrove ecosystems. These continuous operations alter sediment dynamics, hydrological patterns, and natural habitats, potentially leading to localized accretion. However, disturbances to hydrological regimes may also induce erosion downstream or within adjacent mangrove ecosystems. The effluent discharge from these activities enhances primary productivity and sediment deposition, further influencing accretion in nearby areas. The intricate interplay between sand dredging and sedimentary processes highlights the complex nature of coastal dynamics. Consequently, sand dredging operations near mangrove coastal lines have multifaceted and interconnected impacts, mediating both accretion and erosion processes. This underscores the necessity of understanding and managing anthropogenic influences on coastal ecosystems to ensure their ecological robustness.

Moreover, private tour companies and sport fishermen frequently traverse mangrove coastal lines, causing both erosion and accretion through various mechanisms. Sand dredging operations can disturb sediment equilibrium and hydrological dynamics, leading to localized instances of erosion or accretion. Similarly, the routes used by private tour companies and the areas frequented by sport fishermen along major waterways result in localized sedimentation and accretion, particularly within these specific routes and high-activity zones. Therefore, the cumulative effects of these activities create intricate and interconnected repercussions, affecting both erosion and accretion processes along mangrove coastal lines. A thorough understanding and management of these interactions are imperative for the development of sustainable coastal management strategies.

In conclusion, the intricate interplay between human activities, sediment dynamics, and mangrove ecosystems is a crucial factor in shaping coastal erosion and accretion processes. Effluents from shrimp farms, sand dredging operations, and recreational activities near mangrove coastal lines contribute to both erosion and accretion through complex mechanisms. A comprehensive understanding of these interactions and their broader implications is essential for the effective implementation of coastal management strategies aimed at mitigating adverse effects and preserving the ecological integrity of mangrove ecosystems. Integrated approaches that consider the interconnectedness of human activities and natural processes are vital for promoting sustainable coastal development and preserving coastal communities and ecosystems.

[CONCLUSIONS]

The research employs satellite imagery in conjunction with DSAS Software to examine alterations in the shoreline over a four-year period, focusing on a region in western Sarawak designated as a Ramsar Wetlands Site. Utilizing satellite images captured in 2019 and 2023, DSAS software facilitates shoreline data extraction and temporal change computation. Notably, a substantial portion of the shoreline experienced erosion processes during this timeframe, prompting a deeper investigation into contributing factors. Proximity to the shrimp farm emerged as a significant determinant, with areas closer to the farm displaying heightened rates of accretion. This underscores the complex interplay between human activities and coastal dynamics, with implications for natural ecosystems and human settlements.

Despite recognized hydrological benefits of coastal regions within the Kuching Wetland National Park (KWNP), research on sedimentation and water quality remains limited. Nonetheless, ongoing shoreline monitoring is crucial for understanding coastal landscape evolution and formulating effective management strategies. Given identified erosion risks, stakeholders must prioritize adaptive measures, including improved land management practices and infrastructure reinforcement. Protection of natural barriers like mangroves and erosion-induced socio-economic loss mitigation are paramount. This study emphasizes interdisciplinary approaches to address coastal management challenges and underscores the need for further research to inform sustainable coastal development initiatives.

Future coastal monitoring efforts in the Ramsar Wetland Site should leverage satellite monitoring techniques using cost-effective, remotely sensed data to more precisely identify trends in coastal change. Ground verification should also be prioritized to validate findings, ensuring the accuracy of extracted shoreline data. This can be enhanced by generating multispectral imagery with higher spatial resolution and conducting field visits equipped with GPS receivers to assess changes in the KWNP region, determining whether erosion or accretion is predominant.

To thoroughly understand shoreline changes, it is suggested to integrate advanced geo-spatial techniques and open-source software. This includes using high-resolution satellite imagery and drones to capture detailed data with improved accuracy. Machine learning algorithms can aid in automated shoreline detection, enhancing efficiency. Open-source tools like the Shoreline

Analysis and Extraction Tool (SAET) allow for automatic shoreline position detection with subpixel accuracy. Integrating these methods enables a more precise evaluation of shoreline changes, aiding in understanding erosion and accretion impacts on coastal environments. Future research could explore shoreline extraction from Sentinel-2 imagery using the Modified Normalized Difference Water Index (MNDWI) for more accurate monitoring. Utilizing satellites like Sentinel-2 with multispectral capabilities and high spatial resolution can contribute to better coastal management strategies through detailed monitoring.

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