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Prediction of Shoreline Changes using Digital Shoreline Analysis System (DSAS) in Likas Bay, Sabah

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ABSTRACT

Shoreline changes are dynamic processes influenced by natural forces and human activities. Natural factors, including wave action, tidal currents, sediment supply, and geological processes play a crucial role in shaping coastal morphology and determining the rate of shoreline change. Shoreline retreat (erosion) can have detrimental effects, including habitat loss, infrastructure damage, and increased vulnerability to coastal hazards. Likas Bay, located along the Tanjung Lipat coastline of Kota Kinabalu, Sabah, has undergone significant shoreline changes in recent decades due to coastal development, reclamation projects, and hydrodynamic forces. This study assesses and predicts shoreline change rates from 2015 to 2024 using the Digital Shoreline Analysis System (DSAS). Using satellite imagery data, the shoreline positions were digitized and analyzed to compute rates of change, including End Point Rate (EPR) and Linear Regression Rate (LRR). Based on these rates, projections were generated for the next 10 and 20 years (2034 and 2044). The results revealed that the maximum and minimum EPR values are -2.57 and 0.08, and the minimum and maximum LRR values are -2.94 and 0.11, respectively. The prediction of shoreline change rates in Teluk Likas for the next 10 and 20 years indicates that the affected areas are 2.4 ha and 4.21 ha, respectively. The findings provide valuable insights for coastal management and sustainable development in Likas Bay. Predictive modeling indicates that continuous erosion will occur in specific hotspots unless mitigation measures are implemented. These findings provide valuable insights for coastal management and mitigation strategies, emphasizing the need for sustainable development and conservation efforts in Likas Bay and offering valuable insights for coastal management and policy planning in Sabah.

Keywords:
Shoreline change rate; DSAS; shoreline prediction; Likas Bay

1. Introduction

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Shoreline change refers to the ongoing adjustment of the coast resulting from natural processes and human activities. Recognizing and tracking these changes are essential because shorelines protect ecosystems, support human livelihoods, and hold economic, social, and cultural significance. The shoreline is significant because it marks the dynamic boundary between land and water. Its significance can be seen in environmental, economic, social, and cultural aspects. Rapid erosion often results in adverse effects, including land loss, habitat destruction, and economic damage. At the same time, accretion may provide temporary land gains but can also interfere with navigation and natural systems.

Accurate determination of shoreline change rates is a key component of coastal management, providing vital insights into the dynamic relationship between land and sea. This is especially important given global climate change and rising sea levels [1]. The rate at which shorelines change is a result of a complex interplay between natural processes and human activities [2]. Natural factors such as wave action, tidal currents, sediment supply, and geological conditions significantly influence coastal morphology and the rate of shoreline change [3]. Shoreline retreat can lead to negative impacts, including habitat loss, infrastructure damage, and increased vulnerability to coastal hazards.

The process of shoreline change can be quantified through various methods, with remote sensing and GIS techniques providing efficient and cost-effective means of assessing shoreline dynamics over extended periods. Analyzing historical shoreline positions using remote sensing data allows for the calculation of shoreline change rates, providing valuable information for coastal management and planning [4]. The integration of GIS and remote sensing techniques enables the analysis of shoreline change patterns and trends, providing valuable insights for coastal management and adaptation planning [5].

Understanding shoreline change patterns is crucial for effective coastal management and engineering interventions, particularly given the dynamic nature of shorelines that respond to various temporal and spatial phenomena [4,6]. The ability to quantitatively assess shoreline changes and predict future coastline positions has become crucial for sustainable coastal zone management as populations and infrastructure continue to grow along coastal areas.

Digital Shoreline Analysis System (DSAS), a widely used software tool, facilitates the statistical analysis of shoreline change rates from multi-temporal spatial data, offering valuable insights into coastal erosion and accretion patterns. These insights are crucial for making well-informed decisions on coastal development, infrastructure planning, and natural hazard mitigation. Moreover, predicting future shoreline positions enables proactive measures to safeguard coastal communities and infrastructure from the adverse impacts of coastal erosion and sea-level rise. In regions experiencing significant coastal development, the ability to quantify and predict shoreline changes is crucial for striking a balance between economic growth and environmental sustainability.

Furthermore, the use of remote sensing techniques provides a cost-effective approach to extracting shoreline positions from satellite imagery, with integration into GIS environments enabling comprehensive analysis of shoreline changes [7]. The utilization of multi-spectral satellite data is critical for shoreline extraction and change assessment studies in coastal regions [1]. The application of remote sensing data and GIS techniques provides valuable insights into shoreline changes, aiding in the assessment of coastal dynamics and the impacts of climate change. Shoreline change analysis, especially using tools like the Digital Shoreline Analysis System, helps in understanding coastal dynamics and predicting future changes.

The coastal region of Sabah, Malaysia, faces a complex array of challenges, including shoreline erosion, habitat degradation, and the increasing threat of climate change. Malaysia's economic and social activities heavily depend on its coastal areas, with many facilities already damaged or at risk due to shoreline erosion [8].

Numerical models can be effectively used in local coastal planning to understand the impacts of human activities and infrastructure development on longshore sediment transport and wave climate effects [9]. Coastal barriers often serve as the first line of defense against meteorological and oceanic forces, with extreme storms capable of causing significant morphological changes [10]. To mitigate adverse impacts, comprehensive planning and management of coastal regions are essential [11]. The coastal regions are greatly impacted by land loss and significant erosion [12].

Coastal adaptation strategies, including planned and preventive measures, are generally more cost-effective than reactive ones, emphasizing the need for proactive policy development and planning. The importance of adaptation has been acknowledged globally, with coastal protection and integrated management being crucial for addressing the effects of climate change and mitigating the impact of increasing human activities [13]. Currently, many coastlines worldwide face erosion challenges, which are exacerbated by climate change and rising sea levels, and may soon become increasingly difficult to manage [3].

Furthermore, approximately 30% of Malaysia's shoreline is affected by erosion, particularly along the coast of Peninsular Malaysia [8]. Given the economic importance of coastal zones, it is crucial to assess coastal vulnerability in order to manage these zones effectively. Rising sea levels, changes in storm patterns, and human activities are exacerbating coastal erosion, threatening coastal communities and ecosystems. The Selangor coast of Malaysia is vulnerable to erosion due to sea-level rise, highlighting the need for comprehensive coastal vulnerability assessments [14]. This highlights the importance of implementing effective coastal management strategies to mitigate the impacts of climate change and ensure the long-term sustainability of Sabah's coastal resources. In managing coastal areas, studying vulnerability is needed due to threats from sea level rise, abrasion/erosion, as well as high waves that can damage infrastructure and cause losses [15].

Coastal erosion in Southeast Asia is a growing concern, with climate change exacerbating the problem in densely populated coastal regions [16]. Additionally, Terengganu, a shoreline state in Peninsular Malaysia, is a growing hub for port industries and tourism, making it essential to address soil erosion and liquefaction hazards along its coastline [17]. Many coastal areas in Malaysia are experiencing erosion, which is expected to worsen due to climate change and human activities [18].

DSAS developed by the United States Geological Survey (USGS), is a widely used tool for analysing shoreline changes using geospatial data. This study employs DSAS to analyze historical shoreline changes in Likas Bay and predict future trends, providing a scientific basis for coastal planning and conservation. Likas Bay, situated in Sabah, Malaysia, serves as a compelling case study for examining shoreline changes due to its exposure to various natural and anthropogenic influences. The region's coastal morphology is characterized by a dynamic interplay of natural processes, including wave action, tidal currents, and sediment transport, which continuously shape the shoreline. It is imperative to acknowledge the effects of human activities, such as coastal development, urbanization, and tourism, which have significantly altered the region's coastal environment. Thus, understanding these dynamics is essential for effective coastal management and conservation efforts in Likas Bay.

The study aims to analyze historical shoreline positions in Likas Bay from 2015 to 2024, calculate statistical shoreline change values using EPR and LRR, and forecast future shoreline positions for the next 10 and 20 years with DSAS. While shoreline change analysis has been widely applied globally through remote sensing and GIS tools, there are few studies focused specifically on Likas Bay, Sabah, despite its ecological, socio-economic, and cultural importance. Most research in Sabah focuses on general patterns of coastal erosion and accretion, but often lacks quantitative prediction models that utilize standardized tools, such as the Digital Shoreline Analysis System (DSAS). Additionally, the long-term forecasting of shoreline changes over the next 10–20 years for Likas Bay remains limited, providing stakeholders with insufficient scientific data for effective coastal planning, conservation, and risk mitigation.

This study offers a scientific foundation for managing Sabah's coastal zones by utilizing DSAS to forecast shoreline changes in Likas Bay. The results will serve as early warnings for potential erosion and accretion zones, enabling proactive mitigation. They also support local authorities and policymakers in making well-informed choices regarding coastal infrastructure development and conservation.

2. Methodology

2.1 Study Site

Likas Bay is a narrow estuary with a depth of 15 to 20 meters, situated on Sabah's West Coast, encompassing the city of Kota Kinabalu, the capital. It is well known throughout the country for its white sandy beach, tourist resorts, and luxury seafront properties. Like the rest of Kota Kinabalu, the coastal development in Likas Bay, Sabah, has garnered significant attention due to the rapid development period this region has experienced over the last two decades. One consequence of this urbanization is the rapid rate of development located near the shoreline. Coastal management and engineering practices related to urban coastal development are interested in forecasting shoreline change to predict and anticipate potential future problems if the current trend of seafront development continues. Figure 1 shows a map of Sabah and Likas Bay.

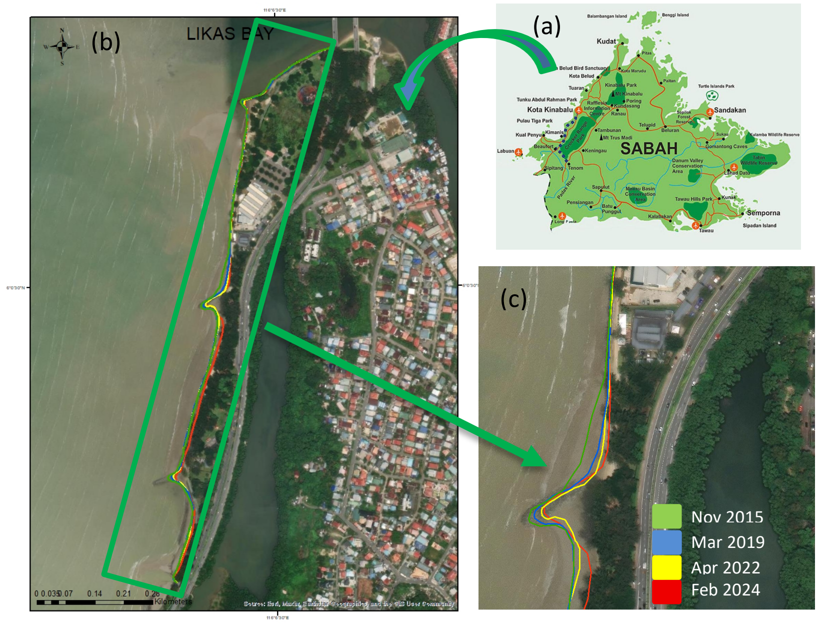

Fig. 1. (a) Map of Sabah, (b) and (c)Map of Likas Bay

Likas Bay, also known as Tanjung Lipat, is a scenic coastal stretch in the Likas sub-district of Kota Kinabalu, Sabah. This beautiful bay extends roughly 7 km from the city's port area toward the iconic Tun Mustafa Tower. This area is a popular urban retreat, offering tranquil seaside vibes that are ideal for walking, jogging, cycling, and unwinding by the water. The amenities that were provided in this area included a food court, restrooms, playgrounds, and a spot for picnicking (Figure 2a, 2b and 2c).

Fig. 2 (a) Spot for picnicking

Fig. 2 (b) Jogging track and cycling

Fig. 2 (c) Food court

Fig. 2. Infrastructure and amenities in Likas Bay. a) Spot for picnicking, b) Jogging track and cycling, and c) Food court

2.2 Data Collection

Investigating shoreline changes at Likas Bay using DSAS involves several key steps, beginning with the acquisition of historical shoreline data from various sources. These data are then processed and analyzed using DSAS to determine rates of shoreline change, identify areas of erosion and accretion, and assess the overall stability of the coastline. This information can then be used to develop effective strategies for managing coastal erosion, protecting coastal infrastructure, and preserving the natural beauty of Likas Bay.

The shoreline of 1.52 km along the Likas Bay was digitized from Google Earth for four years: 2015, 2019, 2022, and 2024. DSAS is an ArcGIS extension tool that calculates the rate of change of the shoreline position. DSAS offers three methods to create a baseline: a) Buffer, b) Pre-existing baseline, and c) New feature class, but in this study, “the new feature class method was used.” DSAS is an essential tool for monitoring and forecasting shoreline changes. Its ability to compute rate-of-change statistics over a series of shoreline positions makes it valuable for analyzing coastal change. These statistics help evaluate shoreline dynamics and identify trends in change. Figure 3 illustrates the detailed step-by-step process of data collection and processing.

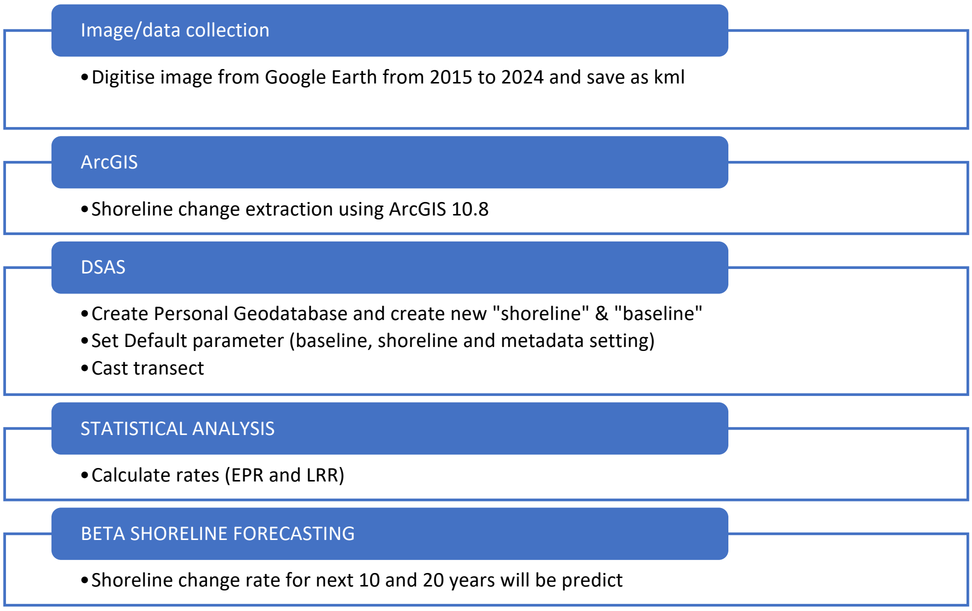

Fig. 3. Flow chart of data collection and processing using DSAS

2.3 Statistical Analysis

DSAS was used to calculate shoreline change rates using the End Point Rate (EPR) and Linear Regression Rate (LRR) methods. Perpendicular transects were generated at 50-meter intervals along the coastline to measure shoreline movement. Areas of erosion (land loss) and accretion (land gain) were identified based on shoreline movement. EPR was calculated to determine erosion and accretion rates within the 286 transect (Figure 4). EPR, a crucial metric, is derived by dividing the distance of shoreline movement by the time elapsed between the oldest (2015) and the youngest (2024) shoreline positions (Figure 4) based on Eq. 1.

$$\mathrm{EPR} = \frac{\mathrm{NSM}}{\text{time between oldest and most recent shoreline}} \tag{1}$$

where Net Shoreline Movement (NSM) is the distance between the oldest and the youngest shorelines.

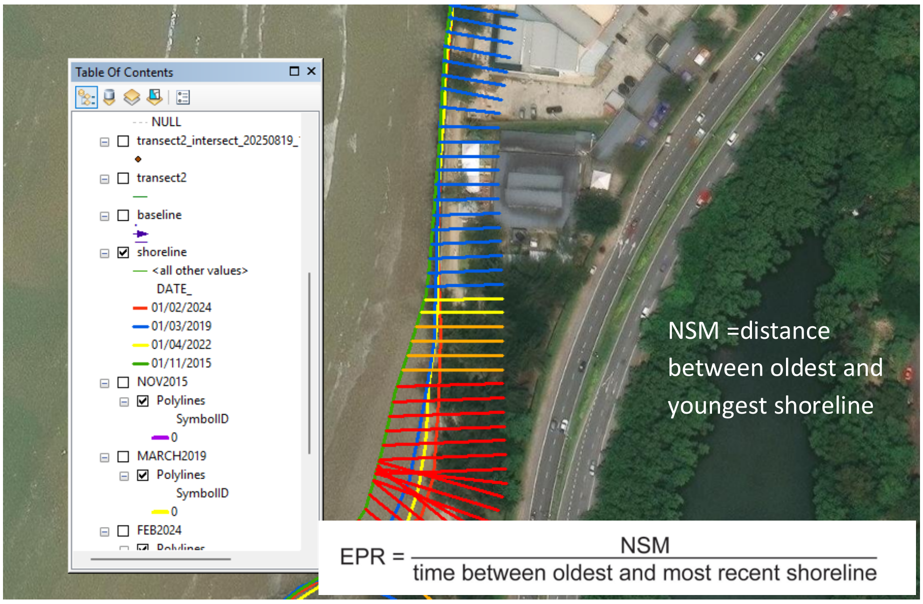

Fig. 4. Transect and shoreline changes for 2015, 2019, 2022, and 2024

LRR was applied to estimate the average rate of change using the four shoreline positions over time, with the changed statistics resulting from fitting a least-squares regression (Eq. 2) to all shorelines at each transect (Figure 4).

$$y = mx + c \tag{2}$$

where y = distance from baseline, m = the slope (LRR method) and c = y intersect

2.4 BETA Shoreline Forecasting

The Kalman filter model is the most advanced state-space stochastic model, providing a joint statistical estimate of the long-term shoreline trend and the immediate shoreline changes over a forecasting period. DSAS offers an option to forecast shoreline positions 10 and 20 years into the future based on historical data. The forecasting method employs the Kalman filter, as developed by Long and Plant [19], which combines observed shoreline data with model estimates to predict future positions. The Kalman filter in DSAS is initialized using the linear regression rate from DSAS itself. It then calculates the shoreline position and change rate every tenth of a year, also providing an estimate of positional uncertainty at each step.

Mapping and predicting shoreline change involves analyzing historical shoreline positions to forecast future features. DSAS can be employed for long-term shoreline mapping and forecasting over 10 to 20 years. Coastal erosion results from natural factors, such as wave action, tidal patterns, and sediment transport, as well as human activities like land use changes and urban development [20]. Precise predictions of coastline changes are crucial for sustainable coastal resource management, particularly in ecologically sensitive areas such as mangrove forests. The step for BETA shoreline forecasting to calculate the prediction of shoreline change rate is summarised in Figure 5.

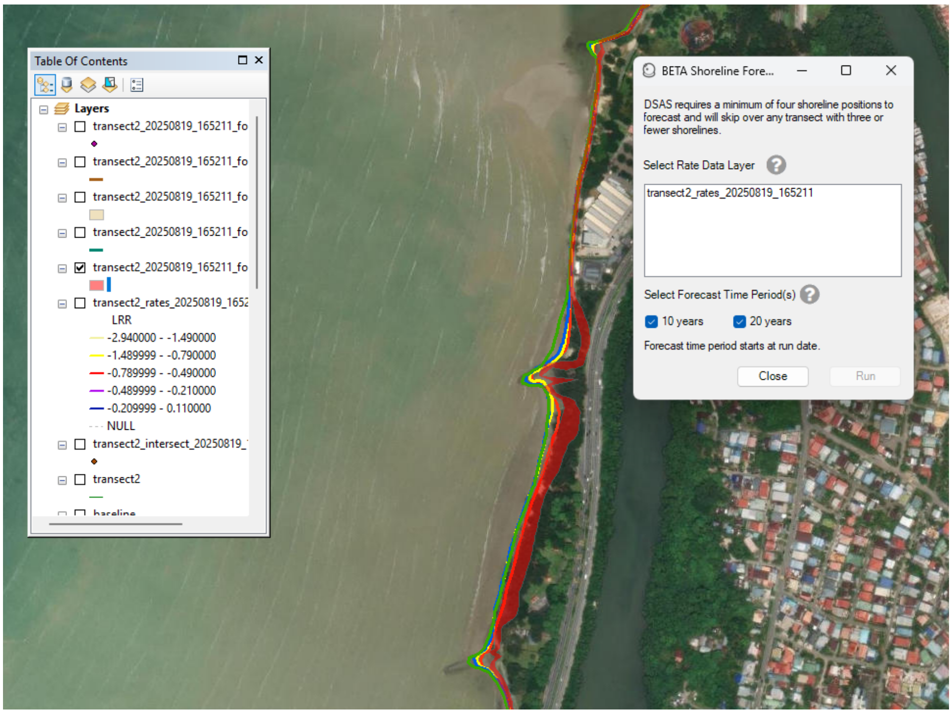

Fig. 5. BETA shoreline forecasting to predict erosion

3. Results and Discussion

3.1 Shoreline Change Rate Analysis

The study site, Likas Bay was selected because its dynamic coastal environment is crucial for recreation and tourism, yet it is vulnerable to shoreline changes. EPR and LRR are statistical analyses that can calculate erosion and accretion. Figure 6 shows the map of EPR and LRR along the Likas Bay transect. Negative results mean erosion, while positive results mean accretion. The result is divided into five categories. Red color is very high erosion, orange is moderate erosion, yellow is low erosion, blue is accretion, and green is high accretion.

The analysis of shoreline positions between 2015 and 2024 reveals dynamic changes along Likas Bay. Using DSAS, both the End Point Rate (EPR) and Linear Regression Rate (LRR) were calculated along 286 transects distributed across the 1.52 km study stretch. The spatial distribution of erosion and accretion was visualized in transect-based maps (Fig. 6). Results are categorized into five classes (Table 1).

Table 1
Shoreline change rate ranking

Level	Value	Color
Very high erosion	-2.0 m/year and beyond	red
High erosion	-1.0 to-2.0 m/year	orange
Low erosion	-0.1 to -1.0 m/year	yellow
Low accretion	+0.01 to+0.05 m/year	blue
High accretion	>+0.05 m/year	green

The analysis reveals that erosion is predominant in specific northern and central transects, while localized accretion is concentrated in areas near reclamation and infrastructure development. The results emphasize the dual influence of natural and anthropogenic drivers on shoreline dynamics in

Likas Bay. The negative EPR and LRR values (–2.57 m/year and –2.94 m/year, respectively) signify substantial erosion in northern and central stretches. This aligns with global findings that exposed coasts are more vulnerable to wave energy, longshore sediment transport, and tidal currents. Reclamation projects and coastal reinforcement primarily affect areas with low positive EPR and LRR values. Artificial shoreline stabilization introduces new land but simultaneously disrupts natural sediment balance, often exacerbating erosion in adjacent unprotected areas. Figure 6 shows a map of EPR and LRR along Likas Bay.

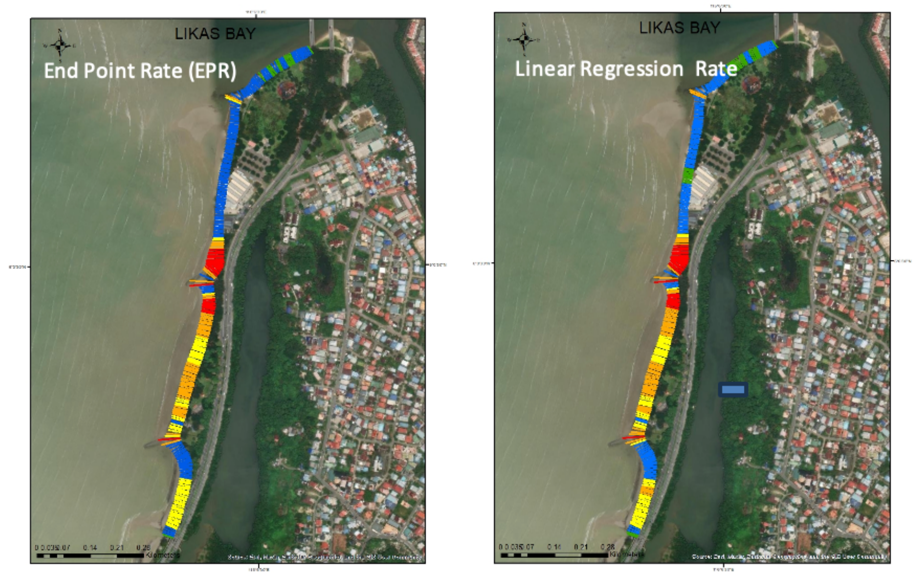

Fig. 6. Map of EPR and LRR along Likas Bay. Red=very high erosion, orange=moderate erosion, yellow=low erosion, blue=low accretion and green=high accretion

3.2 Statistical Analysis

DSAS software also analyzes statistical methods such as NSM, EPR, LRR, LR2, WLR, WR2, and WSE; however, for erosion and accretion analysis, it only considers EPR and LRR. From the 286 transect, the maximum and minimum EPR are 0.08 and -2.57, while the maximum and minimum LRR are 0.11 and -2.94. These results indicate that while some sectors experience stability or slow accretion, significant stretches of the bay are undergoing rapid erosion. Notably, the LRR values reinforce long-term erosion patterns, whereas EPR highlights the net change between the earliest and latest shoreline positions (Figure 7).

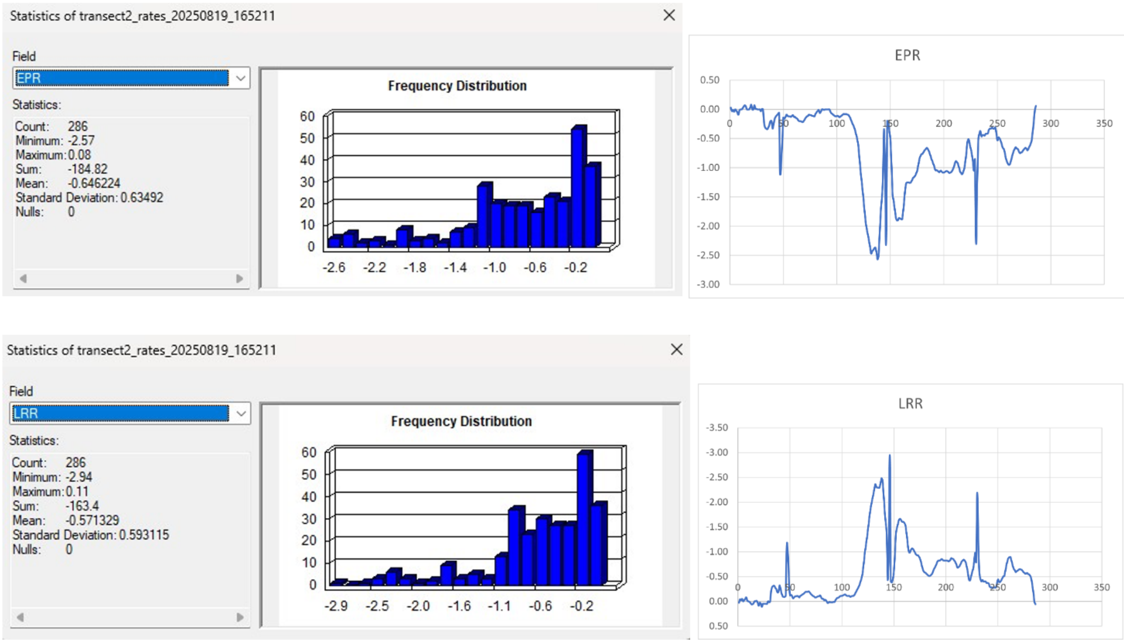

Fig. 7. Statistical analysis for EPR and LRR

3.3 Prediction of Shoreline Change Rate

Shoreline change prediction is a critical aspect of coastal zone management, enabling proactive measures to mitigate erosion and plan for future coastal development. Using historical data from 2015 to 2024, the shoreline change rate can be predicted for the next 10 years (2034) and the next 20 years (2054). A Kalman filter model was used to forecast the erosion and accretion. The result shows the area affected along the shoreline. For the next 10 years, approximately 2.4 ha of area were affected, including amenities, a jogging track, and a recreational area.

The erosion footprint expands to 4.21 ha, with further inland retreat likely to endanger infrastructure, including cycling tracks, food courts, and adjacent green areas. These forecasts suggest that without intervention, continuous erosion will degrade the coastal recreational landscape and compromise the resilience of infrastructure in Likas Bay.

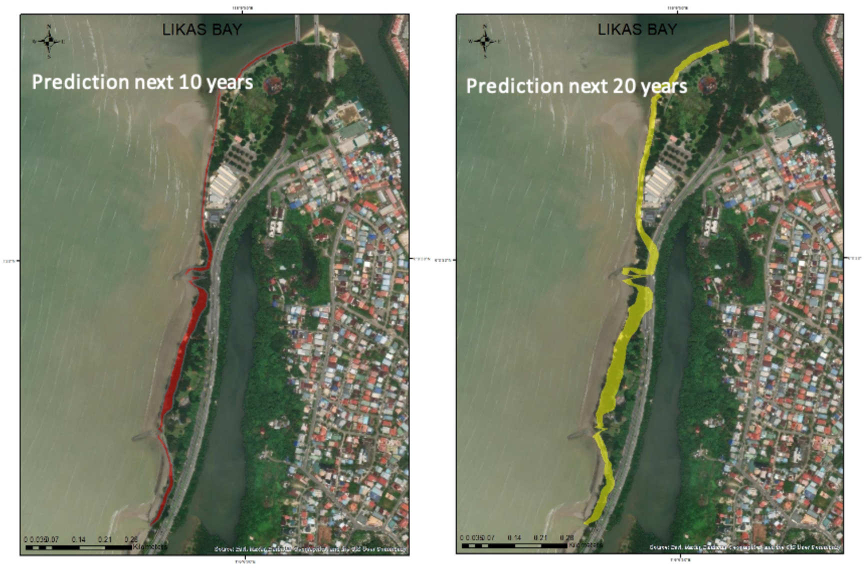

Fig. 8. Prediction of shoreline change rate. a) following 10 years and b)next 20 years

4. Conclusions

This study demonstrates the effectiveness of DSAS in quantifying shoreline change and projecting future scenarios in Likas Bay, Sabah. Analysis of shoreline data from 2015–2024 reveals a combination of erosion and accretion trends, with erosion being more severe and widespread. Maximum EPR (–2.57 m/year) and LRR (–2.94 m/year) indicate severe erosion hotspots. Forecasting predicts land losses of 2.4 hectares by 2034 and 4.21 hectares by 2044, directly threatening recreational and infrastructural assets. Erosion patterns are strongly linked to natural coastal dynamics and amplified by anthropogenic activities such as reclamation. The results underscore the urgent need for proactive shoreline management, which integrates engineering solutions with ecosystem-based approaches. Protecting Likas Bay requires collaboration between policymakers, urban planners, and environmental managers to ensure that development remains balanced with long-term coastal resilience.

DSAS proves to be a valuable decision-support tool, offering quantitative insights into shoreline change processes and enabling sustainable planning for the future of Sabah's coastlines. Predictive modeling indicates significant erosion risks in the northern bay and ongoing seaward expansion in reclaimed areas. These insights underscore the need for proactive coastal management and sustainable urban planning in Kota Kinabalu to strike a balance between development and environmental preservation.

As Likas Bay is a prime recreational and residential area in Kota Kinabalu, unchecked erosion will have socio-economic consequences. Facilities like jogging tracks, cycling lanes, and picnic areas are directly threatened, potentially diminishing tourism and public use. Results reinforce the need for sustainable coastal zone management in Sabah, aligning with Malaysia's broader strategies to adapt to the impacts of climate change. The balance between urban development and environmental conservation is crucial, especially given Sabah's reliance on coastal ecosystems for livelihoods and tourism.

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