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Comparative Analysis in Shoreline Changes in Kelantan, Malaysia Using Digital Shoreline Analysis System (DSAS)

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ABSTRACT

Kelantan is a Malaysian state renowned for its beautiful jungles and coastal districts. Kelantan, which is susceptible to monsoons and tidal waves, witnessed a tsunami-like inundation that affected its coastline landscape in 2014. This study does a comparative examination of shoreline alterations between 2013 and 2021 using the Digital Shoreline Analysis System (DSAS) technology. The coastline has grown by approximately 4.03 percent, from 62.1 kilometres to 64.6 kilometres, as a result of the implementation of digitalisation procedures. This highlights the increase in coastline areas between 2013 and 2021. Using GIS and satellite data, the study identifies considerable sedimentation in Pantai Geting and Lagun Jubakar, Tumpat, as well as severe erosion in Pantai Kundur and Pantai Cahaya Bulan, Kota Bharu. The analysis of the Shoreline Change Envelope (SCE) and Net Shoreline Movement (NSM) reveals an accretion rate of 728.44 m/year and a negative distance of -281.91 m/year, which indicates erosion. The paper concludes by emphasising Kelantan's shoreline expansion over the previous decade, stressing the significance of monitoring coastal changes for effective environmental management and catastrophe preparedness.

Keywords: *DSAS; GIS; shoreline change; Kelantan; coastal accretion.*

1. INTRODUCTION

Coastal areas are commonly home to dense human populations [1]. The coastal zone is one of the most vulnerable regions in Malaysia, and environmental threats have an immediate impact on its fragile ecosystems and local inhabitants [2]. A coastline is the demarcation line between land and water. A line is drawn between the readings for low tide and high tide. The position of a country's coastline influences its territorial boundaries [3]. Coastline alterations are regarded as one of the most significant dynamic changes in coastal regions, with the position of the shoreline altering due to natural and anthropogenic events. As has been studied, coastal erosion is typically caused by natural processes that modify shorelines by combining river flow, waves, currents, and other factors [1, 4]. Despite an increasing population and unplanned growth in coastal areas, the changes are the result of human activity. A shoreline [2, 5] that is unstable and prone to alter over time is one of the primary obstacles for coastal zones in defining a region's boundaries. Consequently, identifying the location of a region's shoreline is a crucial aspect of delineating its boundaries. Consequently, shoreline change analysis is a crucial

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component of coastal management. Moreover, protection planning including risk and disaster management, for instance through numerical technique calibration and verification, sea-level rise assessment, and the creation of hazard zones, as well as the policy-making process for coastal area development, enables future proactive solutions [6].

In this context, the dynamic significance of shoreline analysis is effectively proven through numerous ways, with Geographic Information System (GIS) being one of the most important approaches (GIS). GIS is widely used in multidisciplinary research, where it executes exhaustive analysis based on specified parameters and attribute table data. Utilizing the ArcGIS subsystem, specifically ArcMap, to visualise and analyse data demonstrates its versatility. Notably, the Digital Shoreline Analysis System (DSAS), a notable GIS component, is integrated into the ArcMap subsystem to present data in a statistical manner [7]. DSAS, an add-on for Esri ArcGIS Desktop, enables users to calculate rate-of-change statistics utilising historical shoreline points. It features a beta model for shoreline prediction that may generate shoreline horizons and uncertainty bands. In addition, DSAS provides an automated method for finding measurement locations, computing rates, and acquiring the statistical data required to evaluate the robustness of these rates. The intuitive interface directs the critical phases of the shoreline change analysis. This study's primary objective is to utilise the user-friendly DSAS method to measure the variability of shorelines in the coastal region of Kelantan. This analysis is likely to have substantial repercussions, including impacts on tourism, fishing, land erosion, and infrastructure damage in the research area [5, 8].

2. METHODOLOGY

2.1 Research Area Selection

The geolocation of Kelantan stretches nearly 80 kilometres of coastal areas starting from Tumpat to Cherang Ruku. The location itself makes it prone to North-East Monsoon with heavy rainfalls, high tides, and waves which will lead to severe erosion and sedimentation as the movement of the waves comes directly from the South China Sea [6]. The area's susceptibility to the North-East Monsoon's effects, such as heavy rainfall, high tides, and strong waves, intensifies the erosion and sedimentation processes [8]. This climatic feature creates an ideal setting to study how natural forces impact shoreline dynamics. The coastal characteristics and erosion processes in Kelantan can serve as a comparative benchmark for similar coastal areas in the region or globally, contributing to broader research on shoreline dynamics.

2.2 Shoreline Data Acquisition

The shoreline data was obtained from the Malaysia Space Agency (MYSA) archives, with a focus on data collected during the period from October to February. This selection aligns with the wet-dry season, which is characterised by two monsoon regimes: the southwest monsoon occurring from May to September and the northeast monsoon occurring from November to March. The year 2013 was specifically chosen to portray the shoreline condition before the notable flood event that transpired in 2014. Subsequently, data from 2021 was selected to provide a current representation of the area, utilising the latest available data from MYSA via the same Path/Row of 269/338. The research utilised satellite images acquired on two distinct dates: October 7, 2013, and February 24, 2021. These images were processed with projections and spatial references implemented using Datum WGS84 (GCS_WGS_1984 as the XY Coordinate System). Additionally, each image consisted of 4 bands.

The images were subsequently imported into ArcMap, utilising a layer of Personal Geodatabase. A new shapefile field was created, accompanied by a novel feature class that was divided into baseline and shoreline polylines. The attributes for each feature class were established following the guidelines outlined by USGS Users Guidelines on DSAS V5, as depicted in Table 1 [7].

Table 1: The USGS Guidelines on DSAS Feature Class attribute

Baseline		Shoreline	
Attribute	Type	Attribute	Type
OBJECTID*	ObjectID	OBJECTID*	ObjectID
SHAPE*	Geometry	SHAPE*	Geometry
ID	Long Integer	UNCERTAINTY	Double
Group_	Long Integer	DATE_	String
OFFshore	Short Integer	SHAPE_Length	Double
CastDir	Short Integer		
SHAPE_Length	Double		

2.3 Shoreline Changes

The satellite images served as references for digitising both the baseline and shoreline. The digitisation process was conducted using the Kertau RSO Malaya Meters as the projected coordinate system, employing Rectified Skew Orthomorphic Natural Origin as the projection method. The digitisation process was initiated by tracing the shoreline, ensuring precision through alignment with the satellite images. Subsequently, both the baseline and shoreline underwent DSAS analysis utilising the Distance Measurement functionality. The parameters were configured for the baseline analysis, specifying onshore placement and a baseline orientation where *Land was to the Left* (L), along with extended log file output. The shoreline parameter settings were similarly configured, linking to the shoreline data field (digitised attribute). Default uncertainty was set at 4.4 ± metres, and the analysis involved seaward intersection, also generating extended log file output [7].

The map in Figure 1 displays a polyline representation integrated onto a topographic map, serving to visualise the morphological transformation of Kelantan's coastal area in the years 2013 and 2021. The data extraction was executed through a process of digitisation and tracing, incorporated into a Kertau RSO Meters Projection Shapefile. This extraction was based on SPOT 5 & 6 Pansharp satellite images dated July 7, 2013 (on the left) and February 24, 2021 (on the right). The length of the polyline for each respective year spanned from 62.1 to 64.6 kilometres, extending from Pantai Geting in Tumpat to Bachok. As observed in Figure 1, both shorelines have exhibited gradual changes between 2013 and 2021. The map specifically highlights prone areas around Tumpat, notably in the vicinity of Lagun Jubakar. Additionally, certain regions around Kota Bharu displayed mild sedimentation, potentially influenced by the transport of tidal waves over time. Notably, a substantial difference of around 2.5 kilometres between 2013 and 2021 emerged, primarily attributed to increased sedimentation, resulting in shoreline expansion. Figure 2 portrays the overlapping changes in shorelines, emphasising that the expansions are concentrated predominantly between Tumpat and Kota Bharu.

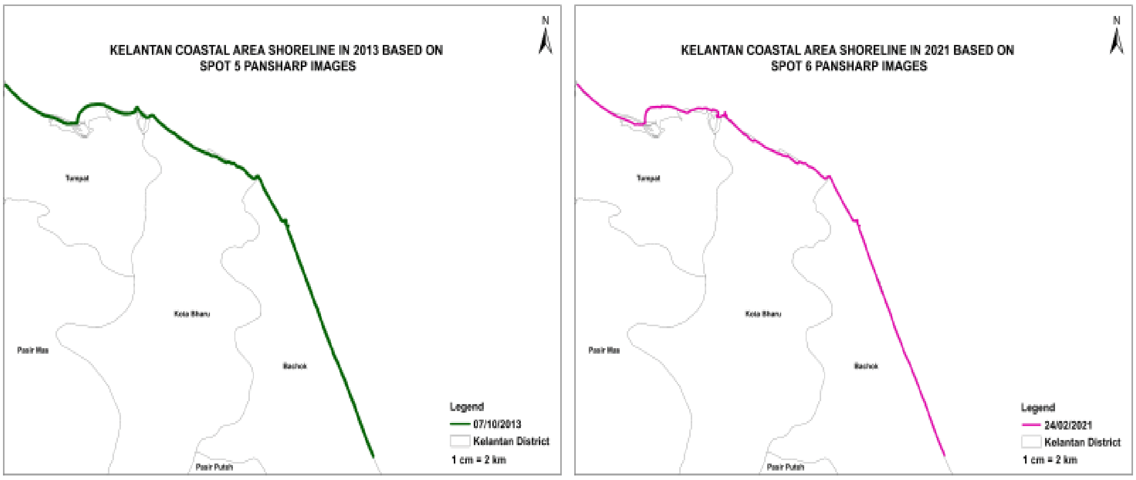

Figure 1: Comparison Topographic map of Kelantan, Malaysia shoreline in 2013 and 2021

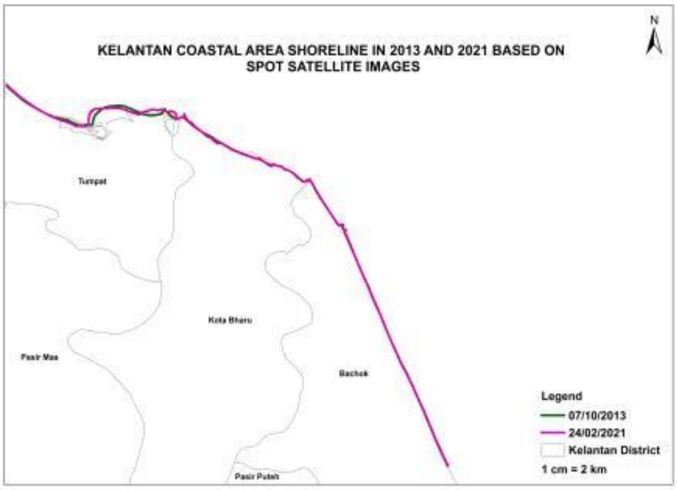

Figure 2: Topographic map of Kelantan, Malaysia shoreline changes between 2013 and 2021

3. RESULTS & DISCUSSION

Digital Shoreline Analysis System (DSAS) was utilised in this study to determine change rates in the shoreline. Two distinct statistical methods were employed, namely distance and rate, to estimate the changes along the coastline. The End Point Rate (EPR) and Linear Regression Rate were employed to describe the rate of shoreline change, while the Shoreline Change Envelope (SCE) and Net Shoreline Movement (NSM) were used to represent the distance [7]. At each transect, the SCE was calculated as the difference between the shoreline that was farthest from and closest to the baseline. This helped assess the overall change in shoreline movement across all shoreline positions. In contrast, the NSM provided a measure of the separation between the earliest and most recent shorelines, representing the overall distance. While SCE and NSM provided insights into shoreline distance, their findings did not reveal the speed at which the shoreline shifts. NSM indicated the total distance between the oldest and most recent shorelines for 2013 and 2021, respectively. On the other hand, SCE estimated the largest distance between all shorelines without taking into account the specific year of the shoreline.

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3.1 Shoreline Change Envelope

The distance measurement of SCE captures the disparity between shorelines located farther or closer to the baseline [7], drawing from the analysis conducted using the digitised data from 2013 and 2021. Ten distinct colour variations were employed to represent various classifications concerning erosion and accretion rates. The colour spectrum ranged from green tones, representing minimum values and indicating areas of erosion, to red tones, signifying maximum values of accretion. Notably, the SCE showcases highly dynamic scenarios, particularly evident in the Tumpat and Kota Bharu regions, where a notable number of changes were recorded.

Observing the area of Lagun Jubakar from Figure 3 below, each green-marked transect signifies land loss from 2013 to 2021, while reddish areas depict accretion. Through analysis, land loss was observed to reach up to 225 metres, whereas the accretion rate exhibited an increase of up to 520 metres. Snapshot of Tumpat and Kota Bharu reflects comparable patterns in erosion and accretion, with measurements ranging from 224 to 290 metres. The snapshot of Bachok area in Figure 3 below showcases a minor alteration, wherein the shoreline extended by 0.0 to 72 metres. Coastal dynamics stem from weather and hydro-oceanographic variables, occasionally yielding destructive consequences that impact public facilities, infrastructure, and the environment. Kelantan's shoreline changes are linked to the region's dynamic tidal waves, which intensify during the Northeast Monsoon from November to March [5]. Furthermore, these changes can be attributed to the area's geomorphology; Kelantan's sandy beaches are typically more porous than other locations. In conjunction with wave action, this porosity leads to progressive erosion and sedimentation.

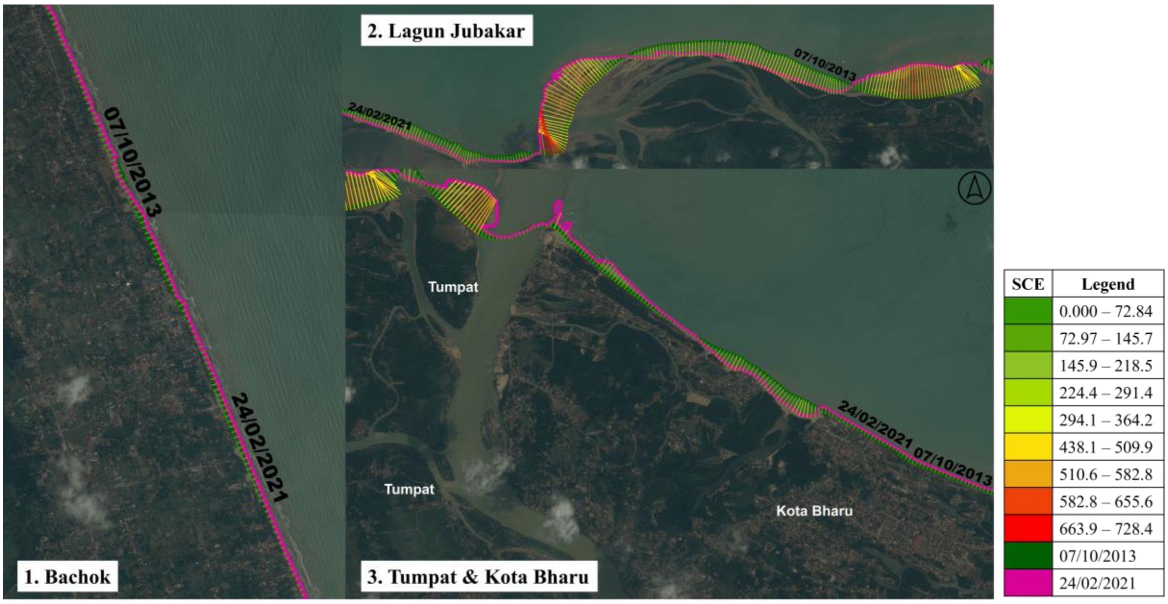

Figure 3. Shoreline Change Envelope map snapshot in Tumpat, Kota Bharu and Bachok, Kelantan, Malaysia

The presence of waves and winds contributes to coastal erosion and sediment movement. This phenomenon is primarily attributed to Kelantan's geographical alignment with the South China Sea (SCS). The SCS typically experiences wind speeds of 9 to 19 knots directed towards the shore, resulting in the generation of coastal waves. On Malaysia's east coast, diurnal and semidiurnal tides play a role. Diurnal tides lead to daily fluctuations in high and low water levels, while semidiurnal tides cause water levels to rise and fall twice each day [13]. The SCE serves as a comprehensive summary of the changes observed following the completion of the analysis. The statistical methods employed for the analysis provide outputs that are summarised in the analysis summary. Figure 4 illustrates the SCE histogram generated using ArcMap software. Notably, the shoreline changes display high dynamics, particularly in the transects ranging from 800 to 1080. In this range, the recorded changes show the most significant accretion, varying from 300 to 728 metres (Transect ID: 1062). The most pronounced shoreline alterations occurred along transects 1000 to 1100, primarily situated in Tumpat. Additionally, the figure depicts the SCE at transects 997 to 1079, with actual satellite images serving as reference. Figure 5 illustrates the shoreline alterations in this region. In 2013, there was a noticeable degradation of the headline sedimentation, resulting in erosion and net sediment transport towards the embayment area. However, by 2021, a new sedimentation area had formed, characterised by the highest sedimentation levels within the region [9-12]

SCE Overall Averages:

total number of transects: **1231**

maximum distance: **728.44**

maximum distance transects ID: **1062**

minimum distance: **0**

minimum distance transects ID: **816**

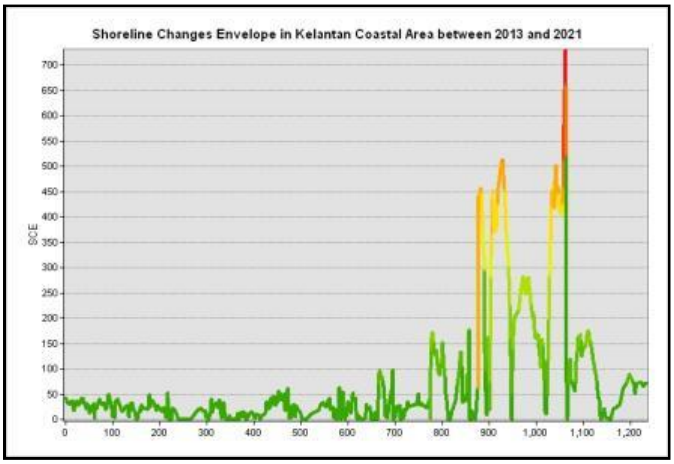

Figure 4: SCE Overall Averages Statistics and Histogram

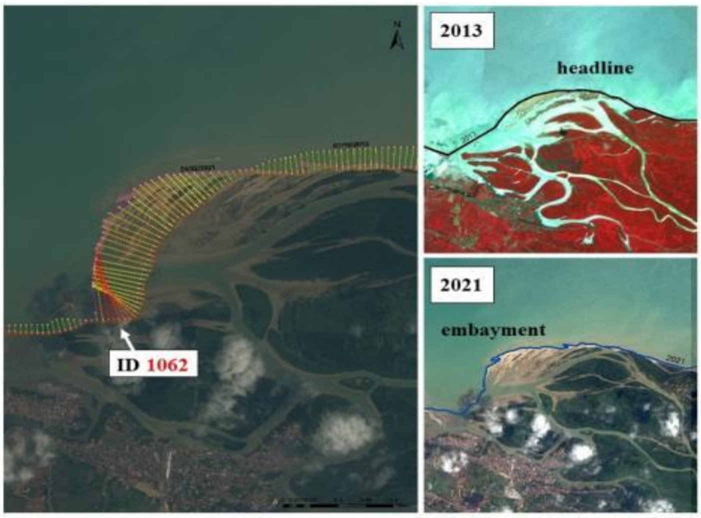

Figure 5: Highest SCE area and the changes on satellite images in 2013 and 2021

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3.2 Net Shoreline Movement

Rising water levels along Kelantan's coast amplify the risk of erosion and sediment buildup, a characteristic that has earned Kelantan the status of a flood-prone region in Malaysia. The area frequently faces abrupt floods due to heavy rainfall, worsened by increased water levels in both freshwater and coastal zones. Within DSAS applications, accounting for uncertainty is crucial to address potential human impact and natural events. This involves establishing an uncertainty value, where a 95% Confidence Interval and a shoreline uncertainty of 5 metres were selected. Additionally, specific attention must be paid to the influence of tides on SPOT satellite images [14-15]. The distance measurement conducted on NSM depicted movements across 1231 transects, represented by 910 positive transects indicating accretion and 321 negative transects indicating erosion. Ten distinct colour variations illustrate different classifications between erosion (negative distance) and accretion (positive distance) rates. The colour spectrum ranges from red, indicating minimum values and signifying erosion areas, transitioning to yellowish tones, and culminating in blue tones representing maximum values of accretion or sedimentation. In the area of Lagun Jubakar from Figure 6, the level of sedimentation was recorded high along Tumpat area between transects 1021 – 1070. The sedimentation area in Tumpat increased up to 728 metres in 2021. Few areas between Tumpat and Kota Bharu from Figure 6 also depicted a similar amount of erosion and sedimentation where the movement of the shoreline was recorded as stable which increases up to 47 metres (transects 822 – 859) and loss of about 56 metres (transects 780 – 811). Areas around Bachok show an increase of shoreline movement between transects 1 – 472 with 30 – 52 metres changes.

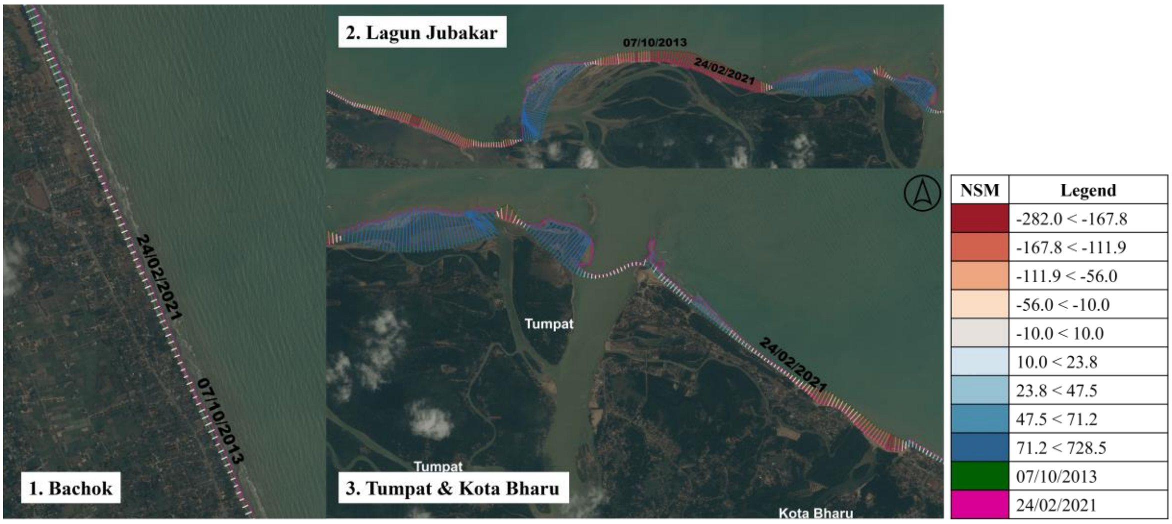

Figure 6: Net Shoreline Movement map snapshot in Tumpat, Kota Bharu and Bachok, Kelantan, Malaysia

In Figure 7 below, NSM provides a concise overview of the analysis results after completion. Referring to Figure 7, the NSM analysis summarises that the maximum accretion occurred at transects 1062, where the shoreline extended by 728.44 metres. Conversely, the greatest erosion was observed at transects 972, leading to a land loss of 281.91 metres. Additionally, the NSM analysis furnishes percentages for positive and negative distances: 29.08% for erosion and 73.92% for sedimentation. These figures indicate an expansion of the shoreline from 2013 to 2021. Notably, shoreline variations may occur due to fluctuating water levels. It can be confidently stated that DSAS's distance measurement yields compatible data for shoreline studies. DSAS also illustrates that the headline sedimentation in 2013 eroded, subsequently giving rise to new sedimentation in the embayment area by 2021. Further investigations are required to ascertain if the rates of sedimentation and erosion can evolve while maintaining consistent outputs. This information stands to benefit not only authorities but also raises awareness within the community about potential scenarios in their living environments.

NSM Overall Averages:

transects with negative distance: **321**

% of -ve distance : **26.08% (erosion)**

transects with positive distance: **910**

% of +ve distance: **73.92% (accretion)**

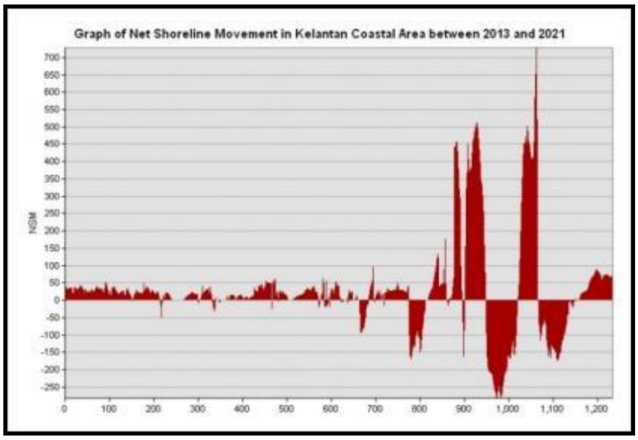

Figure 7: NSM Overall Averages Statistics and Histogram

4. CONCLUSION

The differences in erosion and accretion rates are illustrated through analysis and discussion of the resulting data. The shoreline changes in Kelantan, Malaysia has depicted positive skewed changes where most of the places happen to be sedimented from 2013 to 2021 and increases to 73%. The changes of shoreline between 2013 and 2021 have already depicted the shoreline expansions with 2.5 kilometres. After thorough analysis in ArcGIS, it can be seen that the shoreline does progressively change over time. The most sedimented areas were located around Tumpat, Kelantan (Pantai Geting; Lagun Jubakar; and a few beaches along Bachok), while the most eroded areas were located around Kota Bharu, Kelantan (along Pantai Kundur and Pantai Cahaya Bulan). The SCE and NSM analysis via implementing DSAS Distance Measurement will broaden the understanding of Kelantan, Malaysia shoreline changes activity.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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