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Assessment of Shoreline Changes along Batu Pahat Coastline Using Digital Shoreline Analysis System

Fitrah Hayazi[1], Mardiha Mokhtar[2]*, Effendi Daud[1], Nor Baizura Hamid[2], Mohammad Ashraf Abd Rahman[3]

[1] *Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA*
[2] *Department of Civil Engineering, Centre of Diploma Studies, Universiti Tun Hussein Onn Malaysia, (Pagoh Campus), Pagoh Higher Education Hub, Jalan Panchor, MALAYSIA*
[3] *Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, (Pagoh Campus), Pagoh Higher Education Hub, Jalan Panchor, MALAYSIA*

*Corresponding Author: mardiha@uthm.edu.my
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Abstract

Coastal areas particularly in Malaysia are among the most vulnerable regions that poses a significant risk to the local ecosystem and communities. This research aims to assess shoreline changes along Batu Pahat coastal area using the Digital Shoreline Analysis System (DSAS) over 10 years period which is from 2015 to 2024. Satellite imagery from Landsat 8 and Landsat 9 was utilized with DSAS to monitor the shoreline changes throughout the seven identified study areas along Batu Pahat coast. Three statistical indicators were selected to assess the shoreline changes which are the End Point Rate (EPR), Net Shoreline Movement (NSM) and Shoreline Change Envelope (SCE). The findings reveal that Batu Pahat coast was more exposed to erosion than accretion with the percentage of 50.62% and 49.38% respectively. Based on the End Point Rate (EPR) analysis, the maximum erosion rate recorded was -9.42 m/year whereas the maximum accretion rate reached 32.31 m/year, indicating significant spatial variability in shoreline changes. These findings provide valuable insight regarding the current condition of the coastal area thus appropriate mitigation can be implemented to protect the coastline.

1. Introduction

Malaysian's coastline is highly vulnerable to a coastal change, thus highlighting the necessity to address these challenges. Since Malaysia is surrounded by sea, the coastal region is said to plays a significant role towards the socio-economic activities [1]. These coastal zones are among the risk area as its shoreline is exposed to threats of coastal erosion and sea level rise [2].

A shoreline is defined as the demarcation line between land and water. Shoreline changes are substantial dynamic changes in coastal regions, resulting from natural and anthropogenic factors that shift the shoreline position [3]. Shoreline changes provide valuable insights for coastal protection and risk disaster management. Monitoring shoreline changes is essential to determine ways to nourish the area that are exposed to coastal erosion.

In recent years, rapid technological advancement has led to an increasing demand for technological approach in research [4]. One of the greatest challenges that arise in costal monitoring is obtaining timely and consistent data that can be analysed effectively for short and long-term management, decision making, restoration planning and resilience studies. Therefore, this research adopts Geographic Information System (GIS) integrated with the Digital Shoreline Analysis System (DSAS) to assess shoreline changes using the statistical approach along the study area. Previous studies have demonstrated the effectiveness of DSAS in shoreline change analysis in Kelantan Malaysia. Zakwan *et al.,*[3] utilized DSAS integrated with ArcGIS to analyze shoreline dynamic in Kelantan and revealed that the shoreline experience positives change due to sedimentation process in several coastal region.

Despite numerous research on shoreline changes using DSAS globally, limited research had focussed on Batu Pahat coastal area particularly using satellite imagery dataset integrated with GIS analysis. Furthermore, there is a lack of details shoreline analysis in Johor that incorporates statistical indicator such as EPR, NSM and SCE. Therefore, this research aims to fill the gap by implementing Digital Shoreline Analysis System (DSAS) to assess the shoreline changes along Batu Pahat coastal area by quantifying statistical indicators over 10 years period.

The Digital Shoreline Analysis System (DSAS) is a software that accessible in Environmental System Research Institute (ESRI) [5]. It is an open-source tool that include features to calculate the rate of change of shoreline using statistical approaches based on the historical shoreline data. It is also known as a tool that work relatively with the Geographic Information System (GIS) environment for monitoring the shoreline. By utilizing numerous shoreline positions, the Digital Shoreline Analysis System (DSAS) able to compute rate of shoreline change statistic from a time series. This software executes several statistical data include End Point Rate (EPR), Net Shoreline Movement (NSM), Shoreline Change Envelope (SCE), Linear Regression Rate (LRR) and Weighted Linear Regression (WLR) [6]. The findings from this research will enlighten the pattern of the shoreline changes and provide valuable insight regarding the condition of the coastal area; thus, authorities could find a way to manage the coastal area.

2. Methodology

2.1 Study Area

Batu Pahat is located in Johor which is on the west coast of Malaysia with its coastline bordering the Malacca straits. It is selected as the study area due to its coastline experiencing significant shoreline changes and severe coastal erosion due to the wave and sea-level rise impact [7]. This research focuses on the coastline between Pantai Teluk Wawasan to Pantai Punggur, covering the district's shoreline. Pantai Teluk Wawasan marks the starting point of the study area wheras Pantai Punggur represent the end point that covers approximately 40.0 kilometers of coastline along Batu Pahat. Fig. 1 shows the maps of seven identified study area and Table 1 shows the list of study areas along Batu Pahat coast.

Fig. 1 *Location of study area along Batu Pahat Coast*

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Table 1 *List of study areas along Batu Pahat Coast*

No	Study Area	Latitude	Longitude
1	Pantai Teluk Wawasan	1°49'39.42" N	102°52'8.64" E
2	Pantai Minyak Beku	1°47'42.82" N	102°53'16.22" E
3	Pantai Sungai Lurus	1°43'39.55" N	103°01'42.23" E
4	Pantai Parit Hailam	1°42'19.08" N	103°04'13.51" E
5	Pantai Parit Berong Laut	1°41'44.39" N	103°05'13.76" E
6	Pantai Perpat	1°40'41.09" N	103°06'27.74" E
7	Pantai Punggur	1°41'27.30" N	103°05'50.54" E

2.2 Data Acquisition

Shoreline data which is Shuttle Radar Topography Mission (SRTM) is initially obtained from United States Geological Survey (USGS) website to facilitate the extractions of shoreline. As this research aims to assess the shoreline changes from 2015 to 2024 using Digital Shoreline Analysis System (DSAS), the data needed ranging in 10 years periods. A total of 10 cloud-free images were selected to ensure data reliability. The collection of data includes Landsat 9 covers the satellite imagery from 2022 to 2024 and Landsat 8 covers the satellite imagery from 2015 to 2021 with a spatial resolution of 30m. Table 2 shows the details of satellite image utilize for this research.

Table 2 *Details of satellite image*

No	Satellite	Acquisition Date (dd/mm/yyyy)	Spatial Resolution (m)	Path	Row
1	Landsat 9 OLI	30/10/2024	30	126	059
2	Landsat 9 OLI	24/07/2023	30	126	059
3	Landsat 9 OLI	10/01/2022	30	126	059
4	Landsat 8 OLI	16/02/2021	30	126	059
5	Landsat 8 OLI	17/03/2020	30	126	059
6	Landsat 8 OLI	11/02/2019	30	126	059
7	Landsat 8 OLI	08/02/2018	30	126	059
8	Landsat 8 OLI	09/03/2017	30	126	059
9	Landsat 8 OLI	12/07/2016	30	126	059
10	Landsat 8 OLI	16/02/2015	30	126	059

2.3 Satellite Image Processing in ArcGIS and Global Mapper

Once the data acquisition process is completed, the TIFF format file will be imported into ArcMap software for the pre-processing step which is to convert the satellite image into the Normalized Water Index (NDWI) layer to facilitate accurate shoreline digitization. Generally, the SRTM data sets were obtained from various spectral band. However, satellite image of Band 3 (Green) and Band 5 (Near- Infrared) are two bands that is essential for NDWI analysis. This band was utilized during the pre-processing stage to convert the SRTM data into NDWI.

By using the spatial analysis tool in the ArcGIS, these bands are used in the raster calculator within this software to compute NDWI. This process aiding in the identification of water bodies. Fig. 2 shows the NDWI layer that has been converted into ArcGIS software using raster calculator from SRTM data sets. This process will be repeated for 10-year dataset which is from year 2015 until 2024. The NDWI layer from ArcGIS will be exported for shoreline digitization in Global Mapper software. The pre-processing steps is crucial to prepare datasets for readability of Global Mapper software.

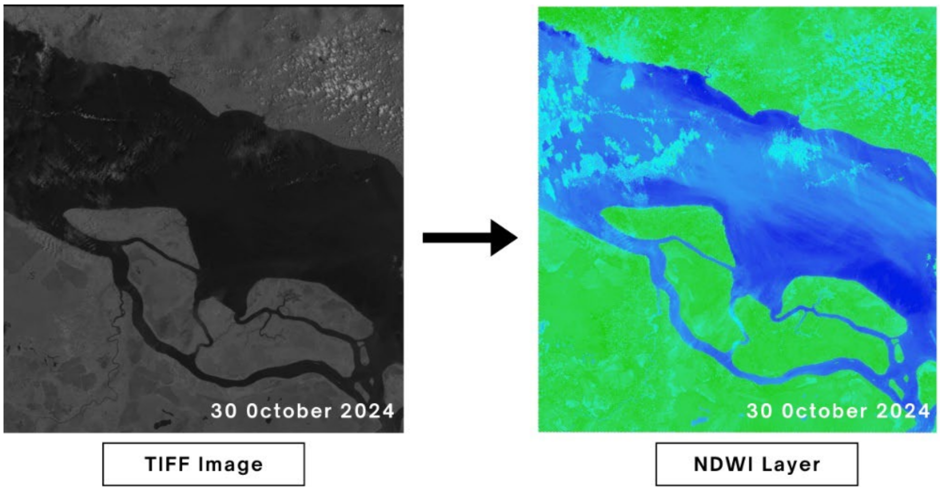

Fig. 2 *The NDWI layer converted from SRTM datasets*

The pre-processing step in ArcGIS is essential for Global Mapper to read the satellite imagery from SRTM datasets. Next, the NDWI layer derived from SRTM data exported from ArcGIS is subsequently export into Global Mapper software for shoreline digitization. This step is necessary as satellite imagery in its raw form cannot be directly loaded into Global Mapper for shoreline extraction. Global Mapper is unable to interpret the spectral characteristic to distinguish water bodies from land.

Once the image is successfully converted into an NDWI layer, the process of digitizing the shoreline will proceed. This research implements semi-automated shoreline extraction together with manual digitizing methods to ensure high accuracy in coastal boundary delineation. For semi-automated shoreline extraction, the generating contour feature in the software will be utilized. Several parameters need to be set for generating shoreline including the elevation range and contour bounds. The elevation range of the contour is set to ensure that the generated line accurately follows the precision of NDWI layer. By utilizing contour features, the resolution of extracted shoreline is enhanced contributing to more precise and continuous representation of the coastal boundary. Fig. 3 shows the shoreline digitization using contour feature. After completing the shoreline digitization process, finalized shoreline will then be exported as shapefile (.shp) and imported to ArcGIS for shoreline change assessment using DSAS.

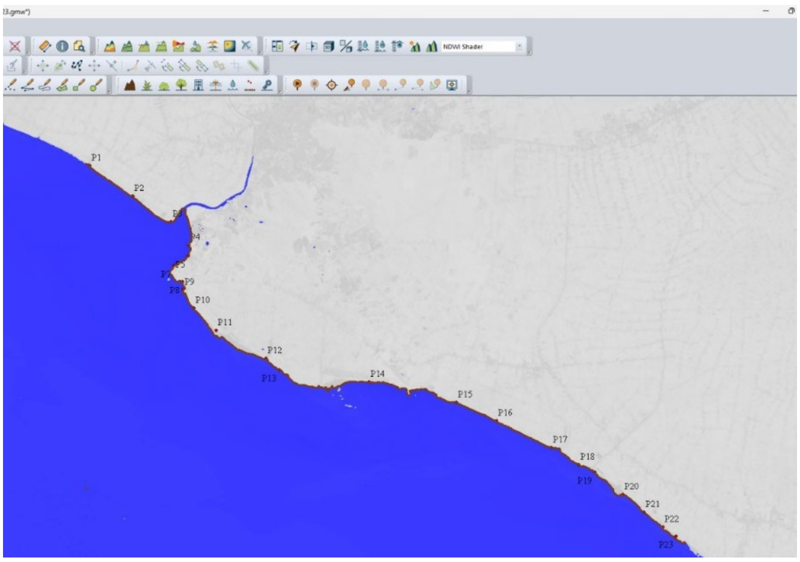

Fig. 3 *Shoreline digitization using contour features*

2.4 Shoreline Change Analysis Using DSAS

The next step after shoreline digitization is the shoreline analysis process using Digital Shoreline Analysis System (DSAS) software. For this research, the baseline is used as a reference point for the transect to compute the distant change. There are three ways to create the baseline, which are to start with a new feature class, smooth or buffer

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an existing shoreline, or update an existing baseline. For this study, the baseline is created using buffer techniques[8]. The key steps in shoreline change analysis is establishing the baseline, which acts as reference for all the transect.

For this research, shoreline approximately 40 km long will be digitized for 10 years data sets. The distance is measured from the baseline to each intersect point along with the corresponding shoreline date. Once the digitized shoreline is imported into the ArcGIS software and the baseline created using the layer of Personal Geodatabase. A new shapefile is created consist of baseline and shoreline polylines. The primary steps for the shoreline change analysis is to define the attribute for each feature class referring to the guideline from USGS. Table 3 shows the USGS guideline used for this research [9].

Table 3 *The USGS guideline*

Baseline		Shoreline	
Attribute	Type	Attribute	Type
OBJECT ID	Object ID	OBJECT ID	Object ID
SHAPE	Geometry	SHAPE	Geometry
SHAPE_Length	Double	SHAPE_Length	Double
ID	Long Integer	Date_	Text
DSAS_Group	Long Integer	DSAS_uncy	Double
DSAS_Search	Double		

The subsequent action is to cast transects of the imported shoreline in ArcMap. A transect can be defined as a line that crosses the shoreline at a predefined interval, and it is cast perpendicularly, and it is used to calculate the statistical rate of change for a time series [5]. Fig. 4 illustrates the evaluations of shoreline changes in Digital Shoreline Analysis System (DSAS) using three key metrics which is Net Shoreline Movement (NSM), End Point Rate and Shoreline Coastal Envelope (SCE).

For this research, the transect distance apply for the shoreline analysis is 100 m. The transect is said to indicate the shoreline profile thus using the shorter transect distance contributes to high accuracy output [10]. As the analysis of shoreline change covers a 40.0 km along the coastal area, approximately 400 transect will be generated by DSAS. Upon the completion of casting a transect, with finalize distance of transect and its smoothing distance value, the calculation of rate can proceed.

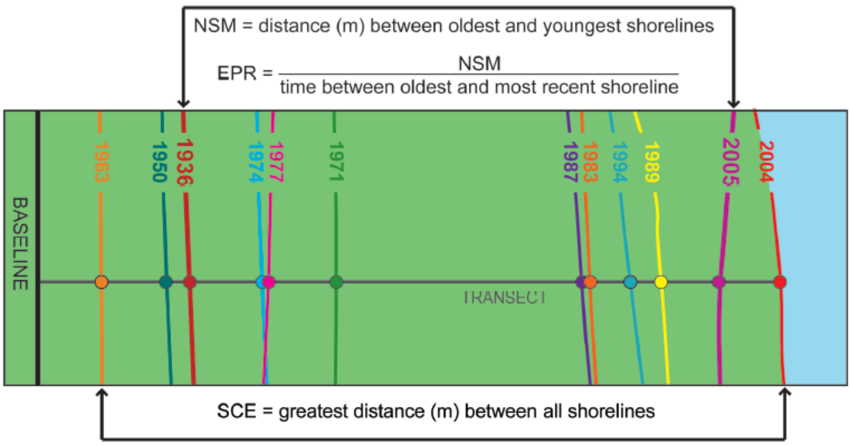

Fig. 4 *Illustration of EPR, NSM and SCE from DSAS [9]*

3. Results and Discussion

3.1 Shoreline Digitization at Batu Pahat Coastal Area

The initial steps prior to calculating rate of change in Digital Shoreline Analysis System (DSAS) are the shoreline digitization. Shoreline digitization involves the process of extracting the shoreline from remote sensing data and delineating the water and land boundary. Fig. 5 shows the results of digitized shorelines for 10 years.

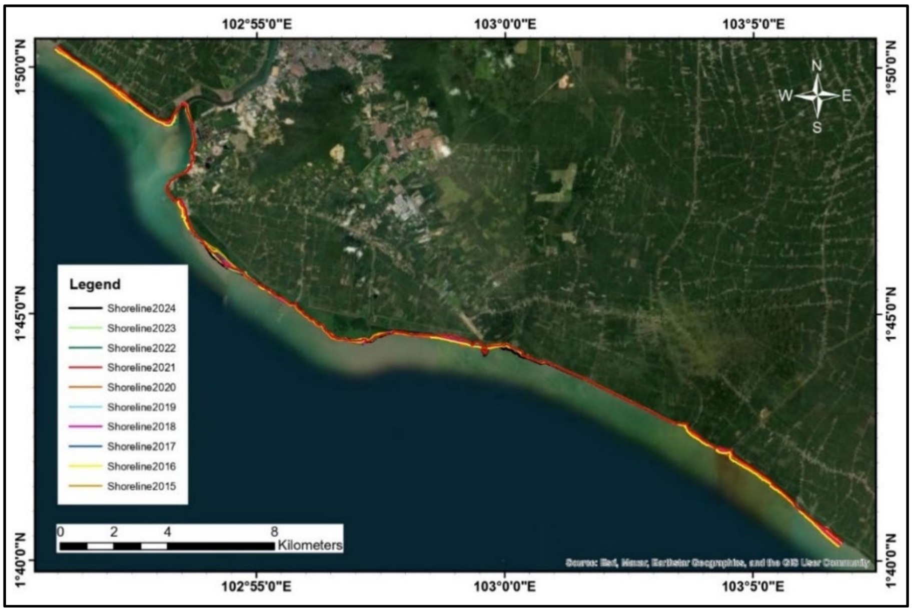

Fig. 5 *Digitized shoreline of Batu Pahat coastal area from 2015 to 2024*

From the compilation of shoreline data spanning over a 10-year period, it can conclude that each shoreline exhibits different position along the coast. The movement of shorelines along the area indicates that the coastal area experiences coastal erosion and accretion throughout the period. Table 4 shows the date for shoreline data for 10 years.

Table 4 *Date of shoreline for 10 years data*

No	Shoreline (Year)	Date
1	Shoreline 2024	30th October 2024
2	Shoreline 2023	24th July 2023
3	Shoreline 2022	01st October 2022
4	Shoreline 2021	16th February 2021
5	Shoreline 2020	17th March 2020
6	Shoreline 2019	02nd November 2019
7	Shoreline 2018	02nd August 2018
8	Shoreline 2017	03rd September 2017
9	Shoreline 2016	07th December 2016
10	Shoreline 2015	16th February 2015

Based on the result from the shoreline extraction analysis, the shoreline at several sections of the study area has shifted landward over time, this indicates the coastal erosion process experiences by the area. Conversely, other areas demonstrate that the shorelines move seaward indicating the occurrence of coastal accretion. This is the conclusion make by the visual interpretation. However, further analysis will be undertaken to statistically observe the shoreline changes over a 10-year period utilizing the Digital Shoreline Analysis System (DSAS). The result will indicate the details analysis of the changes for each transect.

3.2 Digital Shoreline Analysis

3.2.1 End Point Rate

This research used SRTM from Landsat 8 and Landsat 9 to monitor shoreline changes throughout seven identified study areas along Batu Pahat coastline for 10 years period. It comprised one of the methods, which is the End Point Rate, one of the statistical outputs offered by Digital Shoreline Analysis System (DSAS). End Point Rate can be defined as the distance of shoreline shift by time [11]. In this research it refers to the distance of the shoreline change divided by time elapsed in 2015 to 2024. Fig. 6 shows the End Point Rate map for 2015 to 2024 whereas Fig. 7 shows the End Point Rate graph.

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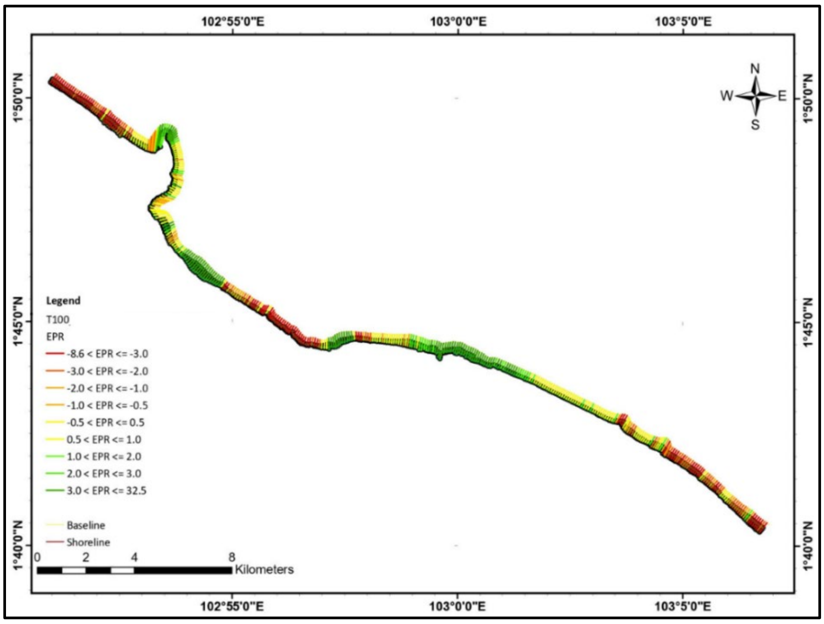

Fig. 6 *End Point Rate (2015-2024)*

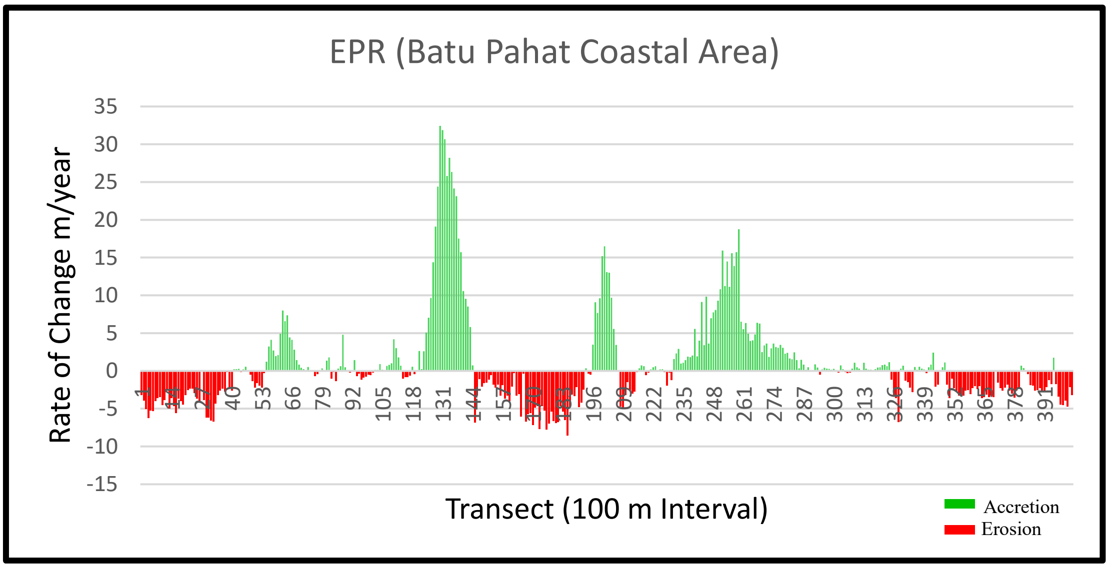

Fig. 7 *Graph of End Point Rate*

In the End Point Rate (EPR) analysis, the positive rate of shoreline changes indicates accretion whereas the negatives rates show erosion [12]. The graph shown above illustrates both erosion and accretion trend are present across the transect cast along the study area. Based on the EPR analysis, Batu Pahat coast was more exposed to erosion than accretion with the percentage of 50.62% and 49.38%.

3.2.2 Net Shoreline Movement

In DSAS, the distance of shoreline change is measured using Net Shoreline Movement (NSM). The Net Shoreline Movement (NSM) analysis illustrates the spatial displacement of the shoreline across the study area based on transects spaced at 100-meter intervals. The NSM measures the distance in meters between the older and the recent shoreline for each transect[13]. As for this research, the shoreline changes were measured between the years 2015 and 2024. Fig. 8 shows the Net Shoreline Movement Map (2015-2024) whereas Fig. 9 shows the Graph of Net Shoreline Movement.

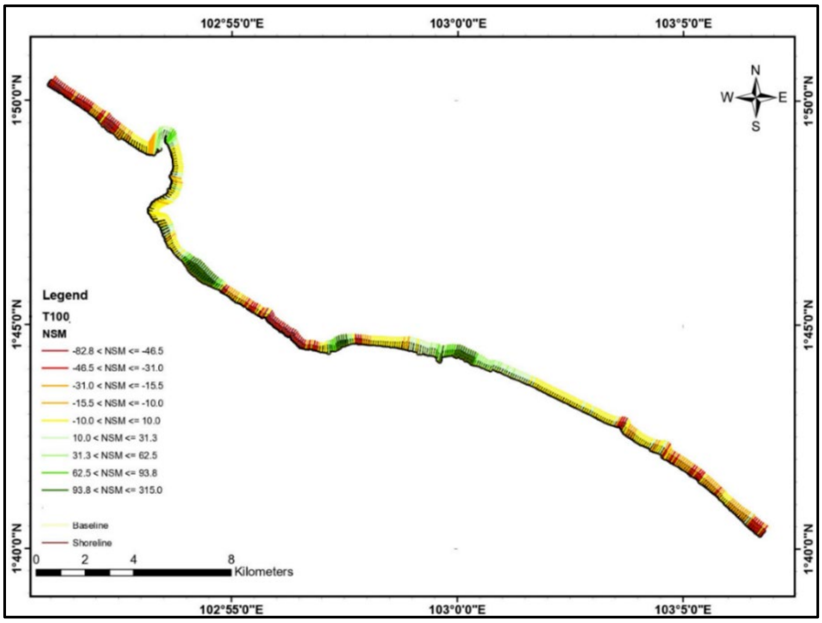

Fig. 8 *Net Shoreline Movement (2015-2024)*

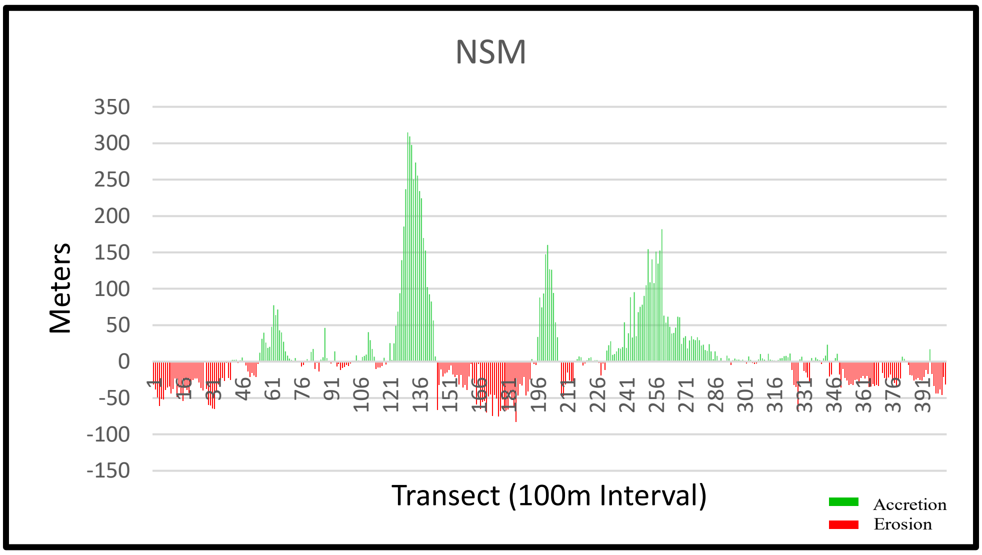

Fig. 9 *Graph of Net Shoreline Movement*

For Net Shoreline Movement analysis, the positive distance of the shoreline changes signifies accretion while the negatives distance indicates erosion [14]. The graph above demonstrates the erosion and accretion trend across Batu Pahat coastal area. The percentage of erosion is 50.62% whereas the percentage of accretion is 49.38%. The analysis shows that the negatives distance transects exceed the positive distance transect throughout the study area.

3.2.3 Shoreline Change Envelope

The other statistical output offer by Digital Shoreline Analysis System (DSAS) is Shoreline Change envelope known as SCE. Unlike EPR, SCE aids in measuring distances not the rate of the shoreline change. It refers to the greatest distance within all the shorelines intersect on a transect without factoring the year of the shoreline [15]. SCE differs from the NSM even though it is used to calculate distance. SCE provides information regarding the overall displacement of the shoreline. However, it does not convey the magnitude of the movement. Fig. 10 shows the Shoreline Change Envelope Map (2015-2024) whereas Fig. 11 shows the Graph of Shoreline Change Envelope.

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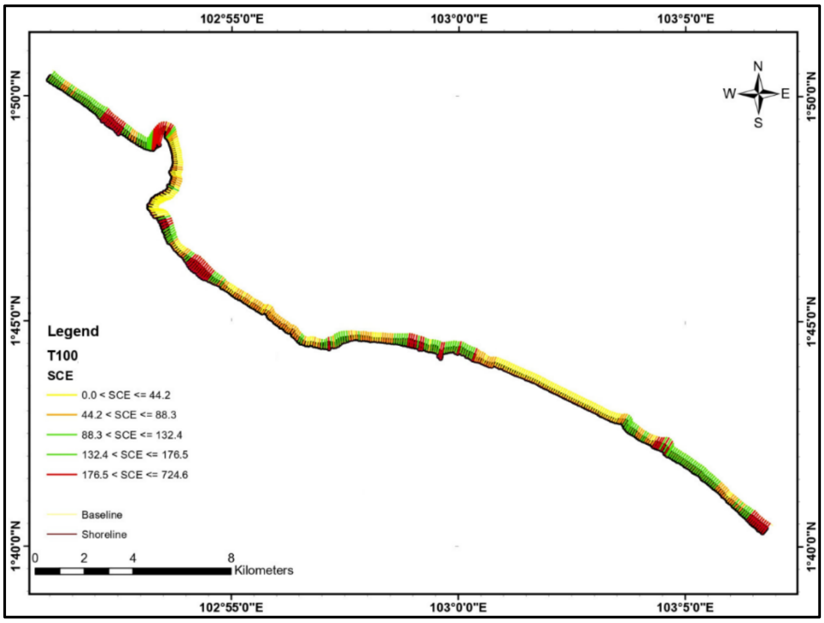

Fig. 10 *Shoreline change envelope (2015-2024)*

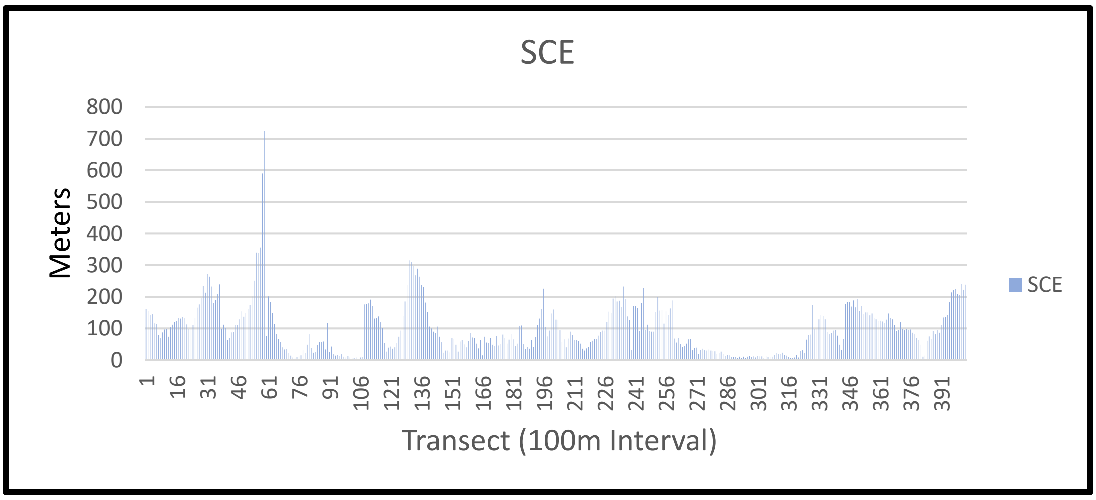

Fig. 11 *Shoreline change envelope*

In this research a total of 403 transects with 100-meter intervals were analyzed in the DSAS to calculate the Shoreline Change Envelope. As illustrated in the graph of Shoreline Change Envelope, the highest recorded SCE is 724.51 m at transect 59 which is located at Pantai Teluk Wawasan. In contrast the lowest SCE value is 6.6m observed at transect 259 at Pantai Sungai Lurus indicating that this part is relatively stable. Significantly, the highest shoreline change envelope is likely to experience a more dynamic coastal process which could be affected by natural factors or anthropogenic impact. Other than that, many other parts of the coastline show much smaller changes, reflecting a more stable shoreline.

3.3 Summary of Shoreline Changes at Batu Pahat Coastal Area

The shoreline analysis was conducted along Batu Pahat coastal area which consists of seven study areas from Pantai Teluk Wawasan to Pantai Perpat from 2015 to 2024. Table 5 shows the percentage of erosion and accretion at each study area. The analysis revealed significant variation in erosion and accretion patterns for each study area.

Table 5 *Percentage of erosion and accretion*

Study Area	Erosion	Accretion
Pantai Teluk Wawasan	61.46%	8.54%
Pantai Minyak Beku	43.43%	56.57%
Pantai Sungai Lurus	9.26%	90.74%
Pantai Parit Hailam	57.14%	42.86%
Pantai Parit Berong Laut	100%	-
Pantai Puggur	90%	10%
Pantai Perpat	92.13%	7.69%

Pantai Sungai Lurus recorded the highest percentage of accretion with 90.74% meanwhile recorded 9.26% of erosion thus concluded that only a certain transect along the area experience erosion. This dominance of erosion is consistent with findings by Mokhtar *et al.*,[1], which reported that nearly 80% of the Batu Pahat coastline is subjected to erosion. Based on seven identified areas along Batu Pahat coast, Pantai Parit Berong recorded the highest percentage of erosion which is 100%. The consistent erosion trend across the regions concluded that this area is critically unstable, emphasizing the need of prompt mitigation in this area to control the impact of erosion. The highest erosion percentage were followed by Pantai Punggur and Pantai Perpat.

4. Conclusion

This research highlights the capability of integrating the remote sensing data with GIS technology in long term shoreline analysis. Based on the result from this research, it can be concluded that Batu Pahat coastal area experiences noticeable changes for 10 years period from 2015 to 2024 with approximately 50.62% of the 40 km coastline experience erosion. The findings from this research revealed that the highest erosion rate is -9.42m/ years while the maximum accretion rate is 32.32 m/year based on the End Point Rate (EPR) analysis. The Net Shoreline Movement (NSM) confirmed both landward and seaward shift of the shoreline whereas the Shoreline Change Envelope (SCE) recorded maximum value of 724.51m indicating highly dynamic coastal process experience by this research area. Based on the analysis, Batu Pahat coastal area is more prone to erosion than accretion. Pantai Parit Berong Laut, Pantai Perpat and Pantai Punggur were identified as the most affected, where more than 90% of the coastline is eroding. The significant changes are driven by the natural factors and anthropogenic influences. From a coastal management perspective, the finding from this research emphasized the need for mitigation strategy, particularly at high-risk erosion zone to protect the coastal area, infrastructure and ecosystem. For future research, several improvements can be made to enhance shoreline changes analysis by incorporating higher spatial resolution satellite data such as Sentinel-2 or Landsat panchromatic imagery. The utilization of higher resolution data will improve shoreline delineation accuracy thus aid higher accuracy analysis.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

*The author confirmed contribution to the paper as follows: **study conception and design**: Fitrah Hayazi, Mardiha Mokhtar; **data collection**: Fitrah Hayazi, Nor Baizura Hamid; **analysis and interpretation of results**: Mardiha Mokhtar, Effendi Daud; Mohammad Ashraf Abd Rahman**; draft manuscript and preparation**: Fitrah Hayazi; Mardiha Mokhtar, Nor Baizura Hamid, Effendi Daud, Mohammad Ashraf Abd Rahman.*

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