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Monitoring the Dynamics of Sedimentary Load Variations Along Coastal Regions Using UAVs After Monsoon and High Tide Events at Pantai Punggur and Pantai Perpat, Batu Pahat, Johor

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ABSTRACT

This research investigates the changes in sedimentary load along the Pantai Punggur to Pantai Perpat coastline in Batu Pahat, Johor, particularly during the northeast monsoon period from October 2022 to February 2023. The study aims to produce a mapping diagram of the shoreline profile and volume changes across various locations and their association with monsoon changes. The research utilised aerial images captured by UAVs, which were analysed using Pix4D and Global Mapper software. Data was collected for six months from September 2022 to February 2023, with the observation period experiencing a high tide phenomenon on November 24, 2022, resulting in a significant change in the data for that month. Shoreline profile results did not establish a conclusive link between sediment load changes and erosion or accretion due to the lack of volumetric data. Consequently, an analysis of volume changes was conducted using the Global Mapper application. In conclusion, the northeast monsoon wind and high tide phenomena during November 2022 significantly impacted the shoreline profile and total volume of the Pantai Perpat and Pantai Punggur areas.

1. Introduction

Malaysia is a country in Southeast Asia with latitude coordinates of 5° 21' 49" and 5° 16' 39" N and longitude coordinates of 103° 7' 44" and 103° 19' 56" T between the South China Sea and the Malacca Strait. The South China Sea separates these flanks by 640 kilometres. Malaysia has a total coastline of 4,809 kilometres, including more than 1,300 kilometres of shoreline [1].

The collection of knowledge on coastal sediment dynamics has grown significantly and is now in line with the demands of society. This research aims to produce an orthophoto mapping of coastal geomorphology in the study area using an unmanned aerial vehicle (UAV) at the minimum low tide level every month for a six-month study period. The tide table issued by the National Hydrographic

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Centre served as a reference for scheduling the data collection. The focus of this study is on modifications in sedimentary load along the Pantai Punggur to Pantai Perpat coastline. The primary objective is to produce a mapping diagram of shoreline profiles and volume changes across different locations that have been observed and associated with monsoon changes. The monsoon season, which occurs from November to March, is characterised by Northeast Monsoon winds blowing over the South China Sea from Asia's depths [2].

All compartments reflect basic sediment transport (start of motion, erosion, transport, flocculation, aggregation, settling in homogenous or stratified fluids, dampening of turbulence by high concentrations, deposition). Some processes are unique to the study areas, such as tidal pumping and the formation of the estuarine turbidity maximum, shelf distribution through the plume and bottom nepheloid layer dynamics, and sediment transport caused by swash. Each study of one of these processes is intimately related to hydrodynamics and sediment movements [3]. The essential sediment transport processes (start of motion, erosion, transport, flocculation, aggregation, settling in homogeneous or stratified fluids, dampening of turbulence by high concentrations, deposition) are reflected in all compartments. Some processes, like tidal pumping and the development of the estuarine turbidity maximum, shelf distribution through the plume and bottom nepheloid layer dynamics, and sediment transport brought on by swash, are specific to the study locations. Each investigation into one of these processes is closely tied to sediment transport and hydrodynamics [3]. There has been a lot of global research done on the dynamics of sedimentary load fluctuations along shorelines due to such natural processes as storm-induced erosion, sea level rise, coastal over-wash, longshore sediment transport, and floods [4].

Coastal geomorphological mapping changes may be estimated by examining shoreline changes resulting from sediment transport. Various approaches have been utilised for shoreline examinations. Sediment transport refers to the deposition of sediment caused by weathering, which can lead to the erosion of the sediment and alterations of the land and bottom surface [5]. Furthermore, sediment movement leads to the creation and evolution of numerous landforms as well as the bathymetry of an area [1].

Sediment deposit composition offers information on the environmental processes involved in transit and deposition, as shown in Figure 1 [6]. The high rate of erosion and accretion is caused by the soil's low shear strength, which implies soil loss owing to poor soil quality [7].

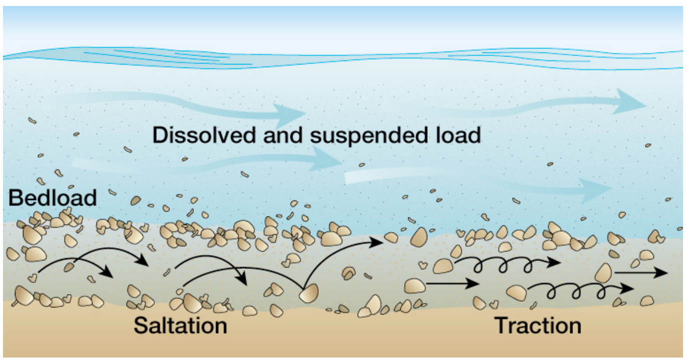

Fig. 1. Mode of sediment transport [6]

The surface of a beach is formed by the movement of air, known as aeolian transport, rather than the action of tides or waves [8]. As stated by the Integration and Application Network (2012), flowing water and winds crossing the water surface create slow water movement, which, when continuous, leads to the formation of wave elements. Aeolian transport is influenced by several factors, including wind velocity, sediment characteristics, beach shape, moisture content, and the presence of rough elements like driftwood and vegetation [9].

Waves on the west coast of Malaysia are influenced by the southwest monsoon, Sumatra winds, and local winds, namely sea breezes and land breezes. The dynamic process of coastal morphs changes when the wave direction angle shifts 20 degrees from southwest to northeast and results in monsoon wind movement [10]. The change in monsoon wind direction has the greatest effect on the wave direction, as shown in Figure 2.

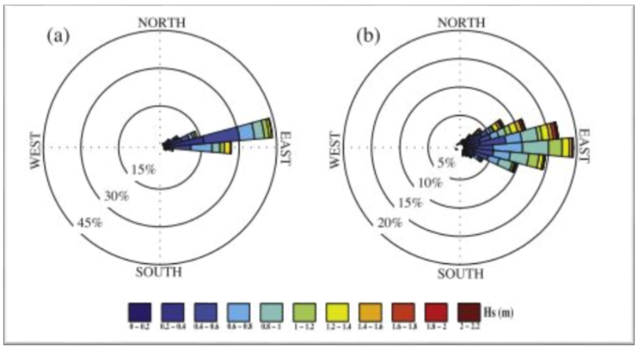

Fig. 2. Wave direction affects the average wave of (a) simulation and (b) ADCP [11]

Over the last forty years, research on sediment dynamics in the area of the coast and along the shoreline has improved significantly. Their successors expanded the study area to include coastal and shoreline zones between the 1970s and 1990s by, for example, launching extensive campaigns to investigate in situ coastal processes using new sensors and technologies and creating extensive field or lab studies for coastal processes. Researchers now have access to a much broader range of technologies compared to what they had in the 1990s and 2000s, and even more recently. It benefits from a technology revolution that gives the community low-cost or free tools for in-field investigation (e.g., sensors, gliders), remote sensing (satellite data, footage captured by UAVs), and modelling (which is open licence modelling). These changes encourage the use of new approaches to monitoring [3].

Prior investigations have been conducted regarding the shoreline evolution at Pantai Punggur, which is among the beaches situated in the Batu Pahat locale exhibiting significant erosion. Unmanned aerial vehicles (UAVs) have been employed on a monthly basis over a one-year period to measure alterations in the shoreline. By utilising UAV photogrammetry techniques, this approach has the potential to yield comprehensive mapping of coastal change [13]. It has demonstrated its uniqueness by providing temporal data for the study area [20].

Researchers are presently conducting an inquiry into a novel technology aimed at advancing the technology sector with an emphasis on dependability, affordability, and efficacy. Unmanned aerial vehicle (UAV) technology is rapidly emerging as a feasible solution for monitoring coastal erosion and accretion. Its application may be especially beneficial in situations where Light Detection and Ranging (LiDAR) systems offer superior quality but entail exorbitant costs [14]. UAVs pose a threat to many damaged coastal areas, and they are uncontrollable. In bad weather, specially designed drones may fly around the beach, taking high-quality photographs of the ever-changing shoreline [15].

2. Methodology

Based on prior studies on UAVs, some information can be useful in research. Introduction to UAVs, kinds of UAVs, UAV applications, and advantages in civil engineering may be relevant in this research. It was important to map and characterise the area for studying debris flow, as it helps identify the factors causing hydro-geomorphological changes [19]. Figure 3 shows the use of a DJI Phantom 4 Pro version 2.0 UAV in this investigation. DJI Phantom 4 Pro V2.0 has OcuSync HD transmission technology that can be connected wirelessly by supporting automatic dual-frequency band switching. DJI Phantom 4 Pro V2.0 comes with a 20-megapixel, 1-inch sensor that can record 4K/60 fps, and burst mode is 14 fps. The autonomous flight system contains a dual-sensor rear vision system and an infrared sensing system with a total of 5-way obstacle detection and 4-way obstacle prevention [13].

Fig. 3. DJI Phantom 4 Pro V2.0 UAV model

Table 1 describes the specifications of the DJI Phantom 4 Pro V2.0 model.

Table 1
DJI Phantom 4 Pro V2.0 model specifications (Source: DJI, 2023)

Model Specifications	Details
Weight (Including Battery & Fan)	1375 g
Maximum Climb/Fly Speed	5 m/s
Maximum Descent Speed	3 m/s
Maximum Speed	31 mph
Maximum Service Ceiling Above Sea Level	6000 m / 19685 feet
Maximum Wind Speed Resistance	10 m/s
Maximum Flight Time	approximately 30 minutes
Satellite Positioning System	GPS / GLONASS

Before the research begins, a site inspection in the study region is required to identify the circumstances of the inquiry and the right time to apply flight planning. In this study, the weather is also important when deciding whether the correct time to fly the drone is required [16]. UAVs are prevented from flying during rainy weather to avoid issues during research and to guarantee that UAVs are always in good condition when aerial observation data is collected. Figure 4 shows an aerial view of Pantai Perpat and Pantai Punggur in September 2022 using a DJI Phantom 4 Pro V2.0 UAV.

(a) (b)

Fig. 4. Figures (a) Pantai Perpat and (b) Pantai Punggur show an aerial view of the study area in Sept 2022

Daily, the National Hydrographic Centre Malaysia issues a source from which the tide forecast can be obtained. During site visits, the projected tide level will be employed. Table 2 shows the predicted tide level in Kuala Batu Pahat, Johor, with latitude 1.48 N and longitude 102.53 E.

Table 2
Tide Table (Source: National Hydrographic Centre Malaysia, 2023)

Year	Month	Date	Low Tide	
			Time	Height (m)
	September	27-09-2022	1729	0.19
	October	10-10-2022	1651	0.14
2022	November	25-11-2022	1748	0.27
	December	24-12-2022	1732	0.35
	January	23-01-2023	1811	0.32
2023	February	20-02-2023	1716	0.32

The study area has Ground Control Points (GCPs) that are uniformly distributed and dispersed throughout the study region. The GCPs serve as reference points, and Variance Points (VPs) will also be provided. A depiction of the GCPs and VPs positioned along the shoreline can be observed in Figure 5.

Fig. 5. Position of GCP and VP in the study area

A number of features must be taken into account when GCP is placed on the coast. The features are as follows:

i. The GCP should be installed above the High Water Level (HWL) [13].
ii. The permanent GCP must be at the same location [13].
iii. GCP cannot be installed in the main part of the public space because Pantai Perpat and Pantai Punggur are open beaches and community recreation sites [17].
iv. The height of the GCP must be less than the GNSS RTK device to allow accurate measurements [16].
v. In order for the GCP to be included in the processing procedure, the GCP must be clear and observed in the orthophoto [13].
vi. In the Pix4D Capture application, the GCP should be placed in the study area and correspond to the map in the flying mission [15].
vii. The GCP material needs to be chosen because the GCP needs to be able to withstand the sun and rain throughout the research period [13].

GCP must be placed through the connection of the GCP platform to the mangrove plant. The selected mangrove tree must be strong and robust enough to remain at a certain point for a long time, as shown in Figure 6. The trees must also be on high ground to ensure that the GCP is not damaged or destroyed by high tides.

Fig. 6. GCP boards are placed on mangrove trees

Work involving GCP georeferencing data collection needs field surveying experience. According to readings from reference sources, using the MyRTKnet technology is more effective and accurate for work in difficult-to-access fields. The site is in the Senggarang area. In the beginning, the reading work at the nearby GPS station is done. The station involved is GPS Station 49, located at Tampok Laut Recreation Center. The distance from the study area to this station is about 11.9 km. Figure 7 shows the JUPEM stone labelled GPS Station 49.

Fig. 7. JUPEM GPS Station (GPS Station 49)

After standing the base device at the GPS station, the Rover should be taken to the Benchmark Station (BM) close to the study area to obtain data readings. The BM chosen is J5582. This BM station is located on the shoulder of Jalan Pontian and is easily accessible. Figure 8 shows the actual location of the BM station placed by JUPEM.

Fig. 8. JUPEM Benchmark Station (J5582)

After completing the data collection at these two stations, the GCP data collection in the study area can be done. The base should be established at BM J5582 when taking GCP readings. This is because this benchmark (BM) is used as a height reference in the study area. The rover will be taken to each GCP to take latitude, longitude, and altitude. Figure 9 shows the data collection work at each GCP. A total of 12 GCPs were read to be used as coordinates during the image georeferencing process. North and east root mean square (RMS) readings should be 0.020 m to get more accurate data. The researcher placed 12 GCPs for taking early steps in the event of loss or damage from human and natural factors such as waves.

Fig. 9. Collect the data at each GCP

The Nevada Department of Transportation concluded that the minimum requirement is to install more than 5 to 10 GCPs. The ratio of the GCP number to the root mean square error (RMSE) is shown in Figure 10. As a result of the mapping process, the minimum number of GCPs used and required is only 4 GCPs. The RMSE accuracy does not increase more than 4 GCP, as it remains no more than 0.1 RMSE. The maximum number of GCPs in the research field, according to some studies, is only 9 [18]. For a fairly accurate survey, only about 4 GCPs are needed.

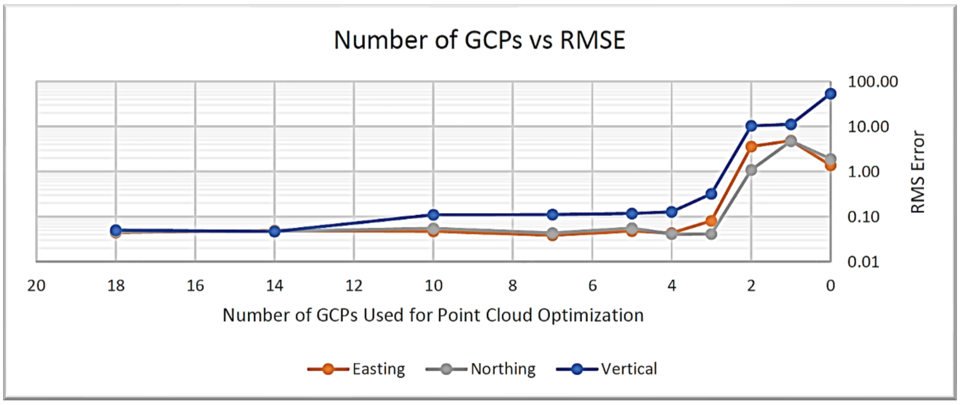

Fig. 10. GCP number ratio against Root Mean Square Error (RMSE)

The data collection method was allocated during the UAV flight. The UAV was used as a reference for the entire image at an altitude of 70 meters. The weather must be suitable, i.e., on a sunny day, so as not to affect the data collection process. Only one person is required to be the pilot of the UAV during the data collection. The coordinates of the control points should be taken so that the collected data can provide a better 3D representation when the procedure is completed. The latitude, longitude, and elevation coordinates of the coastal area must be used to obtain the relative location of each reference point. Data collection is essential to generating a 3D model of shoreline change for the study area.

Calibration is a critical step in conducting the investigation at the shore. If the drone's calibration is incorrect, it may not land at its take-off point, increasing the risk of water damage. Consequently, calibration must be performed as a protective measure for drones. The shoreline image was then captured using the Pix4D Capture application, which can be seen in Figure 11.

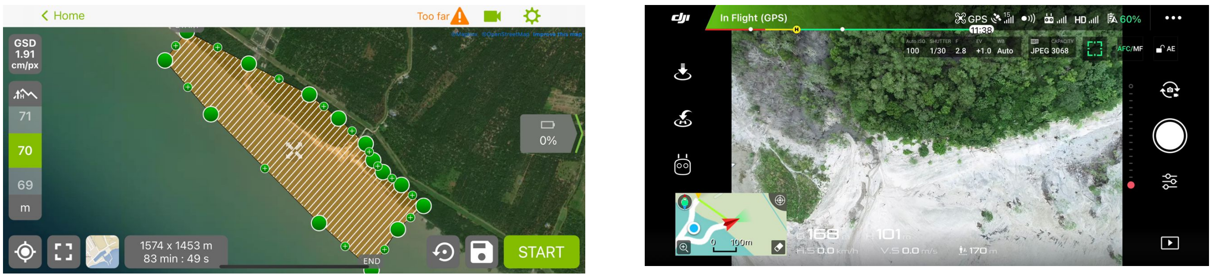

Fig. 11. Flight planning at the study area

The results of six different flight pattern data sets will be processed using an application known as Pix4D Mapper software to generate the required 3D images, and the created images will be checked using Global Mapper software to obtain the results. It was examined to identify the shoreline variations that occur along the coastline.

Pix4D Mapper is a professional drone photogrammetry software that creates a map from all the pictures acquired by the UAV. This software is easy to operate. This software is used to generate data from Pix4D capture and build maps. To improve data accuracy, ground control points (GCP) are included in this software. The map was based on image coordinates obtained from a UAV, so this study does not use tachometry to obtain the correct GCP. As a result, the observation results obtained are not very accurate.

The Pix4D Mapper software will process the images as the drone flies and capture all 1,989 image slices in the study area. The procedure in the Pix4D Mapper software allows all pictures to be combined into one large 2D model. One flight to the procedure takes three days. The first step in

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Pix4D Mapper is to perform basic processing. Check 1 for Initial Processing as shown in Figure 12, and make sure all options for Initial Processing, such as Digital Surface Model (DSM), Orthomosaic,

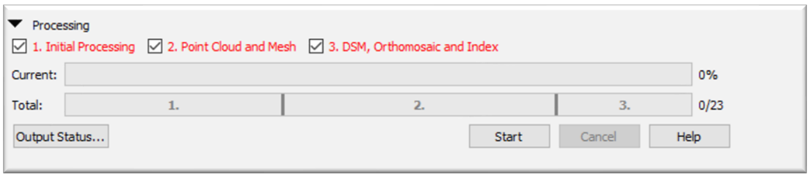


Fig. 12. Pix4D Mapper Software shows Initial Processing

Additional Output, and Index Calculator as shown in Figure 13, are selected.

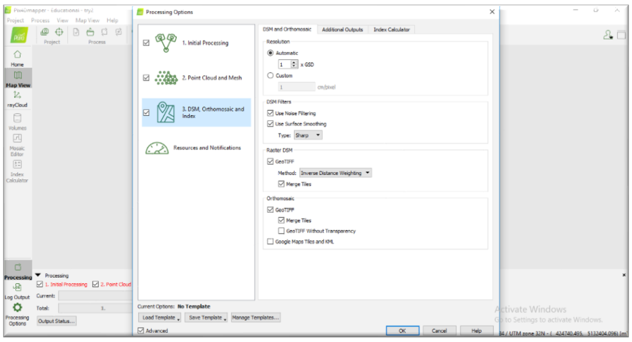


Fig. 13. Pix4D Mapper's Processing options include DSM and Orthomosaic

Since GCP is available in this study, image coordinates are used as GCP but are not as accurate as real GCP through the tachometric method. Figure 14 shows the GCP obtained for the photo coordinates provided by the UAV. A geolocation image with its own coordinates that displays all 1,989 overlapping photographs taken by the UAV must be exported in order to derive GCP from a photograph.

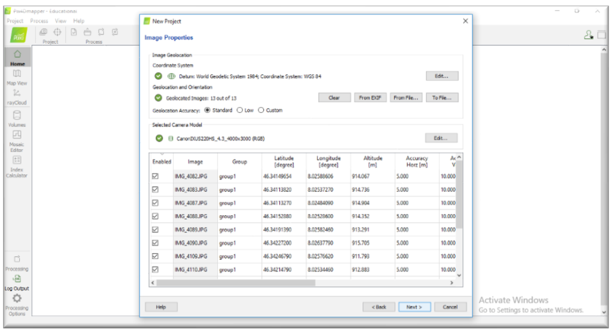


Fig. 14. GCP that provides Geolocation coordinates of Images via UAV

Upon capturing photos with the DJI Phantom 4 Pro V2.0 via Pix4D Mapper, the subsequent course of action involves analysing them through the use of Global Mapper software. Commence the process of analysing the images by selecting an open data file. Subsequently, following the analysis of the data within Pix4D, there may be residual files remaining, as depicted in Figure 15.

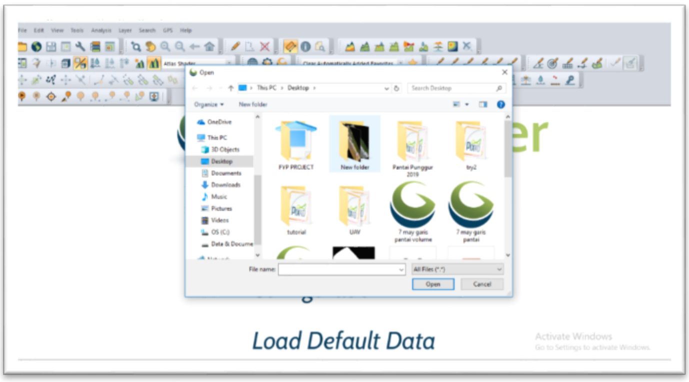


Fig. 15. Optional files from the Pix4D Mapper software

The essential files for evaluating data in Global Mapper software are DSM, mosaic, contour, and DTM. Contours and DTM are supplementary files. To obtain the contours of the research area, select the create contours from terrain grid option. To achieve the results of the photo capture by the drone, there are 9 zones to be marked on this software after completing the analysis and interpretation of data using the Global Mapper software, as shown in Figure 16. Through this software, shoreline profiles and total volume change data can be observed.

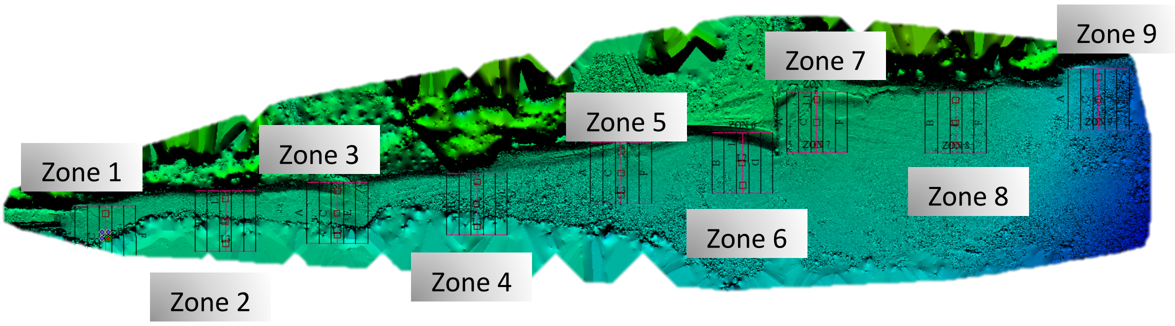


Fig. 16. 9 Zones located along site area

3. Results and Discussion

In the period between September 2022 and February 2023, Table 3 displays the root mean square (RMS) for a duration of six months.

Table 3
Root Mean Square Error (RMSE) each month

Year	Month	Date	RMS (m)
	September	27-09-2022	0.028
	October	10-10-2022	0.031
2022	November	25-11-2022	0.057
	December	24-12-2022	0.106
	January	23-01-2023	0.088
2023	February	20-02-2023	0.023

Table 4 outlines the geographic locations of all zones as per Figure 16.

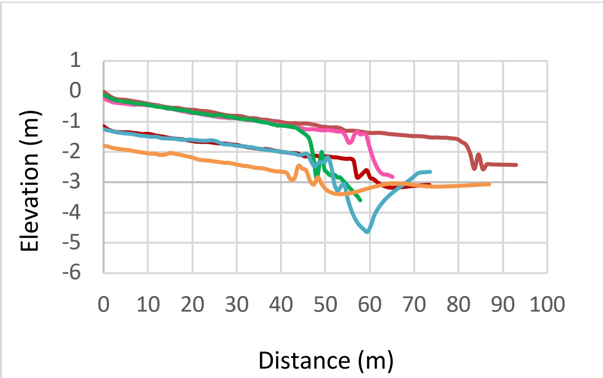
Table 4
Location of all zones and geographic features

Zone	Location	Geographic Features	Picture from UAV
1	Left	Natural flora and fauna (mangrove plants and sandy beaches)	
2			
3			
4			
5	Middle	Mangrove swamp area that was cut down	
6		Near the revetment area (Training Wall) Installed by the Department of Irrigation and Drainage (DID) to prevent coastal erosion in the area	
7			
8	Right	Natural flora and fauna (mangrove plants and sandy beaches)	
9			

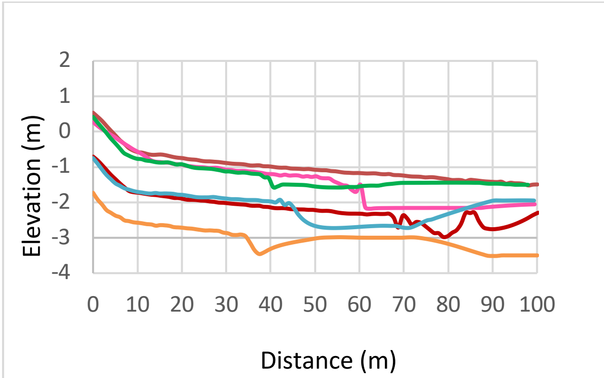
Additionally, Table 5 provides the graph legend, while Figure 17 illustrates the shoreline change data profile across zones between September 2022 and February 2023.

Table 5
Graph legend

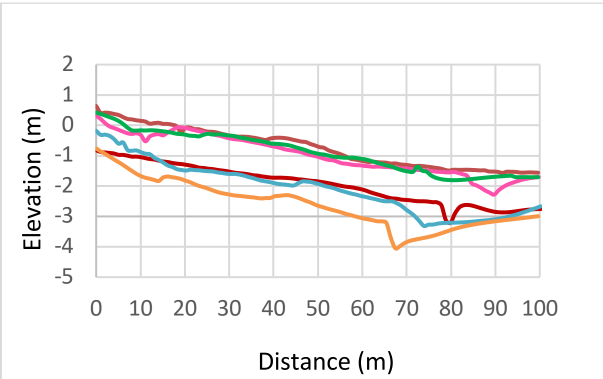
Year	Month	Colour
	September	
	October	
2022	November	
	December	
	January	
2023	February	



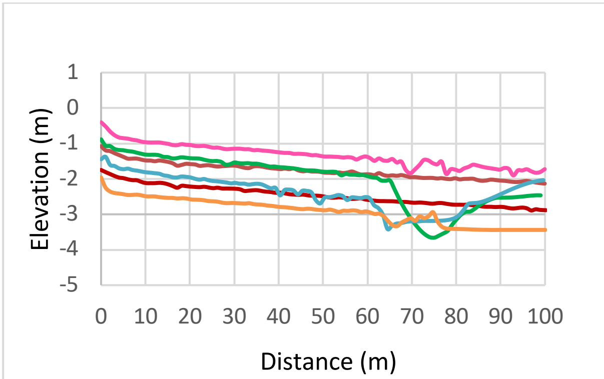
(a) Zone 1



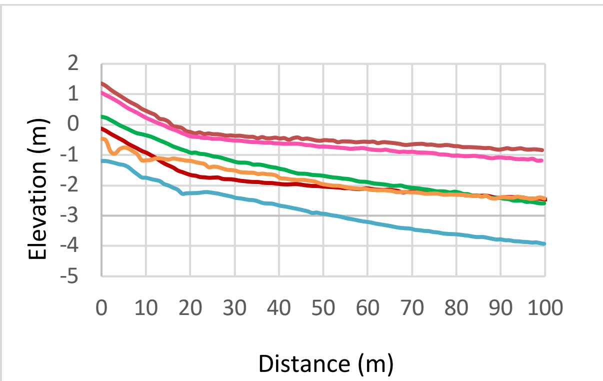
(b) Zone 2



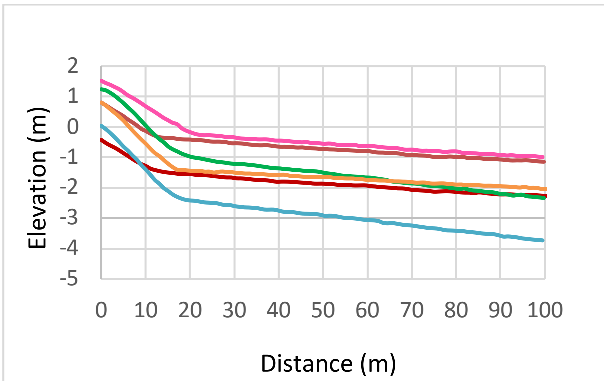
(c) Zone 3



(d) Zone 4



(e) Zone 5



(f) Zone 6

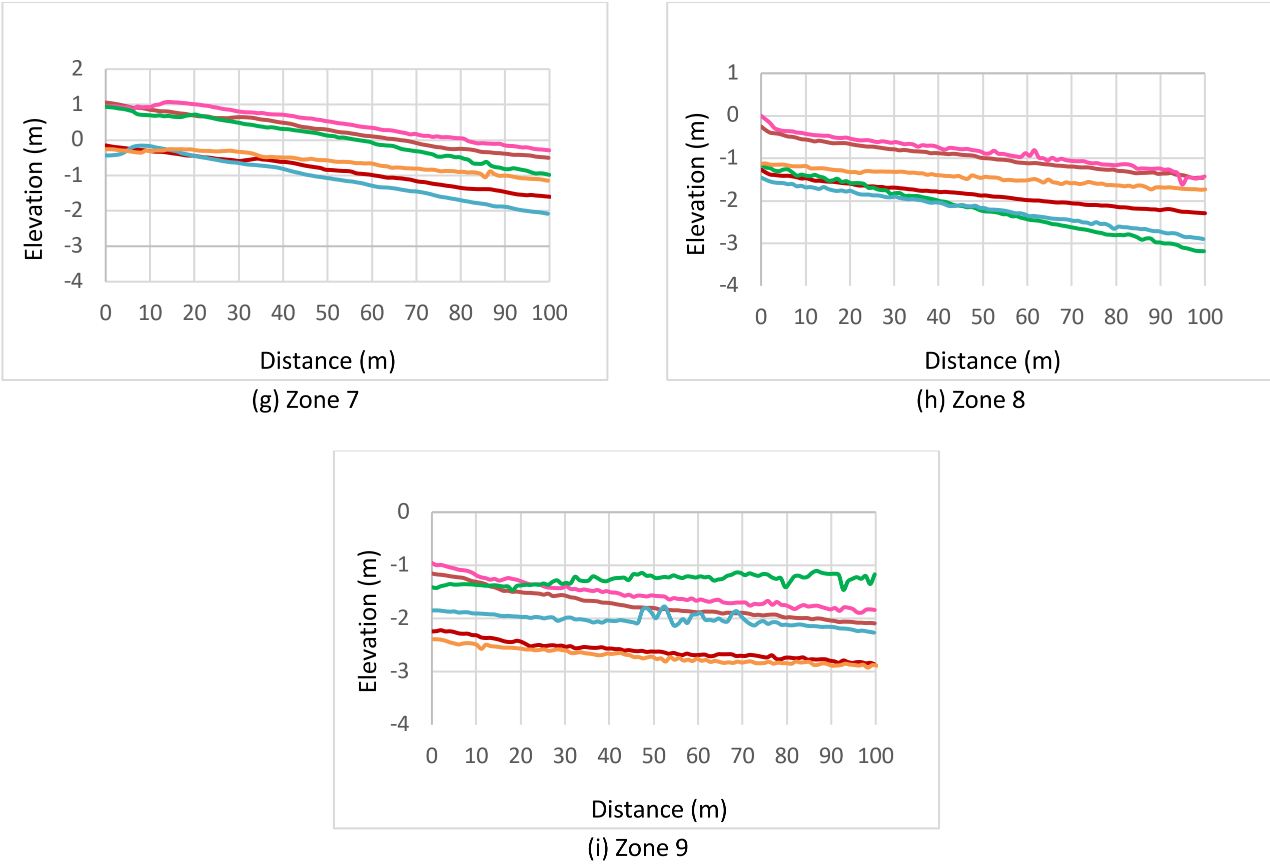
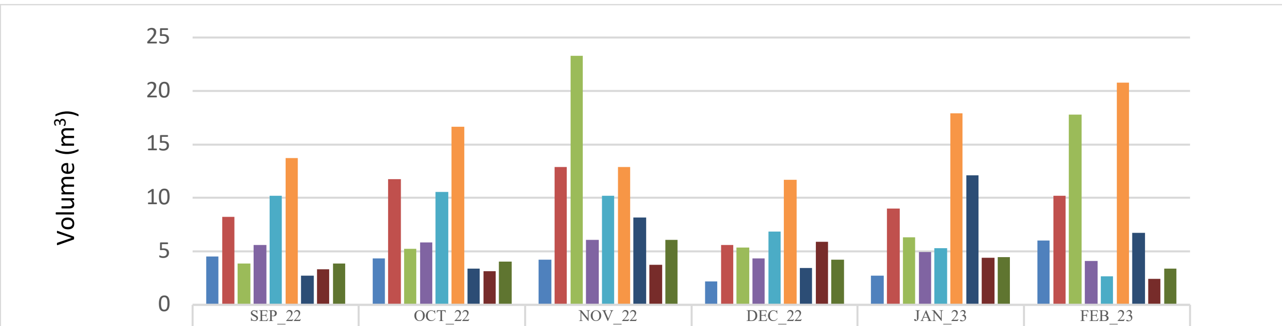


Fig. 17. Data profile shoreline changes at Pantai Perpat and Pantai Punggur by zones during September 2022 until February 2023

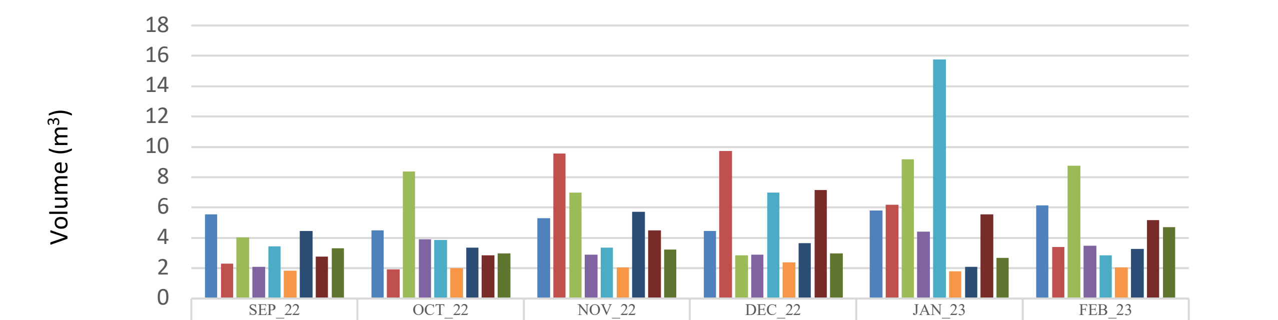
From October to December 2022, there was a noticeable variation in the amount of sediment in all areas. However, this alone does not confirm a connection between sediment changes and erosion or buildup due to the absence of volume data. To better understand the situation, an analysis of volume changes was conducted using the Global Mapper application. Figures 18 through 20 depict the high tide (HT), median tide (MT), and low tide (LT) volume graphs for Pantai Perpat and Pantai Punggur spanning from September 2022 to February 2023.



	SEP_22	OCT_22	NOV_22	DEC_22	JAN_23	FEB_23
1	4.503	4.333	4.222	2.210	2.723	6.022
2	8.249	11.726	12.905	5.599	8.991	10.221
3	3.858	5.265	23.293	5.381	6.309	17.777
4	5.575	5.812	6.094	4.340	4.922	4.083
5	10.213	10.529	10.185	6.874	5.321	2.698
6	13.755	16.652	12.866	11.716	17.892	20.777
7	2.706	3.395	8.149	3.458	12.141	6.750
8	3.314	3.143	3.750	5.875	4.425	2.411
9	3.879	4.042	6.091	4.246	4.471	3.369

Fig. 18. Total volume HT during September 2022 until February 2023

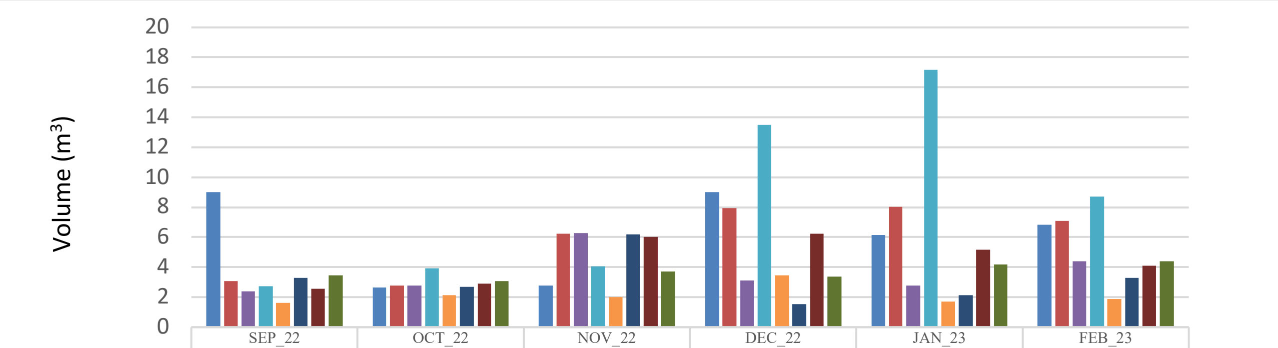
The HT graph indicates a surge in data from October until November 2022, followed by a decline in December. Subsequently, there was a rise in January and February 2023. Specifically, in November 2022, Zone 3 recorded the highest volume of 23.293 m^3, which decreased sharply to 5.381 m^3 in December. Conversely, Zone 6 experienced a consistent increase in volume between December 2022 and February 2023, which can be attributed to the presence of a training wall that stopped the movement of sediment.



	SEP_22	OCT_22	NOV_22	DEC_22	JAN_23	FEB_23
1	5.567	4.509	5.311	4.437	5.823	6.157
2	2.282	1.915	9.576	9.747	6.202	3.386
3	4.018	8.392	6.997	2.853	9.193	8.737
4	2.089	3.915	2.911	2.892	4.423	3.500
5	3.422	3.876	3.336	6.990	15.764	2.844
6	1.844	2.026	2.043	2.383	1.775	2.033
7	4.437	3.375	5.702	3.661	2.076	3.274
8	2.768	2.837	4.487	7.138	5.539	5.157
9	3.318	2.987	3.209	2.962	2.692	4.698

Fig. 19. Total volume MT during September 2022 until February 2023

The data on the MT graph shows an upward trend from October 2022 until January 2023, then a downward trend in February. Notably, Zone 5 had a volume of only 3.336 m3 in November 2022, but by January 2023, it had greatly expanded to 15.764 m3. This can be linked to the construction of a natural headland in the region, which was brought about by the building of a river following a high tide event, as seen in Figure 21.



	SEP_22	OCT_22	NOV_22	DEC_22	JAN_23	FEB_23
2	8.991	2.659	2.764	9.012	6.147	6.814
3	3.056	2.783	6.254	7.961	8.015	7.081
4	2.409	2.767	6.283	3.123	2.784	4.391
5	2.737	3.929	4.063	13.505	17.165	8.707
6	1.630	2.127	1.992	3.466	1.697	1.888
7	3.300	2.669	6.190	1.546	2.150	3.270
8	2.542	2.919	6.030	6.243	5.167	4.082
9	3.440	3.064	3.721	3.373	4.195	4.414

Fig. 20. Total volume LT during September 2022 until February 2023

The LT graph illustrates an increase in data from October 2022 until January 2023, followed by a decrease in February. Specifically, in November 2022, Zone 5 recorded a volume of only 4.063 m^3, which increased significantly to 17.165 m^3. Notably, the data for all zones remained consistent in October. It can be inferred from the map that the existing structure and river impact Zone 3 and Zone 7, including the training wall and the river.

Fig. 21. The river and headland made from backwash during high tide phenomena on November 2022 with 3.4 meter high

Based on the results shown, using a UAV with software assistance was crucial in obtaining data and producing a volume layer for different months. The tides and monsoon patterns seen during the research period can be used to determine changes in the shoreline. The shoreline changes in relation to the movement of sediments carried by the water from the sea. The results indicate that the sediment volume carried was higher from November to January, which coincides with the Northeast Monsoon season. The additional sediments carried by the sea level rise due to tide changes alter the beach profile.

3. Conclusions

This research investigates the dynamics of sedimentary load variations along the coastal regions of Pantai Punggur and Pantai Perpat in Batu Pahat, Johor, after monsoon and high tide events using unmanned aerial vehicles (UAVs). The aim is to study the impact of natural phenomena on the sediment volume and beach profile. Sea level rise has a significant impact on coastal sediment volume and profile changes. Therefore, this study concludes that monsoons and high tide phenomena lead to changes in coastal sediment volume and profile. The study underscores the need for ongoing monitoring and management of coastal resources to address the potential impacts of natural phenomena on coastal environments. UAVs provide an efficient and effective way to monitor and study coastal environments. They can capture high-resolution images and data that allow for the identification of changes in the coastal landscape. This study highlights the usefulness of UAVs for coastal monitoring and management. In summary, this research demonstrates the impact of natural phenomena on coastal sediment volume and profile changes, emphasising the importance of ongoing monitoring and management of coastal resources. Furthermore, it highlights the potential of UAVs as a tool for coastal monitoring and management.

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