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Study of Sediment Deposit Characteristics based on Geotechnical Properties and Geographic Information System (GIS) Approaches

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ABSTRACT

Several sedimentation processes occur in the downstream area between river mouths and the sea. One of the effects of this sedimentation process is the occurrence of siltation around the coast. Not infrequently, this disrupts sea passages when the ship is about to head to the pier or go to sea. Kuala Beach is one of the locations in Pangkalpinang where the sedimentation process continues to occur enough to disrupt the smooth flow of sea traffic. This study aims to provide an overview and analysis of results related to sediment characteristics, spatial analysis of deposits, and predictions of deposition rates around Kuala Beach, Pangkalpinang City. This research was conducted using the following methods: 1) Method of investigating sediment characteristics by collecting data through field testing in the form of hand drills and laboratory testing, 2) Spatial analysis method by mapping the area of sedimentation based on the results of sediment characteristic tests using Agisoft Metashape and QGIS. The results of this study note that sediment deposits are dominated by sediments with sandy grain characteristics (SP symbol based on the Unified Soil Classification System) and a fine grain content (passing sieve number 200) of around 1-3%. The pattern of distribution of sediment deposits is known to have relatively flat contours and relatively uniform characteristics down to a depth of 1.5 m. The coefficient of grain uniformity (Cu) is in the range of 2.43-8.2 with the tendency of uniformity level getting higher to the southeast. The coefficient of grain gradation (Cc) is in the range of 0.44-1.64 with the tendency of the gradation level getting better to the southeast.

1. Introduction

The morphology of the earth's surface constantly changes over time. One of the factors that influences changes in the morphology of the earth's surface is exogenic processes in the form of deposition/sedimentation. The sedimentation process is where sedimentary material is initially transported by sediment transport agents such as water and wind and then deposited in a sedimentation basin. This deposition process occurs due to the loss of the carrying capacity of the sediment transport agent until the sediment is deposited. The dam reservoir is an area with a relatively high level of sedimentation. As happened at the Aswan Dam, on the border between Sudan and Egypt, sedimentation occurred as thick as 4 m in 4 years, which reduced the capacity of the dam [1].

The characteristics of sediment deposits are observed from various scientific points of view, including the geotechnical aspect. The geotechnical characteristics of sediments can be described using the Unified Soil Classification System (USCS). Several parameters that can describe the characteristics of sediment deposits based on USCS are grain size distribution, plasticity index, coefficient of gradation (C_c), and coefficient of uniformity (C_u). Apart from these parameters, specific gravity, resistivity, and CPTU tests were also carried out to describe the characteristics and shear strength parameters in the form of internal friction angles in sedimentary deposits [2]. Other research also states that one of the sediment characteristics is the grain size distribution based on the results of drilling tests and the ISSCS (Indian Standard Soil Classification System) classification [3]. From the geotechnical aspect, this research will examine index

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properties, including the grain size distribution, coefficient of gradation (C_c), and coefficient of uniformity (C_u).

Sediment distribution patterns can be analyzed and observed using a Geographic Information System (GIS) approach. GIS provides information regarding the distribution and contour of a mapped area. The use of the GIS method can be applied in various sedimentation cases such as dam sedimentation [1][4], river sedimentation [5][6], catchment area sedimentation [7], and beach sedimentation [8]. It is necessary to carry out spatial mapping of the sedimentation area. By referring to geotechnical aspects, GIS helps map the distribution of sediment characteristics. GIS can also describe the thickness of sediment deposition and the volume of the mapped sedimentation area [1].

The downstream area where the river and sea meet is also a location for intensive sediment deposition processes. It is not uncommon for this sedimentation process to result in the morphology of coastal areas and downstream rivers experiencing changes or shallowing. Changes in the morphology of the earth's surface in the form of shallowing in areas where rivers and sea meet certainly significantly impact the smoothness of sea transportation. The area where the Baturusa River meets the South China Sea, precisely around Kuala Beach, Bangka Regency, Bangka Belitung Province is an example of where the sedimentation process occurs, as seen in Figure 1.

Sedimentation has an impact on shallowing in areas around the coast and also disrupts sea transportation routes. Furthermore, research related to the characteristics of sediment deposits and sediment distribution around Kuala Beach is essential to become a reference in controlling the sedimentation process in the future. This research also supports the Sustainable Development Goals related to infrastructure sustainability and the marine environment. This research also supports the Indonesian National Research Master Plan, specifically focusing on maritime research.

Based on the Geological Map of North Bangka, the research location is part of the Alluvium (Qa) formation, composed of boulders, gravel, sand, and peat. This formation is spread upstream of the Baturusa River to the Mabat and Nelanding Rivers [9].

2. Research Method

The research was conducted in the Kuala Beach area, Pangkalpinang City, Bangka Belitung Islands Province, Indonesia. The research area coverage is marked in the blue box in Figure 1. The stages of the research method carried out consist of several stages.

Figure 1. Area of sedimentation.

2.1 Field Data Collection

The first step in data collection is taking aerial photography data using a drone. This aerial photography data collection at least goes through the stages: (1) Determination of area boundaries (export .kmz or .kml files from Google Earth); (2) Installation of drone deploy software on Android; (3) Determination of flight path and altitude; and (4) Aerial photography data capture.

Field testing includes taking coordinate point data, aerial drone photography, and soil samples at each boring point shown in Figure 2. Aerial photo data was collected using a DJI Phantom 4 Pro drone with a flying height of 176 ft. The results of taking aerial photos data are 330 aerial photos with a size between 7-8 Megabytes as described in Table 1.

Table 1. Field data

Type of Data	Data Obtained	Tools
Aerial Photograph	330 Images	Drone DJI Phantom 4 Pro series
Soil sample	10 locations	Hand Boring

Soil sampling was carried out at 10 locations spread across the research area with location coordinates in Universal Transverse Mercator (UTM) shown in Table 2. The map of the sampling locations in the research area shown in Figure 3. Soil sampling at each point was carried out at 0 m, 0.75m, and 1.5 m depths. Based on observations in the field, the sediment type is sand grains containing mollusk shells. Figure 4 shows the appearance of the sample in the field. There were 30 soil samples, which were then tested in the laboratory.

Figure 2. Field work of aerial photo with DJI Phantom 4 Pro and soil investigation with hand boring.

Figure 3. Map of hand boring locations.

Table 2. Coordinates of sampling point locations

Point	UTM Coordinate	
	x	y
HB-1	628821	9769233
HB-2	628940	9769160
HB-3	629024	9769112
HB-4	628990	9769219
HB-5	629103	9769068
HB-6	629209	9769010
HB-7	629181	9768949
HB-8	629051	9769174
HB-9	629081	9769023
HB-10	629156	9769113

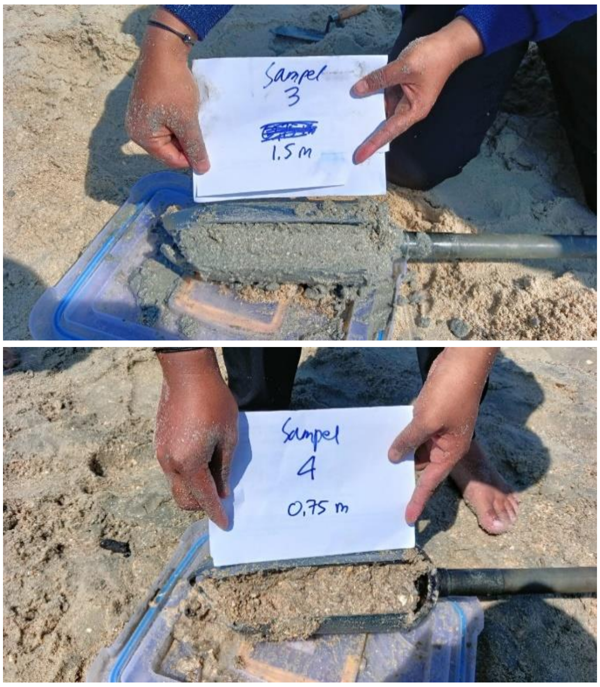


Figure 4. Sediment deposit sampling

Figure 5. Soil laboratory testing

2.2 Laboratory Test

Sieve analysis is carried out to obtain grain size distribution data for each sample from 10 locations point to describe the characteristics of soil samples in the field. The laboratory data collection stage is carried out to determine the characteristics of the soil and sediment samples that have been taken. The test carried out is a sieve test to determine the grain size distribution, uniformity coefficient (Cu), and gradation coefficient (Cc). In the sieve test, the dry weight of the soil used is a minimum of 500 grams [9]. Table 3 is an example of sieve test result data on a sample of 503.73 grams. Figure 5 is a documentation of laboratory testing activities that have been carried out.

One of the sediment characteristics can be seen from the grain size distribution based on the results of drilling tests [2]. After obtaining the sieve test results, a grain distribution graph can be drawn using data on percent passing and sieve hole diameter [10].

Figure 6 is an example of the results of the grain size distribution graph for the HB-1 at the depth of 0.75 m. From this graph, we can determine the values of D_{10}, D_{30}, and D_{60} and then determine the uniformity coefficient (C_u) and gradation coefficient (C_c) values. D_{10}, D_{30}, and D_{60} values known as effective size are taken by looking at the grain size values in the percent pass conditions of 10%, 30%, and 60%, which intersect the distribution graph. Effective size is defined as the percentage of the total grain weight of soil with a diameter smaller than a certain grain size.

In determining the value of the uniformity coefficient and gradation coefficient, the formulas Equation 1 and Equation 2 can be used.

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

$$C_c = \frac{{D_{30}}^2}{D_{60} \times D_{10}} \quad (2)$$

According to the graph (Figure 6), the value of D_{10}, D_{30}, and D_{60} are obtained. D_{10} = 0,16 mm, D_{30} = 0,53 mm dan D_{60} = 1,07 mm. It is found that the values of the uniformity coefficient (C_u) and gradation coefficient (C_c) are as follows:

$$C_u = \frac{D_{60}}{D_{10}} = \frac{1{,}07}{0{,}16} = 6{,}68$$

$$C_c = \frac{{D_{30}}^2}{D_{60} \times D_{10}} = \frac{0{,}28}{0{,}17} = 1{,}64$$

So, concerning the calculation results above, the soil is classified as SW based on the Unified Soils Classification System (USCS).

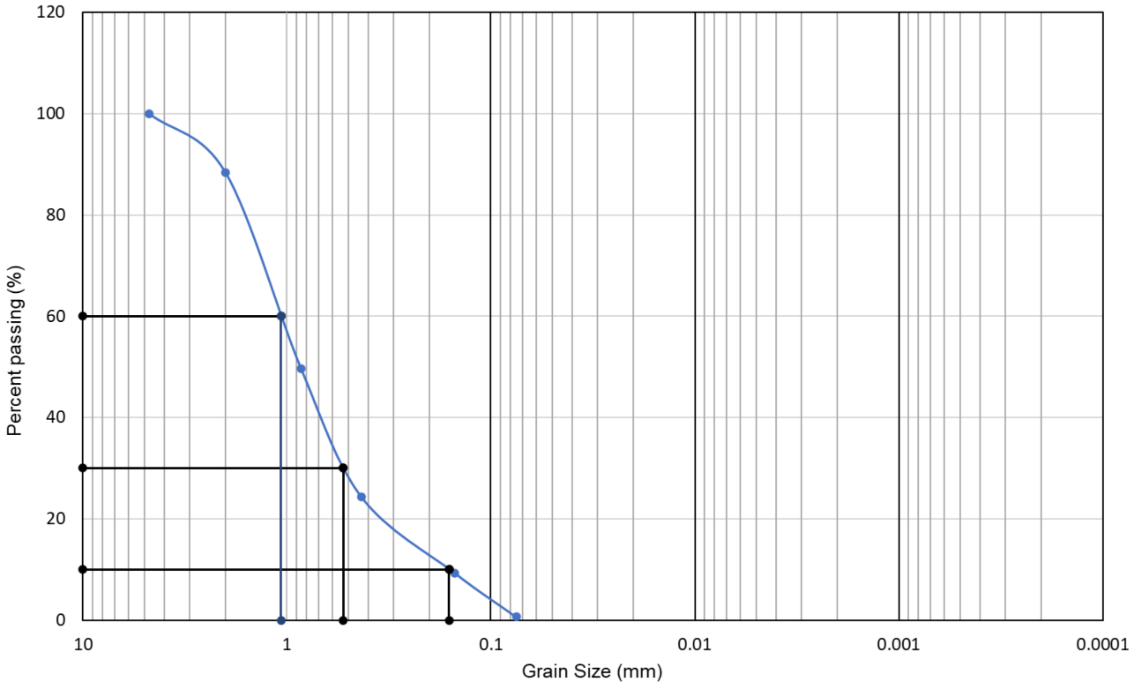


Figure 6. Grain size distribution graph of HB-1 at the depth of 0.75m.

Table 3. HB-1 sieve test data results for soil characteristic analysis

Sieve Number	Sieve diameter	Retain weight	Cumulative retain weight	Passing weight	Percent retain	Cumulative percent retain	Percent passing
	(mm)	(gram)	(gram)	(gram)	(%)	(%)	(%)
4	4.75	0	0	503.73	0.00	0.00	100
10	2.00	58.48	58.48	445.25	11.61	11.61	88.39
20	0.85	195.45	253.93	249.80	38.80	50.41	49.59
40	0.43	127.49	381.42	122.31	25.31	75.72	24.28
100	0.15	75.6	457.02	46.71	15.01	90.73	9.27
200	0.075	43.62	500.64	3.09	8.66	99.39	0.61
PAN	-	3.09	503.73	0	0.61	100	0

2.3 Aerial photograph and spatial data processing

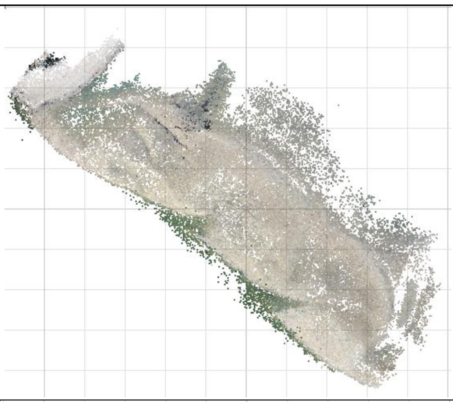
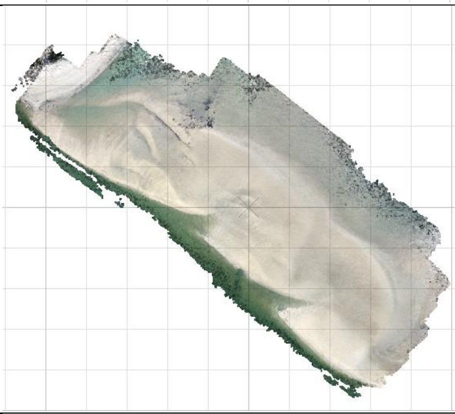
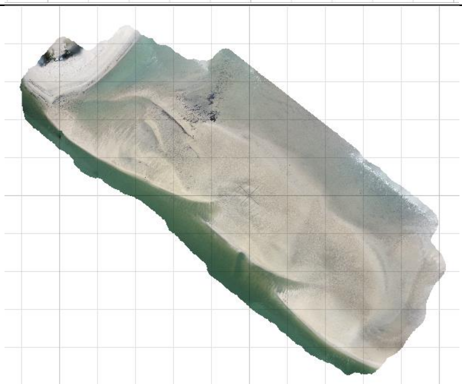
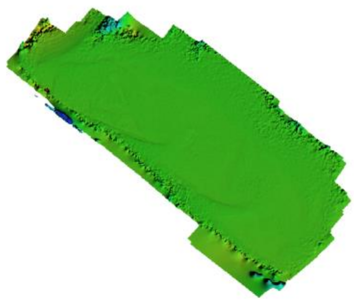
As previously noted, the study area is located near the confluence of the river and the coast. The study area is 76,270 m^2. In the aerial photo analysis stage, 330 aerial photos were input into Agisoft Metashape Professional software. Table 4 shows the models generated from the results of aerial photo analysis using Agisoft Metashape Professional software.

To identify the geographic information on which area is likely to silt, a spatial analysis was carried out. The kriging interpolation approach was used for the geoprocessing operations in this work. Due to the fact that the project border will be entered as a vector layer, the Cu and Cc values will be set as an interpolation attribute.

In the geosciences, kriging has been extensively utilized to include spatially sampled data, estimate the conditional mean field, and calculate the related co-variance [11]. The assumptions of the kriging method are the distance and orientation between data samples show important spatial correlations in the interpolation results [12].

Kriging method has the advantage of accounting for the spatial auto correlation between the data when calculating the interpolated surface and forecasting values at unsampled locations [13]. In the case of limited data, the kriging interpolation method was the best when compared with the inverse distance weighting method, and the polynomial interpolation method was used to spatially interpolate the particle size data at the experimental site [14].

Table 4. Aerial photograph data processing

No	View Model	Description	Result
1	Point Cloud	Point Cloud is a collection of data points plotted in 3D space	
2	Dense Cloud	Metashape makes it possible to generate and visualize dense cloud models. Based on the estimated camera positions, the program calculates the depth information for each camera to combine into a single dense cloud point.	
3	Texture	The texture mapping mode determines how the object texture will be packed in the texture atlas. Choosing the proper texture mapping mode helps to achieve optimal texture packing and results in better visual quality of the final model.	
4	Digital Elevation Model	A digital elevation model that can depict the earth's surface and a method used to sample points from the surface and create digital data that describes the geometry and contours of the earth's surface or a portion of the earth's surface using a set of coordinate points.	

3. Result and Discussion

3.1 Geotechnical Characteristics

The characteristics of sedimentary deposits at the research site are dominated by sand-sized sediment grains. Based on the USCS classification, the characteristics of sediment deposits are classified as SP. Besides, SW symbols at the surface and 0.75 m depth at location point HB-1. SP represented to sandy soil with poorly graded grain. According to Table 5, at the surface (0 m depth), the uniformity coefficient (C_u) values range from 2.43-6.69 and the gradation coefficient (C_c) values range from 0.81-1.64. At 0.75 m depth, the uniformity coefficient values range from 2.55-8.2 and the gradation coefficient values range from 0.8-1.64. At a depth of 1.5 m, the uniformity coefficient values ranged from 3.06-7.22 and the gradation coefficient values ranged from 0.44-1.01. Based on the test results, it can be seen that the deeper the soil elevation, the higher the coefficient of uniformity. This indicates that in general the level of grain size uniformity of sediment deposits is getting better with increasing depth. The coefficient of gradation is seen to decrease as the depth of soil elevation increases as shown in Figure 7.

3.2 Spatial Analysis

The results of the spatial analysis of the geotechnical characteristics of sedimentary deposits in the form of uniformity coefficient and gradation coefficient show some specific patterns. On the surface, the coefficient of grain uniformity value tends to decrease from the direction of land to the ocean or from northwest to southeast. It indicates that the level of uniformity of sediment grain size at the surface is getting higher from northeast to southeast as shown in Figure 8. The coefficient of grain gradation tends to decrease from northwest to southeast. It indicates that the more heading toward the sea, the more well-graded of sediment grains.

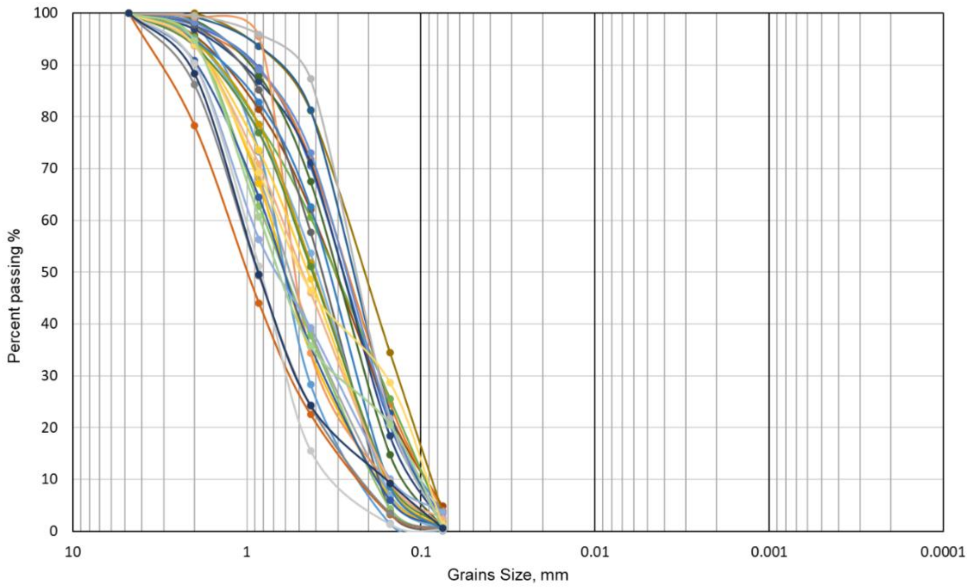


Figure 7. Grain size distribution curve in research area

Table 5. Data on uniformity coefficient (C_u) and gradation coefficient (C_c) of the study site

Point	Coordinates		Depth 0 m		Symbol	Depth 0.75 m		Symbol	Depth 1.5 m		Symbol
	x	y	C_u	C_c		C_u	C_c		C_u	C_c	
HB-1	628821	9769233	6.69	1.64	SW	8.2	1.1	SW	7.22	0.44	SP
HB-2	628940	9769160	2.94	1.06	SP	3.94	0.83	SP	6.25	0.67	SP
HB-3	629024	9769112	3.38	0.81	SP	2.55	0.84	SP	3.25	0.81	SP
HB-4	628990	9769219	4.76	1.1	SP	5.32	1.13	SP	4.08	0.97	SP
HB-5	629103	9769068	4.39	0.81	SP	2.98	0.8	SP	3.69	0.77	SP
HB-6	629209	9769010	2.43	0.96	SP	3.63	1.64	SP	3.2	1.01	SP
HB-7	629181	9768949	2.77	0.94	SP	2.71	0.93	SP	3.06	0.85	SP
HB-8	629051	9769174	2.59	0.84	SP	3.09	0.97	SP	4.42	0.72	SP
HB-9	629081	9769023	3	1.22	SP	3.94	1.13	SP	4.17	0.93	SP
HB-10	629156	9769113	3.47	0.92	SP	3.47	1.03	SP	3.18	0.95	SP

At the 0.75 m depth, the coefficient of uniformity value tends to decrease from northwest to southeast as presented in Figure 9. It indicates that the level of uniformity of sediment grain size at the 0.75 m depth is getting higher from northeast to southeast. The coefficient of grain gradation tends to decrease from northwest to southeast. It indicates that the more heading toward the sea, the more well-graded of sediment grains.

At the 1.5 m depth, the coefficient of uniformity value tends to decrease from northwest to southeast as Figure 10. It indicates that the level of uniformity of sediment grain size at the 1.5 m depth is getting higher from northeast to southeast. The coefficient of grain gradation tends to decrease from northwest to southeast. It indicates that the more heading toward the sea, the more well-graded of sediment grains.

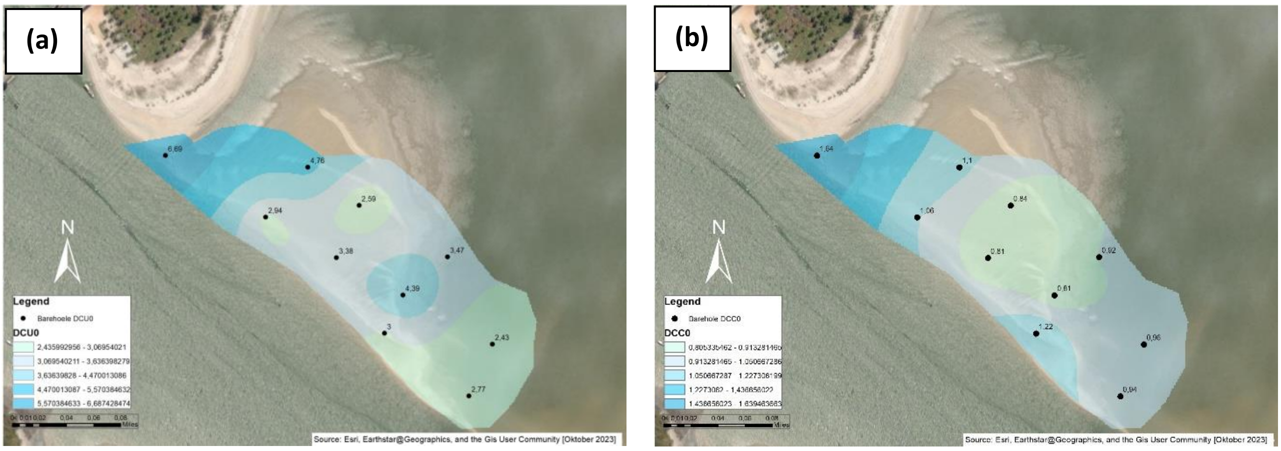


Figure 8. Map of (a) coefficient of uniformity and (b) coefficient of gradation at the surface.

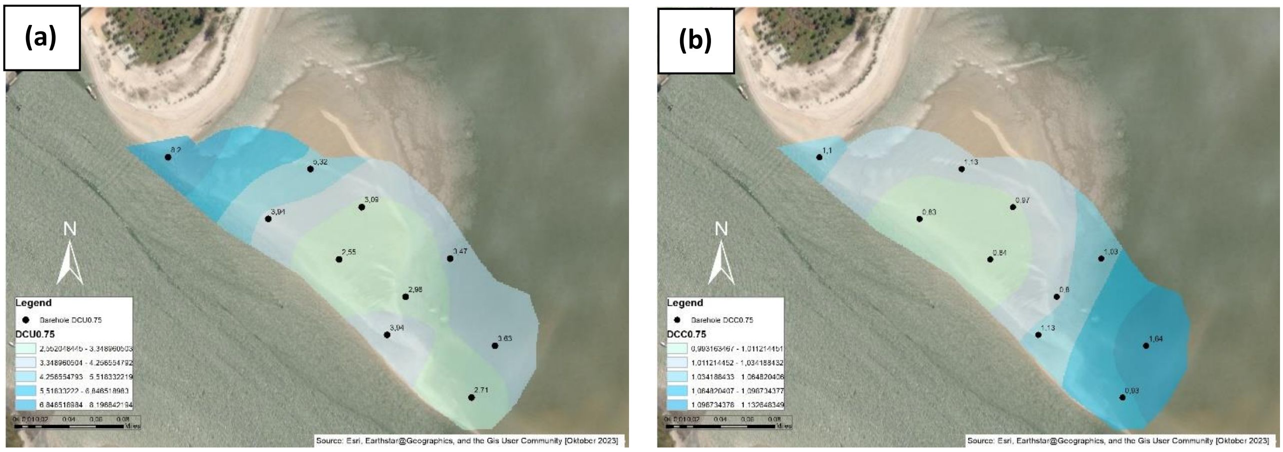


Figure 9. Map of (a) coefficient of uniformity and (b) coefficient of gradation at the 0.75 m depth.

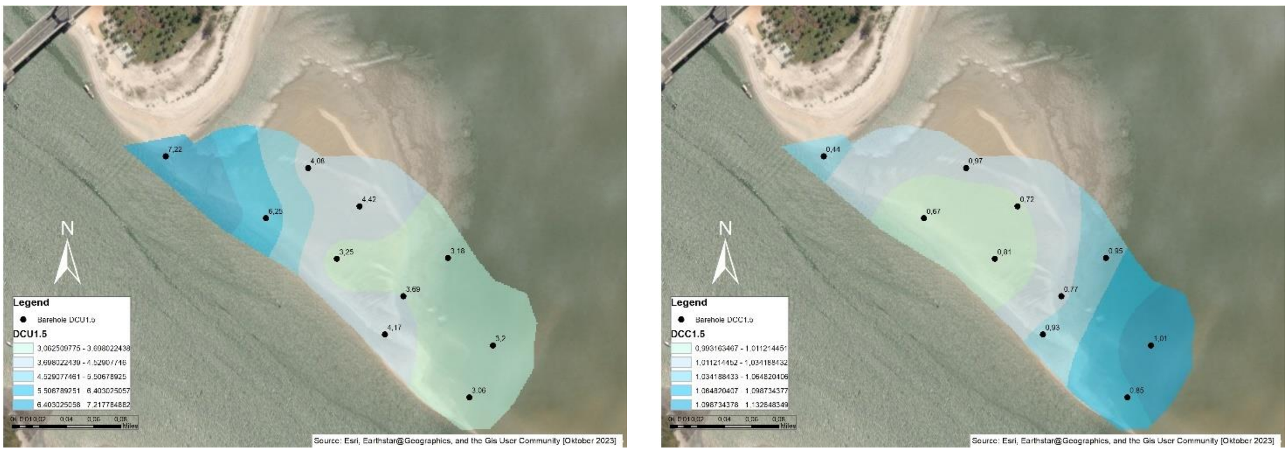


Figure 10. Map of (a) coefficient of uniformity and (b) coefficient of gradation at the 1.5 m depth.

In general, there is no significant difference in the value of the coefficient of grain uniformity between the surface, 0.75 m depth, and 1.5 m depth. For the gradation coefficient, there is a slight decrease in value, especially in the northeastern part of the study area. In the southeastern part of the study area, it tends to increase the value of the gradation coefficient. It indicates that in the northeast area, grain gradation is getting more "well-graded" as the sediment layer deepens. However, on the contrary, in the southeast area, the grain gradation gets more "poorly-graded" as the sediment layer deepens.

4. Conclusion

The characteristics and spatial extent of sedimentary deposits in the Kuala Beach area of Pangkalpinang have been conducted using geotechnical and geographic information system (GIS) approaches. The results show that the type of sediment deposits is generally sand with grain size 0.07-4 mm and the classification symbol SP. The coefficient of grain uniformity (Cu) is in the range of 2.43-8.2, with the tendency of uniformity level getting higher to the southeast. The coefficient of grain gradation (Cc) is in the range of 0.44-1.64, with the tendency of the gradation level to get better to the southeast. This research has not discussed the prediction of sedimentation direction. In the future, the results of this research can help future sedimentation prediction studies.

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