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Grain size distribution and heavy minerals in the sediments of Sungai Dungun, Terengganu

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Abstract: Twenty-one samples of sediments were collected from the center of the river channel and 13 sediment samples collected from the riverbank were analysed for their textural parameters (mean, standard deviation, skewness, and kurtosis) to determine the mineral size. The results indicate that sediments from both the center of the channel and the riverbank were dominated by very coarse sand and very fine gravel. Heavy minerals in the sediment were separated using bromoform for density separation, as well as magnetic separation. Ilmenite, magnetite and cassiterite were abundant in the middle of the channel whereas rutile and zircon were found to be dominant at the riverbank.

Keywords: Grain size, heavy minerals, river, estuary, riverbank

INTRODUCTION

Heavy minerals refer to the minerals that are of higher density (at 2.65 g/) than quartz. Some of these heavy minerals have economic value (Mustafa Ergin *et al.,* 2007; Ali Mohammad *et al.,* 2020; M. Julleh Jalalur Rahman *et al.,* 2022; Omran E. Frihy *et al.,* 2022; Uddin *et al.,* 2022) due to their properties and prevalence and are useful materials for industries such as paints and pigments, ceramics, and sandblasting.

Heavy minerals can be found in mineable concentrations in various type of placer deposits. The heavy minerals accumulated in the placers due to physical processes beginning with weathering, erosion, transportation and finally deposition. Placer deposits can be divided into seven categories, i.e., alluvial placers, colluvial placers, fluvial placers, glacial placers, littoral placers, aeolian placers and marine placers (MacDonald, 1983).

Malaysia has been producing heavy minerals for the past few decades; most coming from amang (heavy mineral separates) and sand derived from tin mining activities. The trend of heavy mineral production in Malaysia has been rapidly declining since 2013 (Department of Mineral and Geoscience Malaysia, 2022) which can be attributed to the declining tin mining activity which in turn reduced the production of amang. In view of the situation, river sand can be evaluated as an alternative source for heavy minerals. Currently, river sand is mainly used in the mixing of concrete in the construction industry. At present, there is no exploration work on river sand for heavy minerals. However, studies have shown that river sand does contain heavy minerals together with other sediments. Therefore, this study is carried out to determine the heavy mineral content and as well as the grain size distribution of sediments from Sungai Dungun, Terengganu. Sungai Dungun is selected based on the geology in the upper reaches area of the river which suggest the presence of heavy minerals in the river sediments.

Grain size plays an important role in determining the energy of deposition as well as the transportation and sorting of sediments. The most common method used for grain size analysis is the Folk & Ward (1957) method which characterizes grain sizes based on mean, standard deviation, skewness, and kurtosis (Folk & Ward, 1957; Wan Hanna Melini *et al.,* 2015, 2017; Oladipo *et al.,* 2018). The mean value reflects the dominant grain size which is influenced by the source supply and environment of deposition. The standard deviation or sorting measures the uniformity of the particle size distribution whereby well sorted particles would have a narrower range of grain size when compared to poorly sorted particles. Skewness reflects the asymmetry of the particle distribution whereby

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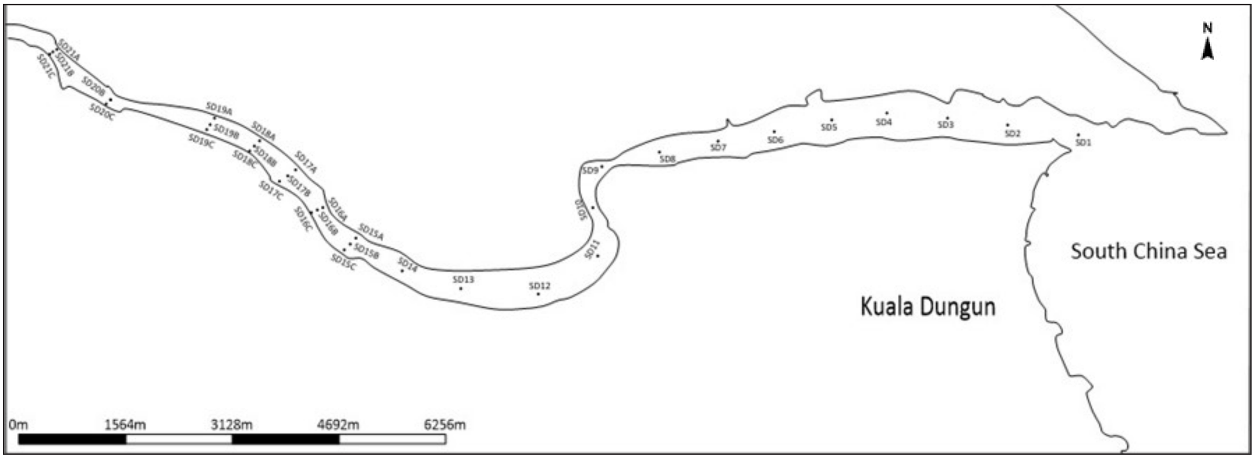

Figure 1: Map of study area.

positive skewness indicates abundance of larger grains that corresponds to low energy environment whereas negative skewness indicates otherwise. Kurtosis describes the peakedness of the grain size distribution such that positive kurtosis indicates coarser grain size whereas negative kurtosis indicates finer grain size.

STUDY AREA

The study area (Figure 1), Sungai Dungun is located in the southeastern part of Terengganu state within the latitudes 4°46’49.07”N and 4°47’18.94”N and longitudes 103°25’45.92”E and 103°20’45.46”E. Sungai Dungun is in the Dungun district of Terengganu which is located about 67 km to the south of Kuala Terengganu and 3 km to the north of Kuala Dungun town. The river, Sungai Dungun, is a meandering river with a sinuosity index of 1.66.

Geologically, the area is underlain by a meta-sedimentary rock sequence known as the Sungai Perlis Beds of Lower Carboniferous age (Chand, 1978). The Sungai Perlis Bed is made up of a rock sequence dominated by shale, slate, phyllite as well as schist with some quartzite, metaconglomerate and hornfels.

The study area covers a distance of approximately 11.5 km along Sungai Dungun, starting from the upper reaches of the river and ending with the estuary.

METHODOLOGY

The study integrates statistical and qualitative analyses (Figure 2) to characterize the distribution of grain size and heavy mineral content in the sediments of Sungai Dungun.

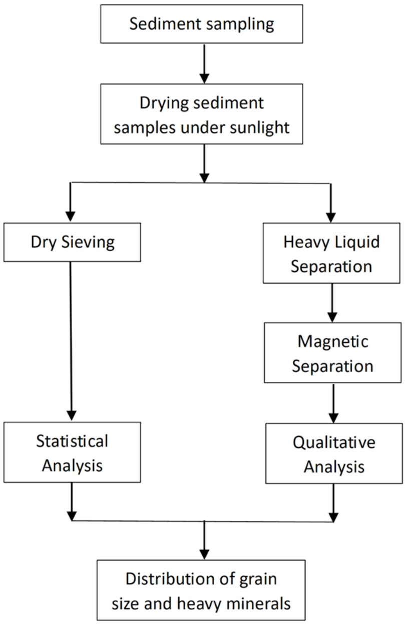

Figure 2: Workflow of study.

SEDIMENT SAMPLING

Sediment sampling was conducted along the river to collect sediment samples along the middle of the river and at the riverbank. A total of 34 sediment samples were collected. The interval between each sampling point is about 500 metres with additional sampling points added within similar transect line if river width is too wide. Sediment samples were not collected at the banks of the estuary due to the extensive development which deems as unsuitable for sampling. The samples were collected using grab sampling method at depths ranging between 1 metre to 7 metres. The sampling process was carried out using a Ponar grab sampler and the sediment samples were placed in airtight plastic bottles with labels.

STATISTICAL ANALYSIS

Statistical analysis (Figure 3) was carried out to identify the grain size of the sediments. The samples were air dried during the day for 4 days to remove moisture from the sediment samples. The dried samples were then sieved using mesh sizes of 32 mm, 16 mm, 8 mm, 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.0625 mm,

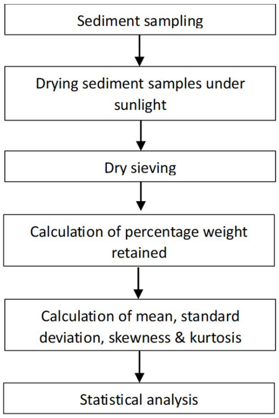

Figure 3: Statistical analysis procedure.

0.031 mm, 0.0156 mm, 0.0078 mm, 0.0039 mm, and 0.00006 mm. The stacked sieves of various sizes were placed in a mechanical shaker for ten minutes to ensure the accuracy and consistency of the sample distribution in the sieves. The percentage of sample retained in each sieve was calculated according to equation 1 (Table 1). From the data obtained, the mean, standard deviation, skewness, and kurtosis for each sample is calculated according to equations 2 to 5 (Table 1).

QUALITATIVE ANALYSIS

Qualitative analysis (Figure 4) was carried out to distinguish heavy minerals present in the sediments. The dried samples were panned to concentrate the heavy minerals. The heavy mineral concentrate was then mixed with bromoform (2.89 g/cm^3) in a separatory funnel and left for an hour to allow the separation of heavy and light minerals. The heavy minerals will settle to the bottom of the separatory funnel due to its higher density. The heavy mineral concentrate was then separated from the bromoform using filter paper. The heavy mineral concentrate was dried on a hot plate to remove residual bromoform. The dried heavy mineral concentrate was loaded onto the Frantz Magnetic Separator and separated according to the heavy mineral's magnetic susceptibility i.e. hand magnet, 0.4 A, 0.7 A, 1 A and non-magnetic. The segregated heavy minerals were identified using a binocular microscope.

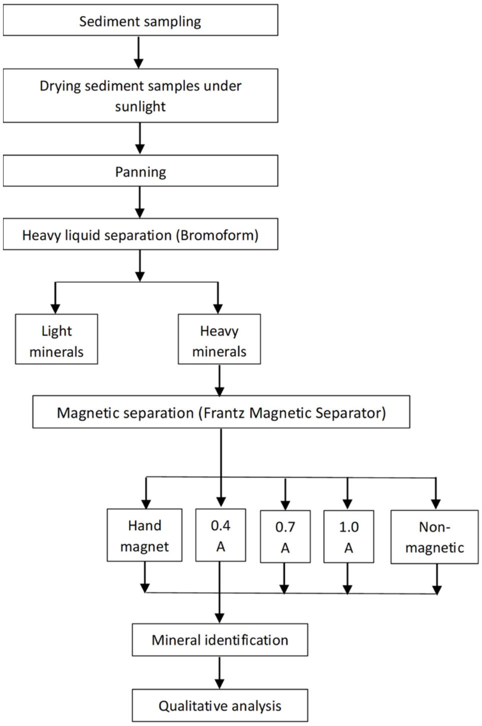

Figure 4: Qualitative analysis procedure.

RESULTS AND DISCUSSION

Mid-channel sediments

Grain size analysis

Grain size parameters (mean, sorting, skewness, and kurtosis) were generated on the 21 sediment samples taken from the middle of the river channel using the method from Folk & Ward (1957). Based on the mean (Table 2), the distribution of grain size of mid-channel sediments (Figure 5) is dominated by very coarse sand (71%), followed by very fine gravel (19%) and coarse sand (10%). The sediments are poorly sorted, except for sampling point SD13, where they are moderately sorted. Skewness is variable, with most samples being symmetrically skewed, with other samples ranging between coarse skewed and very fine skewed. Kurtosis is also variable, with samples ranging between leptokurtic and platykurtic, with most samples being mesokurtic.

Table 1: Equations of statistical analysis.

No.	Parameter	Equation
(1)	Percentage weight retained	% retained = (weight retained (g))/(total weight retained (g)) × 100
(2)	Mean, M_Z	$M_Z = (\varphi_{16} + \varphi_{50} + \varphi_{84})/3$
(3)	Standard deviation/Sorting, σ_1	$\sigma_1 = (\varphi_{84} - \varphi_{16})/4 + (\varphi_{95} - \varphi_5)/6.6$
(4)	Skewness, S_k	$S_k = (\varphi_{16} + \varphi_{84} - 2\varphi_{50})/(2(\varphi_{84} - \varphi_{16})) + (\varphi_5 + \varphi_{95} - 2\varphi_{50})/(2(\varphi_{95} - \varphi_5))$
(5)	Kurtosis, K_G	$K_G = (\varphi_{95} - \varphi_5)/(2.44(\varphi_{75} - \varphi_{25}))$

Table 2: Textural interpretation of samples of middle of the river.

Sampling Point	Mean, M_Z	Sorting, σ_1	Skewness, S_k	Kurtosis, K_G
SD 1	Very Coarse Sand	Poorly Sorted	Symmetrical	Mesokurtic
SD 2	Very Coarse Sand	Poorly Sorted	Coarse skewed	Mesokurtic
SD 3	Very Fine Gravel	Poorly Sorted	Very Fine Skewed	Mesokurtic
SD 4	Very Coarse Sand	Poorly Sorted	Symmetrical	Mesokurtic
SD 5	Coarse Sand	Poorly Sorted	Coarse skewed	Mesokurtic
SD 6	Very Coarse Sand	Poorly Sorted	Very Coarse Skewed	Mesokurtic
SD 7	Very Fine Gravel	Poorly Sorted	Very Fine Skewed	Leptokurtic
SD 8	Very Coarse Sand	Poorly Sorted	Coarse skewed	Mesokurtic
SD 9	Very Coarse Sand	Poorly Sorted	Coarse skewed	Leptokurtic
SD 10	Very Coarse Sand	Poorly Sorted	Symmetrical	Mesokurtic
SD 11	Very Coarse Sand	Poorly Sorted	Symmetrical	Mesokurtic
SD 12	Coarse Sand	Poorly Sorted	Symmetrical	Mesokurtic
SD 13	Very Coarse Sand	Moderately Sorted	Symmetrical	Platykurtic
SD 14	Very Coarse Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
SD 15B	Very Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
SD 16B	Very Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
SD 17B	Very Coarse Sand	Poorly Sorted	Symmetrical	Leptokurtic
SD 18B	Very Fine Gravel	Poorly Sorted	Fine Skewed	Leptokurtic
SD 19B	Very Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
SD 20B	Very Coarse Sand	Poorly Sorted	Symmetrical	Mesokurtic
SD 21B	Very Fine Gravel	Poorly Sorted	Very Fine Skewed	Mesokurtic

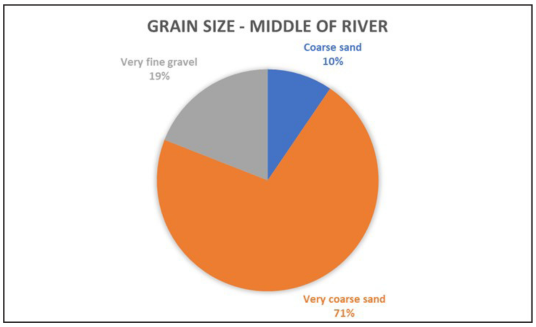

Figure 5: Distribution of grain size in mid-channel sediments.

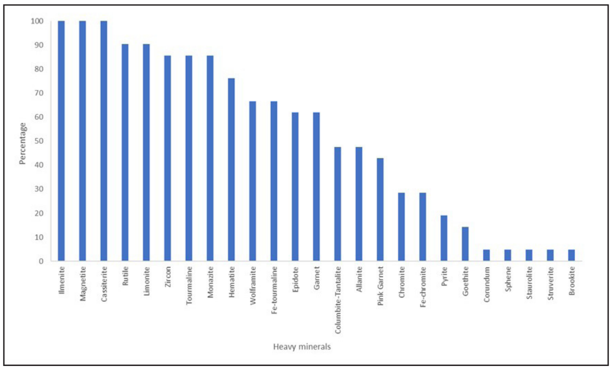

Figure 6: Distribution of heavy minerals in mid-channel sediments.

Heavy mineral distribution

All mid-channel sediment samples contain ilmenite, magnetite and cassiterite. Other heavy minerals found in abundance were rutile, limonite, zircon, tourmaline, and monazite. Heavy minerals present in minor amounts (<10%) were corundum, sphene, staurolite, struverite, and brookite (Figure 6).

Distribution of heavy minerals in grain size fractions

Mid-channel sediments were mainly made up of very coarse sand, followed by very fine gravel and coarse sand. Heavy minerals were mainly associated with very coarse sand (Figure 7). The presence of heavy minerals in

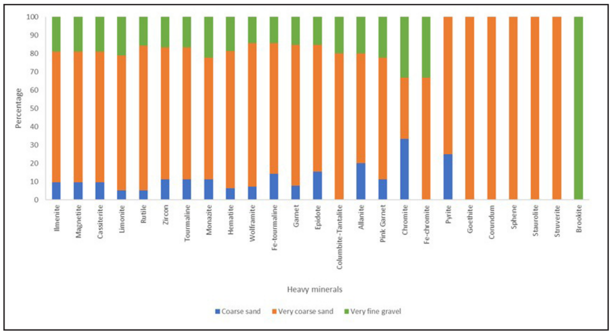

Figure 7: Distribution of heavy minerals and grain size of middle of river.

very coarse sand is between 33% and 100%, whereby the least mineral found is chromite (33%). Common heavy minerals found in very coarse sand include columbite-tantalite, rutile, wolframite, and garnet. Five types of heavy minerals, such as goethite, corundum, sphene, staurolite, and struverite, are exclusively present in the very coarse sand situated along the middle of the river channel. The sole heavy mineral absent in very coarse sand is brookite.

Heavy minerals present in very fine gravel in mid-channel sediments range between 14% to 100%. The heavy minerals least commonly present are wolframite and Fe-tourmaline (14%) followed by garnet and epidote (15%). The most common heavy minerals present include chromite and Fe-chromite (33%) as well as monazite and pink garnet (22%). Brookite is only found in very fine gravel along the middle of the river. The six (6) types of heavy minerals which are not present include pyrite, goethite, corundum, sphene, staurolite and struverite.

Heavy minerals in mid-channel sediments are found in small amounts in coarse sand i.e. 5% to 33%. The most common heavy mineral present is chromite (33%) followed by pyrite (25%). Heavy minerals present in minor amounts (<10%) include limonite, rutile, hematite, wolframite, and garnet. Apart from that, eight (8) types of heavy minerals, namely columbite-tantalite, Fe-chromite, goethite, corundum, sphene, staurolite, struverite and brookite, are absent in coarse sand in mid-channel.

Riverbank

Grain size analysis

13 samples taken from both the left and right banks of the river were analysed for grain size distribution (Table 3 and Figure 8). The samples were dominated by very fine gravel, followed by very coarse sand, medium sand, and fine sand. 69% of the samples were poorly sorted with the remaining being moderately sorted. Skewness was found to be highly variable, with samples ranging through symmetrically skewed, coarse skewed, fine skewed, very fine skewed and very coarse skewed. Kurtosis ranged from mesokurtic, platykurtic, leptokurtic to very leptokurtic.

Heavy mineral distribution

All 13 samples taken from the riverbank contain rutile, while zircon was found in 92% of the samples (Figure 9). Ilmenite, magnetite, cassiterite, tourmaline and monazite were found in 85% of the samples. Chromite and anatase were the least common minerals found along the riverbank, occurring in less than 10% of the samples.

Distribution of heavy minerals in grain size fractions

Riverbank sediments were found to contain very fine gravel, very coarse sand, medium sand, and fine sand. The various heavy minerals make up 20% to 100% of the

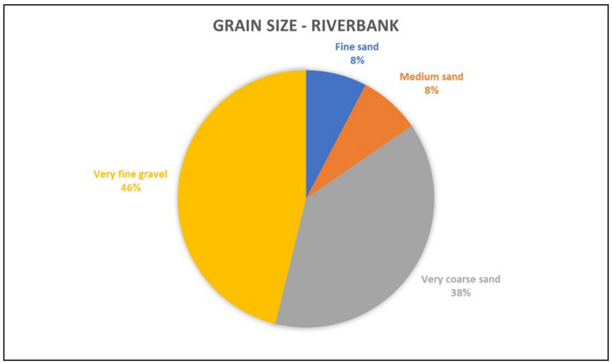

Figure 8: Distribution of grain size in riverbank sediments.

Table 3: Textural interpretation of samples of riverbank.

Sampling Point	Mean, M_Z	Sorting, σ_1	Skewness, S_k	Kurtosis, K_G
SD 15A	Fine Sand	Poorly Sorted	Very Coarse Skewed	Mesokurtic
SD 15C	Very Fine Gravel	Poorly Sorted	Very Fine Skewed	Very Leptokurtic
SD 16A	Very Fine Gravel	Poorly Sorted	Coarse Skewed	Very Leptokurtic
SD 16C	Very Fine Gravel	Moderately Sorted	Symmetrical	Very Leptokurtic
SD 17A	Very Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
SD 17C	Medium Sand	Poorly Sorted	Symmetrical	Platykurtic
SD 18A	Very Coarse Sand	Poorly Sorted	Symmetrical	Platykurtic
SD 18C	Very Fine Gravel	Moderately Sorted	Fine Skewed	Mesokurtic
SD 19A	Very Coarse Sand	Moderately Sorted	Symmetrical	Mesokurtic
SD 19C	Very Fine Gravel	Poorly Sorted	Fine Skewed	Leptokurtic
SD 20C	Very Fine Gravel	Poorly Sorted	Very Fine Skewed	Leptokurtic
SD 21A	Very Coarse Sand	Poorly Sorted	Coarse Skewed	Leptokurtic
SD 21C	Very Coarse Sand	Moderately Sorted	Coarse Skewed	Mesokurtic

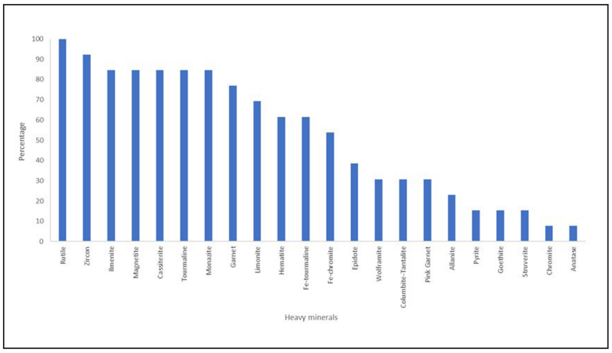

Figure 9: Distribution of heavy minerals at riverbank.

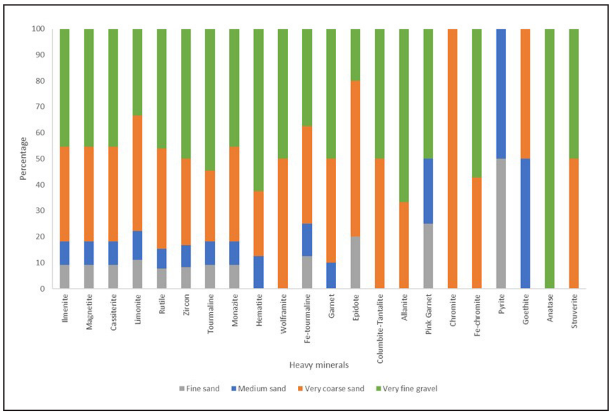

Figure 10: Distribution of heavy minerals and grain size of riverbank.

very fine gravel fraction (Figure 10), with epidote being the heavy mineral that makes up the smallest fraction of this grain size fraction. Common heavy minerals found include allanite, hematite, and Fe-chromite. Equal parts of wolframite, columbite-tantalite and struverite are found in very fine gravel and very coarse sand. Anatase is exclusively found in very fine gravel of the riverbank. Heavy minerals such as chromite, pyrite and goethite are absent in the very fine gravel.

Heavy minerals make up between 25% to 100% in very coarse sand fraction. Some common heavy minerals include epidote, goethite, columbite-tantalite, and wolframite. Hematite and tourmaline are the two least heavy minerals found. Anatase, pyrite and pink garnet are not present in very coarse sand. However, chromite is exclusively found in very coarse sand.

Heavy minerals make up between 8% to 50% in both fine sand and medium sand fractions, with the majority of the heavy minerals making up between eight and nine percent of the fine and medium sand fractions. Pyrite makes up 50% of both medium sand and fine sand. The least common heavy minerals present are rutile and zircon. Hematite, garnet, and goethite are absent in fine sand, whereas epidote is not present in medium sand.

INTERRELATIONSHIP BETWEEN GRAIN SIZE, HEAVY MINERALS AND ENVIRONMENT OF DEPOSITION

Correlation between grain size and environment of deposition demonstrates that very coarse sand is observed in the middle of the river channel whereas very fine gravel is observed at the riverbank. The correlation between grain size and heavy minerals expresses that heavy minerals are mostly found in very coarse sand and very fine gravel. In short, heavy minerals are concentrated in very coarse sand of middle of river and very fine gravel of riverbank.

CONCLUSION

The study area is divided into two parts, namely middle of river channel and the riverbank. The sediments found in mid-channel is primarily very coarse sand, very fine gravel, and coarse sand. The most abundant heavy minerals found in mid-channel sediments are ilmenite, magnetite, and cassiterite. Majority of the heavy minerals are found in samples of very coarse sand in mid-channel. Goethite, corundum, sphene, staurolite, and struverite, are exclusive to samples of very coarse sand whereas brookite is exclusive to samples of very fine gravel.

The riverbank is dominated by very fine gravel, very coarse sand, medium sand, and fine sand. Most of the heavy minerals are present in samples of very fine gravel and very coarse sand. The most dominant heavy minerals here are rutile and zircon. Chromite is exclusive to very coarse sand whereas anatase is exclusive to very fine gravel. Concisely, the distribution of grain size and heavy minerals for both, middle of river and riverbank exhibit a chaotic trend.

It is essential to consider potential impacts and implement measures to minimize adverse effects towards the environment which could affect the distribution of sediments in the river. Some countermeasures which could be implemented is monitoring sediment transport to track sediment transport dynamics within the river. Apart from that, erosion control measures should be executed in areas where sediment disturbances are likely to occur during sampling activities. Long-term monitoring could be carried out to assess the sedimentation rates, erosion patterns and changes in sediment composition over time in the river. In short, these countermeasures could be implemented to minimize the impacts of sampling activities towards the sediment distribution in the river.

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AUTHORS CONTRIBUTION

INDAA contributed to the data analysis, data interpretation and writing of the manuscript. MSI contributed to the conceptualization of the study, writing, and reviewing of the manuscript. MSS helped with the data collection and fieldwork. SNFJ helped with the illustrations, figures and reviewing of the manuscript.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare regarding the content of this paper.

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