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Geochemistry, textural studies and its environmental implications on the core sediment of Kadalundi estuary, Kerala

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The study area Kadalundi estuary is fully occupied with mangroves, and conserved as a bird sanctuary. In this estuary, systematic studies on sedimentological and geochemical aspects are not done so far. Hence, an attempt has been made in this area to infer the paleo environmental significance in this region. A core of length 185 cm was taken and sub sampled in 5 cm intervals. The sand-silt-clay analyses indicate higher concentration of sand in the core and overall low calcium carbonate content. The organic matter content is highly concentrated at the top and bottom core, whereas in the middle core it is slightly decreased. The sorting values depict poor sorting which indicates mixed environment condition. i.e, one derived from riverine/aeolian environment and the other derived from marine environment. This is due to the widely varying nature of sediments and change in gradients of the coastline. The heavy mineral assemblage of the study area shows the distribution of low and high ranked metamorphic and some basic igneous rocks. The presence of a little amount of zircon in the top core implies the influence of marine inputs by reworked sediments. XRF data resembles a sudden rise in the concentration towards the bottom core suggests that the trace elements show a positive relation with silt, clay and organic matter in the sediments. XRD analysis projects the presence of Illite in all the samples suggesting the emergence of estuary into Arabian Sea and the reworking of waves. From the overall study it is concluded that the river discharge from Kadalundi, deposits an additional sub-population of sand with a mean size of sediments from medium to fine grained, where low-energy conditions prevails and accretionary processes are taking place with mixed environments.

[**Keywords**: Geochemistry, Kadalundi River, Kerala, Mangorve sediments, Sedimentology, South West coast of India]

Introduction

Estuaries are found along most of the world's coastlines and sedimentary records of estuarine environments have been found in many marginal marine depositional sequences[1]. In terms of sedimentation, estuaries are very complex environments or strictly series of environments. Geochemical and sedimentological evaluation from a river mouth should be primarily considered because it acts as the heart of an ecosystem. A proper understanding on the vertical column of sediments at an affordable depth helps us to give a holistic picture of the erosional transformational and depositional nature of marine and fluviatile source of origin as well as the geological formation of that area. The collection of geochemical information not only provided a close sight on the present environment quality of the system but also serves as baseline data for future investigations. Similarly, textural studies are also important to delineate environmental conditions. Based on the above information, one core sample has been collected in the mangrove area of Kadalundi estuary.

Study Area

The study area Kadalundi is one of the four most important rivers flowing through Malappuram district, Kerala. Kadalundi River serves as a borderline between the Kozhikode and Malappuram districts (Fig. 1). The Kadalundi River is in total 130 km long with a drainage area of 1274 sq. Km. The river lies between the east of Karuvarakkundu village in the district of Calicut in Kerala state at 76^0 15' longitudes and 11° 18' latitudes at an elevation of 900 m. It is known for the wide variety of fish, mussels and crabs.

Materials and Methods

A core sample was collected from the mangrove area; in the eastern side of the estuary of length 185 cm. Geological logging was carried out using PVC pipe (Fig. 2). Core sample was litho logged and sub sampled with 5 cm interval. Lithological variation

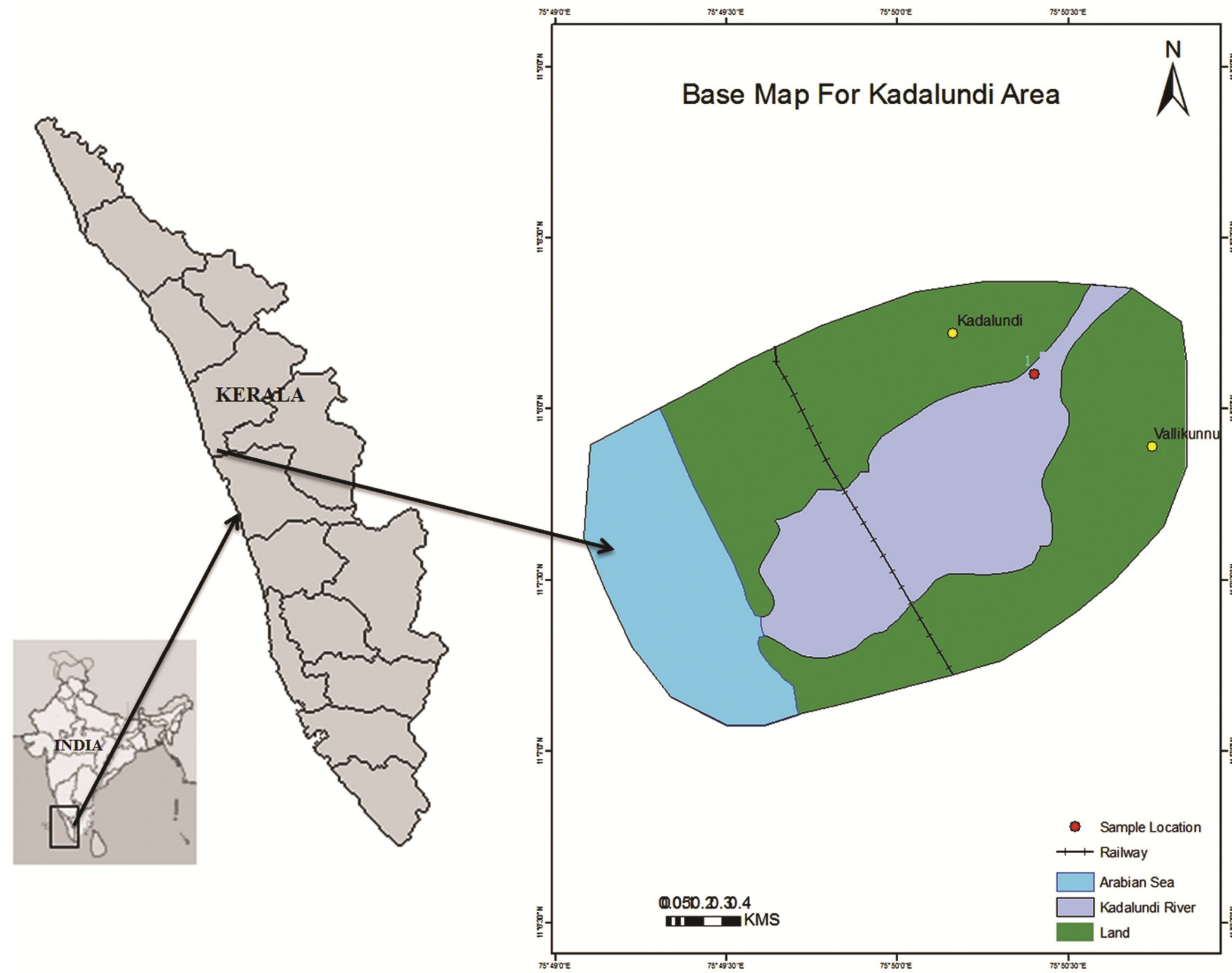

Fig. 1 — Maping showing the Study area

was found while lithologging in the core sample *viz.*, the top section is from 0-60 cm, middle is from 60-120 cm and the bottom is from 120-185 cm. The top layer contains coarse to medium sand with mixture of clay packets and broken shells of pelecypods and gastropods. The middle layer is compact, medium to fine grained sand with sticky clay and few pteropoda shells and shells of lamellibranches are noticed. The carbon content in the bottom layer is having alternate fine sandy silty and sticky clayey layers of sediments. The readily oxidisable organic bottom layer is determined by the Walkey-Black method, as outlined by Jackson[2]. Calcium carbonate was determined by using rapid titration method[3]. The fine fraction (silt and clay) in the washings is analysed by the pipette method in accordance with the procedure adopted by Krumbein and Pettijohn[4]. Trefethen's[5] textural nomenclature has been used to describe the sediments in the present study.

Particle size analysis is carried out using Malvern Hydro 2000 mu instrument from the Department of Geology, Anna University, Chennai. The pure distilled water is used in the wet dispersion unit as a liquid medium to disperse the sample. About 800 ml of water was taken in a beaker and about 3-4 gm of sample was dispersed into the medium. A unique dip-in pump and stirrer head was immersed in this beaker and measurements were carried out. An integral ultrasonic probe is assisted to correct the sample dispersion. Due to the continuous rotation of the stirrer head inside the beaker the particles will rotate and the counting results can be obtained on the monitor which is connected to it. Efficient pump/stirrer design ensures effective unbiased sample presentation across a wide range of size. SOP operation

Fig. 2 — Core sample collections at Kadalundi Mangrove area and subsampling from laboratory

via software promotes easy data generation. The heavies in this fraction were separated using bromoform (specific gravity ~2.89). The separated heavy minerals were mounted on slides using Canada Balsam. Around 300 heavy mineral grains were identified and counted under a petrographic microscope using standard micrographic techniques.

Major element and trace element concentrations are determined adopting the X-ray fluorescence spectrometry method following the procedures given by Calvert[6] (NCESS Tvrm). The XRF intensities measured from elements in dry samples show variations depending on the XRF absorption rates[7]. The major determined were SiO_2, TiO_2, Al_2O_3, MnO, Fe_2O_3, CaO, MgO, Na_2O, K_2O, P_2O_5 and the trace elements were Cr, Ni, Cu and Zn. To determine the mineralogical content of the core, a total of 5 samples were selected from three sections of the core with high clay content for XRD analysis. Out of 5 samples, four are confined to the bottom of the core.

Results and Discussion

Grain size analysis

From the particle size analysis, it is observed that the top core consists of fine sand and medium sand, the middle and bottom core with medium sand ranges 21.02 % to 30.8 %. The particle size data indicates that the major grain-size component in the top core consist of poorly sorted muddy samples. However, significant textural changes occur in the down core with poorly sorting. The silt content of the mud fraction could be readily dispersed once disaggregated and resuspended. Kadalundi core sample shows that a major textural change occurred below at a depth of 45 cm and 100 cm. The presence of several modes reveals that the sediments have been derived from several sources.

In the study area, the frequency pattern points towards the presence of Polymodal distribution with peaks at 0.5 φ 1.5 φ and 3 φ (Fig. 3). The first population constitutes 20 to 30 % of the medium

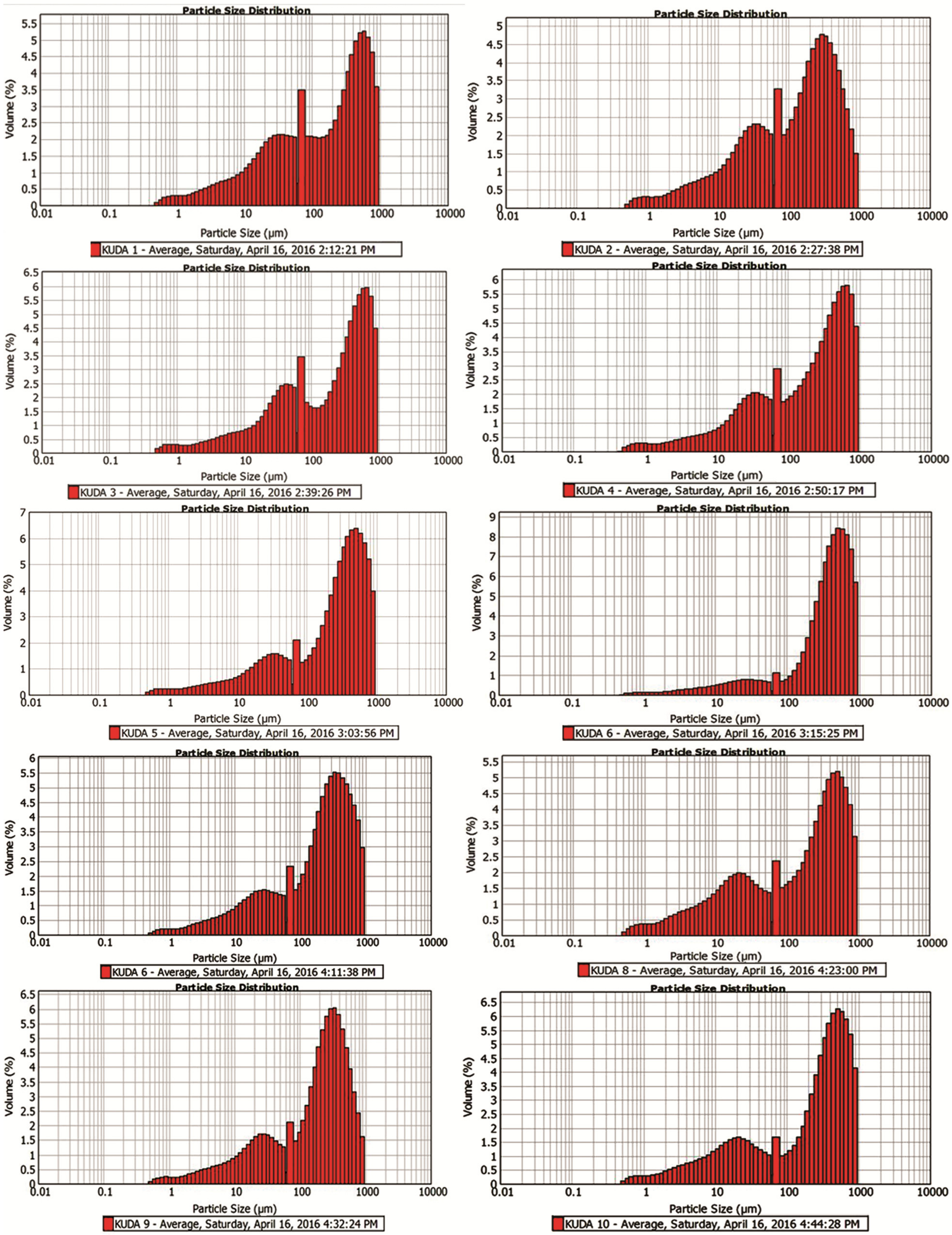

Fig. 3 — Frequency Curve of the study area

Table 1 — Results of textural analysis

S. No	Depth (cm)	Sediment Type	Mode	Mean (M_z)	Sorting		Skewness		Kurtosis	
1	0-5	Fine Sand	Polymodal	2.094	Poorly Sorted	1.396	Fine Skewed	0.181	Platykurtic	0.819
2	20-25	Medium Sand	Polymodal	1.862	Poorly Sorted	1.482	Fine Skewed	0.259	Platykurtic	0.732
3	40-45	Medium Sand	Polymodal	1.809	Poorly Sorted	1.517	Very Fine Skewed	0.325	Platykurtic	0.776
4	60-65	Medium Sand	Polymodal	1.750	Poorly Sorted	1.433	Fine Skewed	0.254	Platykurtic	0.821
5	80-85	Medium Sand	Polymodal	1.570	Poorly Sorted	1.266	Fine Skewed	0.221	Mesokurtic	0.962
6	100-105	Medium Sand	Bimodal	1.169	Poorly Sorted	1.035	Very Fine Skewed	0.356	Mesokurtic	1.013
7	120-125	Medium Sand	Polymodal	1.769	Poorly Sorted	1.266	Fine Skewed	0.105	Mesokurtic	0.909
8	140-145	Medium Sand	Polymodal	1.728	Poorly Sorted	1.350	Fine Skewed	0.222	Platykurtic	0.876
9	160-165	Medium Sand	Polymodal	1.860	Poorly Sorted	1.203	Fine Skewed	0.102	Mesokurtic	0.969
10	180-185	Medium Sand	Polymodal	1.416	Poorly Sorted	1.218	Very Fine Skewed	0.305	Mesokurtic	1.021

sand. In the study area, mean value ranged from 1.416 φ to 2.09 φ indicating a prominent distribution of medium to fine sand in the core sample. All along the core sample a medium sand size is observed. Due to the low-energy wave conditions, the finer sediments are settled near the river mouth, leading to the accumulation of heavy minerals of a finer size grade. Sorting depicts the nature of sediment type and mode of transportation of sediment. Accordingly, in the study area, sorting values ranges from 1.035 φ to 1.517 φ indicating poorly sorted and mean value ranges from 1.416 φ to 2.09 φ (Table. 1) with a prominent distribution of medium to fine sand implying that the sediment sizes are mixed. The mean values demonstrate a similar trend in this area. The growth of the spit and bar at Kadalundi river mouth region impedes the movement of sediment-laden littoral currents; as a result, lateral up drift causes sediment deposition, especially in the river mouth region. The distribution of finer sediments in few locations in the study area might have occured from the disloading of coarser lighter sediments by the panning action of high velocity waves.

The range of skewness values is 0.102 to 0.356. In general, based on the classification of Folk and Ward[8] the skewness values ranges from very fine skewed to fine skewed sediments showing a positively skewed nature indicating the prevalence of mixed energy environment with the blow of waves in low-high energy conditions in different directions, entailing a mixed distribution of fine sediments.

The graphic kurtosis varies in the study area ranges from 0.732 to 1.021. In other word, on the basis of Folk's classification, the surface samples were Mesokurtic and Platykurtic. The Mesokurtic and Platykurtic nature indicates mixed environment. Accordingly, various plots of mean vs. standard deviation, skewness vs. mean, skewness vs. standard deviation, skewness vs. kurtosis, etc., suggest the dominant influence of riverine environment in the study area.

Hydrodynamic C-M pattern

The C-M diagram or passega[9] diagram is very influential in hydrodynamic interpretation of sediments to reveal its source of supply. This can be highly applicable in the case of estuarine environment in define the sediments contribution either by river or by marine activities. Here C stands for 1 percentile value and M stands for median. The units of these parameters can be in phi or in micron. It is featured with several fields such as (pelagic suspension, uniform suspension, gradual suspension, rolling and ground suspension, rolling) corresponding to the various transportation and deposition conditions in the marine, littoral or fluvial domains. The obtained results from the gradistat is plotted on a logarithemic diagram (CM pattern) indicates, all the samples fall under rolling section. Which suggest that, the sediments are the product of tractive currents (Fig. 4) i.e. the deposits can be transported either by river, marine or bottom currents which strongly tells us the environment compiles a mixed low-turbulent wave energy condition in the study area.

Heavy mineral analysis

Based on the lithological down core variation, those samples containing higher percentage of sand were selected from the top, middle and bottom sections for the heavy mineral analysis. The heavy mineral assemblage of the study region is governed by the distribution of different type of minerals. However, the assemblage is restricted to the dominance of few selective minerals like pink garnet, Opaques, rutile, chlorite, epidote etc. The top and middle core is dominated with opaques. Zircon founds only on the top section. The middle core

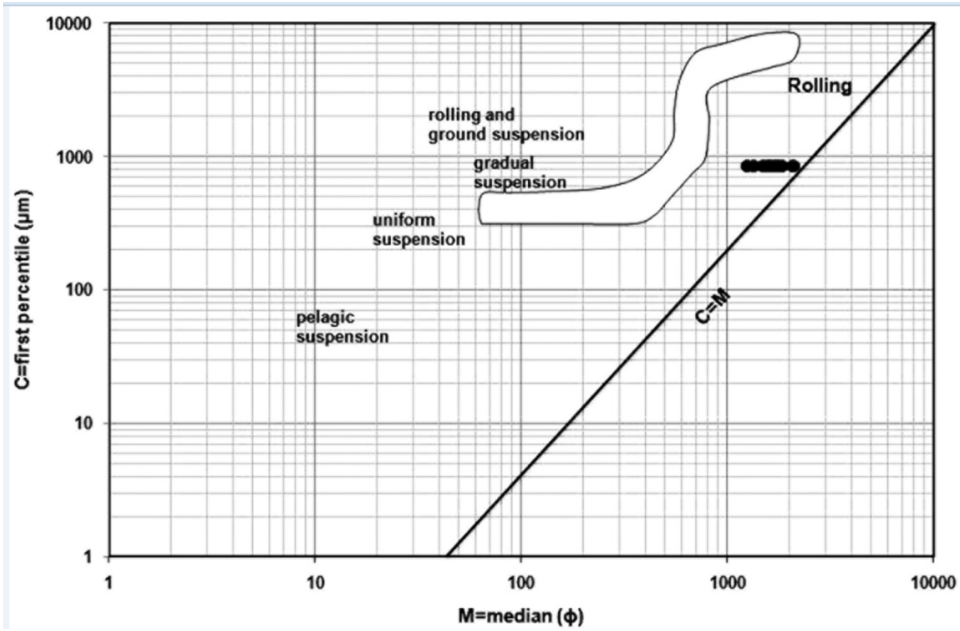

Fig. 4 — C-M plot for sediment transport

contains numerous opaques, garnets and chlorites. The bottom core depicts a least distribution of heavy minerals (Table 2). The highest number of opaques can be seen in the middle core. Most of the garnets were pink coloured and good greenish sections of chlorites are observed in the thin sections. Over all most of the minerals were euhedral and well rounded and shows a fresh nature (Fig. 5). Comparatively the numbers of non opaque minerals are less in number. Chlorite is found in more or less equal in number in three sections. The chlorites are of prismatic and acicular in nature and elongated in form.

Table 2 — List of distribution oh heavy minerals

Minerals	Top core	%	Middle core	%	Bottom core	%
Opaques	99	49	131	51.37	50	39.68
Chlorite	32	15.8	35	13.72	23	18.25
Zircon	2	0.99	0	0	0	0
Epidote	11	5.44	10	3.92	9	7.14
Garnet	33	16.34	40	15.68	22	17.46
Glucophane	17	8.42	26	10.19	12	9.52
Hypersthene	4	1.98	5	1.96	4	3.17
Sillimanite	0	0	1	0.39	1	0.79
Biotite	4	1.98	7	2.75	4	3.17
Rutile	0	0	0	0	1	0.79
Total	202		255		126	

Geochemical analysis

The study of major elemental geochemistry of sediments is essential in view of the fact that it provides information on the source of sediments and the process of sedimentation. The total major element concentration *viz.* Si, Al, Fe, Na, K, Ca and Mg (in oxides) are measured in the core sediments of Kadalundi estuary.

The analysis on major elements shows the following decreasing order in mean values as well as range of concentration Si>Al>Ca>Mg>Fe>Na>K. Silicon is one of the most abundant elements in the Earth's crust and it is the major constituent in most of the rock forming minerals. The higher values of Si in the core samples indicate the influence of terrigenous and as well as mixing of river sediments in the coastal zone area. The mean values of Si/Al in this core samples were observed to be slightly higher than the upper continental crustal value of 3.83[ref. 10]. The higher value of Al is attributable to the clayey nature of the sediments and it can be due to the terrestrial input from river. The higher concentration of Fe may be due to the direct precipitation of iron from the overlaying water column, the clayey nature of the sediments or due to the direct mixing of the leached laterites spread on the premises of the study area. The value of potash is very low. The behaviour of K and Na largely reflects the distribution of potash and sodic feldspar in sediments. The Ca value is very low in the core sample due to the fewer amounts of carbonate shells and the absence of skeletal components, corals, molluscs and microfossils. The absence of biogenic carbonates leads to less amount of Mg content in the core sample. The major

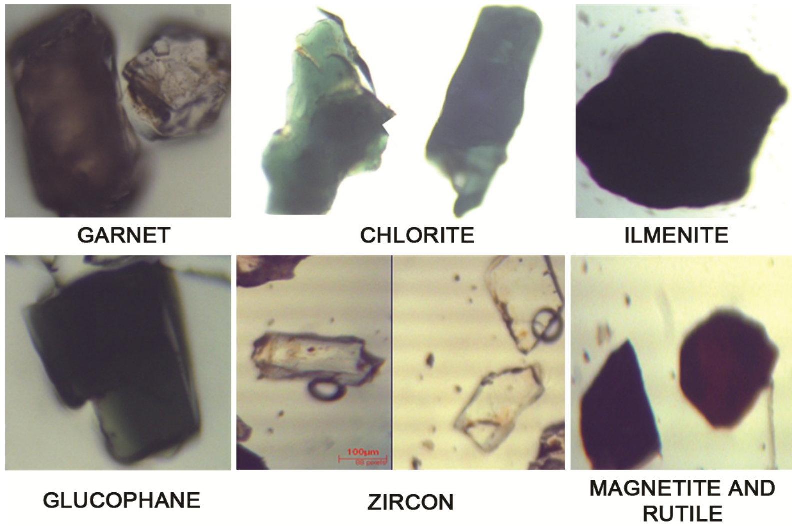

Fig. 5 — Heavy mineral distribution in the study area

oxide geochemistry of the present study indicates a homogenous and unwearthered source for the sediments.

Down core variation of Fe, Mn, Cr, Ni, Cu and Zn are depicted in Table 3. Comparing to other elements chromium is more in concentration. Nickel registers an increase from top core to bottom core but at a depth (80 cm and 95 cm) least amount of nickel can be observed. In this particular depth, all the elements are showing a sudden depletion which may be due to any other environmental disturbance in that specific time of deposition. The sudden increase in the concentration of all the elements at a depth of 130 cm depicts that these trace elements mainly get associated with silt and clayey materials in the sediments. The order of abundance of elements in the core is Fe > Mn > Cr > Cu >Ni >Zn. These elements show a positive relation with silt, clay and organic matter in the sediments.

In geochemical study, it is evident that mangroves are having the mechanism of trapping trace elements in sediments. Fe and Mn are found enriched in sediments pointing to a terrigenous source of oxy-hydroxide metal accumulation. Further, the metal enrichment present in mangrove zone indicates the typical nature of mangrove sediments to capture trace metals. The heterogeneous distribution of these elements in this region might be ascribed to anthropogenic inputs coupled with bioturbation activities, erosion and physical mixing of the sediments. Our findings also corroborated by Chaterjee *et al.*[11]. Increase of heavy metals in the mangrove sediment may be attributed to the abundance of fine particle with greater surface area indicating the source for the sediments in the study area are Charnockite and Garnetiferous granulites (Fe and Mn) over finely dispersed particles[12]. High concentrations of these trace metals in mangrove sediments indicates that the mangrove systems are physical traps for fine material, and their transported load of metals constitutes a chemical trap for precipitation of metals from solution[12]. Even though the study area is not much highly polluted by the direct observations, the presence of Cr and Ni and other trace elemental concentration shows that there is an effect of industrial effluents and urban runoff from nearby regions of the study area.

Table 3 — Results of trace element analysis

Sample no (cm)	Fe (ppm)	Mn %	Cr %	Ni %	Cu %	Zn %
0-5	30495	154	88	34	59	22
20-25	33572	154	94	43	51	24
50-55	39307	232	122	53	49	37
75-80	22241	154	64	16	29	ND
90-95	19933	77	48	16	72	18
100-105	24200	232	71	22	52	10
125-130	46861	154	126	63	66	42
150-155	29306	154	83	32	80	26
165-170	31124	154	91	37	69	17
175-180	52107	154	140	73	85	49
Min	1993	77	48	16	29	10
Max	52107	232	140	73	80	49

The higher concentration of Fe in this region may be due to the contribution from detrital mineral grains supplied through Kadalundi River. The low Manganese registered in the core sample indicate that, dissolved Mn ions will readily undergo diffusion, advection processes. The similar trend of Mn distribution was also observed in the core sediments in Muthupet mangroves, southwest coast of India[13]. The enrichment of copper shows the zigzag concentration. The higher copper values in this core is mainly derived from detrital sources and also by contribution from clay[14]. The Nickel concentration in the core sample is low because, Ni rarely forms thermodynamically stable minerals with carbonates[15]. Metal concentrations found in this work are very similar to the values found in similar studies carried on in other mangrove areas of India[16], only Fe, Cr and Zn exhibit bit higher concentration. Co, Cu, and Ni are lower than the background concentrations reported in the above (Table 3).

In the present study, using XRD analysis the clay minerals were analysed for the selected samples containing more clay content (based on sand- silt – clay analysis). Samples of depth 35-40 cm, 130-135 cm, 155-160 cm, 160-165 cm, and 180-185 cm were chosen for the analysis. All the samples denotes illite and monmorillite with high d-spacing values as clay minerals and silicate and aluminous minerals as non clay minerals (Quartz and Feldspar, Magnetite, Fluro-apatite, Fluorite, Ilmenite, Oligoclase, Muscovite, Marcasite, sepiolite, stauralite, Silimanite). The X-ray diffraction response to Illite often indicates the digenetic and low- grade metamorphic history of sedimentary rocks besides change in pH to alkaline environment[17]. Since the estuary emerges to the Arabian Sea, the floor of the sea is much abundant in clay minerals also tells us the influence of the reworking of sediment transport and transcurrent waves in mixed environment conditions.

Conclusion

A core of length 185 cm was taken and sub sampled in 5 cm intervals. The sand-silt clay content results showed that in the study area throughout the core it is dominated with sand, and the calcium carbonate content is very low in amount. The variation in the down core suggests that the calcium carbonate will be less when the sand is high and calcium carbonate will be high when sand is less. Due to the sandy environment, the organisms cannot thrive in this region. The higher values of organic matter content is observed in the top and bottom core, where as in the middle core it is slightly decreased due to the low energy mixing environment. The fluvio-marine organic debris's settles down with various depositional periods of the whole sediment formation. The higher organic matter in these core sediments is mainly due to source of nearby mangrove settlings.

The heavy mineral assemblage of the study region is governed by the distribution of different type of minerals. The incompatibility of the heavy mineral assemblage on the beach sediments with respect to the nature of catchment rocks and river sources has indicated a multi various source for the heavy minerals assemblage. By identifying the minerals it is understood that the area is composed of low and high ranked metamorphic rocks and some basic igneous rocks such as Granulites, charnokites, laterites, leptinite etc. The presence of a little amount of zircon in the top core implies the influence of marine inputs by reworked sediments.

From the geochemistical results it is evident that that there is trend of increase in iron and aluminium suggests the extended surface area on the fine clayey substratum for the settling of trace metals. The presence of Ni and Cr also indicates the influence of terrestrial sediments and effluents supply from the catchments of the estuary. From the overall study it is concluded that the core sediments consists of medium to fine sands with a mixed low energy environment.

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Conflict of Interest

The authors declare that there are no known competitions or personal intentions that could have appeared to influence the work reported in this paper.

Author Contributions

The present work has been carried out in cooperation of both the authors. Both the authors investigated the site and done the sample collection. Abiya Lukose carried out subsampling, laboratory analysis, Data creation, Interpretation and prepared the draft of the manuscript. MSG provided all the technical support and Resources and supervised during the course of work, identified the minerals, interpreted the data and edited the manuscript.

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