Accumulation trend of heavy metals in the surfacial sediments of Muthalapozhi near shore, south west coast of India

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Abstract— Contamination of marine sediments with trace metals has become a great concern around the world as it is an important task in marine pollution research. Heavy metals entering the aquatic environment finally accumulate in human body causing harmful effects to the internal organs. This study aimed to evaluate the trace metal concentration along with textural and organic carbon (OC) percentage in surface sediments of Muthalapozhi near shore, south west coast of India by scheming contamination factor (CF), enrichment factor (EF) and geoaccumulation index (Igeo). The study indicates the major and minor elements showed significant correlation with Al and the aluminosilicates present in the mud fraction along with OC are the major natural carries of trace elements and rare earth elements to the open ocean. The geochemical indices designate the enrichment of Zr which may be due to the presence of heavy minerals along the Kerala coast. The study highlights the minimal enrichment of light lithophile elements (Rb and Sr) and heavy rare earth elements (Y).

Index Terms— near shore, surface sediments, geochemistry, CF, EF and Igeo

1 Introduction

Sediments play an imperative part in shaping pollution pattern, history of pollutants, record of catchment input to aquatic environments etc. The major and minor elements introduced into the aquatic environment by multifaceted routes like natural weathering, run off, atmospheric/riverine contribution and anthropogenic impact like discharge from agricultural, municipal, residential and industrial waste[1], [2], [3]. Also rapid urbanisation due to the population growth has a major role in decreasing infiltration and increases impervious area, runoff and chances for urban flash flood [4]. Trace metal accumulation in coastal and estuarine region is of interest to environmentalist as they are the important sinks for pollutants. The toxic non degradable contaminants deposited in the sediments cause adverse effects such as disease in flora and fauna, loss or modification of habitat etc. This metal taken up by organisms enters food chain and ultimately reaches humans [5], [6].

Near shore environment are the focus for various anthropogenic activities like construction of sea port and harbour, marine aquaculture, shipping, urbanization, recreation and many more. The west coast of India has always attracted the geoscientist for the past few decades on various aspects of geology. Being a part of west coast, the coastal plains of Thiruvananthapuram received little attention on geochemistry and its pollution aspects even though drastic development activities are taking place. Muthalapozhi coastal plains experienced numerous engineering constructions which has converted the natural setup of this environment. Earlier, this interconnected shallow brackish water tract whose depth not more than 5m, was seasonally connected with the Arabian Sea through the opening of the sandy bar at Muthalapozhi.

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For rest of the year a temporary spit forms at the mouth rendering the estuary "blind''. This caused many difficulties to the fisherman communities including capsizing of fishing boat. After the construction of breakwaters and due to dredging activities natural condition have changed and opened way to the sea for the Akathumuri –Anchuthengu - Kadinamkulam estuary (A-A-K) causing continuous mixing of fresh and seawater. This has encouraged salt water intrusion in the lower reaches of Vamanapuram River leading to degradation of this environment.

Knowledge of elemental concentration in near shore sediments is the foremost pace in quantification of natural and anthropogenic contribution to marine ecosystem. The information on the coastal geochemistry of Muthalapozhi near shore is essential in the context of coastal pollution and consequent productivity of the Lakshadweep Sea. The present study was therefore undertaken with a view to provide much needed information on the metal distribution in the coastal ecosystem of Muthalapozhi.

2 Study Area

Muthalapozhi coast is part of an almost straight, NW-SE trending coast between Veli inlet and Varkala cliff. The study area extending from Thumba (lat.9^0.66′35″N: long.76^0.36′00″ E) – Neduganda (lat.8^0.69′75″N: long. 76^0.73′83″E) sector is a part of a high energy sandy coast adjoining a tidal inlet at Muthalapozhi which is characterised by backwater/lagoon system into which Vamanapuram River drains. The study area is of 17 Km long with an average width of about 200 m and comprises the inner shelf zone up to 20 m isobaths. The sea floor is smooth, with an average seaward gradient of approximately 1:77 between the inshore area and 30m isobaths [7]. The inlet has divided the coast into 2 distinct sediment cells as south and north of the harbour where construction of breakwaters

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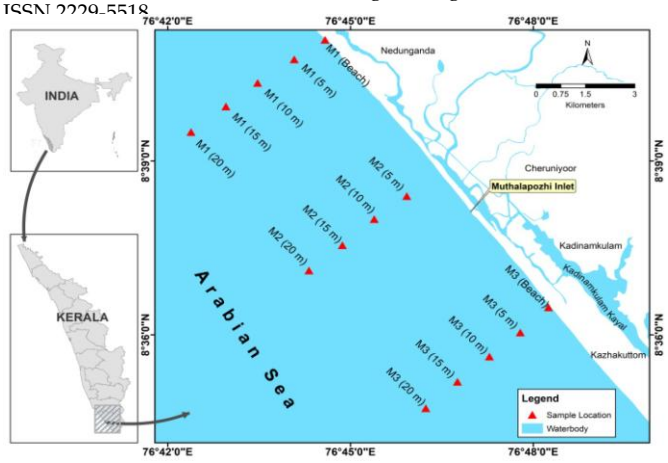

Fig. 1. Map showing study area with sampling locations

has aggravated the erosion situation along the north. Being an eroding coast seawalls and groins has been constructed towards the north of the tidal inlet. As part of inlet stabilization, seawalls were also constructed in the south side, close to the inlet.

3 METHODOLOGY

14 surface samples were collected from the near shore region at varying depth up to 20m isobaths using Peterson grab sampler (Fig 1). The Muthalapozhi coast is part of an almost straight, NW-SE trending coast between Veli inlet and Varkala cliff. The study area extending from Thumba (lat.9^0.66′35″N: long.76^0.36′00″ E) – Neduganda (lat.8^0.69′75″N: long. 76^0.73′83″E) sector is a part of a high energy sandy coast adjoining a tidal inlet at Muthalapozhi which is characterized by backwater/lagoon system into which Vamanapuram River drains. The study area is of 17 Km long with an average width of about 200 m and comprises the inner shelf zone up to 20 m isobaths. The sea floor is smooth, with an average seaward gradient of approximately 1:77 between the inshore area and 30m isobaths [7]. The inlet has divided the coast into 2 distinct sediment cells as south and north of the harbour where construction of breakwaters has aggravated the erosion situation along the north. Being an eroding coast seawalls and groins has been constructed towards the north of the tidal inlet. As part of inlet stabilization, seawalls were also constructed in the south side, close to the inlet.

Three locations represent, the northern transect Neduganda (M1), Muthalapozhi inlet (M2) and Thumpa (M3) the southern transect. After pre-treatments of the sediments, grain size was analysed[8]. The total organic carbon was determined [9]. Analysis of major and trace elements was done using XRF facility which consists of a Bruker Model S4 Pioneer sequential wave length dispersive X-ray spectrometer and sample preparation units. The present study focus on the major and trace metal contamination and its relation with sediment samples properties and to ascertain the metal pollution status in the sediments using contamination factor (CF), geo accumulation index (I_{geo}) and Enrichment factor (EF).

The EF was calculated using by the formula:

$$EF = (Metal/Al)sample \div (Metal/Al)background \quad (1)$$

Where, (Metal/Al) background is the element to Al ratio of the average shale value [10]. In this study, the EF enrichment was interpreted following [11]. EF < 1 indicates rock sources with no enrichment, EF 1–3 slight enrichment, EF = 3–5, intermediate enrichment, EF = 5–10, moderate to severe enrichment, EF = 10–25, significant enrichment, EF = 25–50, very severe enrichment and EF > 50 extremely strong enrichment.

CF is determined by using the metal content in sediment and continental shale as background value [12]. It gives the level of contamination of sediments by a metal. CF can be calculated as:

$$CF = C(sample) \div C(crust) \quad (2)$$

Where C (sample) represents the concentration of each studied metal and C (crust) stands for earth's crustal value. In CF, the concentration levels are differentiated based on their intensity on a scale varying from 1 to 6 as < 1 indicates low contamination, 1–3 moderate contamination, 3–6 strong contamination and > 6 significantly strong contamination.

The geo accumulation index (I_{geo}) is to assess the quantification of metal contamination in sediments [13]. The geoaccumulation index (Igeo) was quantified using the below formula:

$$Igeo = Cn/1.5Bn \quad (3)$$

Where (Cn) is the measured concentration of studied element (n) and (Bn) is the background value of metal (n). The factor 1.5 is introduced to decrease the effect of feasible difference in the background values, governed by geogenic or anthropogenic influences. The Igeo index is divided into six classes that represent sediment quality as: 0 (practically no pollution), 0–1 (no pollution to slightly polluted), 1–2 (moderately polluted), 2–3 (moderately to severely polluted), 3–4 (strongly polluted), 4–5 (strongly to extremely polluted) and > 5 (extremely polluted).

4 RESULT

The sediment textural composition was assessed as the percentage of sand silt and clay as shown in table 1(fig 2 (a), (b) and (c)). The near shore sediments is mainly floored by sand and the percentage was found in the order M3> M2> M1 (fig 3 (a) and (b)) [14], [15]. Transect M1 and M2 showed similar trend in mud percentage indicating a supply of finer particles from the estuarine region into the open ocean. The organic carbon content in the surface sediments shows marked variation in different sampling stations, which ranged from 0.05% to 4.76% with an average of 1.91%. Also highest value for OC (4.76%) was observed in the beach sediments for transect M1 while the lowest (0.05%) at a depth of 20m for transect M3. A sudden decrease of OC compared to the other transects is observed in M3 whereas in M2 transect a decreasing tendency towards depth was observed.

The concentrations of major elements are depicted in the table 2. The summarized geochemical data reveals that SiO_2

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constitutes 85% of the oxides followed by Al_2O_3, FeO, CaO and TiO_2. Other than SiO_2, TiO_2 and CaO are greater in near shore samples when compared to shale value. The highest average for SiO_2 was shows in the southern transect M3 (90.19%) which also coincides with the percentage of sand in this sector. The M1 transects shows highest average value for TiO_2 (1.94%) than the other two. The lower content of calcium was noticed in the bar mouth, transect M2 (1.88%) which can be attributed to the effects of turbulence of the tidal flow which hamper the growth of organism. The other two transect showed similar trend. Among the transition trace metals V, Cr and Zr (table 3), Zr shows higher concentration than average shale value in all the sampling locations, with an overall average of 2912 ppm and a maximum average concentration of 49000 ppm for tran sect M1. V exceeds the limit only in M1, where as Cr is within the limits. Large ion lithophile elements (LILE) like Rb and Sr are within the average shale limits, but a sudden increase in Sr concentrations was noticed in all the three transect at a depth of 5 and 10m. A similar pattern was shown by Light Rare Earth Element (LREE) La also. As shown in table 4 the elemental correlation suggests that a positive correlation of Si with sand and negative correlation with all other elements. Al shows positive correlation with silt, clay, Ca, Na, K and P and with trace elements like Cr, Rb, Y. Fe is having good correlation with Ti, Zr, V, La and Sr. Silt and clay showed good correlation with Al, Ca, Na, K, P, Cr and Rb whereas OC shows positive correlation with Ti, V and La only. Rb is showing good correlation with mud, Al, Ca, Na, K. P and Cr while elements like La, Rb, Sr and Y are having good correlation among themselves.

4.1 Enrichment Factor, Contamination Factor & Geo accumulation Index

The enrichment factor (EF) generally helps us to decide the amount of trace element pollution anthropogenically sourced in an environment. Various metals including Fe, Al, K are applied as normalizing elements to diminish the deviation governed by the sediments. In the present study EF (fig 4) calculated for the trace elements depicts that Zr shows extremely strong enrichment for all the transects. Ti shows significant enrichment for M1 and moderate to severe for M2 and M3, while the condition reverses for V showing significant enrichment in M3. Similarly Cr and Sr shows moderate enrichment for M2 and M1 transect respectively and moderate to severe enrichment for other two transect. La showed moderate to severe enrichment for all transects. EF is in the order of Zr>Ti>La>V>Cr>Sr>Y>Rb for M1, Zr>Ti>V>Sr>La>Cr>Rb>Y for M2 and Zr>V>Ti>Sr>La>Cr>Y>Rb for M3.

To study and evaluate environment pollution using a single parameter, the contamination factor (CF) acts as a fundamental indicator for the sediment. In the present study CF ranges form 0.23-2.58 for Ti, 0.29-1.5 for Cr, 31.88- 1.55 for Zr, 0.54-1.17 for V, 0.31-1.98 for La, and 0.09-0.53 for Rb. The average CF for Zr shows nearly three time higher for transect M1 and nearly twice higher for the other two transect. Cr, Rb, Sr and Y shows low contamination for all the three transect and Ti, V and La shows moderate for M1 transect and low for the other two transects (table 5). The calculated Igeo values (fig 5) is in accordance with the CF values for Zr showing extreme status in transect M1, moderate to strong values (2-3) in transect M2 and M3. All the other studied elements show slight pollution.

5 DISCUSSION

Sediments are final destination of trace metals which are the potentially excellent gauges of the state of environment. The accumulation of metal into the sediments occurs as a result of adsorption, desorption, precipitation, diffusion processes, chemical processes, biological activity and amalgamation of these phenomena [16]. Once they are discharged into estuaries and coastal water, there fortune is controlled by the redox potential in the sediment water interface present in the biological systems [17]. The origin of major part of these sediments in such environment is from terrestrial input and also a considerable amount was incorporated by adsorption and other process [18].

The higher percentage of sand in the near shore area may be due to the current from the abrasion zone which transport the finer particles and prevent them from settling [19]. The sediments have >90% of sand suggests the relict nature of the sediment, probably the part of paleo shoreline. The presence of relict sediments at seaward stations suggests the modern detrital sediments from land that are probably trapped by the Akathumuri-Anchuthengu-Kadinamkulam estuary thereby detrital sediments that escape from these marginal body may spread as a continuous blanket across the inner shelf. Steep bathymetry and winnowing action of waves may also contribute higher concentration of sand in the area. The long shore currents flowing towards the north and constant flushing activity of tide along with the impact of wave, remove finer fractions. The construction of breakwater caused deposition in the south and accelerated erosion the northern side of the Muthalapozhi inlet. The sand percentage reported for Adimalathura to Kovalam sector was 89.9 to 99.7% [7]. Also the Poovar – Varkala sector shows steep gradient with medium size grains indicating a high energy coast [20], [7].

The distribution of OC mainly depend of the sediment grain size, hydrodynamic process, rate of supply of sediment, rate of deposition and primary productivity [21], [22], [23]. The enhancement of organic carbon in fine-grained sediments is also due to the correspondence in sinking and performance of finer particles and organic matter [24]. Also organic residue appears to be subsided more in the surface by percolation process. The higher contribution of organic carbon and lower percentage of sand in the northern transect (M1) may be due to increased input from agriculture activities and inflow of organic rich waste form the established hinterland tourist and pilgrimage centre Varkala. Earlier it was reported that a calm environment for the Neduganda region as it falls in the shadow region of the Varkala Cliff and also due to the construction of groin north of Nedunganda [7]. Increased organic content in sediments is also produced by hydro carbon oxidizing bacteria which enhance biological productivity from the land discharge. Similar observations were reported for Visakhapatnam coastal sediments, Cochin and Chettuva coast of Kerala [25, 26]. The lower organic content in transect M3 can be owing to the diffusion of free oxygen and oxidising salts in the coarse sediments of the sub surface which support the eradica-

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tion of organic matter [27]. Also the coarser nature of the sediments along with soaring tidal activity supports poor absorbability of organics [28]. The lower percentage of OC in transect M3 is in well accordance with the reported values for Adimalathura to Kovalam (0.1 – 0.8%), which lies further south of this transect [29].

The abundance of SiO_2 and Al_2O_3 suggest felsic composition for the source rock in the provenance [30]. The calcium values obtained are a function of carbonate and non-carbonate since the chemical analysis was performed on bulk sediment. In the tropical warm waters organisms separate $CaCO_3$ by precipitation and extraction [31]. The calcium carbonates and non carbonates are principally originating from fish bones and other biogenic debris in marine sediments in the form of calcium phosphate and in plagioclase [32]. The ratio between K_2O and Al_2O_3 are used to represent ancient sediment composition. Its ratio for clay is <0.3 and for feldspar ranges from 0.3 to 0.9. In the present study, ratio for the near shore samples ranges from 0.01 to 0.27, indicating weak influence of clay in the surface sediments [33]. Higher percentage of TiO_2 is due to the presence of heavy minerals along the Kerala coast. Ilmenite and rutile are the important Ti bearing heavy minerals present in the west coast of India. Similar reason was explained for Cochin estuary and Thengapattanam estuary [34], [35].

Zr is considered as High Field Strength Element due to their resistant to weathering in alteration process. The high concentration of Zr in the study area is due to the heavy mineral content in the beach sands of the area. The study area is adjacent to the largest heavy mineral deposit of Chavara where the heavy minerals include ilmenite (35-64%), zircon (2-17%), sillimanite (4-9%), rutile (2-11%), monazite (1-2%) and leucoxene (1-2%) [36]. The heavy mineral concentration results from the hinter land geology, laterization of gneissose rocks, presence of small streams and the sorting by waves and tides. The provenance for the placer minerals of south west coast of India are from the charnockite and khondalite and gneissic rocks [37], [38]. Factors like cliffs, shore processes; long shore currents etc. are responsible for the concentration of modern beach placers along Kerala coast [39]. The geochemical behaviour of Cr in sediment is controlled by its two-oxidation states Cr (Ill) and Cr (IV). Under oxic condition Cr (IV) is the dominant species and is more soluble and mobile where as Cr (Ill) which usually occur in reduced condition is not only less mobile but also rather insoluble and therefore strongly absorbed by organic matter. Chromium (IV) is the most toxic form for bacteria, plants and animals, after release in the pore waters they migrate downward into the reducing zone and precipitations again as Cr $(OH)^2$ [40], [41]. Minerals like Ca, Mg, Mn, Ni, Co, Cu and Zn decreases during the weathering process of Illmenite while, two elements like Cr and V increase [42]. The increase in Sr concentration along particular depth of 5 and 10m may perhaps due to the increase in biogenic carbonates [43]. Sr in marine sediments is linked to the carbonate phase and particularly in the skeletons of foraminifera, coccoliths, corals and sponges. The anthropogenic sources for Sr are due to industrial and waste disposal including hazardous radioactive waste. The natural Sr concentration in soil is 0.2 mg/Kg. The Sr concentration reported for the soil samples from inhabited areas of near KMML, Chavara, Kollam ranged from 138 – 524ppm which is in accordance with the present study [44]. Y is also a High Field Strength element of the group III A and considered as REE due to their similarity in chemistry as that of REE. Highest concentration of Y can be observed in monazite on the beach sands. Higher concentration of REE was reported in the inner shelf from Ponnani to Vizhinjam > 200 mg/kg and this sector show highest concentration of La which ranges between 1.08 to 78.57 mg/Kg [45]. The sources reported for the concentration of LREE are detrital monazite, apatite and sphene in the heavy minerals. The enrichment of LREE reflects the abundance of REE in continental crust whereas the enrichment of HREE reflects the ability of these elements to form soluble complex. During the transport of REE from estuaries to ocean half of the dissolved rare earth elements gets removed through adsorption by microorganisms and by co-precipitation with oxyhydroxides [46], [47], [48], [49].

There is a negative correlation between Si and Al which indicates predominance of weathering and also the ratio between them provide an estimation of textural maturity. The smaller ratio implies smaller sedimentary cycle, and decrease in the grain size [50]. The positive correlation of Si with sand and negative correlations with almost all of the other metals suggests dilution of trace metals by sandy detrital sediments [51]. The positive correlation of Al and Fe with majority of the studied elements may be due to the similar redox condition which helps in incorporation and adsorption on to their oxides. These correlations suggest same origin for the studied metals. Al is extremely immobile and held in lattice of alluminosilicates minerals. The negative correlation between Al and Fe shows less control of clay which is evident from the textural parameters of the study area. The good correlation between Al and K indicates their origin from the weathering of parent rock in the source area. The positive correlation of Ti with Fe and Zr usually relates to silicate components of terrestrial origin and that the source of titanium might have been fixed by hydrous ferric oxide. These minerals are considered as indicators of high energy deposition zones [10], [52]. The study indicates that even though the area is having coarse grained texture, the major and minor elements showed significant correlation with Al, Fe and OC. The sediment chemical composition, grain size and distribution of organic carbon appreciably force the distribution of heavy metals in the nearshore environment. Positive correlation between them also designate that the metal have familiar source, reciprocated dependence and matching performance during their transportation and depositional period. A similar result was reported for the continental shelf of India [53] and in the coastal sediment of Caspian [54]. Salinity and pH of the ocean water also bias the association of metals with fine particles through flocculation and coagulation [55].

The divergence in EF values may be due to the diversity in the amount of contribution of metal or the difference in the rate of exclusion metal from the sediments [56]. EF values lower than 0.5 can be a sign of loss of these elements or an increase of reference metal [57]. EFs close to one or less than one point to crustal origin or they are depleted relative to crustal abun-

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dance however element with greater EF (>10) should be viewed with caution as they imply preferential release of these metals, making them bio available [58]. In case of trace metal if the value of EF>1.5 it can be considered that these metals are delivered from other anthropogenic sources suggesting environmental contamination [59]. Since, the toxicity of any trace metals depends on its chemical form and concentration. It can be inferred that samples with higher EF for trace metals along with higher labile fractions are potential sources for mobility and bioavailability in the aquatic ecosystem [60]. According to Muller scale the geo-accumulation index for the studied elements are less than 1 suggesting that the Muthalapozhi nearshore region has not been polluted, whereas in contract the mean geo accumulation index of Zr reached 3.56. The Igeo value reported for the nearshore area off Calicut shows highly polluted with Cr, Pb and Ni [61].

6 Conclusion

The grain size analysis showed that the sand fraction dominates the near shore region constituting more than 90% for the studied samples. The organic carbon showed a decreasing trend from north to south transects. Distribution pattern of the textural parameters indicates that the supply of finer particles with organic matter from the adjacent estuary gets transported due to the long shore current and constant winnowing action of the waves. Steep bathymetry and high wave energy aided the deposition of sand in this region. In this study the distribution of major elements (Fe, Ca, Mg, Na, Al, K and P) and selected trace elements (Cr, Zr, V, La, Rb, Sr and Y) were examined in the surface sediments. The measured level of the studied elements followed the decreasing concentration order of Si> Ca> Al>Fe>Ti>Mg>K>Na>P. It was observed that inorganic scavengers like Al and Fe along with OC are the dominant factors controlling trace metal distribution in the nearshore sediments of Muthalapozhi. The ecological risk valuation based on Igeo, CF and EF designate high Zr content in the surface sediments, could be mainly due to the heavy mineral distribution along the coastal tract of Kerala. The study area is along the southern side of Chavara, the richest ilmenite sand in the world having an estimate reserve 32.8 metric tones of ilmenite. Large lithophile elements Rb and Sr and heavy rare earth element Y shows minimal enrichment in the area. The present study reveals that the area is stress free in terms of heavy metal accumulation. These finding provide useful information about the sediment quality which can be used for development strategies of contaminable control required for marine environment/human health protection.

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TABLE 1

Sand, silt, clay and OC percentage and textural nomenclature of Muthalapozhi surface sediments

Sample No:	Sand %	Silt %	Clay %	After Folk and Ward (1970)	After Flemming (2000)	OC (%)
M_1B	99.13	0.42	0.33	Sand	Sand	4.76
M_15	98.2	0.73	1.05	Sand	Sand	4.04
M_110	98.32	1.1	0.57	Sand	Sand	4.36
M_115	92.73	1.07	6.19	Sand	Sand	4.14
M_120	99.06	0.51	0.42	Sand	Sand	0.68
M_25	99.14	0.44	0.4	Sand	Sand	3.39
M_210	97.63	0.48	1.87	Sand	Sand	1.91
M_215	97.77	0.44	1.77	Sand	Sand	0.61
M_220	96.12	0.67	3.19	Sand	Sand	0.71
M_3B	99.36	0.34	0.28	Sand	Sand	0.48
M_35	99.33	0.14	0.28	Sand	Sand	0.49
M_310	98.85	0.69	0.45	Sand	Sand	0.42
M_315	99.08	0.56	0.34	Sand	Sand	0.66
M_320	98.9	0.62	0.47	Sand	Sand	0.05

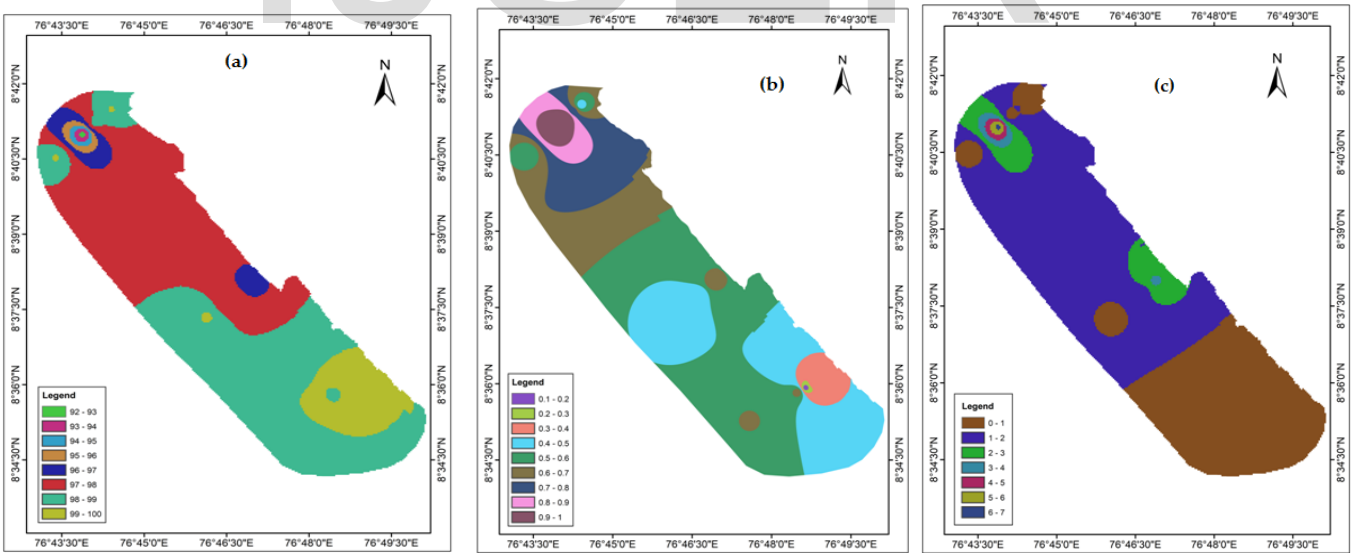

Fig. 2. Spatial distribution of (a) Sand, (b) silt and (c) clay percentage of Muthalapozhi near shore sediments

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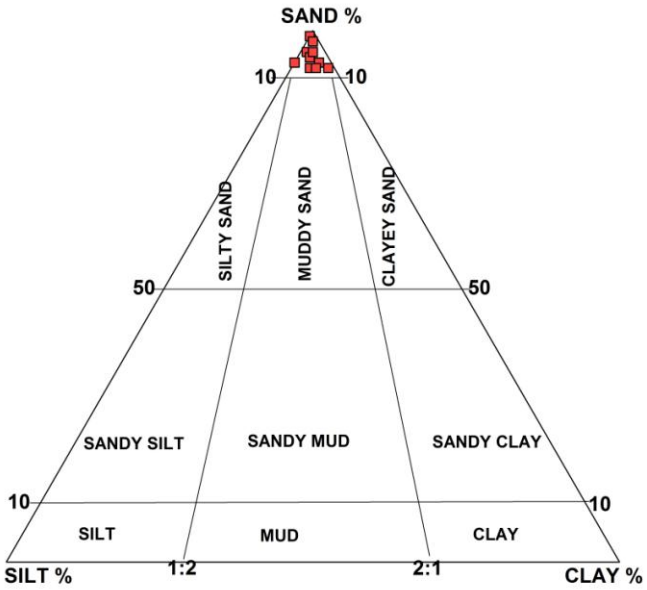

Fig. 3 (a). Textural nomenclature of Muthalapozhi surface sediments based on (Folk and Ward, 1970)

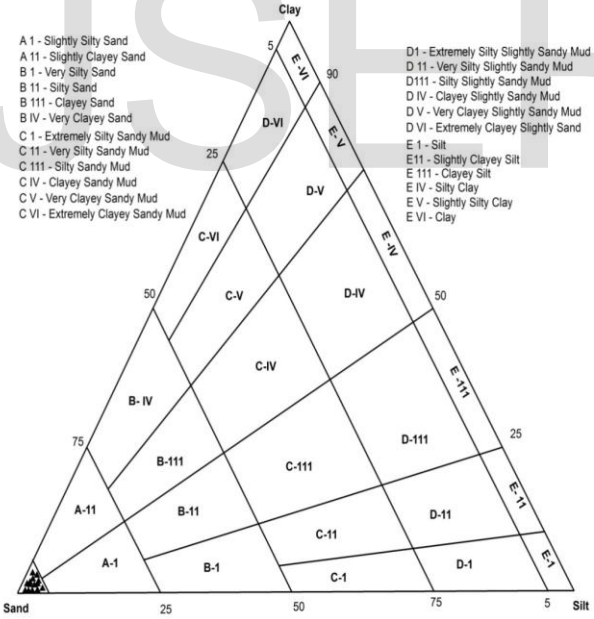

Fig. 3(b). Textural Nomenclature of Muthalapozhi surface sediments (Flemming, 2000)

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TABLE 2
Concentrations of major elements in Muthalapozhi near shoresediment samples

Sample name	Depth	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO (%)	MgO	Na_2O	K_2O	P_2O_5
M1 B	Beach	88.97	1.75	3.33	1.26	1.65	0.39	0.32	0.22	0.08
M1 5	5m	78.04	2.61	5.72	2.85	3.56	1.22	0.99	0.84	0.19
M1 10	10 m	80.78	2.3	3.77	2.58	4.11	1.01	0.94	0.45	0.14
M1 15	15 m	91.68	2.11	1.09	1.61	1.2	0.34	0.27	0.01	0.06
M1 20	20 m	93.88	0.94	1.27	0.71	1.16	0.15	0.17	0.04	0.05
M2 5	5 m	88.74	0.42	1.42	0	0.67	3.45	0.56	0.38	0.28
M2 10	10 m	84.88	1.17	3.56	1.61	3.51	0.71	0.61	0.45	0.11
M2 15	15 m	93.33	0.76	1.53	0.74	1.32	0.35	0.28	0.09	0.05
M2 20	20 m	91.99	0.53	1.35	0.79	2.01	0.43	0.32	0.1	0.06
M3 B	Beach	93.26	0.51	1.11	0.54	1.79	0.29	0.2	0.13	0.06
M3 5	5 m	83.62	1.98	4.12	1.85	2.88	0.81	0.6	0.58	0.12
M3 10	10 m	85.82	0.73	3.31	1.7	3.08	0.82	0.87	0.58	0.11
M3 15	15 m	91.19	0.5	0.76	1.08	2.62	0.54	0.54	0.06	0.08
M3 20	20m	97.04	0.18	0.47	0.58	0.43	0.11	0.35	0.03	0.04

TABLE 3
Concentrations of minor elements in Muthalapozhi surface sediment samples

Sample name	**Depth**	**Cr**	**Zr**	**V**	**La**	**Rb**	**Sr**	**Y**
					(ppm)			
M1 B	Beach	74	3500	147	68	14	118	3
M1 5	5m	141	7500	176	123	24	248	36
M1 10	10 m	77	8200	172	80	18	204	8
M1 15	15 m	46	3100	154	31	10	64	3
M1 20	20 m	42	2200	105	41	12	71	2
M2 5	5 m	39	2200	83	20	19	154	2
M2 10	10 m	67	2200	121	45.5	22.5	178.5	3
M2 15	15 m	36	2270	102	26	15	84	2
M2 20	20 m	34	642	88	23	15	101	2
M3 B	Beach	31	394	88	25	14	113	2
M3 5	5 m	84	2500	152	89	21	208	14
M3 10	10 m	51	5100	100	21	24	187	3
M3 15	15 m	26	726	89	20	15	117	3
M3 20	20m	27	248	70	14	12	41	2

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TABLE 4

Correlation coefficient between textural parameters, OC, major and trace metal in near shore sediments of Muthalapozhi

	sand	silt	clay	OC	SiO_2	TiO_2	Al_2O_3	Fe2O3	CaO	MgO	Na_2O	K_2O	P_2O_5	Cr	Zr	V	La	Rb	Sr	Y
sand	1																			
silt	-0.96	1																		
clay	-0.97	0.86	1																	
OC	-0.2	0.32	0.09	1																
SiO_2	0.87	-0.81	-0.86	-0.2	1															
TiO_2	-0.01	0.21	-0.15	0.68	-0.12	1														
Al_2O_3	-0.89	0.8	0.91	0.18	-0.98	0.04	1													
Fe_2O_3	0.29	-0.12	-0.41	0.36	0.22	0.77	-0.3	1												
CaO	-0.84	0.78	0.83	0.17	-0.96	0.13	0.94	-0.09	1											
MgO	-0.02	0.07	-0.02	0.16	-0.16	-0.1	0.09	-0.28	-0.03	1										
Na_2O	-0.64	0.67	0.58	0.23	-0.85	0.2	0.79	-0.02	0.82	0.39	1									
K_2O	-0.78	0.69	0.8	0.12	-0.96	-0	0.96	-0.4	0.88	0.2	0.83	1								
P_2O_5	-0.88	0.79	0.9	0.12	-0.94	-0.1	0.96	-0.52	0.85	0.23	0.76	0.96	1							
Cr	-0.64	0.65	0.59	0.47	-0.83	0.54	0.8	0.19	0.79	0.11	0.78	0.75	0.67	1						
V	-0.35	0.5	0.2	0.71	-0.46	0.93	0.39	0.59	0.46	-0.06	0.45	0.32	0.23	0.76	0.65	1				
La	-0.14	0.25	0.05	0.52	-0.37	0.85	0.29	0.62	0.37	0	0.42	0.25	0.11	0.78	0.64	0.86	1			
Rb	-0.87	0.77	0.9	0.09	-0.97	-0.1	0.99	-0.4	0.92	0.14	0.81	0.97	0.98	0.74	-0.2	0.27	0.19	1		
Sr	0.19	-0.07	-0.29	0.24	-0.05	0.54	-0.1	0.63	0.09	0.41	0.39	-0.06	-0.2	0.37	0.69	0.45	0.62	-0.08	1	
Y	-0.5	0.53	0.44	0.35	-0.65	0.53	0.6	0.33	0.62	0.05	0.63	0.54	0.46	0.89	0.37	0.66	0.79	0.54	0.42	1

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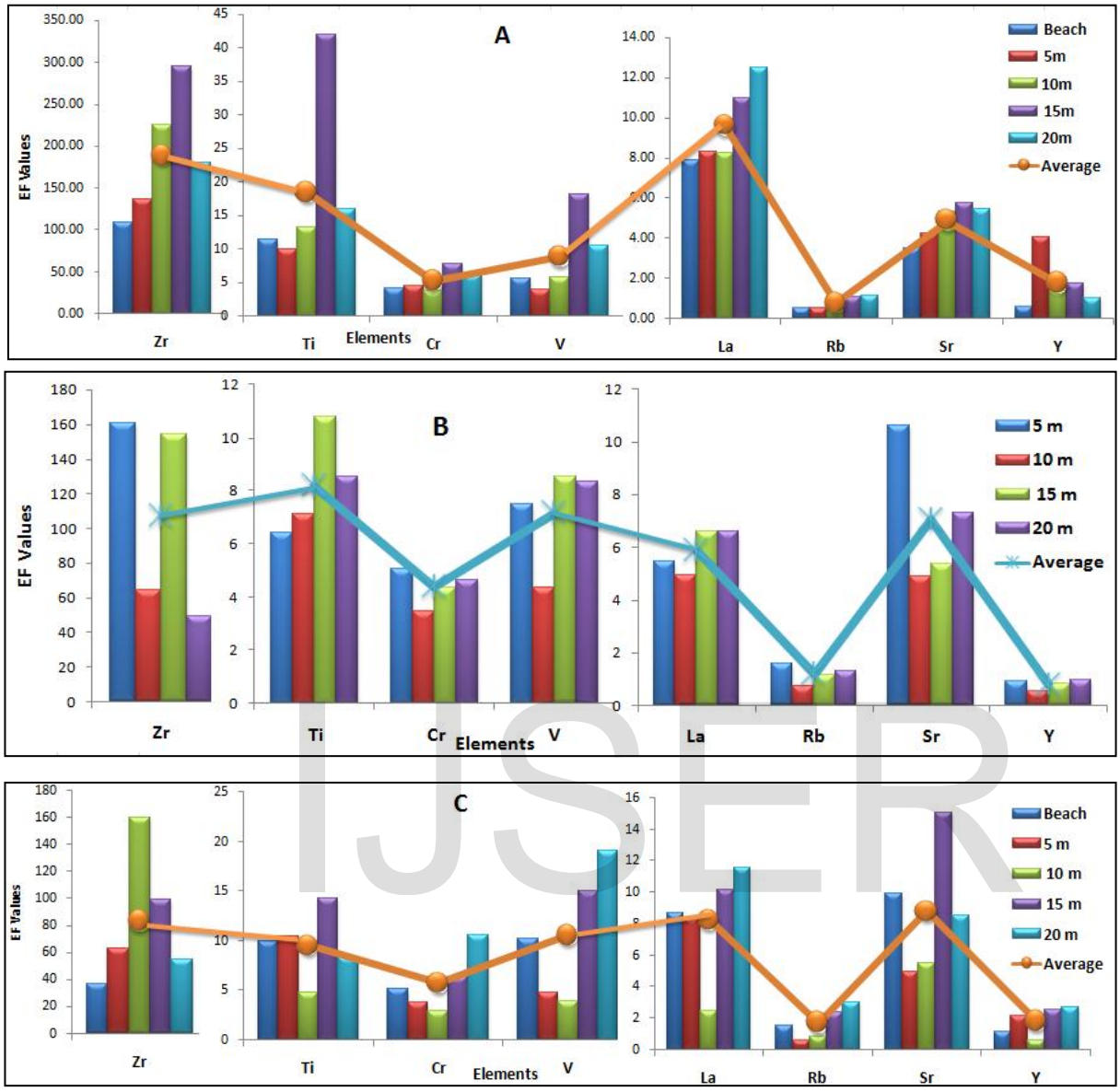

Fig.4. EF values of Muthalapozhi surface sediments (A) transect M1 (B) transect M2 and (C) transect M3

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TABLE 5

Contamination factor for various trace elements in surface sediments of Muthalapozhi

Transect	Ti	Cr	Zr	V	La	Rb	Sr	Y
M1	2.53	0.84	30.63	1.16	1.52	0.11	0.83	0.40
M2	0.94	0.49	11.43	0.83	0.86	0.13	0.76	0.09
M3	1.02	0.49	11.21	0.77	0.75	0.12	0.78	0.18

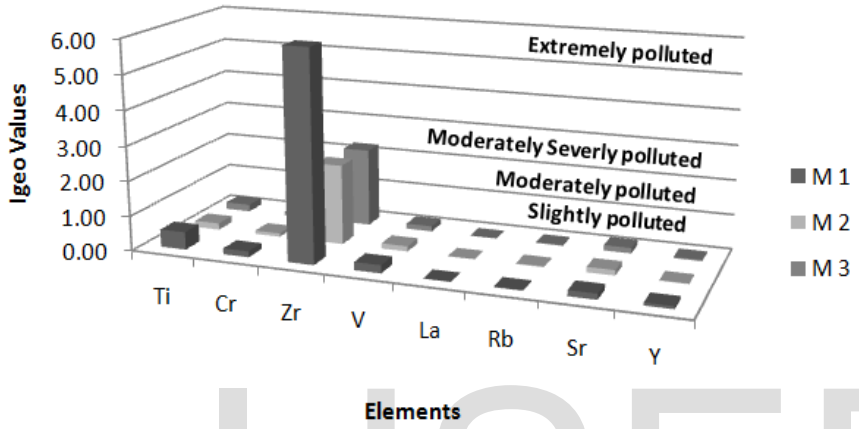

Fig. 5. Igeo values of various trace metals in Muthalapozhi surface sediments

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