Assessment of Heavy Metal Pollution Indices in Surface Sediments From Southwestern Bay of Bengal, India

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Research Article

Keywords: Marine pollution, Assessment, Heavy metals, Shelf sediments, Bay of Bengal.

Posted Date: February 15th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-159678/v1>

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Abstract

The study of heavy metal distribution in the shelf sediments of Southwestern part of Bay of Bengal is essential in determining the distribution pattern and to understand the consequences of marine pollution beside the coastal environment. The south eastern coastal areas of India are affected by several disturbances and contamination associated with accelerated industrialization and urbanization. Twenty-nine surface sediment samples were collected from shelf region of Southwestern part of Bay of Bengal and analyzed for sediment texture, organic matter and heavy metals. Pollution indices such as Enrichment Factor (EF), Geoaccumulation Index (Igeo), Contamination Factor (CF) as well as multivariate statistical analyses were used to recognize the pollution pattern and probable sources for metal contamination. Comparatively, the concentration of heavy metals in the study area is closely associated with finer fractions and organic matter. The results demonstrate that Cu, Co, Mn, Pb, Zn, Cr and Ni in most of the sites are extremely contaminated in terms of Igeo. The computed values of CF indicate very high contamination of the metals like Pb, Zn and Cr followed by uncontamination to moderate contamination of Cu, Mn, Ni, Co. Based on factor analysis, domestic and industrial activities from adjacent land areas are found to be the major contributors of heavy metals in the shelf sediments.

1. Introduction

The coastal zones are the areas which act as a major sink for heavy metal contaminants since the industrial revolution. Heavy metals are highly harmful due to their accumulative behavior and non-biodegradability, and are the major cause of marine pollution. Anthropogenic activities play a major role in releasing these heavy metals into the marine environment. Heavy metals viz. Zn, Cu and Pb are sourced from automotive traffic in the urban environment; Ni and V from marine traffic; Cu and Hg from paint industries (Lewan, 1984; Tamim et al., 2016; Xianmeng., et al 2018). These heavy metals reside for a longer time in ocean water and are transported to the sea bottom (Xigui et al., 2018). The heavy metal pollutants effectively retain on marine particles and involve themselves in all the physical, chemical, and biological processes of marine organisms. (Yunhai Li et al., 2018; Tansel and Rafiuddin, 2016). Heavy metals accumulated in sediments become entrained in the food web as contaminants. Thereafter they undergo bio-magnification and accumulation in marine organisms, which when consumed by human beings can pose serious health problems (Wang et al., 2013; Mokhtar et al., 2009). Heavy metal in the sediments directly influence benthos community (Pan and Wang, 2013), but with high storm and tide, they can be re-suspended, re-dissolved and either re-deposited or transported to affect further oceanic and near shore environments (Xigui Ding et al., 2016). Those heavy metals which are not carried offshore will lead to secondary pollution of coastal areas (Islam et al., 2017). The preservation capacity of sediments is perhaps related to its physicochemical properties viz. organic matter and grain size (Ihejirika et al., 2016). Moreover, major industrial plants of many countries are established in the cities which are located in the coastal areas and along the banks of major rivers. The effluents released from those industries are dumped into the fluvial or marine environment without any treatment (Sarraf et al., 2016). The present study focuses on the evaluation of heavy metal pollution of sediments from marine environment using indices viz. Enrichment factor (EF), Geoaccumulation Index (Igeo), Contamination Factor (CF). And with the help of multivariate statistical analysis we attempted to probe the source and activities controlling the discharge of heavy metals.

2. Material And Methods

From the study area, 29 surface sediment samples were collected from different depths using Van Veen grab sampler in September 2017 (Fig. 1). The collected samples were then preserved by transferring into pre-cleaned polyethylene bag using a plastic spatula. In the laboratory, a representative portion of each sample was used for textural analysis. The remaining portion of each sample was used for chemical analysis.

2.1 Study Area

2.1.1 Geography

The study area is located in the South-western part of Bay of Bengal, between the coordinates 11.705213° N 79.798297° E and 11.231771° N 79° 56' 10.248" E (Fig. 1). There are ephemeral rivers viz. Coleroon, Uppanar, Vellar, and Gadilam drains the continent and finally opens into the Bay of Bengal.

2.1.2 Climate and Rainfall

The maximum and minimum temperature recorded in the study area is 32.3°C and 21.18°C respectively. The study area receives maximum rainfall due to northeast monsoon with an average annual rainfall of about 1393.3mm (DEIAA, 2018).

2.1.3 Geology

The adjacent part of the study area is composed of Precambrian granitic basement overlaid by sedimentary rocks belonging to different geological periods. This Precambrian basement is marked by a series of horst & graben structures (Vasudevan et al., 1998). In this region, sandstone consists of rounded pebbles (fragment and pebbles), lateritic and laterite gravels belonging to Cuddalore formation and are overlaid by red sandy soil (Jayaprakash et al., 2016).

2.1.4 Industries

The rivers adjacent to the study area, in addition to flooded water, also carries untreated industrial effluents released by the industries located on its banks such as paint industries, chemical industries, cotton mills, rubber, plastic, petro-products, metal-based industries, electrical machinery, transport equipment companies, tanneries, and oil companies, etc. (Jayaprakash et al., 2016). Besides, Cuddalore port and Thirumullaivasal fishing harbour are located along the estuarine part of the study area. Since 1990 this area is affected by rapid industrialization leading to the degradation of the aquatic system (Jonathan et al., 2008). Several studies regarding marine pollution have been carried out during the past decades in the coastal and marine sediments along the south east coast of India. Moreover, the coastal ecosystem was often affected by several devastating cyclones and rarely by Tsunami in December 2004.

2.2 Textural Analysis

The textural analysis was carried out by sieving and pipetting method, first the sediment samples were pre-treated with H_2O_2 solution for the removal of organic matter. Then they were wet sieved through a 63 μm mesh for 15 min in a sieve shaker. The sample that held on the sieve was weighed and indicated as sand. The mud fraction which includes silt and clay ($> 0.063 \text{ mm}$) were determined using the pipet method. The textural classification was determined based on the mud content after Flemming, (2000) and Pejrup, (1988) classification (Fig. 2). (See Fig. 3.)

2.3 Organic matter

The sediments were dried in an oven at 50°C and then standardized. The standardized samples were pulverized into fine powder using FRITSCH Pulverisette 7 Agate Ball mill. From each of the powdered samples, 5g was taken and decarbonized with 1N solution of Hydrochloric acid and then washed three times with deionized water and centrifuged to remove absorbed HCl in the sediment. The samples were dried and standardized again for analysis in CHNS analyser (model: Vario el cube Odu). The results of total organic matter in each sample were expressed in terms of percentage (Table 1).

2.4 Heavy metal analysis

For heavy metal analysis, the sediments samples were oven-dried at 60°C and dried samples were crushed into fine powder using FRITSCH pulverisette7 Agate ball mill to use later in the chemical analysis. Approximately 0.01g of the sample was taken in Savillex Teflon pressure decomposition vessel for digestion and these were pre-treated with 1:1 H_2O_2 to remove the organic matter present in the sample. The samples were digested using 3–4 ml of acid mixture proportion 7:3:1 ratio of HF, HNO_3 and HCl. Further HCl in the ratios of 3:1 were added into the solution and dried frequently till the silicon tetrafluorides were entirely fumed out. After complete digestion, the dried samples were dissolved with 2 ml of 2% HNO_3 and diluted to 100 ml. This final diluted solution is the stock solution and from the stock solution, 2 ml was again diluted up to 10 ml in clean scintillation vials.

2.5 Statistical Analysis

Using IBM SPSS (version 20) statistical software, the data were subjected to multivariate statistical analysis viz. Pearson Correlation, Hierarchical Cluster Analysis (HCA) and Principal Component Analysis (PCA). PCA was done to group the parameters having identical characteristics in one way or the other and to identify the relation between elements and sampling locations. Cluster analysis was carried out to identify any similarities between sampling locations with regard to organic matter, grain size, depth, and heavy metal concentration. Pearson correlation analysis was carried out to examine the relationship between the variables (grain size, organic matter, and heavy metals)

2.6 Enrichment factor

Enrichment factor (EF) is one of the pollution indices, calculated to differentiate the anthropogenic and natural sources for metals enriched in sediments (Abraham et al., 1998 and Dickinson., 1996). The EF were derived by normalizing the measured trace elements, rare earth elements and actinides concerning metals like Fe, Al or Sc (Ashraf et al., 2016; and Ravichandran et al., 1995). The EF was calculated based on the following equation:

$$EF = (C_x / Fe_x)_{\text{sample}} / (C_{\text{ref}} / Fe_{\text{ref}})$$

where C_x is the concentration of an element in the sample, Fe_x is the concentration of Fe in the sample; C_{ref} is the concentration of an abundant and common element in the average sediment and Fe_{ref} is the concentration of Fe in the average sediment (Wedepohl and Turekian, 1961). In the present work, Fe was selected as the normalisation element to calculate the enrichment factor. In marine sediments Fe is mainly derived from the natural weathering process thus it is typically used to standardize the metal concentration.

The EF values thus obtained are categorized into five tiers, as suggested by (Sutherland, 2000). The elemental ratios show consumption to minimal enrichment when $EF < 2$ and moderate enrichment if the values fall within 2 and 5. However if the $EF = 5$ to 20, significantly enriched; 20–40 very highly enriched; and if $EF > 40$ extremely enriched. Average crustal abundance values of the heavy metals are frequently used as elemental background concentration for resemblance. In the work average crustal abundance was used as background reference (Taylors, 1964).

2.7 Geo-accumulation index

The intensity of pollution for each sampling location is derived by the geo-accumulation index (Igeo). The Igeo is a quantified measure of the degree of the contaminant in sediments (Forstner et al., 1990) and it is calculated by the following equation:

$$I_{\text{geo}} = (C_n / 1.5 \cdot B_n)$$

Where B_n is the geochemical background of a provided element and C_n is the concentration of elements considered in the sediment. Muller (1979) categorized the sediment based on the Igeo value, as; $I_{\text{geo}} > 5$ = extremely contaminated, 4 to 5 = strongly to extremely contaminated, 3 to 4 = strongly contaminated, 1 to 2 = moderately contaminated, 0 to 1 = uncontaminated to moderately contaminated and < 0 = uncontaminated.

2.8 Contamination factor (CF)

CF is perceived to be a valuable method of measuring pollution in sediments over time. It is the ratio of each metal in the present sample to the background values in the same metal

$$CF = C_{\text{heavy metal}} / C_{\text{background}}$$

CF can be classified into four groups (Pekey et al., 2004). If CF values < 1, there is no metal contamination by geogenic or anthropogenic inputs; CF < 3 for a particular metal indicates that sediment is moderately contaminated; CF < 6 there is considerable contamination; and CF > 6, there is very high contamination for that metal. Taylor's (1964) average crustal abundance values of the trace metal was used as the background reference material.

3. Results

A total of 29 surface sediment samples from the study area have been analysed and the result of organic matter, textural class and heavy metal concentrations are given in table 1 and 8.

3.1 Sediment properties

The textural class of the sediments of the study area is shown in the Table 1. There are three types of sediments- sand, slightly muddy sand, and muddy sand. Textural analysis indicates a good correlation between depth and grain size (Table 1). The surface sediments are dominated by coarse grains in the shallower part and finer sediments in the deeper part, whereas the transect 2 (station number 10) and transect 3 (station number 14, 15 and 16) do not show the above observations. The sandy sediments occur in the stations 3,4,13 and 28 while slightly muddy sand occurs at stations 2, 5, 7, 8, 12, 16, 18, 19, 20, 22, 23, 24, 25 and 26. Samples from the station 1, 9, 17, 27, 11 and 6 are muddy sand and 10, 14, 15 and 21 occur as sandy mud (Fig. 3).

3.2. Heavy metal Distribution

Heavy metal analysis of surface sediment samples from the Bay of Bengal and their perceptive values and crustal average (Taylor, 1964) are shown in table 2. In the present study area, C_{org} content in coarse sediments was particularly lower than the finer sediments. The concentration of Cu, Co, Fe, Mn, Pb, Zn, Cr and Ni ranged from 4.89 to 79.23 ppm, 6.38 to 146.28 ppm, 9004.49 to 44483.12ppm, 215.47 to 1036.13 ppm, 134.50 to 15569.84ppm, 324.90 ppm to 1958.14 ppm, 46.41ppm to 582.35 ppm respectively. The mean values of concentration of different heavy metal in the present area are as follows in the descending order: Fe (29712.16 ppm) >Zn (6693.86 ppm) >Pb (4443.13ppm) >Cr (966.98 ppm) >Mn (526.01 ppm) >Ni (258.13) >Co (66.46 ppm) >Cu (30.26 ppm). The higher concentration of Cu, Co and Mn are observed in station no.6 (Transect 1) although Pb, Zn and Cr are encountered in station no.29 (Transect 6) and Fe and Ni is observed in station no.15 (Transect 3) and 18 (Transect 3) respectively (Fig. 4 and 5). The Mn concentrations in the present study area are higher than that of off Karaikal coast surface sediments in the Bay of Bengal; Cu and Zn concentrations are higher than that of, off Cuddalore coast, off Ennore, off Pichavaram, off Tuticorin coast, shelf sediments of Gulf of Mannar in the East Coast of India (table 2).

3.3 Organic matter

Organic contents vary between 0.23% and 2.40% with an average of 0.88%. The high values of organic matter are associated in the deeper part samples and low values occur in the shallower part (Fig. 3). High organic matter concentration in the present study is enriched in muddy sediments and low in sandy type sediments except for the transects 1 and 3 (station number 1 and 14).

3.4. Statistical Analysis

3.4.1 Principle Component Analysis

The PCA was performed to group the pollutants and identify the influencing factors for the distribution of heavy metals in the study area. The PCA analysis was applied for the organic matter, grain size (sand and mud) and heavy metals. The Kaiser-Meyer-Olkin normalisation technique was used to extract maximum factors that influence the distribution of heavy metals. The technique takes into account only those factors with eigenvalues greater than 1, for each procedure. The Varimax rotation yielded 5 factors. Additionally, factor loading communalities for the first three factors were taken as the percentage of variance and the cumulative percentage of variance was derived (Table 6 and Fig. 6).

First principle component shows maximum loadings of Cr (.915), Ni (.814), Zn (.752) and sand (.652) (Fig. 6). The second PC analysis shows significant loadings of Fe (.87), Mn (0.83), Cu (0.63), mud (.61), Co (0.42). Fe and Mn has the highest positive loadings, Cu, mud and Co show medium positive loadings (Fig. 6). The third PC has significant loadings of Organic matter (0.86), Cu (0.48), Ni (0.34) and Cr (0.31). Organic matter exhibits the highest positive loadings. Cu exhibits low positive loadings while Ni and Cr exhibits very low positive loadings (Fig. 6).

3.4.2 Pearson correlation

The correlation analysis was performed on the normalized data set to test the relationship between the environmental parameters (table 7). According to the Pearson correlation analysis, Fe shows a strong positive correlation with Mn ($r=.732$) whereas Zn shows a strong positive correlation with Cr ($r=.784$) and Ni ($r=.605$) and Cr show strong positive correlation with Ni ($r=.700$). The heavy metals viz. Cu ($-.394$) and Mn ($-.361$) exhibit negative correlation with sand while Zn (.283), Cr (.448), Ni (.466), Pb (.101) show low to moderate correlation with sand. Mud has significant correlation with Fe (.495). Weak positive correlation with Cu (.394) and Mn (.361) while negative moderate correlation with Cr ($-.448$) and Ni ($-.283$) and negative weak correlation with Pb ($-.283$) and Zn ($-.101$).

3.4.3 Q mode cluster

The consequent dendrogram of Q-mode hierarchical cluster analysis provides the grouping of samples according to the heavy metal, organic matter, grain size and depth. The dendrogram exhibits four groups, cluster 1(12, 24, 20, 10, 13, 18, 19, 9, 11, 5, 22 and 7) cluster 2(16, 25, 6, 21, 26, 27, 17, 8) cluster 3(14, 29, 23 and 15) cluster 4 (4, 28, 1, 2 and 3) (Fig. 7).

3.5 Enrichment factor

The mean values of EF are as follows Mn > Pb > Cr > Zn > Cu > Co > Ni. Mn is moderately enriched followed by Cu, Pb, Ni, Co and Zn. According to the Muller (1969) Sutherland (2000) classification, the majority of the metals show minimal enrichment to significant enrichment in the sediment sample (Table 3).

3.6 Contamination factor

The mean values of CF for the metals in the shelf sediments are shown in table 4. CF in the present study area is as follows Pb < Cu < Co < Ni < Cr < Zn < Mn < Fe. The calculated CF value indicates that all the sediment samples have been very highly contaminated by Fe. There is also significant Zn, Pb and Cr contamination in most of the sampling stations in the study area.

3.7 Geo accumulation index

Geo accumulation index shows that most of the samples are extremely contaminated in Pb and Zn. Certain samples are moderate to strongly contaminated in Cr and are uncontaminated to moderately contaminated by Ni and Co. The study area is found to be uncontaminated by Cu and Mn (table 5).

4. Discussion

4.1 Sediment

Sediment transportation and deposition are the essential factors which impact the distribution of fine-grained sediments in the marine ecosystem (Tavakoly et al., 2014). The study area is predominantly covered with sandy sediments in the shallower part and can be correlated with incidents of high wave energy condition (Murray, 1963); subsequent erosion (Viveganandan et al., 2013) and the presence of submarine canyon (Narayanan et al., 2015). The higher concentration of mud in the deeper part of the study area is consequent of low energy conditions. Besides, the higher concentration of mud content was found in the shallow depth of transect 1 and 3 suggesting input of freshwater with finer particles from the Coleroon and kollidam river which is then deposited to the sea bottom where the current and wind speed reduces near the shoreline, mostly in the estuarine region (Thomson Becker and Luoma, 1985). The textural characteristics signify that they are mainly dependent on different dynamic processes which affect only the shallow part of the current study area instead of the deeper part; it fluctuates during the November to February (Gopalakrishna and Sastry, 1985)

4.2 Organic matter

The significant quantity of organic matter was found to be strongly associated with muddy sediment in the present study area. This implies that the organic matter in the sediments had high adsorption ability and tends to adsorb fine particles (Li et al., 2015b). Earlier studies in sediments also made a similar observation in the estuaries and offshore areas of both India's East and West Coast (Nobi et al., 2010; Magesh et al., 2011; Jayaprakash et al., 2014; Chakraborty et al., 2015; Chakraborty et al., 2015a, 2015b; Kasilingam et al., 2016; Gopal et al., 2016; Nethaji et al., 2017; and Godson et al., 2018). The fluctuation in the concentration of organic matter demonstrates that the textural parameters and dynamic process are dependent on each other. The higher concentration of organic matter in the study area is due to the fact that (i) The distribution of organic matter is provided mainly by terrestrial inputs from the adjacent land area, (ii) Perhaps, in some areas it might be result of direct discharge of domestic waste (iii) Due to sea-grasses, sea-weeds and algae bottom facies, there can be high organic productivity and (iv) The huge rate of sedimentation (Mansour et al., 2013).

4.3 Heavy metal

The concentration of Cu, Co, Fe, Mn, Pb, Zn, Cr, Ni were in ranges of 4.89–79.23 ppm, 6.38–146.28 ppm, 9004.49–44483.12 ppm, 134.50–15569.84 ppm, 215.17–1036.13 ppm, 3938.03–9886.03 ppm, 324.90–1958 ppm, 46.41–582.35 ppm with average of 30.26 ppm, 66.46 ppm, 29712.16 ppm, 4443.13 ppm, 526.01 ppm, 6693.86 ppm, 966.98 ppm, 258.13 ppm respectively (Figs. 4 and 5). The mean concentration of the study area shows the following decreasing order: Fe > Mn > Zn > Cr > Pb > Ni > Co > Cu.

The concentration of Fe and Mn being considerably higher than the other heavy metals in all sampling sites indicates that they originated through fluvial input into the coast of the study area through minor rivers (Sandler et al. 1993). The higher values of Fe and Mn associated with muddy sediment with high organic matter is a consequence of the input of dissolved particles into the water (geogenic and anthropogenic) discharged into the study area. The excess concentration of Fe and Mn in marine sediments are due to industrial effluents which are denoted by the presence of ferrous manganese (Fe vs. Mn: $r = .732$). These are brought to the open sea by small rivers. (Buckley et al. 1995). The heavy metals Cu and Co are higher in the shallower part and are associated with sandy sediments. The dominance of heavy metals such as Co, Cu, Pb and Zn in the surface sediments is caused by the nitrate dominated fertilizers in the agricultural areas of the study area (Liaghati et al. 2003 and Jayaprakash 2015), while the anti-fouling paints that seep from the boat/ship are the source of Cu and Zn in the sediment sample (Goh and Chou 1997). The enhancement of heavy metals in the sediments is high in the mud fractions as fine particles adsorb soluble metals from the natural waters and carry them to the bottom sediments (Lijklema et al., 1993; Maher et al., 1999). Moreover, Cr, Ni and other metals also subsequently join the study area through anthropogenic activities like burning of oil, inorganic sewage, phosphate-containing fertilizers, chemical and industrial waste (Gonnelli and Renella, 2010). The total heavy metal concentration is found to be high from the northern and central part of the study area due to the shipwreck located near the study area which is still lying on the seabed at a depth of 20m (<https://www.facebook.com/mvmothi/>). Moreover, past records suggests that it is submerged with iron ores on board.

5. Conclusion

The present study has been carried out to assess the concentration and understand the spatial distribution of heavy metals in the surface sediments from the south-western part of Bay of Bengal. The relatively higher concentration of Cu, Pb, Zn, Ni and Co in the mud fractions shows that heavy metal concentration was quite dependent on the particle size characteristics. The larger surface area of the sediments helps to bind or adsorb heavy metals easily. The results of

the study demonstrate that the mean concentration of Cu and Mn is lower than the background value. The concentration of Co, Pb, Zn, Cr and Ni were also much higher than the background value of surface sediments indicating enrichment of these metals in the study area. Such anomalous behaviour clearly shows the role of human activities in contributing metal toxicity to the environment. The various sediment quality indices used in the current study reveal different aspects of pollution. The values of CF factor and Igeo suggest that the study area is extremely contaminated by Pb and Zn and are sourced from mining activities and effluents released from industrial and agricultural activities. Whereas, Igeo and CF values which focus on the anthropogenic influence suggest that Co, Mn, Cr and Ni, mainly originates from the manmade activities such as ship scrapping, antifouling paints used in boats and ships, industries, metal smelting, dredging and land reclamation action in the coastal areas and sewage effluents. The positive correlation of Fe with various heavy metals (Pb, Zn, Cu, Ni and Cr) is due to the metal scavenging phase of Fe oxyhydroxides. The positive PCA loadings of Zn (0.92), Pb (0.876), Cu (0.788), Fe (0.745) and Cr (0.488) demonstrate the common source i.e. anthropogenic origin.

Declarations

Ethical Approval: Not Applicable

Consent for publication: Not Applicable

Availability of Data and Materials: The datasets generated and/or analyzed during the current study are not publicly available due to further investigation of the study but are available from the corresponding author on reasonable request.

Funding: This work was supported by Government of Kerala Post metric fellowship. Grant number B3-8502/19.

Authors' contributions:

1. Conceptualization, Methodology, Formal analysis, Investigation and Writing: Harikrishnan, S.

2. Writing - review and editing: Nitin Agarwal, M. Sridharan, and N. Anbuselvan

3. Supervision: Senthil Nathan

4. Competing Interest- The authors of this manuscript declare that there are no competing interests.

5. Consent to Participate- Not Applicable

Acknowledgement

We wholeheartedly thank the University Grants Commission (UGC), New Delhi, for financially supporting the work being done. In addition, we extend our sincere gratitude to Central Instrumentation Facility and the laboratory facilities in Pondicherry University. We would like to use this space to thank the **National Institute of Ocean Technology** (Ministry of Earth Sciences, Government of India) for tremendous assistance in collecting samples, especially to **Mr. D. Rajasekhar** (Head of Vessel Management Cell), **Mr. K. Ramasundaram** (Scientific Officer II), **Mr. Thiruvathi Babu** and **Mr. Mohan Raj** for their support and immense participation during sampling. Special thanks to Mr Harikrishnan P R, Research scholar Dept. of Earth sciences, Pondicherry University for his help to use Arc GIS software.

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Tables

Table 1: Sample number, coordinates, depth, sand (%), mud (%), organic matter (%) and textural class in the study area.

Sl.No	Latitude	Longitude	Depth(m)	Sand	Mud	Org	Textural class
1	11.705213°	79.798297°	3	64.26	35.74	1.53	Muddy sand
2	11.706511°	79.805263°	7	76.68	23.32	0.434	Slightly muddy sand
3	11.704835°	79.811672°	12	98.72	1.28	0.528	Sandy
4	11.704141°	79.842150°	18	97.24	2.76	0.375	Sandy
5	11.702957°	79.887639°	29	80.2	19.8	0.415	Slightly muddy sand
6	11.699927°	79.978918°	50	52.16	47.84	1.837	Muddy sand
7	11.502285°	79.799394°	5	88.5	11.5	0.367	Slightly muddy sand
8	11.501472°	79.809983°	10	79.64	20.36	0.465	Slightly muddy sand
9	11.501143°	79.821923°	16	73.8	26.2	0.332	Muddy sand
10	11.500621°	79.840273°	22	22.66	77.34	0.391	Sandy mud
11	11.500469°	79.863224°	30	61.16	38.84	0.775	Muddy sand
12	11.498797°	79.910585°	50	94.52	5.48	1.891	Slightly muddy sand
13	11.434539°	79.829538°	4	95.08	4.92	0.425	Sandy
14	11.432874°	79.840041°	10	39.52	60.48	1.837	Sandy mud
15	11.431878°	79.851176°	15	29.42	70.58	0.764	Sandy mud
16	11.432918°	79.862972°	24	14.54	85.46	0.595	Slightly sandy mud
17	11.432094°	79.939082°	52	61.96	38.04	2.219	Muddy sand
18	11.432554°	79.950294°	85	93.12	6.88	2.361	Slightly muddy sand
19	11.345169°	79.850270°	5	90.22	9.78	0.231	Slightly muddy sand
20	11.346099°	79.857946°	11	87.38	12.62	0.244	Slightly muddy sand
21	11.347631°	79.864518°	18	44.56	55.44	0.503	Sandy mud
22	11.345722°	79.891578°	37	87.24	12.76	0.334	Slightly muddy sand
23	11.342831°	79.951158°	53	82.4	17.6	0.726	Slightly muddy sand
24	11.342655°	79.978775°	80	77.76	22.24	2.408	Slightly muddy sand
25	11.238341°	79.867520°	5	80.98	19.02	0.376	Slightly muddy sand
26	11.239205°	79.875840°	10	83.26	16.74	0.47	Slightly muddy sand
27	11.238961°	79.884701°	15	56.1	43.9	0.594	Muddy sand
28	11.238876°	79.907130°	31	97.32	2.68	0.266	Sandy
29	11.231771°	80.001305°	57	85.66	14.34	2.018	Slightly muddy sand

Table 2: A comparison of heavy metals concentration: present study, average crustal abundances, different areas of Bay of Bengal and some regions of the world.

Metal	This study	Taylor, 1964	Muthu Raj and Jayaprakash(2007)	Jayaprakash et al. (1999)	Ramanathan et al. (1999)	Devanesan et al. (2017)	Jayaraju et al. (2009)	Jonathan et al. (2004)	Ikram Naifar et al. (2018)	Yang-Guang Gu (2017)
		Average crustal abundance	Off Ennore	Cuddalore coast	Pichavaram	Karaikal coast	Tuticorin coast	Gulf of Mannar	Southern coast of Sfax	Zhelin Bay, South China
Fe (ppm)	29712.16	56300	27800	10900	24998	66216	28717	27200	15740	-
Cu (ppm)	30.25	55	506.21	39.54	132.3	-	52	57	359	-
Co (ppm)	66.46	25	8.1	7.37	-	23	-	15	-	-
Mn (ppm)	526.18	950	373	291	-	1641		305	-	751.32
Pb (ppm)	444.122	12.5	32.36	33.92	143.8	50	42	16	39.7	35.69
Zn (ppm)	67	70	126.83	37.67	106	90	247	73	375	74.95
Cr (ppm)	966	100	194.83	127	617	383	15	177	381	23.07
Ni (ppm)	258.12	75	38.61	39.21	252	42	75	24	59.9	7.5

Table 3: Enrichment factor of different heavy metals in surface sediments of the study

S.No	Cu	Co	Mn	Pb	Zn	Cr	Ni
1	0.21	0.20	0.1	2.01	1.32	0.1	0.12
2	1.32	3.50	2.2	0.24	1.12	0.3	0.30
3	2.69	0.10	1.7	4.21	1.11	1.8	0.20
4	1.08	0.10	8.8	2.10	1.74	3.3	0.11
5	1.32	0.30	5.4	0.05	1.65	2.2	0.06
6	0.06	2.80	1.5	3.23	1.32	0.4	0.02
7	0.09	0.07	1.4	4.44	1.21	0.1	0.63
8	1.08	0.40	1.2	2.36	1.25	1.4	0.21
9	0.1	1.30	1	0.02	1.52	0.1	0.44
10	7.68	1.30	8.83	0.01	1.65	0.14	0.79
11	3.6	1.90	8.65	0.01	1.33	7.78	0.56
12	5.32	0.40	1.1	0.02	1.54	1.88	0.10
13	3.2	0.10	1.2	0.02	4.23	3.96	0.20
14	3.65	0.01	1.4	5.62	1.74	0.1	0.36
15	2.36	2.58	9.3	3.50	2.80	5.2	0.37
16	5.36	2.36	9.4	6.22	5.40	0.1	0.21
17	5.03	1.60	8.1	6.30	0.60	1.3	0.41
18	2.06	1.23	0.1	9.60	3.20	1.9	0.22
19	5.04	0.01	9.7	12.40	6.32	3.22	0.32
20	1.56	1.70	9.8	2.50	5.41	2.22	0.10
21	0.03	1.50	9.3	2.70	1.45	7.36	0.41
22	1.60	0.11	8.6	3.54	1.24	0.16	0.23
23	0.21	1.65	7.6	6.03	0.23	4	0.10
24	0.01	0.00	5.6	4.87	5.21	0	0.22
25	0.03	1.36	1.2	6.32	1.23	1.7	0.32
26	0.02	4.32	0.1	6.58	0.01	6.7	0.63
27	0.00	1.70	1.7	5.32	0.36	7.19	0.11
28	4.38	1.40	8.6	4.21	1.01	9.07	0.41
29	0.19	0.07	7.02	0.10	3.50	1.9	0.22

Table 4: Contamination factor of heavy metals in surface sediments of the study area.

S.No	Cu	Co	Fe	Mn	Pb	Zn	Cr	Ni
1	0.32	0.70	2915.19	0.31	607.28	56.26	5.98	1.30
2	0.51	5.63	1599.38	0.36	62.21	102.07	12.85	5.03
3	0.53	0.47	2836.83	0.49	95.25	90.33	10.62	4.07
4	0.09	0.20	2662.70	0.24	821.28	85.23	10.02	2.28
5	0.11	1.49	5099.59	0.29	405.59	112.10	11.80	2.82
6	1.44	5.85	7033.47	1.09	427.13	104.48	11.82	5.44
7	0.50	3.30	4603.90	0.57	423.23	79.77	8.89	1.89
8	0.09	2.26	6256.92	0.76	459.26	92.30	7.77	2.67
9	0.46	1.19	4445.73	0.48	150.19	75.50	5.89	1.64
10	0.82	3.44	5562.22	0.49	16.31	77.17	4.76	2.42
11	0.35	4.21	4556.29	0.39	241.30	65.78	4.88	2.39
12	0.10	1.94	5210.41	0.60	25.02	90.59	8.68	1.94
13	0.23	5.64	5882.40	0.75	-10.76	104.21	7.49	3.33
14	0.84	1.01	7043.56	1.04	847.62	68.24	3.25	0.62
15	0.41	1.82	7901.09	0.74	547.58	134.67	10.83	1.21
16	1.28	3.00	6941.91	0.66	183.08	80.76	7.77	1.12
17	0.86	4.06	6375.48	0.52	169.49	115.65	11.51	3.25
18	1.09	3.29	5643.94	0.61	352.99	132.26	12.92	7.76
19	0.17	0.38	5346.32	0.52	214.01	118.17	11.86	3.29
20	0.12	3.30	5034.91	0.49	101.65	104.01	10.86	3.90
21	0.44	2.93	6038.22	0.60	159.63	75.11	5.53	1.96
22	0.80	5.28	4842.64	0.42	391.17	106.31	12.82	4.69
23	0.21	2.58	5361.42	0.43	1115.06	93.98	11.34	3.84
24	0.58	-0.26	5223.62	0.30	41.36	98.01	13.79	5.02
25	1.25	2.06	6979.64	0.85	235.98	88.12	4.34	4.19
26	0.38	1.39	6127.65	0.73	151.44	83.02	12.46	4.55
27	0.45	4.38	6279.64	0.64	29.44	83.05	6.61	4.71
28	0.24	1.04	2616.38	0.23	798.67	114.82	13.52	5.31
29	1.26	4.51	6625.23	0.47	1245.59	141.23	19.58	7.16

Table 5: Geo accumulation index of heavy metal in surface sediments of the study area

S.No	Cu	Co	Fe	Mn	Pb	Zn	Cr	Ni
1	2.25	1.11	10.92	2.29	8.66	5.23	1.99	0.21
2	1.55	1.91	10.06	2.05	5.37	6.09	3.10	1.75
3	1.49	1.68	10.89	1.62	5.99	5.91	2.82	1.44
4	4.08	2.94	10.79	2.66	9.10	5.83	2.74	0.60
5	3.73	0.01	11.73	2.35	8.08	6.22	2.98	0.91
6	0.06	1.96	12.20	0.46	8.15	6.12	2.98	1.86
7	1.58	1.14	11.58	1.39	8.14	5.73	2.57	0.34
8	4.00	0.59	12.03	0.98	8.26	5.94	2.37	0.83
9	1.70	0.34	11.53	1.64	6.65	5.65	1.97	0.13
10	0.86	1.20	11.86	1.61	3.44	5.69	1.67	0.69
11	2.08	1.49	11.57	1.93	7.33	5.45	1.70	0.67
12	3.94	0.37	11.76	1.33	4.06	5.92	2.53	0.37
13	2.69	1.91	11.94	1.00	2.84	6.12	2.32	1.15
14	0.83	0.57	12.20	0.53	9.14	5.51	1.12	1.28
15	1.86	0.28	12.36	1.02	8.51	6.49	2.85	0.31
16	0.23	1.00	12.18	1.19	6.93	5.75	2.37	0.42
17	0.80	1.44	12.05	1.53	6.82	6.27	2.94	1.12
18	0.47	1.13	11.88	1.29	7.88	6.46	3.11	2.37
19	3.12	1.98	11.80	1.53	7.16	6.30	2.98	1.13
20	3.70	1.14	11.71	1.60	6.08	6.12	2.86	1.38
21	1.75	0.97	11.97	1.32	6.73	5.65	1.88	0.38
22	0.91	1.82	11.66	1.85	8.03	6.15	3.10	1.65
23	2.81	0.78	11.80	1.81	9.54	5.97	2.92	1.36
24	1.37	0.13	11.77	2.34	4.79	6.03	3.20	1.74
25	0.27	0.46	12.18	0.81	7.30	5.88	1.53	1.48
26	1.98	0.11	12.00	1.05	6.66	5.79	3.05	1.60
27	1.73	1.54	12.03	1.23	4.29	5.79	2.14	1.65
28	2.66	0.52	10.77	2.73	9.06	6.26	3.17	1.82
29	0.25	1.59	12.11	1.69	9.70	6.56	3.71	2.26

Table 6: Factor loadings and communality values of heavy metals and sand, mud, organic matter after varimax with kaiser Normalization.

Variables	Factor1	Factor2	Factor3	Communalities
Cu	.761	.315	-.016	.678
Co	.400	.376	-.607	.670
Fe	.821	.017	.045	.676
Mn	.730	-.072	-.198	.577
Pb	.011	.211	.759	.621
Zn	.085	.812	.149	.689
Cr	-.170	.851	.266	.825
Ni	-.027	.904	-.113	.830
Sand	-.742	.519	-.030	.822
Mud	.742	-.519	.030	.822
OM	.423	.354	.431	.490

The bold values indicate that the values are high and significant.

Table 7: Correlation coefficient matrix of sediment texture, organic matter with heavy metals in the study area.

	Sand	mud	org	Cu	Co	Fe	Mn	Pb	Zn	Cr	Ni
Sand	1										
mud	-1.000	1									
org	<i>-.373</i>	<i>.373</i>	1								
Cu	<i>-.394</i>	<i>.394</i>	<i>.427</i>	1							
Co	-.148	.148	.175	<i>.383</i>	1						
Fe	-.495	.495	.367	<i>.448</i>	.198	1					
Mn	-.361	.361	.145	<i>.453</i>	.259	.732	1				
Pb	.101	-.101	.518	.075	-.138	.014	-.092	1			
Zn	.283	-.283	.116	.163	.204	.206	-.044	.221	1		
Cr	<i>.448</i>	<i>-.448</i>	.135	.092	.097	-.125	-.330	.321	.784	1	
Ni	<i>.466</i>	<i>-.466</i>	.043	.340	.330	-.065	-.095	.099	.603	.700	1

Bold values indicate significance at 0.01 level (2 tailed).

Italic values indicate significance at 0.05 level (2 tailed).

Table 8: Heavy metal concentration (ppm) in the surface sediments of study area.

Parameters	Minimum	Maximum	Mean	Median	SD
Cu (ppm)	4.88	79.23	30.25	24.86	21.79
Co (ppm)	6.3	146.27	66.46	64.61	43.58
Fe (ppm)	9004.49	44483.12	29712.2	30184.8	8530.02
Mn (ppm)	215.46	1036.12	526.01	493.28	201.96
Pb (ppm)	134.49	15569.84	4443.12	2949.72	4129.31
Zn (ppm)	3938.03	9886.02	6693.86	6460.93	1439.11
Cr (ppm)	324.9	1958.14	966.97	1061.63	360.48
Ni (ppm)	46.41	582.35	258.12	246.64	130.89

Figures

Figure 1

Study area and sampling locations. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Plots showing sand, organic matter and mud content in each sample.

Figure 3

Spatial distribution map of sand, mud and organic matter.

Figure 4

Spatial distribution map of Fe(ppm), Cu(ppm), Cr(ppm) and Co(ppm)

Figure 5
 Spatial distribution map of Mn(ppm), Ni(ppm), Pb(ppm) and Zn(ppm)

Figure 6

Figure 7

Dendrogram representing sampling stations with similar sediment geochemistry.