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

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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; Xinnamon, 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 Rafiuuddin, 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$_2$O$_2$ 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 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 pulviserisette 7 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$_2$O$_2$ 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:

\[ EF = \frac{(C_x/Fex)_{sample}}{(C_{ref}/Fe_{ref})} \]

where $C_x$ is the concentration of an element in the sample, $C_{Fe}$ 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:

\[ Igeo = \frac{(C_{n}/1.5*Bn)}{Bn} \]

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; Igeo > 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\text{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 44483.12 ppm, 215.47 to 1036.13 ppm, 134.50 to 15569.84 ppm, 324.90 ppm to 1958.14 ppm, 46.41 ppm 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 (4443.13 ppm) > Cr (966.98 ppm) > Mn (526.01 ppm) > Ni (258.13 ppm) > Co (66.46 ppm) > Cu (30.26 ppm). The higher concentration of Cu, Co and Mn are observed in station no. 6 (Transact 1) although Pb, Zn and Cr are encountered in station no. 29 (Transact 6) and Fe and Ni is observed in station no. 15 (Transact 3) and 18 (Transact 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 the 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 (.83), Cu (.63), mud (.61), Co (.42). Fe and Mn has the highest positive loadings, Cu, and Co show medium positive loadings (Fig. 6). The third PC has significant loadings of Organic matter (.86), Cu (.48), Ni (.34) and Cr (.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
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 from the south-western part of Bay of Bengal show that heavy metal concentration in the mud fractions is higher than in the fine fractions, indicating that heavy metals are associated with the mud fraction.

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 northern and central part of the study area through anthropogenic activities like burning of oil, inorganic sewages, 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 suggest that it is submerged with iron ores on board.

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., 2013). The higher 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 (Lianghati et al.2003 and Jayaprakash 2015), while the anti-fouling paints that seep from the boat/ship are the source of Cr 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 sewages, 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 suggest that it is submerged with iron ores on board.

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, 4693.86 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 is uncontaminated to moderately contaminated by Ni and Co. The study area is found to be uncontaminated by Cu and Mn (table 5).

4.4 Geoaccumulation index

Geo-accumulation index shows that most of the samples are strongly 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).

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 originate from the manmade activities such as ship scraping, 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.

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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
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References

1. Abraham, J. (1998). Spatial distribution of major and trace elements in shallow reservoir sediments: an example from Lake Waco, Texas. Environmental Geology, 36(3-4), 349–363. doi:10.1007/s002540050351.
2. Balkhair, K. S., & Ashraf, M. A. (2016). Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of Saudi Arabia. Saudi Journal of Biological Sciences, 23(1), S32–S44. doi: 10.1016/j.sjbs.2015.09.023.
3. Buckley, D. E., Smith, J. N., & Winters, G. V. (1995). Accumulation of contaminant metals in marine sediments of Halifax Harbour, Nova Scotia: environmental factors and historical trends. Applied Geochemistry, 10(2), 175–195. doi:10.1016/0883-2927(94)00053-9.
4. Chakraborty, P., Sarkar, A., Vudamala, K., Naik, R., & Nath, B. N. (2015). Organic matter — A key factor in controlling mercury distribution in estuarine sediment. Marine Chemistry, 173, 302–309. doi: 10.1016/j.marchem.2014.10.005.Chakraborty, S., Chakraborty, P., & Nath, B. N. (2015) a. Lead distribution in coastal and estuarine sediments around India. Marine Pollution Bulletin, 97(1-2), 36–46. doi: 10.1016/j.marpolbul.2015.05.056.
5. Dickinson, W. W., Dunbar, G. B., & McLeod, H. (1996). Heavy metal history from cores in Wellington Harbour, New Zealand. Environmental Geology, 27(1), 59–69. doi:10.1007/bf00770603.
6. Ding, X., Ye, S., Laws, E. A., Mozdzer, T. J., Yuan, H., Zhao, G., … Wang, J. (2019). The concentration distribution and pollution assessment of heavy metals in surface sediments of the Bohai Bay, China. Marine Pollution Bulletin, 149, 110497. doi: 10.1016/j.marpolbul.2019.110497.
7. District Environment Impact Assessment Authority (DEIAA), Cuddalore.
8. Flemming, B. (2000). A revised textural classification of gravel-free muddy sediments on the basis of ternary diagrams. Continental Shelf Research, 20(10-11), 1125–1137. doi:10.1016/s0278-4343(00)00015-7.
9. Förstner, U., Ahlf, W., Calmano, W., & Kersten, M. (1990). Sediment criteria development. In Sediments and environmental geochemistry (pp. 311-338). Springer, Berlin, Heidelberg.
10. Godson, P. S., Magesh, N. S., Peter, T. S., Chandrasekar, N., Krishnakumar, S., & Vincent, S. G. T. (2018). A baseline study on the concentration of trace elements in the surface sediments off Southwest coast of Tamil Nadu, India. Marine Pollution Bulletin, 126, 381–388. doi:10.1016/j.marpolbul.2017.11.027.

11. Goh, B. P. L., & Chou, L. M. (1997). Heavy metal levels in marine sediments of Singapore. Environmental Monitoring and Assessment, 44(1-3), 67-80.

12. Gonnelli, C., & Renella, G. (2012). Chromium and Nickel. Heavy Metals in Soils, 313–333. doi:10.1007/978-94-007-4470-7_11.

13. Gopal, V., Krishnakumar, S., Simon Peter, T., Nethaji, S., Suresh Kumar, K., Jayaprakash, M., & Magesh, N. S. (2017). Assessment of trace element accumulation in surface sediments off Chennai coast after a major flood event. Marine Pollution Bulletin, 114(2), 1063–1071. doi:10.1016/j.marpolbul.2016.10.019.

14. Ihejirika, C., Njoku-Tony, R., Ebe, T., Enwereuzoh, U., Izunobi, L., Asheigbu, D., & Verla, N. (2016). Anthropogenic Impact and Geo-accumulation of Heavy Metal Levels of Soils in Owerri, Nigeria. British Journal of Applied Science & Technology, 12(1), 1–9. doi:10.9734/bjast/2016/19357.

15. Islam, M. S., Ahmed, M. K., Raknuzzaman, M., Habibullah-Al-Mamun, M., & Kundu, G. K. (2017). Heavy metals in the industrial sludge and their ecological risk: A case study for a developing country. Journal of Geochemical Exploration, 172, 41–49. doi:10.1016/j.gexplo.2016.09.006.

16. Jayaprakash, M., Gopal, V., Anandasabari, K., Kalaivanan, R., Sujitha, S. B., & Jonathan, M. P. (2016). Enrichment and toxicity of trace metals in near-shore bottom sediments of Cuddalore, SE coast of India. Environmental Earth Sciences, 75(19). doi:10.1007/s12665-016-6882-7.

17. Jonathan, M. P., Srinivasasalu, S., Thangadurai, N., Ayyamperumal, T., Armstrong-Altrin, J. S., & Ram-Mohan, V. (2008). Contamination of Uppanar River and coastal waters off Cuddalore, Southeast coast of India. Marine Pollution Bulletin, 51(1-2), 500–508. doi:10.1016/j.marpolbul.2006.05.051.

18. Krishna, V. V., & Sastry, J. S. (1985). Surface circulation over the shelf off the east coast of India during the southwest monsoon.

19. Li, Y., Li, D., Fang, J., Yin, X., Li, H., Hu, W., & Chen, J. (2015). Impact of Typhoon Morakot on suspended matter size distributions on the East China Sea inner shelf. Continental Shelf Research, 101, 47–58. doi:10.1016/j.csr.2015.04.007.

20. Li, Y., Lin, Y., & Wang, L. (2018). Distribution of heavy metals in seafloor sediments on the East China Sea inner shelf: Seasonal variations and typhoon impact. Marine Pollution Bulletin, 129(2), 534–544. doi:10.1016/j.marpolbul.2017.10.027.

21. Liaghati, T., Preda, M., & Cox, M. (2004). Heavy metal distribution and controlling factors within coastal plain sediments, Bells Creek catchment, southeast Queensland, Australia. Environment International, 29(7), 935–948. doi:10.1016/s0160-4120(03)00060-6.

22. Liang, X., Song, J., Duan, L., Yuan, H., Li, X., Li, N., … Xing, J. (2018). Source identification and risk assessment based on fractionation of heavy metals in surface sediments of Jiaozhou Bay, China. Marine Pollution Bulletin, 128, 548–556. doi:10.1016/j.marpolbul.2018.02.008.

23. Lijklema, L., Koelmans, A. A., & Portielje, R. (1993). Water Quality Impacts of Sediment Pollution and the Role of Early Diagenesis. Water Science and Technology, 28(8-9), 1–12. doi:10.2166/wst.1993.0598.

24. Magesh, N. S., Chandrasekar, N., & Vetha Roy, D. (2011). Spatial analysis of trace element contamination in sediments of Tamiraparani estuary, southeast coast of India. Estuarine, Coastal and Shelf Science, 92(4), 618–628. doi:10.1016/j.ecss.2011.03.001Maher, B. A., & Thompson, R. (Eds.). (1999). Quaternary Climates, Environments and Magnetism. doi:10.1017/cbo9780511535635.

25. Mansour, A. M., Askalany, M. S., Madkour, H. A., & Assran, B. B. (2013). Assessment and comparison of heavy-metal concentrations in marine sediments in view of tourism activities in Hurghada area, northern Red Sea, Egypt. The Egyptian Journal of Aquatic Research, 39(2), 91–103. doi:10.1016/j.ejar.2013.07.004.

26. Mohktar, M. B., Atis, A. Z., Munusamy, V., & Praveena, S. M. (2009). Assessment level of heavy metals in Penaeus monodon and Oreochromis sp. in selected aquaculture ponds of high densities development area. European Journal of Scientific Research, 30(3), 348-360.

27. Muller, G. (1980). Schwermetalle in Sedimenten des staugeregelter Neckars. Naturwissenschaften, 67(6), 308–309. doi:10.1007/bf01153502.

28. Nethaji, S., Kalaivanan, R., Arya Viswam, & Jayaprakash, M. (2017). Geochemical assessment of heavy metals pollution in surface sediments of Vellar and Celeron estuaries, southeast coast of India. Marine Pollution Bulletin, 115(1-2), 469–479. doi:10.1016/j.marpolbul.2016.11.045.

29. Nobi, E. P., Dilipan, E., Thangaradjou, T., Sivakumar, K., & Kannan, L. (2010). Geochemical and geo-statistical assessment of heavy metal concentration in the sediments of different coastal ecosystems of Andaman Islands, India. Estuarine, Coastal and Shelf Science, 87(2), 253–264. doi:10.1016/j.ecss.2009.12.019.

30. Pejrup, M. (1988). The Triangular Diagram Used for Classification of Estuarine Sediments: A New Approach. Tide-Influenced Sedimentary Environments and Facies, 289–300. doi:10.1016/978-94-015-7762-5_21.

31. Pekey, H., Karakaş, D., Ayberk, S., Tolun, L., & Baköğlu, M. (2004). Ecological risk assessment using trace elements from surface sediments of İzmit Bay (Northeastern Marmara Sea) Turkey. Marine Pollution Bulletin, 48(9-10), 946–953. doi:10.1016/j.marpolbul.2003.11.023.

32. Ravichandran, M., Baskaran, M., Santschi, P. H., & Bianchi, T. S. (1995). History of Trace Metal Pollution in Sabine-Neches Estuary, Beaumont, Texas. Environmental Science & Technology, 29(6), 1495–1503. doi:10.1021/es00006a010.

33. S.Viveganandan, C.Lakshumanan, M.Sundararajan, S.Eswaramoorthi & Usha Natesan.(2012). Depositional environment of sediments along the Cuddalore coast of Tamilnadu, India.

34. Sandier, A., Halicz, L., & Brenner, I. B. (1993). Distribution of Trace Elements in the Filterable and Acid Extractable Fractions of Waters of the Northern Jordan River. Water Science and Technology, 27(7-8), 405–412. doi:10.2166/wst.1993.0576.

35. Sharifuzzaman, S. M., Rahman, H., Ashkeuzzaman, S. M., Islam, M. M., Chowdhury, S. R., & Hossain, M. S. (2016). Heavy Metals Accumulation in Coastal Sediments. Environmental Remediation Technologies for Metal-Contaminated Soils, 21–42. doi:10.1007/978-4-431-55759-3_2.
37. Sutherland, R. A. (2000). Bed sediment-associated trace metals in an urban stream, Oahu, Hawaii. Environmental Geology, 39(6), 611–627. doi:10.1007/s002540050473.

38. Tamim, U., Khan, R., Jolly, Y. N., Fatema, K., Das, S., Naher, K., ... Hossain, S. M. (2016). Elemental distribution of metals in urban river sediments near an industrial effluent source. Chemosphere, 155, 509–518. doi: 10.1016/j.chemosphere.2016.04.099.

39. Tansel, B., & Rafiuddin, S. (2016). Heavy metal content in relation to particle size and organic content of surficial sediments in Miami River and transport potential. International Journal of Sediment Research, 31(4), 324–329. doi: 10.1016/j.ijscr.2016.05.004.

40. Tavakoly Sany, S. B., Hashim, R., Rezayi, M., Salleh, A., & Safari, O. (2016). A review of strategies to monitor water and sediment quality for a sustainability assessment of marine environment. Environmental Science and Pollution Research, 21(2), 813–833. doi:10.1007/s11356-013-2217-5.

41. Taylor, S. R. (1964). Abundance of chemical elements in the continental crust: a new table. Geochimica et Cosmochimica Acta, 28(8), 1273–1285. doi:10.1016/0016-7037(64)90129-2.

42. Thomson-Becker, E. A., & Luoma, S. N. (1985). Temporal fluctuations in grain size, organic materials and iron concentrations in intertidal surface sediment of San Francisco Bay. Temporal Dynamics of an Estuary: San Francisco Bay, 91–107. doi:10.1007/978-94-009-5528-8_6.

43. TUREKIAN K., Wedepohl, K., 1961. Distribution of the Elements in Some Major Units of the Earth's Crust. Geol. Soc. Am. Bull. 72, 175-192.

44. Vasudevan K, Silvester JM, Murthy JVSSN, Rangachari V, Anathanaryanan PN (1998) Exploration for stratigraphic and subtle traps in Cauvery basin: lessons learnt and future prospective. In: Proceedings of workshop on integrated exploration for stratigraphic and subtle traps, Dehra Dun. Bull Oil Nat Gas Corp 35:75–92.

45. Wang, S.-L., Xu, X.-R., Sun, Y.-X., Liu, J.-L., & Li, H.-B. (2013). Heavy metal pollution in coastal areas of South China: A review. Marine Pollution Bulletin, 76(1-2), 7–15. doi: 10.1016/j.marpolbul.2013.08.025.

46. Zhao, G., Lu, Q., Ye, S., Yuan, H., Ding, X., & Wang, J. (2016). Assessment of heavy metal contamination in surface sediments of the west Guangdong coastal region, China. Marine Pollution Bulletin, 108(1-2), 268–274. doi: 10.1016/j.marpolbul.2016.04.057.

**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°| 79.805263° | 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°| 79.977875° | 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    | 11.238786°| 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 coast | Cuddalore coast | Pichavaram coast | Karaikal coast | Tuticorin coast | Gulf of Manner | 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 | 77.17 | 4.76 | 2.42 |
| 7    | 0.50 | 3.30 | 4603.90 | 0.57 | 423.23 | 90.33 | 10.62 | 1.64 |
| 8    | 0.09 | 2.26 | 6256.92 | 0.24 | 405.59 | 112.10 | 11.80 | 2.82 |
| 9    | 0.11 | 1.49 | 5099.59 | 0.29 | 405.59 | 112.10 | 11.80 | 2.82 |
| 10   | 1.44 | 5.85 | 7033.47 | 1.09 | 427.13 | 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 | 405.59 | 112.10 | 11.80 | 2.82 |
| 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  | -.373 | .373 | 1  |    |    |    |    |    |    |    |
| Cu   | -.394 | .394 | .427 | 1 |    |    |    |    |    |    |
| Co   | -.148 | .148 | .175 | .383 | 1 |    |    |    |    |    |
| Fe   | -.495 | .495 | .367 | .448 | .198 | 1 |    |    |    |    |
| Mn   | -.361 | .361 | .145 | .453 | .259 | **.732** | 1 |    |    |    |
| Pb   | .101  | -.101 | **.518** | .075 | -.138 | .014 | -.092 | 1 |    |    |
| Zn   | .283  | -.283 | .116 | .163 | .204 | .206 | -.044 | .221 | 1 |    |
| Cr   | **.448** | -.448 | .135 | .092 | .097 | -.125 | -.330 | .321 | **.784** | 1 |
| Ni   | **.466** | -.466 | .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 | 201.9 |
| 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 |