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Distribution of trace elements concentration in sediments of Nethravathi-Gurupura estuary south-west coast Mangalore

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Abstract:
The ecology is continually exposed to trace elements from various natural and human-made sources. When the concentration of these trace elements goes beyond certain threshold limits, their excessive intake can become toxic and lead to health disorders in individuals. It is crucial to measure the concentration of trace elements, especially toxic ones, in order to evaluate and forecast risks to the environment and public health. The distribution of trace elements across different ecological patterns is contingent upon the inherent properties of the element and site-specific factors, including the type of matrices and their physicochemical characteristics. Considering these aspects, an effort is made to evaluate the concentration of trace elements and pollution indices in sediment samples obtained from the coastal belt of Nethravathi and Gurupura estuary and possible conclusions are drawn. The results showed that the mean concentrations of the HMs in the sediment samples followed the order Pre-monsoon includes Fe>Mn>, Cr>, Zn>, Cu>, Ni>, Pb>, Co>, and Post-monsoon includes Fe>Mn>, Ni>, Pb>Co>Cd. respectively. The pollution indices of Enrichment Factor EF natural to extremely severe enrichment in the estuarine sediments, whereas Pb and Cd exhibit moderately severe to extremely severe enrichment. The contamination factor CF in both Pre-monsoon and Post Monsoon and Cd shows no pollution up to the category of very high contamination. Geo-accumulation index (Igeo) values the Pre-Monsoon and Post Monsoon Cd and Pb shows pollution up to the category of "strongly" to "extremely" pollute. Pollution Load Index (PLI) in both the season shows no pollution to pollute. The investigation shows pollution in more than half of the samples and also SPI in both the season low polluted sediment to moderately pollute.

Keywords: Estuary sediments, west coast, trace elements, Nethravathi-Gurupura.

INTRODUCTION

In aquatic ecosystems, particularly in marginal marine habitats, sediments can carry the elements and may act as a sink for different contaminants (Liu et al., 2019; Herbert et al., 2020). The hazardous substances present in the aquatic environment have a detrimental effect on the estuarine and marine biota (Islam et al., 2017). Processes involving physical, chemical, and biological elements regulate the distribution of elemental concentrations in sediments (Ramanathan et al., 1999; Selvam et al., 2012). Even at very low concentrations, hazardous substances can be very detrimental to the biological cycle. Understanding the behaviour of the distribution of trace elements is crucial for addressing issues caused by pollution in organisms (Negri and Heyward, 2001). It was shown that the main pathway for contaminants into the open sea is through estuarine sediments. Estuaries filter riverine metals produced by geogenic and artificial sources" (Larrose et al., 2010). Trace element poisoning in estuaries attracts interest from all over the world because of its prevalence, persistence, and environmental toxicity (Ali et al., 2016).

Thorough investigations have been conducted to address the impacts of metal contamination on biota and sediment profiles in coastal and estuarine environments (Liu et al., 2016; Baran et al., 2019). Numerous studies on trace elements, particularly their behaviour in the natural environment, have been done by various authors (Babich, 1978; Bain, 1976). The earth's surface has been changing for a very long time. But because of human activity, changes happen quickly and accumulate. Various chemicals were being used in agriculture and many different sectors. These substances build up on the earth's surface and pollute the environment. The significance of trace elements among all chemical constituents is significant (Kabata-Pendias, 2001). Numerous studies show those metals' geochemical cycles are quickly altering, which causes massive environmental damage (Nrigau and Pacym, 1998).

The beginning of the enrichment of trace metals in sediment characteristics on the Indian subcontinent coincides with the end of the nineteenth-century industrial revolution. Trace metals in aquatic ecosystems eventually settle in the sediments (Caccia et al., 2003). Therefore, the solid phase distribution in the sediments revealed information on the origin of the weathering mechanism and metal accumulation in the sediments from neighbouring places (Forstner and Salomons 1980). The trace elements that received the most attention throughout the past ten years were Cu, Pb, Zn, Ni, Co, Cr, Cd, As, Fe, Mn, Se, and B (He et al., 2005). Some of these elements, like Cd and Pb, were dangerous to the environment because they contaminated the water, soil, and food chains. "While elements such as Cd, Pb, and As can be mutagenic, carcinogenic, or teratogenic, geogenic elements such as Fe, Zn, and Cu become poisonous in higher concentrations" (Yoshida et al., 2006).

The evaluation of trace element-based ecological risk and environmental problems in the estuaries used a wide range of pollution indices. For evaluating, analysing, and disseminating environmental data to the general public, experts, and legislators, polluted indices are a crucial tool (Caeiro et al., 2005). Some of the pollution indices that are frequently used in addressing environmental issues are the enrichment factor (EF), contamination factor (CF), geo-accumulation index (I_{geo}), and potential ecological risk index (PERI).

Investigated Extent/Study area

Dakshina Kannada is a maritime district located in the south-western part of Karnataka state adjoining the Arabian Sea. The geographical area is 4770 sq. km the study area lies in between 12° 56′ 12′′& 12° 57′ 59′′ North latitude and 74° 47′ 57′′& 74°, 48′, 09′′ East longitude. Mangalore town is the district headquarters. Administratively, the district is divided into five taluks viz. Bantwal, Belthangady, Mangalore, Puttur, and Sulya

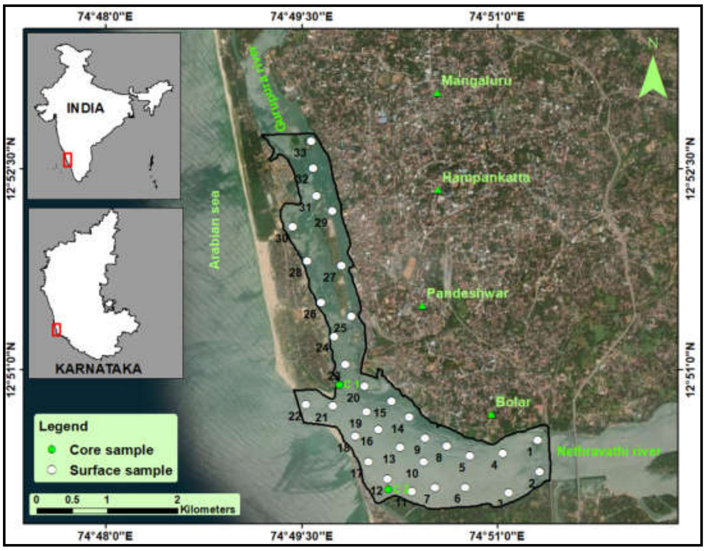


Figure 1: Map showing sample locations in the Netharavathi and Gurupura river estuary

MATERIALS AND METHODS

In total, 33 bottom sediments, for two seasons and surface water were collected from the Nethravathi-Gurupura estuary of Karnataka coast using grid sampling technique and Van Veen grab sampler along with two sedimentary cores, during May and December 2021. The bottom samples were collected with the help of stainless-steel scoops to avoid contamination. The collected samples were kept in properly labelled glass bottles to reduce the sample loss and leakage of samples. The samples were sun-dried (~ 30˚C) and proceeded for further studies.

Trace Element Geochemistry

To determine the trace element content, the bulk sediment was combined and then homogenised using the cone and quartering method. After being mashed with an agate mortar, the homogenised mixture was passed through the 230 ASTM mesh to get the sediment fractions. After that, the ground sediments were placed in airtight containers for additional geochemical analysis. The silt was broken down using a Teflon bomb assembly. The complete digesting strategy is explained in full in the section below. 0.5 g of crushed, fine-grained particles (63 µm) were added to the Teflon beaker along with the acid mixture (HNO3: HClO4: HF - 4:3:2), after which the digesting assembly was properly secured and heated for two hours. The temperature of the hot plate was sustained at 120°C (Hussain *et al.*, 2020). After the digestion process, the digestion assembly was allowed to cool. The final solution was then filtered and made up with 50 mL of deionized double distilled water. For elemental analysis, the prepared solution was maintained in customary plastic jars. At the Department of Geology, University of Madras, Chennai, the elemental analysis was carried out using a Graphite Furnace Atomic Absorption Spectrophotometer (Model No. Perkin Elmer-PinAAcle 900AA). Double replication was maintained in the instrument arrangement, and the mean value was used as the final output for additional analysis.

RESULT AND DISCUSSION

Iron, Manganese, and Trace Elements Distribution In The Surface Sediment

Iron (Fe): The Nethravathi-Gurupur estuary's iron (Fe) content for surface samples of **Pre monsoon** ranges from 5810.31 to 56680.02 ppm, with an average of 18408.109 ppm **(Table.1).** Samples no 20 and 19 had the highest and lowest concentrations of Fe, which are depicted on the map **(Figure. 2).** Iron (Fe) content for surface samples of Post monsoon ranges from 8720.94 to 87962.19 ppm, with an average of 24710.74 ppm **(Table 2).** Sample no 5 and 3 had the highest and lowest concentrations of Fe, which are depicted on the map **(Figure.2).** The concentration of iron observed in the study area was lower than the upper continental crust (UCC) value. The spatial pattern of iron confirms the notion that the inflow of riverine sediments enriches the iron concentration in these estuaries. The iron concentrations in the estuary sediments are a result of the weathering and deposition of the surface sediments during monsoonal downpours along the estuarine banks.

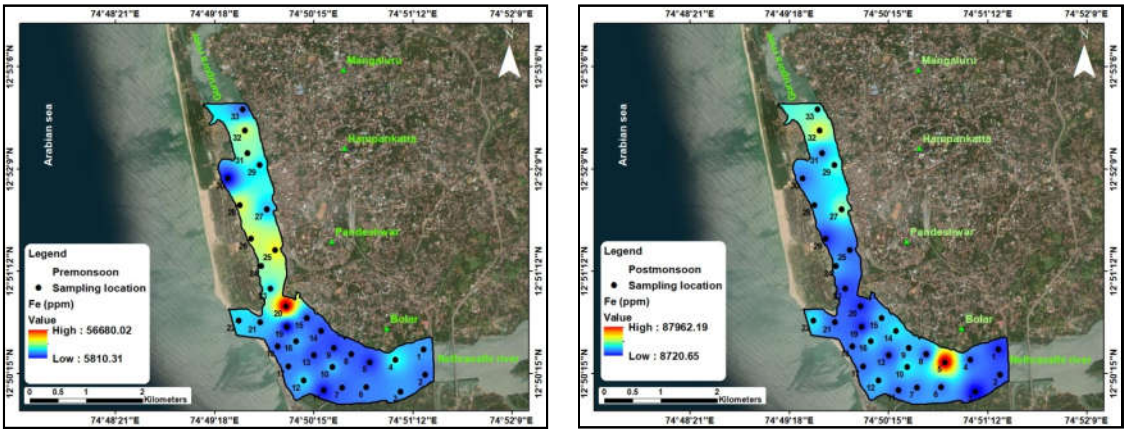


Figure 2: Spatial Distribution map of the element Fe (in µg/g) in the surface sediments selected estuaries in the Nethravathi-Gurupur, India

Manganese (Mn)

The Nethravathi-Gurupur estuary's manganese (Mn) content for surface samples of Pre-monsoon ranges from 252.54 to 1729.40 ppm, with an average of 661.44 ppm (Table 1). Sample no 32 and 30 had the highest and lowest concentrations of Mn, which are depicted on the map (Fig. 3.). Manganese (Mn) content for surface samples of Post monsoon ranges from 248.97 to 2175.86 ppm, with an average of 895.35 ppm (Table 2). Sample no 5 and 1 had the highest and lowest concentrations of Mn, which are depicted on the map (Fig. 3).

Lower Mn concentrations in the surface sediments indicate that processes such as advection and diffusion easily remove dissolved Mn ions with higher mobility from the pore water of the sediments and transport them to the water column (Janaki-Raman et al., 2007). The hydrodynamics, which are commonly brought on by interactions with salinity, pH, temperature, and redox effects, helped the trace elements deposit in the estuary sediments (Jayaprakash et al., 2014). Mn concentrations in the studied area were lower than those in the upper continental crust (UCC).

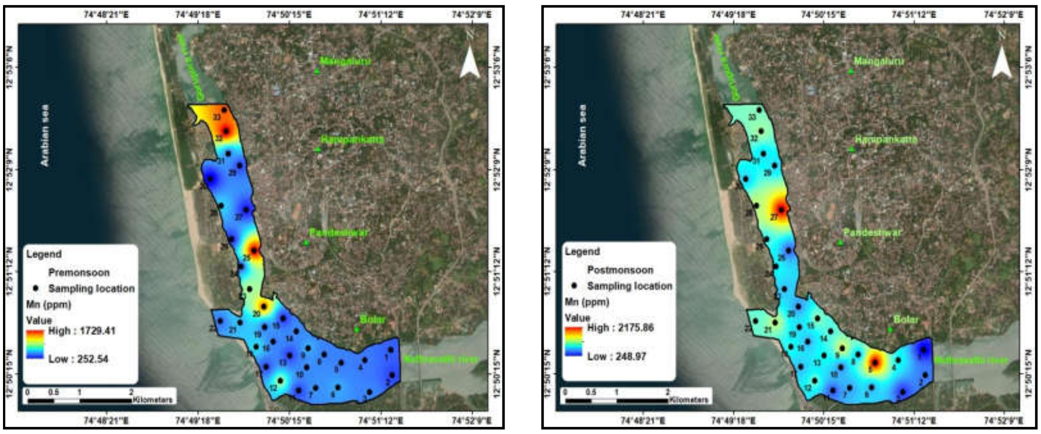


Figure 3: Spatial Distribution map of the element Mn (in µg/g) in the surface sediments selected estuaries in the Nethravathi-Gurupur, India

Lead (Pb)

Similar to mercury, copper, zinc, and cadmium, inorganic lead is harmful to aquatic plants and invertebrates. Alkyl-lead is a poisonous chemical molecule that is frequently employed as an antiknock agent in petroleum products (Denton et al., 1997).

The Nethravathi-Gurupur estuary's lead (Pb) content for surface samples from Pre monsoon ranges from 17.24 to 35.67 ppm, with an average of 28.43 ppm **(Table 1)**. Sample no 11 and 28 had the highest and lowest concentrations of Pb, which are depicted on the map **(Fig. 4).** Lead (Pb) content for surface samples of Post monsoon ranges from 1.77 to 224.29 ppm, with an average of 19.49 ppm **(Table 2).** Sample no 33 and 2 had the highest and lowest concentrations of Pb, which are depicted on the map (Fig.4).

Therefore, the majority of Pb sources may originate from fuel leaks into the water, which then sink into the sediment. In addition to that, the lead also originated from neighbouring residential areas through the deposition of lead-containing materials from nearby companies, including storage batteries, circuit boards from computers and other electronic equipment, pesticides, glass, and paints (Rahman et al. 2015). Pb is most likely to be found in industrial and domestic sewage effluents, as well as boat engine fuel spills (El Sayed and Basaham, 2004; Abu-Zied et al., 2013).

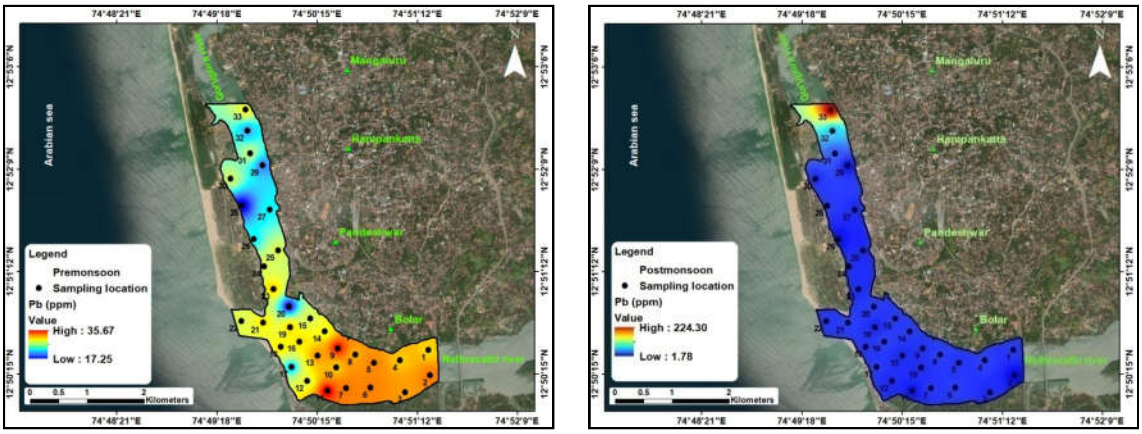


Figure 4: Spatial Distribution map of the element Pb (in µg/g) in the Surface sediments selected estuaries in the Nethravathi-Gurupur, India

Zinc (Zn)

The Nethravathi-Gurupur estuary's zinc (Zn) content for surface samples of Pre monsoon ranges from 7.38 to 129.35 ppm, with an average of 50.10 ppm (Table 1). Sample no 20 and 11 had the highest and lowest concentrations of Zn, which are depicted on the map (Fig. 5.). Zinc (Zn) content for surface samples of Post monsoon ranges from 26.38 to 141.59 ppm, with an average of 61.61 ppm (Table 2.). Sample no 33 and 2 had the highest and lowest concentrations of Zn, which are depicted on the map (Fig. 5).

The concentration of Zn observed in the study area was higher than the upper continental crust (UCC) value. The primary source of zinc from industrial sources, including sewage from households and industries, fishing, foundries, etc., is river runoff.

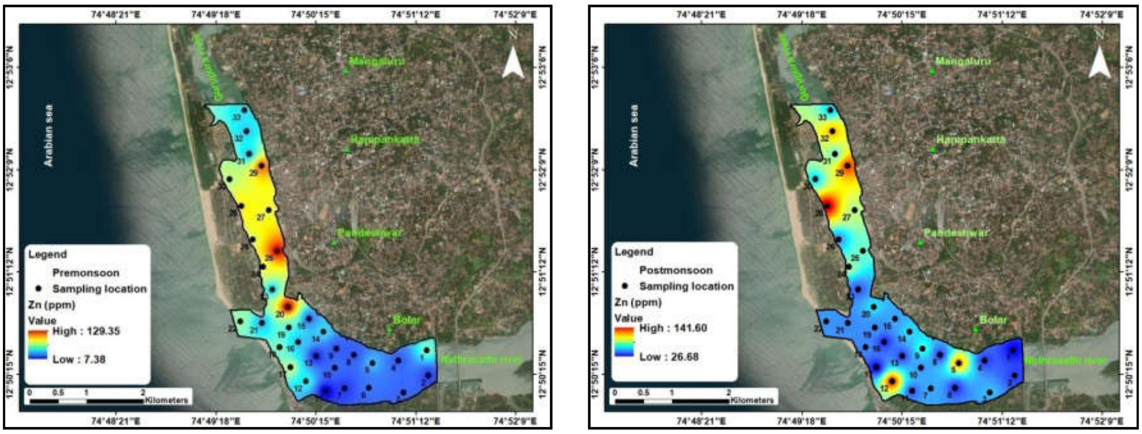


Figure 5: Spatial Distribution map of the element Zn (in µg/g) in the surface sediments selected estuaries in the Nethravathi-Gurupur, India

Copper (Cu)

The Nethravathi-Gurupur estuary's copper (Cu) content for surface samples of Pre monsoon ranges from 15.32 to 164.27 ppm, with an average of 48.26 ppm (Table 1). Samples no 20 and 11 had the highest and lowest concentrations of Cu, which are depicted on the map (Fig. 6.). The copper (Cu) content for surface samples of Post monsoon ranges from 0.66 to 236.64 ppm, with an average of 82.38 ppm (Table 2). Sample no 6 and 1 had the highest and lowest concentrations of Cu, which are depicted on the map (Fig. 6.).

As a result of both geogenic and non-geogenic, or anthropogenic, actions, Cu in sediments is considered to have emerged. Decomposed leaves and antifoulants used in boats both contribute to the higher amount of copper that accumulates in the sediment substrate. Additionally, there are numerous agricultural operations near this station that use various kinds of chemical fertilizers and pesticides, which may possibly be to blame for this silt buildup (Sow, Ismail, and Zulkifli 2012).

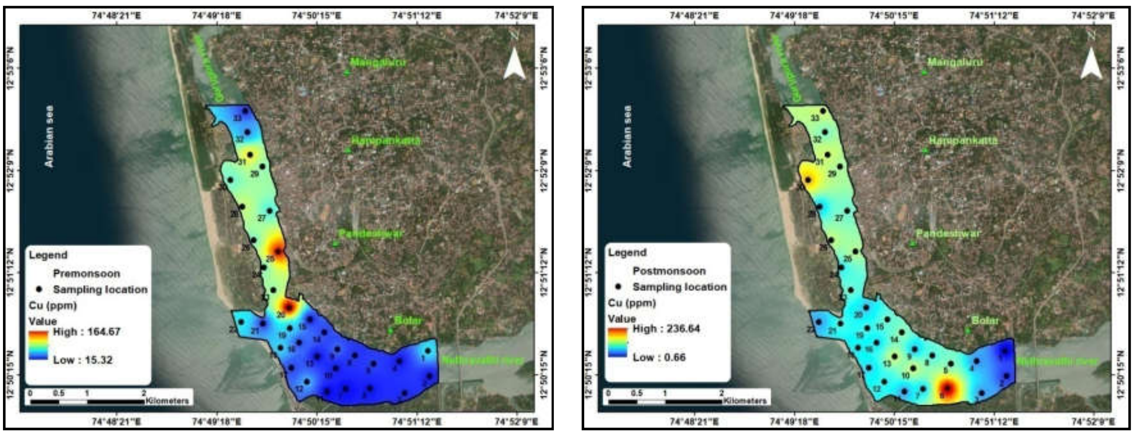


Figure 6: Spatial Distribution map of the element Cu (in µg/g) in the surface sediments selected estuaries in the Nethravathi-Gurupur, India

ENVIRONMENTAL POLLUTION INDICES

Numerous mathematical techniques are used in the assessment of lagoonal and coastal habitats based on trace elements (Muller, 1969; Hakanson, 1980). In this work, numerous pollution indices are systematized to compare the trace metal enrichment in the surface sediments of the chosen estuaries in Mangalore. Several estimation techniques for the impact of pollution have been presented to estimate the degree of metal enrichment in sediments (Ridgway and Schimmield, 2012). The estimated data were transformed into illustrative pollutant intensity bands and ranges (Muller, 1969; Hakanson, 1980; Salomons and Forstner, 1984). According to (Langston et al. 2010), organisms' tolerance levels and resistance mechanisms can be used to determine the negative impacts of sediment pollution. The potential of sediment is often impacted by the standards for sediment quality, depending on pollutants and their amount of accumulation. Therefore, reference data and sediment quality standards were compared with the calculated contamination levels (Hussain et al., 2020)

Enrichment Factor (EF)

The purpose of EF was to ascertain whether human activity (such as contamination) was the cause of the metal concentrations in certain estuary sediments and their surrounding marine environment. AI was utilized as a normalized metal to evaluate metal enrichment and heavy metal contamination (Selvaraj et al., 2004).

The classification of enrichment classes was classified as (Acevedo-Figueroa et al., 2006):

If, EF < 1 indicates no enrichment (natural enrichment),
If, EF 1-3 for minor enrichment,
If, EF 3-5 for moderate enrichment;
If, EF 5-10 for moderately severe enrichment,
If, EF 10-25 for severe enrichment,
If, EF 25-50 for very severe enrichment,
If, EF >50 for extremely severe enrichment

According to the study's findings, the estuary's EF values for the **Pre-monsoon surface** and **Post-monsoon surface** samples ranged from no enrichment to the range of extremely severe sediments, and they also fluctuated from location to location and from metal to metal. Cd shows pollution up to the category of "extremely severe enrichment." All the other elements fall under the category of no enrichment to severe enrichment. In the Estuary, the mean of the EF values of the sediments was moderate to extremely severe enrichment by Cd and Pb. The sediments throughout the entire estuary, however, were no enrichment to moderately severe by other metals such as Fe, Co, Ni, Mn, Cu, Cr and Zn (Table 3 and 4). (Figure. 7& 8)

$$EF = \frac{(M/Al)_{Sample}}{(M/Al)_{Background}}$$

M – Metal concentration of the sediment

Contamination Factor (CF)

The assessment of contaminants in sediments that are easily receptive to aquatic organisms and the physicochemical changes brought on by the release of metals into the aqueous medium depend heavily on trace elements (Jayaprakash et al., 2008). The classification of contamination factor classes is classified as (Tomlinson et al., 1980):

- ➢ From 1 ≤ CF low contamination factor
- ➢ If 1 ≤ CF < 3 moderate contamination factor
- ➢ If 3 ≤ CF < 6 considerable contamination factor
- ➢ If ≥ 6 very high contamination factor.

According to the study's findings, the estuary's CF values for the Pre-monsoon and post-monsoon surface samples ranged from **low to very high contamination**, Cd shows pollution up to the category of very high contamination. All the other elements fall under the category of low to moderate contamination. The mean of the CF values of the sediments was considerable to very high by Cd and Pb. The sediments throughout the entire estuary, however, were low to moderate contamination by other metals such as Fe, Co, Ni, Mn, Cu, Cr and Zn (Table.5 and 6). Figure (7 & 8)

$C^i_f = C^i_{0-1} / C^i_n$

$C_d = \sum^{7}_{i=1} C^i_f$

Where,
C^i_{0-1} - mean content of the substance
C^i_n - reference value for the substance

Geo-accumulation Index (I_{geo})
In this study, the I_{geo} level was counted in the surface sediments of Nethravathi and Gurupura estuary southwest coast utilizing local background data as a normalizing data (Hussain et al., 2020). Muller defined the following ranges to assess sediment quality.

The following I_{geo} value and Sediment Quality ranges were observed:

- ➢ If, $I_{geo} < 0$, Unpolluted;
- ➢ If, I_{geo} 0-1, from unpolluted to moderately polluted;
- ➢ If, I_{geo} 1-2, moderately polluted;
- ➢ If, I_{geo} 2-3, from moderately polluted to strongly polluted;
- ➢ If, I_{geo} 3-4, strongly polluted;
- ➢ If, I_{geo} 4-5, from strongly to extremely polluted;
- ➢ If, $I_{geo} > 5$, extremely polluted.

According to the study's findings, the estuary's I_{geo} values in the Pre-monsoon and Post-monsoon surface samples ranged from **unpolluted sediments to the range of strongly to extremely polluted sediments,** and they also fluctuated from location to location and from metal to metal. Cd and Pb show pollution up to the category strongly to extremely polluted. All the other elements fall under the category of unpolluted to moderately polluted. In the Estuary, the mean of the I_{geo} values of the sediments was moderately to extremely polluted by Cd and Pb. The sediments throughout the entire estuary, however, were unpolluted to moderately polluted by other metals such as Fe, Co, Ni, Mn, Cu, Cr and Zn (Table 7 and 8) (Figure 7 & 8)

$I_{geo} = \log_2 (C_n / 1.5 * B_n)$

Where,
C_n - measured concentration of heavy metal in the sediment
B_n - geochemical background value in average shale (Turekian and Wedepohl 1961) of element ,1.5 - Background matrix correction in factor due to litho-genic effects.

Pollution Load Index (PLI)

The PLI of the Pre-monsoon surface sample indicated sample no 19 with no pollution and samples no 14 was polluted by the metal concentration (Table 9), PLI in Post-monsoon surface sample indicated sample no 12 with no pollution and sample no 21 was polluted by the metal concentration, Anthropogenic influences majorly control the levels of PLI in the sediments. The investigation shows pollution in more than half of the samples with that we conclude the present environment is considered to be moderately polluted based on the PLI study. (Figure. 7& 8)

$CF = C_{metal} / C_{background}$

PLI = n ($CF_1 \times CF_2 \times CF_3 \times$ .... CF_n)
Where,

CF	-	contamination factor
C_{metal}	-	concentration of pollutants in sediment
$C_{background}$	-	background value for the metal
n	-	number of metals

Status: PLI > 1 polluted; < 1 no pollution
Sediment Pollution Index (SPI)
Singh et al. (2002) suggested the sediment pollution index SPI as a way to assess sediment quality in terms of trace metal concentration and metal toxicity.
Based on this pollution classification, the SPI was classified as follows:

- ➢ From 0 to 2 = natural sediment
- ➢ From 2 to 5 = low polluted sediment
- ➢ From 5 to 10 = moderately polluted sediment
- ➢ From 10 to 20 = highly polluted sediment
- ➢ Greater than 20 = dangerous sediment

The SPI of the pre-monsoon surface samples ranging from natural sediments (sample no 31) to low polluted sediment (sample no 1) (Table 9), SPI in post-monsoon surface samples ranging from natural sediments (31 samples) to moderately polluted sediment (sample no 1) (Table 9) (Figure 7 & 8).

Sediment pollution index SPI, ratio was proposed by Singh et al., (2002) to assess the sediment quality concerning trace metal concentration along with metal toxicity. The SPI can be expressed as:

$$SPI = \sum \frac{EFm \times Wm}{\sum Wm}$$

$$EF_m = \frac{Cn}{CR}$$

Here EF_m is the ratio between the measured metal concentration (C_n) and the background metal concentration (C_R), and W_m is the toxicity weight. According to Hakanson (1980), toxicity weight 1 was assigned for Cr and Zn, 2 for Cu and Ni, 5 for Pb and 30 for Cd.

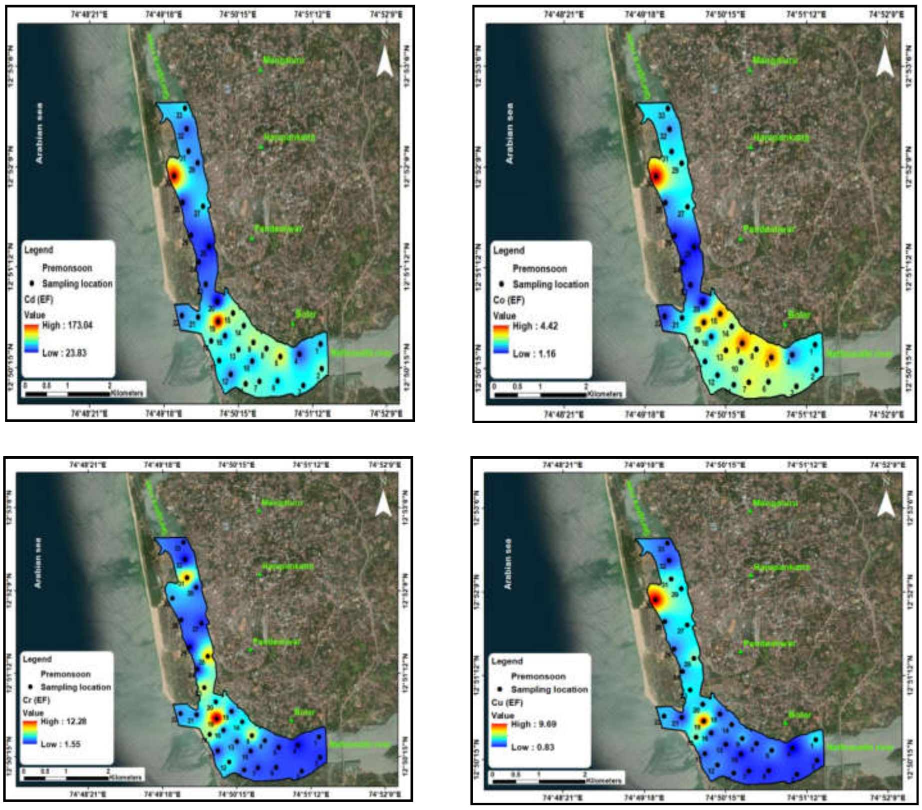
Potential Ecological Risk Index (PERI)

The most frequent environmental contaminants are toxic metals produced by human activities. These trace metals, which are often dangerous to living things as compounds, when consumed exacerbate the negative effects on health that result from their presence in the environment (Rahman et al., 2014). A potential ecological risk index was put up by (Hakanson in 1980). PERI evaluates the effect of heavy metals on the ecosystem using ecological analysis (Guo et al., 2010; Saeedi et al., 2012). Hakonson (1980) classified five groups of ecological risk (Ei) grades and four groups of potential ecological risk index (RI) grades. The risk index (RI) can be calculated using the following formulas. (Table 9) (Figure 7 & 8).

$$C_f^i = C_D^i / C_B^i$$

$$E_r^i = T_r^i \times C_f^i$$

$$RI = \sum_{i=1}^{m} E_r^i$$



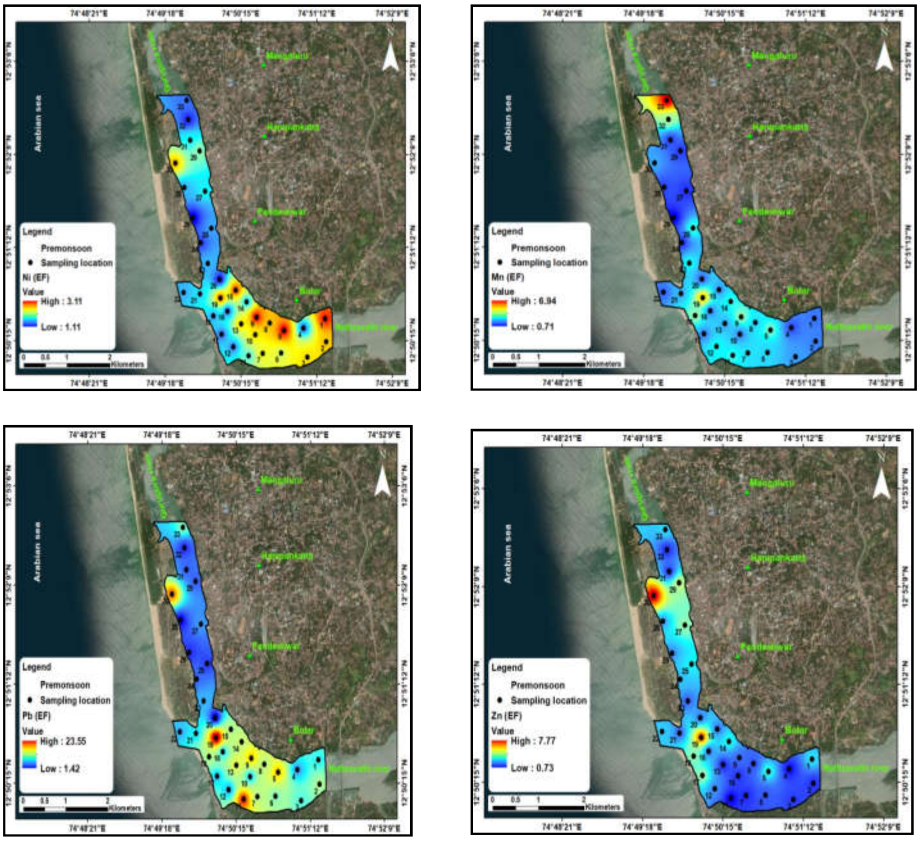
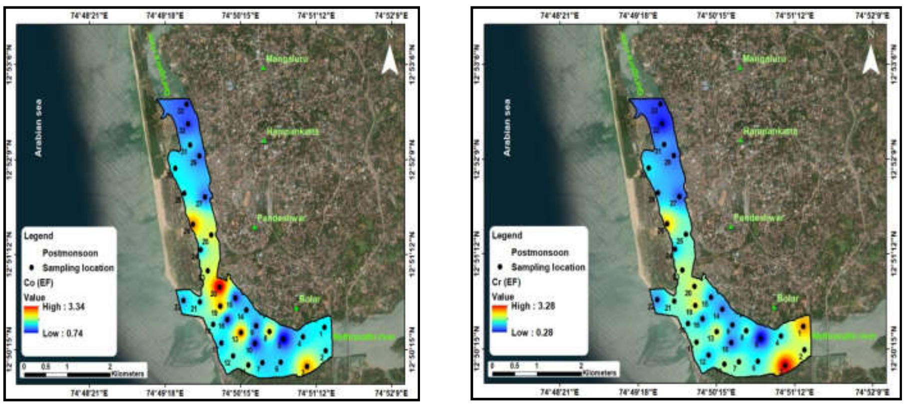


Figure 7: Spatial distribution map of Enrichment Factor (EF), Sediment of Nethravathi-Gupura, estuary (Pre- estuary monsoon)



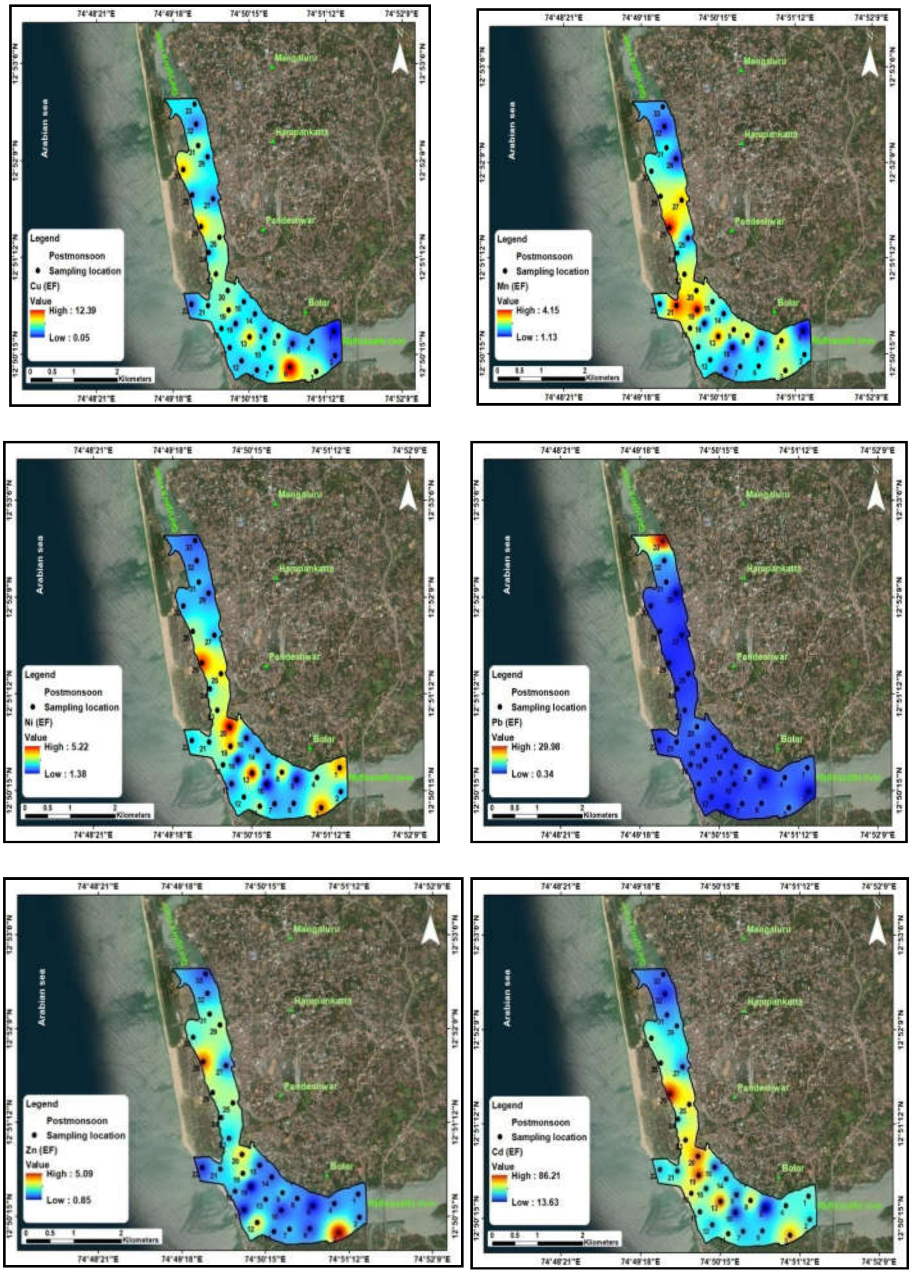


Figure8: Spatial distribution map of Enrichment Factor (EF), Sediment of Nethravathi-Gurupura, estuary (Post-monsoon)

Table 1: Fe, Mn and trace element concentration in the surface sediments Pre-monsoon (all values in ppm)

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Zn	Pb
Avg	3.97	17.42	114.46	48.27	18408.10	661.45	43.96	50.11	28.43
Min	2.54	8.93	36.77	15.32	5810.31	252.54	20.22	7.38	17.25
Max	5.31	29.31	461.11	164.27	56680.02	1729.41	86.57	129.35	35.67

Table 2: Fe, Mn and trace element concentration in the surface sediments Post-monsoon (all values in ppm)

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Zn	Pb
Avg	3.97	17.42	114.46	48.27	18408.10	661.45	43.96	50.11	28.43
Min	2.54	8.93	36.77	15.32	5810.31	252.54	20.22	7.38	17.25
Max	5.31	29.31	461.11	164.27	56680.02	1729.41	86.57	129.35	35.67

Table 3: Enrichment Factor (EF) in the Pre-monsoon surface sediments

	EF Mn	EF Cu	EF Cr	EF Ni	EF Pb	EF Zn	EF Cd	EF Co
Avg	2.365	2.830	3.561	1.990	9.039	2.415	73.044	2.448
Min	0.709	0.830	1.550	1.105	1.419	0.727	23.828	1.165
Max	6.941	9.694	12.282	3.107	23.552	7.773	173.038	4.424

Table 4: Enrichment Factor (EF) in the Post-monsoon surface sediments

	EF Mn	EF Cu	EF Cr	EF Ni	EF Pb	EF Zn	EF Cd	EF Co
Avg	2.358	4.019	1.435	2.946	3.585	2.219	45.699	1.681
Min	1.129	0.053	0.279	1.385	0.339	0.849	13.627	0.745
Max	4.151	12.388	3.285	5.217	29.981	5.094	86.209	3.344

Table 5: Contamination Factor (CF) in the Pre-monsoon surface sediments

	CF Fe	CF Mn	CF Cu	CF Cr	CF Ni	CF Pb	CF Zn	CF Cd	CF Co
Avg	0.327	0.696	0.878	1.145	0.586	2.275	0.716	19.835	0.697
Min	0.103	0.266	0.279	0.368	0.270	1.380	0.105	12.723	0.357
Max	1.007	1.820	2.987	4.611	1.154	2.854	1.848	26.526	1.172

Table 6: Contamination Factor (CF) in the Post-monsoon surface sediments

	CF Fe	CF Mn	CF Cu	CF Cr	CF Ni	CF Pb	CF Zn	CF Cd	CF Co
Avg	0.439	0.942	1.498	0.508	1.137	1.559	0.880	16.813	0.639
Min	0.155	0.262	0.012	0.385	0.698	0.142	0.381	9.976	0.368
Max	1.562	2.290	4.303	0.610	2.582	17.944	2.023	23.035	1.163

Table 7: Geo-accumulation index (Igeo) in the Pre-monsoon surface sediments

	I_{geo} Fe	I_{geo} Mn	I_{geo} Cu	I_{geo} Cr	I_{geo} Ni	I_{geo} Pb	I_{geo} Zn	I_{geo} Cd	I_{geo} Co
Avg	-2.364	-1.285	-1.114	-0.747	-1.438	0.581	-1.337	3.712	-1.153
Min	-3.861	-2.496	-2.429	-2.028	-2.476	-0.120	-3.830	3.084	-2.070
Max	-0.575	0.279	0.994	1.620	-0.378	0.928	0.301	4.144	-0.356

Table 8: Geo-accumulation index (I_{geo}) in the Post-monsoon surface sediments

	I_{geo} Fe	I_{geo} Mn	I_{geo} Cu	I_{geo} Cr	I_{geo} Ni	I_{geo} Pb	I_{geo} Zn	I_{geo} Cd	I_{geo} Co
Avg	-1.938	-0.791	-0.304	-1.572	-0.464	-0.634	-0.919	3.444	-1.275
Min	-3.276	-2.517	-6.961	-1.962	-1.103	-3.398	-1.976	2.733	-2.026
Max	0.059	0.611	1.520	-1.299	0.784	3.580	0.431	3.941	-0.367

Table 9: Pollution indices in the surface sediments

	Pre-monsoon			Post-monsoon		
	PLI	SPI	PERI	PLI	SPI	PERI
Avg	1.058	1.469	22.393	1.104	1.314	23.810
Min	0.510	1.112	15.793	0.445	0.343	7.923
Max	2.273	2.259	42.152	1.849	8.871	109.005

CONCLUSION

The trace element analysis results of the investigated estuarine sediments show the following decreasing order of distribution: Pre-monsoon includes Fe>Mn>, Cr>, Zn>, Cu>, Ni>, Pb>, Co>, and Post-monsoon includes Fe>Mn>, Ni>, Pb>Co>Cd. Fe and Mn were the predominant components found in the chosen estuary sediments, indicating they were sourced from and controlled by the convergence of the terrigenous rocks closer to the estuary's sources.

The values of EF in the selected estuaries show the following results: The trend in metal enrichment mentioned above indicates natural to extremely severe enrichment in the estuarine sediments, whereas Pb and Cd exhibit moderately severe to extremely severe enrichment as the result of both geogenic processes and significant anthropogenic impacts. These two metals suggest that human activity, such as fishing, atmospheric deposition, and coatings used on boats to prevent foiling, is where they came from. It is obvious that Pb controls have been significantly enriched over several trace elements. According to the Pb data, there has been a significant enrichment that may have been influenced by anthropogenic factors such as fisheries, shipping activities that heavily rely on antifouling and anticorrosive paints, ship garbage, and air deposits.

The contamination factor of the selected estuarine surface sediments investigated yields the following results: For Pre-monsoon, surface samples ranged from low to very high contamination, and Cd shows no pollution up to the category of very high contamination. All the other elements fall under the category of low to moderate contamination. The Post-monsoon surface samples showed similar results as the Pre-monsoon samples. In the estuary, the mean of the CF values of the sediments was considerable to very high for Cd and Pb. The sediments throughout the entire estuary, however, were low to moderately contaminated by other metals such as Fe, Co, Ni, Mn, Cu, Cr, and Zn. These elements are most likely the result of several activities, including thermal power plant operations, fisheries, and atmospheric deposition along the coast and in estuaries. Lead and cadmium were found to have very high contamination levels in the selected estuaries, whereas the remaining elements have moderate to significant contamination levels.

I_{geo} values the Pre-monsoon and Post-monsoon surface samples ranged from unpolluted sediments to the range of strongly to extremely polluted sediments, and they also fluctuated from location to location and from metal to metal. Cd and Pb show pollution up to the category of "strongly" to "extremely" polluted. All the other elements fall under the category "unpolluted to moderately polluted." In the estuary, the mean of the Igeo values of the sediments was moderately to extremely polluted by Cd and Pb.

Anthropogenic influences majorly control the levels of PLI in the sediments. The investigation revealed pollution in more than half of the samples, and we conclude that the current environment is moderately polluted based on the PLI study. The SPI values of Pre-monsoon surface samples ranged from natural sediments to low-polluted sediment, the SPI values of Post-monsoon surface samples ranged from natural sediments to moderately polluted sediment .According to SPI observations, the samples ranged from natural sediment to moderately polluted sediment. The PERI of the Pre-monsoon surface samples, the Post-monsoon surface samples fall into the category of low ecological risk category.

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