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GEOCHEMICAL STUDIES OF SEDIMENTS IN THE DOWNSTREAM OF KATHAJODI RIVER

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ABSTRACT

The present study was carried out on the geochemical properties of sediments of Kathajodi river in Odisha, India, which carries natural and anthropogenic pollutants, mainly heavy metal contents which are released from industrial effluents, agricultural runoff and domestic sewage. Kathajodi, which is a distributary of the Mahanadi drains through the Cuttack city, Odisha, India. During the study, the highest mean content of Fe (39.0 g kg^{-1}), Ni (124.0 mg kg^{-1}), Pb (53.9 mg kg^{-1}) and Cd (15.6 mg kg^{-1}) were observed at Khannagar, while lowest Fe (31.0 g kg^{-1}) was recorded at Mirjeipur, Ni (106.6 mg kg^{-1}), Pb (41.1 mg kg^{-1}) at Naraj and Cd (10.2 mg kg^{-1}) at Arilo. The dominance of heavy metals were in the decreasing order of Fe>Mn>Zn>Ni>Cu>Pb>Cd. The enrichment factor of Cd (0.913 to 1.267), Ni (0.895 to 1.082), Cu (0.932 to 1.098), Pb (1.166 to 1.382) and Mn (0.845 to 1.006) were found almost similar but the values for Zn (0.754 - 0.861) found less than one in all the stations studied. The geoaccumulation index (Igeo) of heavy metals revealed that most of the elements belonged to Igeo classes 1 thus their extent are found little higher than their respective maximum background values.

KEY WORDS
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INTRODUCTION

Weathering and mineralisation of rocks and minerals loads a lot of sediments in to the river system. Dumping of industrial, domestic and municipal waste water and agricultural runoff adds additional inputs into the river systems. These geogenic and anthropogenic activities has a lot of bearing on the equilibrium of its ecosystem. Urban discharges, combustion of fossil fuels and waste disposal of mining and smelting operations, processing and manufacturing industries etc, are the primary anthropogenic sources of metal pollution (Klavins, *et al.,* 2000; Yu, *et al.,* 2001; Upadhayay, *et al.,* 2006). Sediments are mixture of several components of mineral species as well as organic debris which represent as an ultimate sink for heavy metals discharged into environment (Bettinetti, *et al.*, 2003; Abbas, *et al.,* 2009) also plays a major role in identifying the pollution load of the river systems by heavy metals (Lietz and Galling, 1989; Huang, *et al.,* 1994; Lapaquellerie, *et al.,* 1995). Sediments conserve important environmental information (Gutierrez, *et al.,* 2004) and increasingly are recognized as both carriers and possible sources of contaminants in aquatic systems (Tessier, *et al.*, 1979). Depending upon the limnological conditions, the sediment can act both source as well as sink for the nutrients and other elements (Thornton *et al.,* 1975) and important sinks for various pollutants like heavy metals. It also plays a significant role in the remobilization of contaminants in aquatic systems under favourable conditions. The release of heavy metals from sediments into the water body depends on the speciation (*i.e.* metals may be precipitated, complexed, adsorbed, or solubilized) of metals and other factors such as sediment pH, physical and chemical characteristics of the aquatic system (Morgan and Stumm, 1991). Usually, concentrations of heavy metals in aquatic ecosystem are determined by measuring its concentration in water and sediments (Camusso, *et al.,* 1995) that generally exist at low levels in water and attain considerable concentration in sediments (Namminga and Wilhm, 1976). The heavy metal pollutants accumulated in the sediment and in the process find its way to food chain through the crop and vegetations. Majority of cities in India are located on the river banks and the untreated sewage of these cities is the main cause of pollution of rivers and lakes (Kamoyatra and Bharadwaj, 2011). Studies on the role of sediments in a natural water body in element cycles, transportation of nutrients and contaminants and preservation of the water quality are important for the understanding of an aquatic ecosystem (Santhosh *et al.,* 2008). Therefore, this study was conducted to assess the impact of sewage discharge of Cuttack city in sediments of river Kathajodi through analysis of heavy metal to determine the distribution and content of Cd, Cu, Fe, Mn, Ni, Pb and Zn in the river sediment. Sewage samples from three discharge points, surface sediment samples from river bed and soil samples from river bank were collected during post monsoon period in the month of December, 2011 and laboratory analysis followed during January and February, 2012. River Kathajodi in the Cuttack urban area is significant distributaries of river Mahanadi. The exponential growth of Cuttack on the left side of Kathajodi river has led to severe water pollution in Kathojodi river. Water coming from upper stream of river Mahanadi also carries sediments containing heavy metals due to its geogenic as well as anthropogenic origin.

Thus the heavy metal pollutants accumulated on the soils of river bank in the process find its way to food chain through the crop and vegetations. Keeping in view the above facts, an attempt has been made for the, geochemical studies of sediments in the downstream of Kathajodi River and investigates the present status of heavy metal.

MATERIALS AND METHODS

Study area

The Cuttack city lies on the east coast of India in the state of Odisha between Latitude: 20º30' Na nd Longitude: 85º49' 60'' E. The river Mahanadi and its distributary Kathajodi surrounded the city forming a delta on which the city Cuttack is situated (Fig.1). The basin displays dendritic to sub dendritic and rarely rectangular and trellises drainage patterns. At the downstream of Khannagar near Urali village, the river Kathajodi bifurcated and after few kilometers again joined creating an island namely Bayalishmauja. The right side flow of river Kathajodi is called as Serua river in some area and after the joining of two flows the river is again named as river Devi. The width of river Kathajodi varies from a few hundred meters to two kilometers and is elongated in west to east direction. The land surface slopes to the centro-axial zone both from the south and north and also has a low regional gradient to the east. As the city is deltaic and being situated between the two rivers, low-lying areas are abundant and these areas are frequently flooded by rain and flood water. The surface elevation of the study area varies from 19 to 20m above mean sea level at the centre and from 24m on the south to 26m on the north. The soil beneath the city is composed of unconsolidated alluvium up to depth of 120m in alternating sequences of sand, silt and clay. These materials reside above Gondwana sedimentary rocks of Archean crystallines (Mahalik, 1992). The depth of the water table changes with the season and during pre-monsoon it is 4 to 6m below ground level and 0 to 2m during post- monsoon (CGWB-1995). The Cuttack city is situated on the N-E side of this river Kathajodi, which receives the sewage of the city whereas plantation and agricultural activities are intense on the other side of the river.

Climate

The city of Cuttack enjoys a subtropical, monsoon climate with three distinct seasons, i.e. summer, rainy and winter. The summer extends from March to June, the rainy season from June to October and the winter season continues from November to February. The average annual rainfall is 154 cm with 74 rainy days and about 85% of the annual rainfall is received from south-west monsoons in rainy season and the maximum precipitation occurs in July and August. Cyclonic weather has been a common phenomenon in the study area as it is situated on the east coast of India. The summer is hot and day time temperature reaches 45ºC with a monthly mean of 39.2ºC. Winter nights reach 8ºC with a monthly mean temperature of 22ºC. The estimated monthly mean combine evaporation and evapotranspiration of the study area is 17.7cm (Das *et al.,* 2002).

Sampling

Ten different sampling stations were selected between Naraj barrage to Koma Shasana village of Jagatsinghpur district namely Naraj, Arilo, CDA, Bidyadharpur, Brahmanigaon, Khannagar, Urali, Mirjeipur, Mattagajapur and Komashasan and were localized exactly by GPS locator (Figure 1. and table 1) and the sampling location of river bed were designated as R1, R2, R3, R4, R5, R6, R7, R8, R9 and R10. Sampling stations were chosen to provide good area coverage of the background and anthropogenic input values. The sampling station was geo-located using geographical positioning system (GPS) to ensure consistency.

The raw sewage water of Cuttack Municipal Corporation is discharged in to the Kathajodi river through sewage drain running through the city at CDA-Bidanasi, Khannagar and Mattagajapur. CDA-Bidanasi sewage discharge point is located at upper end of the city and relatively less quantity of sewage is discharged into the Kathajodi river, at Khannagar, majority of city sewage is discharged without treatment, however at Mattagajapur the sewage is discharged after treatment at a sewage treatment plant present there. Sewage samples at these three discharge points were collected during post monsoon period in the month of December and processed as per standard procedure (Johnson and Thornton, 1987). Water samples were collected in acidified PVC bottles (Duncan and Harrison, 1981). At the sampling sites, water samples were acidified with concentrated HNO_3 to lower the pH of the sample below pH 2.

Surface sediment samples (n=5) were collected from top 2 cm along the river bed during post monsoon period in the month of December. Soil samples were collected from 0-15 cm soil depth from river bank (B1, B2, B3, B4, B5, B6, B7, B8, B9 and B10) and non-flooded area control (NF1, NF2, NF3, NF4, NF5, NF6, NF7, NF8, NF9 and NF10) during post monsoon period in the month of December (figure.1) and processed for laboratory analysis.

Analysis of sewage water, sediment and soil

pH was measured by a pH meter and EC was measured by conductivity bridge (Jackson, 1973) . BOD, COD, TSM and TDS of sewage water were determined by the standard methods established for examination of water and waste water (APHA-AWWA - WPCD, 1975) (Table 2.) Ca^{++}, Mg^{++}, Na^{+}, K^{+}, CO_3^{-2}, HCO_3^{-1}, Cl^{-1} and SO_4^{-2} were determined by standard methods (Black, 1965). Organic carbon of sediment and soil was determined by Walkley and Black titration method (Black, 1965), available N by alkaline $KMnO_4$ method (Subhiah and Asija, 1956), available P by Olsen's extractant and available K by ammonium acetate extractant methods (Jackson, 1973) (Table 2., Table 4. and Table 6.).

Determination of heavy metals in sewage water

Micronutrients and heavy metals were determined by wet digestion method (AOAC, 1990). Standard procedures were used for quantitative estimation of heavy metals Cu, Cr, Cd, Pb and Zn by atomic absorption spectrophotometer (Spectra AA, Variant 55B AAS). Average values of three replicates were taken for each determination. The detection limits for Fe, Zn, Cu, Ni, Cr, Pb and Cd were 0.05, 0.008, 0.025, 0.04, 0.05, 0.06 and 0.009 (mg L-1) respectively.

Determination of heavy metals in sediment and soil

Total metals (Cd, Ni, Cu, Zn, Pb, Mn and Fe) were determined by Atomic Absorption Spectrophotometer technique after acid digestion (Taghinia *et al.*, 2010). The heavy metal concentration of undisturbed non flooded area at Naraj was taken as the background heavy metal concentration of the river Kathajodi basin.

RESULTS AND DISCUSSION

Heavy metal contents in sewage water

During this study the highest mean content of Ni (0.219 mg L^{-1}), Cu (0.063 mg L^{-1}), Zn (0.205 mg L^{-1}), Pb (0.052 mg L^{-1}) , Mn (0.28 mg L^{-1}) and Fe (0.82 mg L^{-1}) were observed in sewage water at Khannagar discharge point while Cd (0.007 mg L^{-1}) were observed at CDA- Bidanasi discharge point (Table 3.). The lowest mean content of all the heavy metal in sewage water were found at Mattagajapur discharge point. This may be attributed to sewage water being discharged to Kathajodi river after being treated at Mattagajapur sewage treatment plant. According to Pescod (1992) threshold values of heavy metals in irrigation water leading to crop damage are 2000 mgL-1 for Zn, 200 mgL-1 for Cu, 5000 mgL-1 for Fe, 200 mgL-1 for Mn, 200 mgL-1 for Ni, 5000 mgL-1for Pb and 10 mgL-1 for Cd. Therefore, during this study the concentrations of these metals in sewage effluents were found within the permissible limits for their use as irrigation water in the study area.

Heavy metal contents in sediment

The highest mean content of Fe (39.0 g kg^{-1}), Ni (124.0 mg kg^{-1}), Pb (53.9 mg kg^{-1}) and Cd (15.6 mg kg^{-1}) were determined in the sediment at Khannagar, while lowest Fe (31.0 g kg^{-1}) was determined at Mirjeipur, Ni (106.6 mg kg^{-1}), Pb (41.1 mg kg^{-1}) at Naraj and Cd (10.2 mg kg^{-1}) at Arilo (Table 5.) The dominance of heavy metals in the sediments of Kathajodi river bed was followed the decreasing order of Fe>Mn> Zn>Ni> Cu> Pb>Cd. While working on Indian river systems Subramanian *et al.* (1985) also reported the dominance of heavy metal contents in the sediments in similar order of Fe>Mn>Zn>Cu~ Pb. The values of Pb, Cd, Cu, Zn were progressively increased from Naraj to Komashasan indicating there enrichment in the soil towards lower stream of Cuttack city which may be not only due to weathering of parent rocks but also due to anthropogenic effluent of industrial area and other pollutants and effluent discharge of the city. However, elements like Fe, Mn and Ni had no specific trend indicating the dominance of only geogenic factors for their occurrence in the sediment. This result indicates that the levels of heavy metals found in the sediments of Kathojodi River might create an adverse effect on the aquatic ecosystem of the river. The presence of Pb, Cd and Cu in the river sediments indicates the possible pollution and contamination of nearby soils. Major portion of lead in the surface water is from mining and smelting,

Table 1: Description of the study area

Sl. No.	Location of sampling station	Sampling station Description	Symbols for the sampling location		
			Sediment	River bank soil	Non flooded soil
1	Naraj (85° 46′47″E 20° 20′13″N)	Just after the barrage constructed on river Kathajodi	R1	B1	NF1
2	Arilo (85°47′8.5″E 20°28′14.9″N)	A bushy wasteland	R2	B2	NF2
3	CDA-Bidanasi (85 48′ 33″E 20°28′3.4″N)	City sewage disposal point	R3	B3	NF3
4	Bidyadharpur (85°49′26.4″E 20°7′14.7″N)	A farming village with fly ash brick factory	R4	B4	NF4
5	Brahmanigaon (85°52′7.3″E 20°26′56.3″N)	A fishing village	R5	B5	NF5
6	Khannagar (85°54′3.5″E 20°44′30″N)	Under a bridge of railway track & Highway and after the raw city sewage disposal point	R6	B6	NF6
7	Urali (85°54′14″ E 20°42′29″ N)	A farming village after the river bifurcated opposite side it receives city sewage	R7	B7	NF7
8	Mirjeipur(85°58′12″ E 20°36′46″ N)	A farming village just before the bifurcated portion joined to its main river	R8	B8	NF8
9	Raghunathpur (85°59′36″ E 20°43′38″ N)	A farming village with farming on river sand and also the sewage disposal in to river after treatment in a STP.	R9	B9	NF9
10	Komashasan (86°02′43″ E 20°36′35″ N)	A village just after join of the river	R10	B10	NF10

Table 2: Physico-chemical characteristics of sewage water from the discharge points during post-monsoon period

Properties	Location D1 Drain from C.D.A- Bidanasi	D2 Drain fromKhannagar	D3 Drain fromMattagajapur
pH(1:2)	7.5±0.15	7.8±0.12	8.2±0.15
EC, dS m^{-1}	0.47±.05	0.51±0.01	0.38±0.02
BOD, mg L^{-1}	57.7±1.13	144.0±1.15	20.0±1.16
COD (mg L^{-1})	151.6±1.14	320.0±1.15	50.9±1.11
DO (mg L^{-1})	1.6±0.14	1.1±0.11	4.00±0.15
TDS (mg L^{-1})	296±1.14	368±1.12	212±1.15
TSS (mg L-1)	135±1.15	132±1.12	125±1.15
Ca (me L^{-1})	0.98±0.02	1.10±0.16	0.89±0.11
Mg (me L^{-1})	0.55±0.05	0.80±0.02	0.35±0.05
Na (me L^{-1})	4.35±0.15	2.65±0.13	3.50±0.15
K (me L^{-1})	0.29±0.11	0.50±0.05	0.35±0.05
CO_3 (me L^{-1})	0.20±0.05	0.01±0.02	0.01±0.03
HCO_3 (me L^{-1})	0.98±0.12	1.04±0.14	1.47±1.15
Cl (me L^{-1})	2.50±0.16	2.40±0.12	2.60±0.15
SO_4 (me L^{-1})	2.00±0.15	1.50±0.15	1.50±0.12

BOD- Biological Oxygen Demand, COD- Chemical Oxygen Demand, DO- Dissolved; Oxygen, TDS- Total Dissolved Solid, TSS- Total Suspended Solid

Table 3: Heavy metal content of sewage water (mg L^{-1}) from discharge points

SlNo	Discharge point	Cd	Ni	Cu	Zn	Pb	Fe	Mn
1	CDA-Bidanasi(D1)	0.007±0.001	0.116±0.042	0.050±0.042	0.183±0.018	0.043±0.011	0.62±0.11	0.21±0.03
2	Khannagar (D2)	0.006±0.001	0.219±0.011	0.063±0.011	0.205±0.032	0.052±0.017	0.82±0.21	0.28±0.04
3	Mattagajapur(D3)	0.005±0.001	0.105±0.031	0.041±0.020	0.169±0.041	0.038±0.014	0.58±0.19	0.29±0.02

Table 4: Chemical parameter in the sediments of river bed

SlNo	Location	pH(1:2)	EC dS m^{-1}	O.C.(%)	Available Nutrients kg ha^{-1} N	P	K
1	R1	6.3±0.13	0.21±0.01	0.34±0.04	62.7±1.13	26.5±1.13	155.9±1.13
2	R2	6.8±0.12	0.30±0.04	0.42±0.08	75.6±1.14	34.5±1.15	177.9±1.11
3	R3	6.1±0.16	0.39±0.01	1.02±0.12	125.4±1.14	35.6±1.14	244.6±1.14
4	R4	6.5±0.14	0.26±0.04	0.65±0.05	175.1±1.11	39.1±1.16	144.5±1.12
5	R5	6.2±0.12	0.44±0.02	0.56±0.04	162.2±1.11	45.6±1.14	255.9±1.11
6	R6	6.5±0.15	0.34±0.01	1.25±0.03	112.5±1.15	28.9±1.11	155.5±1.15
7	R7	6.2±0.12	0.47±0.03	0.93±0.02	75.2±1.12	56.2±1.12	122.7±1.13
8	R8	6.7±0.13	0.26±0.04	0.67±0.01	112.8±1.11	36.7±1.13	135.5±1.14
9	R9	6.2±0.11	0.41±0.01	1.17±0.03	92.3±1.12	33.9±1.11	108.5±1.15
10	R10	6.0±0.15	0.32±0.02	0.85±0.05	125.4±1.14	57.3±1.13	102.8±1.12

Table 5: Total heavy metal content (mg kg-1) in the sediments of river bed

SlNo	Location	Cd mg kg^{-1}	Ni mg kg^{-1}	Cu mg kg^{-1}	Zn mg kg^{-1}	Pb mg kg^{-1}	Mn mg kg^{-1}	Fe g kg^{-1}
1	R1	10.6±0.4	106.6±1.3	91.5±0.6	223.8±0.1	41.1±2.1	328.1±3.2	35.0±1.6
2	R2	10.2±0.8	112.8±1.2	81.9±0.6	213.4±0.6	41.8±1.2	322.2±2.5	31.8±1.8
3	R3	14.5±0.3	115.2±1.1	102.4±0.6	235.2±0.1	42.8±1.3	367.3±2.4	34.5±1.5
4	R4	12.1±0.4	108.6±0.7	89.5±0.7	218.5±0.2	41.2±1.4	345.0±3.6	32.1±1.9
5	R5	13.2±0.6	107.7±1.2	92.5±0.5	223.5±0.5	42.8±1.8	331.2±1.8	36.7±1.7
6	R6	15.6±0.2	124.0±1.5	113.2±0.8	236.6±0.1	53.9±2.1	398.0±2.1	39.0±2.1
7	R7	14.8±0.5	113.8±1.4	94.8±0.7	223.6±0.6	45.5±1.5	367.5±2.5	35.6±1.4
8	R8	11.4±0.2	109.5±1.2	91.2±0.9	214.7±0.7	42.8±1.7	325.4±2.6	31.0±1.8
9	R9	12.9±0.8	113.9±0.9	93.5±0.5	225.8±0.2	45.2±1.4	354.9±3.7	33.8±1.2
10	R10	11.2±0.5	113.2±0.8	91.8±0.8	224.5±0.5	44.9±1.9	340.2±3.1	32.9±2.1

refining etc works. Lead reaches the aquatic sediment through precipitation; erosion and leaching of soil as well as municipal and industrial waste. Sobha *et al.* (2008) also reported the concentration of lead ranging from 21.2 to 99.4 µg/ g during postmonsoon period in Kerala.

Heavy metal concentration in soil

The total heavy metals (Fe, Mn, Zn, Ni, Cu, Pb and Cd) content in soils of different locations are presented in the table 7. There was wide variation in terms of heavy metal contents with reference to the sampling locations. The highest mean

Table 6: Chemical parameter of the Kathajodi river bank soil

SlNo	Location	pH (1:2)	EC dS m^{-1}	O.C. (%)	Available Nutrients kg ha^{-1} N	P	K
1	B1	6.5±0.15	0.57±0.03	0.28±0.06	110.2±1.12	35.6±1.14	177.9±1.11
2	B2	6.4±0.11	0.26±0.04	0.32±0.02	100.5±1.15	39.5±1.15	222.3±1.13
3	B3	5.6±0.13	0.55±0.05	0.85±0.05	175.6±1.14	51.7±1.13	200.1±1.11
4	B4	5.4±0.14	0.46±0.04	0.57±0.03	213.4±1.14	26.2±1.12	255.7±1.13
5	B5	6.7±0.12	0.29±0.01	0.48±0.04	150.7±1.13	23.3±1.13	100.6±1.14
6	B6	6.7±0.13	0.35±0.05	0.75±0.05	125.4±1.14	33.4±1.14	200.1±1.11
7	B7	5.7±0.12	0.34±0.04	0.33±0.01	112.9±1.11	28.9±1.11	234.2±1.12
8	B8	6.9±0.11	0.38±0.02	0.67±0.03	100.3±1.13	29.4±1.16	256.0±1.15
9	B9	6.1±0.16	0.55±0.05	0.47±0.02	137.8±1.12	25.6±1.14	278.2±1.12
10	B10	6.8±0.13	0.49±0.01	0.25±0.05	137.3±1.13	41.7±1.13	207.9±1.11

Table 7: Total heavy metal content in the soils of river bank

SlNo	Location	Cd mg kg^{-1}	Ni mg kg^{-1}	Cu mg kg^{-1}	Zn mg kg^{-1}	Pb mg kg^{-1}	Mn mg kg^{-1}	Fe g kg^{-1}
1	B1	10.6±0.5	112.0±1.2	81.6±0.6	200.2±1.8	31.4±0.9	316.8±1.8	32.5±1.9
2	B2	10.1±0.4	112.4±1.4	90.4±0.7	190.5±1.5	31.2±1.1	317.2±2.2	32.6±1.3
3	B3	10.5±0.3	113.1±1.1	81.8±0.6	221.4±1.6	48.6±1.2	324.5±3.4	31.5±1.5
4	B4	11.6±0.4	106.5±1.5	87.6±0.8	219.4±1.9	33.2±1.1	325.6±2.3	31.2±1.2
5	B5	10.8±0.8	112.8±0.8	90.5±0.9	201.2±1.8	32.2±1.2	337.3±3.2	30.8±1.8
6	B6	14.6±0.6	113.6±0.6	91.1±0.7	195.3±1.7	53.1±0.8	328.2±3.4	36.2±2.1
7	B7	13.2±0.2	113.5±0.7	90.6±0.5	190.7±1.3	52.6±0.9	323.7±2.5	31.4±1.8
8	B8	10.8±0.5	113.4±1.3	90.8±0.5	205.5±1.5	31.5±1.0	313.9±2.1	31.1±1.9
9	B9	11.3±0.6	113.8±1.5	91.3±0.7	198.2±1.6	32.8±1.2	316.4±3.1	32.0±1.4
10	B10	10.6±0.7	112.9±1.1	90.8±0.8	190.8±2.1	31.4±0.8	317.4±2.3	32.3±1.7

Table 8: Total heavy metal content in the nearest non flooded soils

SlNo	Location	Cd mg kg^{-1}	Ni mg kg^{-1}	Cu mg kg^{-1}	Zn mg kg^{-1}	Pb mg kg^{-1}	Mn mg kg^{-1}	Fe g kg^{-1}
1	NF1	6.7±0.2	66.2±1.5	54.6±0.5	162.4±1.8	20.2±0.8	215.6±2.4	20.2±1.8
2	NF2	7.4±0.6	72.4±1.2	54.4±0.6	165.5±1.3	21.2±0.9	217.2±3.2	22.6±2.1
3	NF3	7.5±0.5	73.1±0.9	61.8±0.8	171.4±1.4	28.6±1.1	224.5±3.5	21.5±1.5
4	NF4	7.6±0.7	72.0±0.7	60.6±0.7	169.2±2.1	24.4±1.2	216.8±2.4	22.5±1.4
5	NF5	6.8±0.4	69.8±1.2	60.5±0.9	165.2±1.7	22.2±0.8	237.3±3.3	20.8±1.6
6	NF6	7.6±0.5	73.6±0.6	61.1±0.9	175.3±1.9	27.1 ±0.9	228.2±1.8	23.2±1.2
7	NF7	7.2±0.3	75.6±0.8	56.6±0.6	168.7±1.8	28.6±1.1	223.7±2.7	21.4±1.3
8	NF8	6.9±0.2	71.4±1.4	60.8±0.8	166.5±1.5	21.5±0.9	217.9±3.1	21.1±1.9
9	NF9	7.3±0.5	73.5±0.5	61.3±0.6	173.2±1.6	22.8±0.8	216.4±2.4	22.0±2.1
10	NF10	7.1±0.8	68.9±1.1	60.8±0.5	170.8±1.3	21.4±1.2	217.4±2.6	22.3±1.7

content of Fe (36.2 g kg^{-1}) was found in river bank soil at Khannagar while lowest Fe (30.8 g kg^{-1}) was found at Brahmanigaon. The highest Ni was observed at Mattagajapur (113.8 mg kg^{-1}) and lowest Ni content was observed at Bidyadharapur (106.5 mg kg^{-1}). The highest Pb (53.1 mg kg^{-1}) and Cd (14.6 mg kg^{-1}) was found at Khannagar while lowest Pb (31.2 mg kg^{-1}) and Cd (10.1 mg kg^{-1}) was found at Arilo (Table 6.). The metal content measured in soil at river bank generally found in decreasing order of; Fe>Mn>Zn>Ni>Cu>Pb>Cd. The critical limits of deficiency of Fe, Cu, Mn and Zn are 4.5 mg kg^{-1}, 0.2 to 0.5 mg kg^{-1}, 2.0 mg kg^{-1} and 0.6 mg kg^{-1}, respectively (being used currently in India for separating the deficient soils from the non-deficient ones). However, the critical limit in soil for contamination as per permissible limit of Indian standard (Gupta *et al.,* 2008) for Zn, Cd, Cu, Pb and Ni are 300-600 mg kg^{-1}, 3-6 mg kg^{-1}, 135-270 mg kg^{-1}, 250-500 mg kg^{-1} and 75-150 mg kg^{-1}. All these elements present in the soil of the study area were within the safe limits. The plant micronutrients such as Fe, Cu, Mn and Zn were present above the critical limit of deficiency indicating its higher fertility status with respect to these elements.

Enrichment factor (EF)

Enrichment factor (EF) is a good tool to differentiate the metal source between lithogenic and naturally occurring (Zhang, *et al.,* 2009). Improved interpretations are obtained by normalizing metal content in sediments to percentage of a given grain size or Al, Fe or organic carbon concentrations (Luoma and Rainbow, 2008). Enrichment factor is usually distinguished by aluminum because of its high natural concentration and minimal anthropogenic contamination. It is a structural element of clays, and the metals to Al proportions in the crust are relatively constant (Summers *et al.,* 1996). However, in the present study we used Fe to calculate EF because it is the fourth major element in the earth's crust and most often has no contamination concern. In addition, according to Daskalakis and O'Connor (1995) the main advantages of using Fe as a normalize are: (1) Fe is associated

Table 9: Metal enrichment factor (EF) and geoaccumulation index (Igeo) values in surface sediments of Kathajodi river

LocatioN	Cd		Ni		Cu		Zn		Pb		Fe		Mn	
	EF	Igeo	EF	Igeo	EF	Igeo	EF	Igeo	EF	Igeo	EF	Igeo	EF	Igeo
Naraj	0.913	0.317	0.990	0.344	0.967	0.336	0.795	0.276	1.194	0.415	1	0.347	0.878	0.305
Arilo	0.967	0.305	1.082	0.341	1.061	0.335	0.834	0.263	1.295	0.409	1	0.315	0.949	0.299
CDA	1.267	0.434	1.018	0.349	1.098	0.376	0.847	0.290	1.240	0.425	1	0.342	0.997	0.341
Bidyadharpur	1.136	0.362	1.032	0.329	1.031	0.328	0.846	0.270	1.283	0.409	1	0.318	1.006	0.321
Brahmanigaon	1.084	0.395	0.895	0.326	0.932	0.339	0.757	0.276	1.166	0.425	1	0.364	0.845	0.308
Khannagar	1.205	0.467	0.970	0.375	1.073	0.416	0.754	0.292	1.382	0.535	1	0.387	0.956	0.370
Urali	1.253	0.443	0.975	0.344	0.985	0.348	0.781	0.276	1.278	0.452	1	0.353	0.967	0.342
Mirjeipur	1.108	0.341	1.077	0.331	0.977	0.301	0.861	0.265	1.380	0.425	1	0.307	0.983	0.302
Mattagajapur	1.150	0.386	1.028	0.345	1.023	0.343	0.830	0.279	1.337	0.449	1	0.335	0.983	0.330
Komashasan	1.026	0.335	1.049	0.343	1.032	0.337	0.848	0.277	1.364	0.446	1	0.326	0.968	0.316
Max	1.267	0.467	1.082	0.375	1.098	0.416	0.861	0.292	1.382	0.535	1	0.387	1.006	0.370
Min	0.913	0.305	0.895	0.326	0.932	0.301	0.754	0.263	1.166	0.409	1	0.307	0.845	0.299
Mean	1.111	0.378	1.012	0.343	1.018	0.346	0.815	0.276	1.162	0.439	1	0.340	0.953	0.323

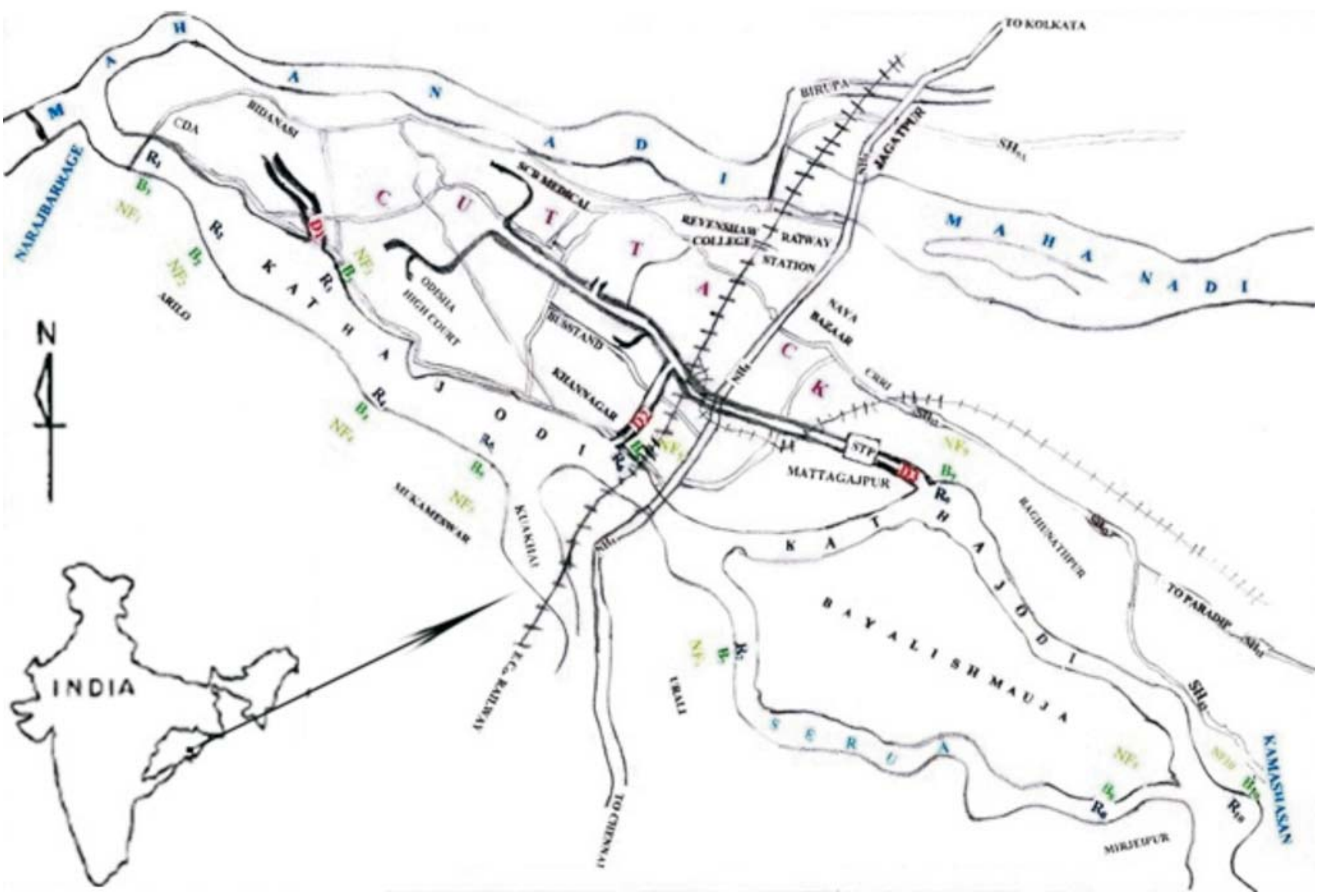

Figure 1: Location of the Study Area

with fine solid surface; (2) Geochemistry of Fe is close to that of many trace metals; and (3) Natural sediment concentration of Fe tends to be uniform. Iron (Fe) has been used successfully by several researchers to normalize metals contamination in river and coastal sediments (Zhang *et al.*, 2007; Amin *et al.*, 2009). The EF for Fe-normalised data is defined by:

EF metal P% (Mx / Fex) sample / (Mc / Fec) shale

Where, Mx is the concentration of metal in the examined sample, Fex is the concentration of Fe in the examined sample, Mc is the concentration of metal in the average shale or undisturbed sediment and Fec is the concentration of Fe in the average shale or undisturbed sediment. In the present study, average shale (Turekian and Wedepohl, 1961) was used as background or undisturbed value for those metals because no such data was available for this study area. The undisturbed sediment values utilized were in mg kg^{-1} 6.70 for Cd, 95 for Zn, 66.2 for Ni, 54.6 for Cu, 162.4 for Zn, 20.2 for Pb, 215.6 for Mn and for Fe undisturbed values is 20.2 g kg^{-1}. The EF values were interpreted as described by Chen *et al.*, (2007) where EF < 1 indicates no enrichment, EF < 3 is minor enrichment, EF = 3-5 is moderate enrichment, EF = 5-10 is moderately severe enrichment, EF = 10-25 is severe enrichment, EF = 25-50 is very severe enrichment and EF > 50 is extremely severe enrichment. The result from this present investigation showed that EF of Cd ranged from 0.913 to 1.267, EF of Zn from 0.754 to 0.861 and varied from 0.895 to 1.082 for Ni, from 0.932 to 1.098 for Cu, from 1.166 to 1.382 for Pb and from 0.845 to 1.006 for Mn (Table 9). The EF values of Zn in all the stations were found to be less than 1 (EF < 1) and the average EF of Zn was found 0.815 which indicated no enrichment. The lowest EF values were determined in Zn (0.754) which probably originated from natural weathering process. The EF values of Pb in all the stations were found to be greater than 1 (EF > 1) which indicated that this metal have minor enrichment. EF value of Cd, Ni and Cu were also found greater than 1 (EF > 1) in most of the sampling stations which indicated that these metals have minor enrichment.

Geoaccumulation Index (Igeo)

The Geoaccumulation Index (Igeo) was calculated to determine metal contamination in sediments of Kathajodi River (Table 9). Muller (1979) proposed geoaccumulation index to calculate metals concentration in sediments by comparing current concentrations with undisturbed or crustal sediment (control) levels. Muller (1981) has classified Igeo in relation to contamination levels into seven classes, Unpolluted (Class 0, Igeo < 0), unpolluted to moderately polluted (Class 1,0 < Igeo < 1), moderately polluted (Class 2 ,1 < Igeo < 2), moderately to strongly polluted (Class 3, 2 < Igeo < 3), strongly polluted (Class 4, 3 < Igeo < 4), strongly to very strongly polluted (Class 5, 4 < Igeo < 5) and very strongly polluted (Class 6, Igeo > 5), the highest grade reflecting a 100-fold enrichment above baseline values.

The geoaccumulation index (Igeo) is represented as: Igeo = log2 (Cn / 1.5 Bn)

Where, Cn is the measured concentration of the sediment for metal (n), Bn is the geochemical background value of metal (n) and factor 1.5 is the possible variations of background data due to lithogenic impacts. The background values of the heavy metals were the same as applied in the enrichment factor calculation.

The geoaccumulation index (Igeo) of heavy metals in this study revealed that most of the elements belonged to Igeo class 1 (unpolluted to moderately polluted). The average mean geoaccumulation index of 0.378, 0.343, 0.346, 0.276, 0.439 and 0.323 suggested that surface sediments of Kathajodi river were unpolluted to moderately polluted (Class 1, 0 < Igeo < 1) by Cd, Ni, Cu, Zn, Pb and Mn respectively. Though, the higher metal values might also be contributions from the already adsorbed metals in the deposited sediments due to turbulence generated by scavenging organisms at the sediment water interface, this contamination of trace metals has potential danger and possibility of entering into food chain.

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