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Heavy metal contamination and its indexing approach for river water

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ABSTRACT: The objective of the study is to reveal the seasonal variations in the river water quality with respect to heavy metals contamination. To get the extend of trace metals contamination, water samples were collected from twelve different locations along the course of the river and its tributaries on summer and the winter seasons. The concentrations of trace metals such as cadmium, cromium, copper, cobalt, iron, manganese, nickel, lead, mercury and zinc were determined using atomic absorption spectrophotometer. Most of the samples were found within limit of Indian drinking water standard (IS: 10500). The data generated were used to calculate the heavy metal pollution index of river water. The mean values of HPI were 36.19 in summer and 32.37 for winter seasons and these values are well below the critical index limit of 100 because of the sufficient flow in river system. Mercury and chromium could not be traced in any of the samples in the study area.

Keywords: *Heavy metal pollution index; Industrial pollution; Seasonal variation*

INTRODUCTION

Rapid urbanization and industrial development during last decade have provoked some serious concerns for the environment. Heavy metals contamination in river is one of the major quality issues in many fast growing cities, because maintenance of water quality and sanitation infrastructure did not increased along with population and urbanization growth especially for the developing countries (Sundaray *et al*., 2006; Karbassi *et al*., 2007; Akoto *et al*., 2008; Ahmad *et al*., 2010).

Trace metals enter in river from variety of sources; it be can be either natural or anthropogenic (Bem *et al*., 2003; Wong *et al*., 2003; Adaikpoh *et al*., 2005; Akoto *et al*., 2008). Usually in unaffected environments, the concentration of most of the metals is very low and is mostly derived from the mineralogy and the weathering (Karbassi *et al*., 2008). Main anthropogenic sources of heavy metal contamination are mining, disposal of untreated and partially treated effluents contain toxic metals, as well as metal chelates from different industries and indiscriminate use of heavy metal-containing fertilizer and pesticides in agricultural fields (Hatje *et al*., 1998; Amman *et al*., 2002; Nouri *et al*., 2006; Nouri *et al*., 2008). Metals enter into river water from mining areas through various ways such as mine discharge, run-off, chemical weathering of rocks and soils, wet and dry fallout of atmospheric particulate matter (Macklin *et al*., 2003; Bird *et al*., 2003; Kraft *et al*., 2006; Singh *et al*., 2008;Venugopal *et al*., 2009). The mine water, run-off from abandoned watersheds and associated industrial discharges are the major source of heavy metal contamination, total dossolved solid (TDS) and low pH of streams in mining area (USEPA, 1997; Mohanty *et al*., 2001; Cravotta, 2008; Shahtaheri *et al*., 2008). Rivers in urban areas have also been associated with water quality problems because of the practice of discharging of untreated domestic and small scale industries into the water bodies which leads to the increase in the level of metals concentration in river water (Rim-Rekeh *et al*., 2006; Khadse *et al*., 2008; Juang *et al*., 2009; Venugopal *et al*., 2009; Sekabira *et al*., 2010).

Trace metal contaminations are important due to their potential toxicity for the environment and human beings (Gueu *et al*., 2007; Lee *et al*., 2007; Adams *et al*., 2008; Vinodhini and Narayanan, 2008). Some of the metals like Cu, Fe, Mn, Ni and Zn are essential as micronutrients for the life processes in animals and plants while many other metals such as Cd, Cr, Pb and Co have no known physiological activities (Kar *et al*., 2008; Suthar and Singh, 2008; Aktar *et al*., 2010). Metals are non-degradable and can accumulate in the human body system, causing damage to nervous

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system and internal organs (Lee *et al.*, 2007; Lohani *et al.*, 2008). However, the rivers play a major role in assimilation or transporting municipal and industrial wastewater and runoff from agricultural and mining land (Singh *et al.*, 2004). The present study aimed to envisage the water quality status of River Brahmani and its tributaries with respect to its heavy metal concentrations in various seasons at Angul district of Orissa**.** The research work was carried during summer (May, 2008) and winter (January, 2009). Metal concentration in river water in various places of India is illustrated in Table 1.

MATERIALS AND METHODS

Study area

The study area (Angul-Talcher region) is bounded by latitudes 20° 37' N to 21° 10' N and longitudes 84° 53' E to 85° 28' E and situated at an average height of 139 m above mean sea level. The river catchment is characterized by Precambrian granites, gneisses and schists of Eastern Ghats with local intrusive and volcanic lithologies; lime stone, sand stone and shales of the Gondwanas (Sene-Johansen, 1995; Panda *et al.*, 2006; Sundaray *et al.*, 2006). The area comes under sub tropic monsoon climate with an average annual rainfall of 1370 mm. The temperature varies from 11.9° C to 44.4° C (Sundaray *et al.*, 2006). At present, it accommodates several large and medium scale industries such as Nalco Smelter and its Captive Power Plant (CPP-960MW), Talcher Super Thermal Power Station, NTPC (TSTPS-3000MW), Talcher Thermal Power Station (TTP-460MW), Iron and Steel industries and various coal mines. The drainage pattern is controlled by the River Brahmani along with its tributaries. River Brahmini play as a major source of water, as well as sink for effluent for the existing industries. These industrial activities affect various components of ecology and the environment and impart heavy metal contamination in the river water.

Field sampling

In order to achieve the research objective, samples were collected from twelve different locations of Brahmani River along with its tributaries in Angul-Talcher Region to evaluate the heavy metal contamination during various seasons (summer and winter) (Table 2). Criteria for selection of sampling station were based on the locations of industrial units and land use pattern to quantify heavy metal concentration. Five sites were selected along the Brahmani River and seven sites were located along its main four tributaries, named as Tikira River, Bangaru River, Nandira River and Kisinda River (Fig. 1). The Samples were taken from 10 to 15 cm below the water surface using acid washed plastic container to avoid unpredictable changes in characteristic as per standard procedures (APHA, 1998). Samples were collected in May 2007 for summer season, and in January 2008 samples were collected for winter season. Care was taken to collect subsequent samples from same location in both the seasons.

Laboratory methods

Water samples were collected from all the respective sampling stations of Brahmani River. The collected samples were filtered (Whatman no. 42) and preserved with 6N of HNO_3 for further analysis (APHA, 1998). Concentrations of heavy metals in water samples were determined with an atomic absorption spectrophotometer (GCB-Avanta) with a specific lamp for

Table 1: Comparison of dissolved metal concentration with other Indian rivers (µg/L)

Metals Rivers	Fe	Mn	Co	Ni	Cu	Zn	Cr	Pb	Cd	Hg	References
Subarnarekha river	66.25	11.38	1.13	15.75	15.88	23.00	1.13	19.13	-	-	Senapati and Sahu (1996)
Hindon river	226.0	129.0	-	24.0	6.6	58.0	15.0	37.0	-	-	Jain and Sharma (2006)
Baitarani river	100.5	1.70	0.7	3.9	3.45	272.3	9.6	3.45	-	-	Nayak *et al.*, (2001)
Mahanadi river	-	96.9	2.4	7.2	5.9	11.0	9.8	2.68	-	-	Konhauser et al. (1997)
Achankovil river	11858	699	-	-	224	415	-	72	6.0	-	Prasad *et al.*, (2006)
Koel (Brahmani) river	481.78	30.33	8.67	24.78	6.67	31.56	10.89	1.67	-	-	Sundaray (2009)
Ganga river	800	260	-	140	10	60	-	120	5	-	Aktar *et al.*, (2010)
Damodar river	480				3950		11550		300		Chatterjee *et al*, (2010)
Brahmani river	5-95	1.5-102	4.0-5.6	9-52	1-4.7	0.4-80.1	-	10-27	0.4-4.0	-	Present study

particular metal. Average values of three replicates were taken for each determination. Appropriate drift blank was taken before the analysis of samples. The working wave length for the heavy metals are 248.3 nm for Fe, 279.5 nm for Mn, 213.9 nm for Zn, 324.7 nm for Cu, 232 nm for Ni, 228.8 nm for Cd, 357.9 nm for Cr, 217 nm for Pb, 240.7nm for Co and 253.7nm for Hg.

Indexing approach

Heavy metal pollution index (HPI) is a method of rating that shows the composite influence of individual heavy metal on the overall quality of water. The rating is a value between zero and one, reflecting the relative importance individual quality considerations and defined as inversely proposal to the recommended standard (Si) for each parameters. Water quality and its suitability for drinking purpose can be examined by determining its quality index (Mohan *et al.*, 1996; Prasad and Kumari, 2008; Prasad and Mondal, 2008).

The calculation involves the following steps

First, the calculation of weightage of i^{th} parameter;

Second, the calculation of the quality rating for each of the heavy metal;

Third, the summation of these sub-indices in the overall index.

The weightage of i^{th} parameter is:

$$W_i = k/S_i \tag{1}$$

Where, W_i is the unit weightage and S_i the recommended standard for ith parameter (i = 1-6), k is the constant of proportionality.

Individual quality rating is given by the expression

$$Q_i = 100V_i/S_i \tag{2}$$

Where, Qi is the sub index of ith parameter, V_i is the monitored value of the ith parameter in µg/L and S_i the standard or permissible limit for the ith parameter.

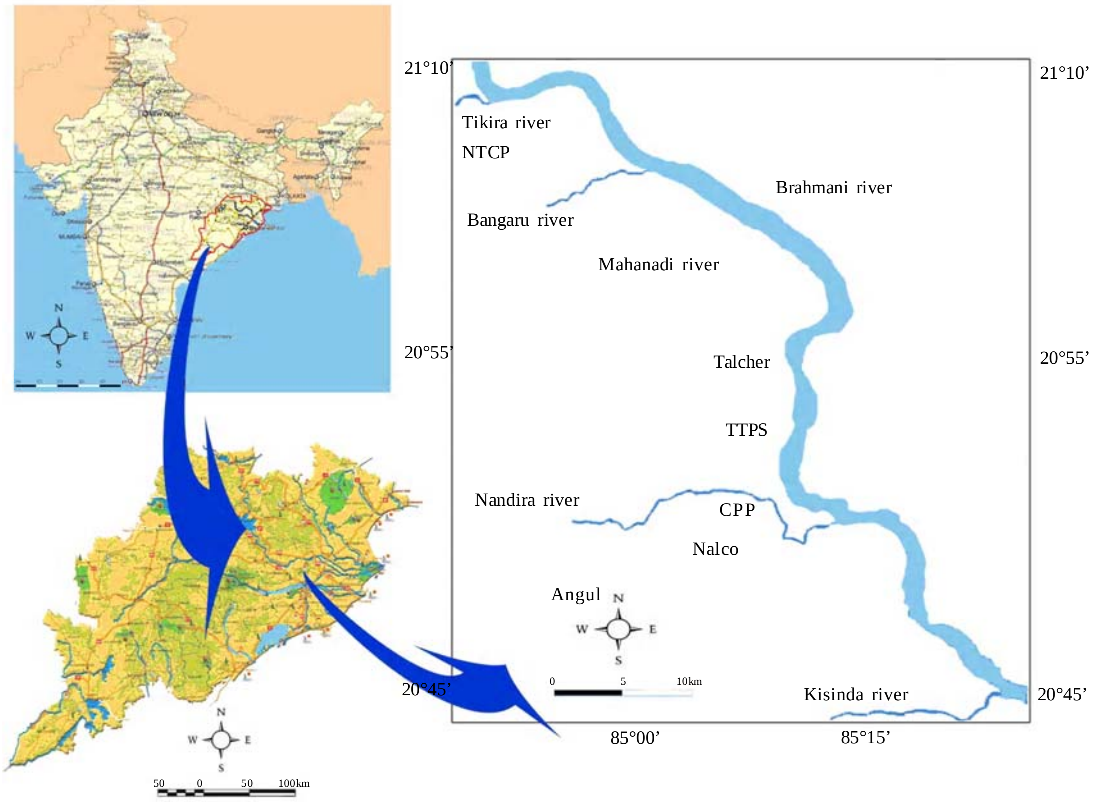

Fig. 1: Geographical representation of the study area

Table 2: Details of surface water sampling location along with their longitude and latitude

Code	Locations	Longitude	Latitude
W1	Tikira nadi just before meeting Brahmani River	85° 06’07”	21° 05'40”
W2	Brahmani river U/S to Tikira river	85°07’19”	21°06’09”
W3	Brahmani river D/S to Tikira river	85°06’37”	21°04’37”
W4	Brahmani river near Samal Barrage	85°08’19”	21°04’22”
W5	Brahamani river U/S to Nandira river	85°15’31”	20°53’30”
W6	Angul canal, near Kumanda village	85°05’14”	20°50’46”
W7	Nandirariver, before meeting to Brahamani river	85°15’35”	20°53’16”
W8	Nandira river near Tentuli village	85°10’52”	20°53’30”
W9	Brahmani River D/S to Nandira river	85°53’19”	20°53’19”
W10	Angul canal at Bargadia chowk	85°02’37”	20°51’09”
W11	Kisinda river, before meeting to Brahamani river	85°16’55”	20°49’03”
W12	Bangaru river, before meeting to Brahamani river	85°11’04”	21°00’17”

The heavy metal index is then calculated as follows:

$$HPI = \sum_{i=1}^{n} (Q_i W_i) / \sum_{i=1}^{n} W_i \qquad (3)$$

Where, Qi is the sub index of ith parameter. W_i is the unit weightage for ith parameter, n is the number of parameters considered. Generally, the critical pollution index value is 100.

RESULTS AND DISCUSSION

The results revealed that in most of the sampling stations, water was slightly alkaline except at very few stations in the upper course of the River where the water was found to be slightly acidic. The range of pH was 7.6-8.5 during the winter, while in summer it was slightly acidic to alkaline (6.0-8.3). The above values usually indicate the presence of carbonates of calcium and magnesium in water (Begum *et al.*, 2009). High pH of the River water may result in the reduction of heavy metal toxicity (Aktar *et al.*, 2010). In the case of Total dissolved solids (TDS), there was a considerable amount of dissolved ions in all the sampling locations. Higher concentration of TDS was observed in the River water near the middle part of the River Basin. It was in the range of 166-330 mg/L and 164-294 mg/L in summer and winter seasons, respectively. Various large and small industries are concentrated in these areas. The effluents from these industries are directed into the River course which increases the concentration of TDS in the water body (Phiri *et al.*, 2005; Rim Rukeh *et al.*, 2006). The concentration ranges, mean and standard deviation of individual metals are illustrated shown in Table 4.

The maximum Fe concentrations were found 64.6 and 95.0 µg/L in summer and winter season respectively. It may be assigned to the soil-water interaction especially within the middle and lower part of the River stretch during winter season. Lead was found in winter season while in summer it was below the detection limit. It may be due to the less soluble of Pb containing minerals in natural water (Venugopal *et al.*, 2009a; b). The maximum lead concentration in River water were observed as 27.0 µg/L) during summer season (Neal *et al.*, 2000). The low values of Cu indicate there is no significant source of pollution. The maximum Cu was found 4.7µg/L and 4.2µg/L in respective seasons. It may be attributed to domestic sewage and run-off from extensive farmed areas (Wu *et al.*, 2008). The relatively higher concentrations of zinc in some of the sampling stations were 80.1µg/L and 75.5µg/L during summer and winter season, respectively. It is attributed to the presence of unused remains of zinc sulphate in fertilizers (Wu *et al.*, 2008). Highest value of Co was found (5.6µg/L) in summer season, it may be due to effluent from metal alloys industries (Brian and Bishop, 2009). The major source of Cd is the coal combustion, metal industry and waste incineration (Brian and Bishop, 2009). The maximum concentration Cd in the area was 4.0 µg/L in summer season. It may be due to coal- combustion which is very frequent in industries (Thermal Power Station) and domestic purpose. The maximum value of Ni was 52 µg/L in winter while Mn was 102 µg/L during summer season. The concentration of Hg and Cr could not be detected in any of the samples. Most of the dissolved heavy metals showed slightly high concentrations during the summer period than that

Table 3: HPI calculation for the surface water based on the Indian drinking water standard (IS: 10500, 1993)

Heavy metals	Mean concentration (Vi)		Highest permitted value for water (Si)	Unit weightage (Wi)
	Summer	Winter		
Pb (μg/L)	12.1	10	50	0.7588
Cd (μg/L)	1.8	0.43	10	3.7939
Zn (μg/L)	15.9	11.31	15000	0.0025
Cu (μg/L)	1.94	1.55	1500	0.0253
Fe (μg/L)	20.32	23.33	1000	0.0381
Mn (μg/L)	24.55	24.13	300	0.1265

Table 4: Statistical Variation (Range, Mean and Standard deviation) among various heavy metals

Parameters	Summer		Winter		Detection Limits (GBC- Avanta)
	Range	Mean ± SD	Range	Mean ± SD	
pH	6.0 – 8.3	7.5 ± 0.70	7.6 - 8.5	8.0 ±0.200	-
TDS (mg/L)	166 - 330	254 ± 53.1	164 - 294	219 ± 4000	-
Pb (μg/L)	< 10.0 - 27.0	12.08 ± 5.23	<10.0	-	10.0
Cd (μg/L)	< 0.40 - 4.00	1.80 ± 1.93	< 0.40 - 0.70	0.43 ± 0.10	0.04
Hg (μg/L)	< 0.05	-	< 0.05	-	0.05
Zn (μg/L)	< 0.40 - 80.1	15.90 ± 28.51	< 0.40 - 75.50	11.31 ± 21.4	0.4
Cu (μg/L)	<1.0 - 4.70	1.94 ± 1.250	< 1.0 - 4.200	1.55 ± 0.90	1.0
Ni (μg/L)	< 9.0 - 44.3	15.73 ± 12.16	< 9.0 - 52.00	16.35 ± 13.2	9.0
Fe (μg/L)	< 5.0 - 64.6	20.32 ± 20.89	< 5.0 - 95.00	23.33 ± 27.8	5.0
Co (μg/L)	<4.0 - 5.60	4.13 ± 0.640	< 4.0 - 5.30	4.14 ± 0.40	4.0
Mn (μg/L)	<1.5 - 102	24.55± 33.74	1.50 - 98.0	24.13 ± 32.9	1.5
Cr (μg/L)	< 3.00	-	< 3.00	-	3.0

of the winter season. These kinds of pattern indicate the accumulation of the metal concentration during low flow condition of River. It may be attributed to high evaporation rate of surface water followed by elevated temperature (Abdel-Satar, 2001). Few metals such as Fe and Ni were high during winter, it may be due to the effect of rain (Phiri *et al.*, 2005). The previous studies has been ensure that the atmospheric precipitation is very much responsible for metal contamination in surface water (Wong *et al.*, 2003; Wu *et al.*, 2008; Pandey *et al.*, 2009).

Statistical tests showed that the metal concentrations were significantly different between sampling stations. It was also observed that for all (ten) metals studied; there was a trend of increasing concentrations from the upstream stations to the downstream stations.

In order to calculate the HPI of the water, the mean concentration value of the selected metals (Pb, Cd, Zn, Cu, Fe, Mn) have been taken into account (Prasad and Mondal, 2008). Table 3 details the calculations of HPI with unit weightage (Wi) and standard permissible value (Si) as obtained in the presented study. The mean of heavy metal pollution index values are 36.19 and 32.37 in summer and winter season, respectively, while the maximum value of HPI was (66.15) found at sampling location (w11) in summer season. It may be attributed to domestic sewage. The critical pollution index value, above which the overall pollution level should be considered unacceptable, is 100 (Prasad and Kumari, 2008; Prasad and Mondal, 2008). This indicates the water is not critically polluted with respect to heavy metals.

CONCLUSION

The present study reveals that most of the water samples of River system at Angul were found less polluted in heavy metal contamination profile and shows a trend in seasonal variation. Very few samples evidenced the slightly significant metal concentration in water samples in the middle of the River catchment during summer season. It is attributed to the concentration of various mines and associated industries along with the River course.

The HPI is very useful tool in evaluating over all pollution of water bodies with respect to heavy metals (Prasad and Kumari, 2008). The HPI values of the present study indicate that the water samples from the River are not critically contaminated with respect to heavy metals. It is due to presence of enough flow rate of River water, the metal concentration from mine water and other industrial effluents has been diluted rapidly with respect to a very small distance. More over metal pollution by mining and associated industrial activities is somewhat mitigated because of strict implementation of clean technology and environmental measures by industries.

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