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Status of sediment with special reference to heavy metal pollution of a brackishwater tidal ecosystem in northern Sundarbans of West Bengal

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Abstract: The study investigated the nutrient status and load of pollution for six heavy metals (Cu, Zn, Fe, Mn, Pb and Cd) in the sediment of Jagannath canal, which receives municipal sewage mixed brackishwater from the Bidyadhari river of north Sundarbans, West Bengal. The concentration of different heavy metals followed the hierarchy: Fe>Mn>Zn>Cu >Pb>Cd. Pollution load index value (1.71) of heavy metals and its relationship with organic carbon indicate that considerable quantity of metals has been carried to the canal by the sewage of Calcutta metropolis. Result of principal component analysis suggests that no collinearity existed among the studied metals. However, emphasis on the monitoring of Cd should be preferred because of its alarmingly higher contamination value.

Resumen: El estudio investingó el estado nutricioal y la carga de contaminantes por seis metales pesados (Cu, Zn, Fe, Mn, Pb y Cd) en el sedimento del canal Jagannath, el cual recibe el drenaje municipal mezclado con agues salobres del Río Bidyadhari en el norte de Sundarbans, Bengala Occidental. La concentración de los diferentes metales pesados siguió la siguiente jerarquía: Fe>Mn>Zn>Cu>Pb>Cd. El valor del índice de carga de contaminación por metales pesados (1.71) y su relación con el carbono orgánico indican que una cantidad considerable de metales ha sido transportada al canal por el drenaje desde la metropolis de Calcutta. El resultado del Análisis de Componentes Principales sugiere la ausencia de colinearidad entre los metales estudiados. Sin embargo, debería preferirse el énfasis el monitoreo de Cd debido a su valor tan alarmantemente alto como contaminante.

Resumo: O estudo investigou o status nutricional e a carga poluente para seis metais pesados (Cu, Zn, Fe, Mn, Pb e Cd) no sedimento do canal de Jagannath, que recebe uma mistura dos esgotos municipais e água salobra proveniente do Rio Bidyadhari do Norte do Sundarbans, na Bengala ocidental. A concentração dos diferentes metais pesados seguiu a seguinte hierarquia: Fe>Mn>Zn>Cu>Pb>Cd. O valor do índice de carga poluente (1,71) em metais pesados e a sua relação com o carbono orgânico indicou que uma quantidade considerável de metais foi transportada para o canal pelo esgoto da cidade de Calcuta. Os resultados da análise das componentes principais sugerem que não existe colinearidade entre os metais estudados. Contudo, deve dar-se a ênfase na monitorização do Cd por causa do seu valor altamente contaminante.

Key words: Heavy metals, sediment, Sundarbans, tidal ecosystem.

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Introduction

The analysis of river sediment is a useful method of studying environmental pollution with heavy metals (Batley 1989). There are basically three reservoirs of metals in the aquatic environment: water, sediment and biota. Metal levels in each of these three reservoirs are dominated by a complex dynamic equilibrium governed by various physical, chemical and biological factors (Murray & Murray 1973). Among these three reservoirs the sediment is the major repository for metals, in some cases, holding over 99% of the total amount of metal present in the system (Renfro 1973). Concentration of metal in sediment of the Indian tidal waters have been documented by Ghosh & Choudhury (1989), Sahu & Bhosale (1991), Satyanarayana *et al.* (1994), Mitra *et al.* (1996), Govindaswamy *et al.* (1997) and Panigrahy *et al.* (1997). Documentation of information regarding quality and nutrient status of soil or different estuarine and mangrove confined saline waterbodies has been done by Gopalaswamy & Roychoudhury (1970), Mahajan & Kanan (1974), Banerjee & Banerjee (1975), Chattopadhyay & Ghosh (1976) and Satyanarayana *et al.* (1993). In the present communication, status of nutrient and pollution load index (PLI) of some heavy metals of a brackishwater tidal ecosystem have been presented.

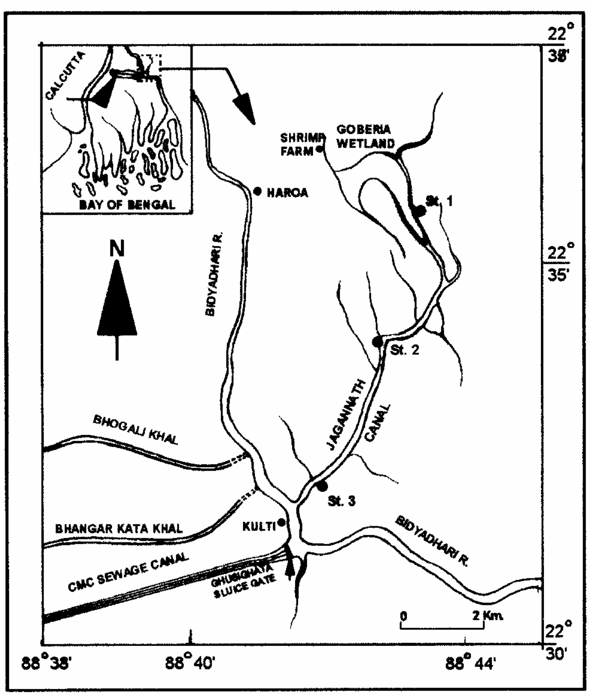

Fig. 1. Map showing the study areas and sampling stations. Inset, map of coastal West Bengal.

Study area

The study was conducted in the Jagannath canal, a brackishwater tidal ecosystem of northern Sundarbans of West Bengal, India. The canal is connected to the Bidyadhari river near Kulti. The southern most end of the canal is about 1.5 km away from the sewage outfall station at Ghusighata of Kulti (Fig. 1). The large quantity of sewage of Calcutta metropolis is being mixed with the brackishwater of Bidyadhari river and flows north-east through Jagannath canal due to tidal pressure (Naskar & Guha Bakshi 1987). Considering this sewage mixed brackishwater for aquaculture, an estimated 36,000 ha shrimp/fish culture 'bheries' have developed along the two banks of the canal and its arteries. In the rainy season, when water becomes almost fresh, most of the 'bheries' have been used for paddy cultivation.

Materials and methods

The study was conducted monthly from March 1995 to February 1997. Three sampling stations were chosen to represent the whole canal (Fig. 1). An Ekman grab (15 x 15 cm) was employed for collecting sediment samples. The surface (0-3 cm) sediment was collected from the central portion of the grab sample. pH of fresh sample was measured by Kelway soil acidity and moisture tester (Model HB-2). Salinity of soil was determined by diluting the fresh sample in distilled water at 1:5 ratio and the suspension was stirred for one hour and filtered. Salinity of the filtrate was measured by Knudsen's argentometric method (Strickland & Parsons 1968) and the result was multiplied by the dilution factor. The collected soil samples were air-dried and crushed into powder in a porcelain mortar and sieved through a nylon sieve (Pore size, 0.45 mm). Organic carbon content of the air dried sample was determined by following Walkley & Black's (1934) wet digestion method using silver sulphate to overcome the influence of chloride ion. Total nitrogen of the air-dried sample was estimated by Kjeldahl method (Jackson 1967) and available nitrogen by alkaline permanganate distillation method as described by Subbaiah & Asija

(1956). Available phosphorus was extracted by 0.5 N sodium bicarbonate (Jackson 1967) and the phosphorus content was determined by the ascorbic acid method (Strickland & Parsons 1968). For the analysis of metals, the air-dried samples were oven-dried at 105°C for 24 h and then powdered and sieved. One hundred milligram of this sample was digested with a mixture of 6 ml HF; 4 ml HNO_3 and 1 ml $HClO_4$ following Agemian & Chau (1976). All analyses were done in triplicate by direct aspiration into Perkin-Elmer atomic absorption spectrophotometer (AAS, Model-3030) against the standard concentration of the metals. Background value of the used acid mixture was considered in computation of the result.

Results and discussion

The sediment of Jagannath canal was around neutral with pH values (average of three stations) ranging from 6.61-7.34, which is favourable for the rich biological regime (Banergea 1967). The average sediment salinity level of the canal ranged from 2.20-9.64‰. The soil organic carbon is a common constituent of all organic matters. As shown in Fig. 2, the average organic carbon content of the canal sediment varied from 0.84 to 1.41%. The monthly variation in total nitrogen concentration showed significant difference in both space and time. The average total nitrogen (986.88-1430.27 mg kg^{-1}) showed strong correlation ($r = 0.9413$, $p<0.01$) with organic carbon. Fraction of soil nitrogen as amino acid, peptide and easily decomposable proteins constitutes easily available form of nitrogen, which contained 12.48-15.21% of the total nitrogen. Phosphorus along with nitrogen plays a decisive role in determining aquatic production. Monthly variation in mean available phosphorus showed significant difference in space and time and the mean values ranged from 8.41-27.91 mg kg^{-1} (Fig. 2).

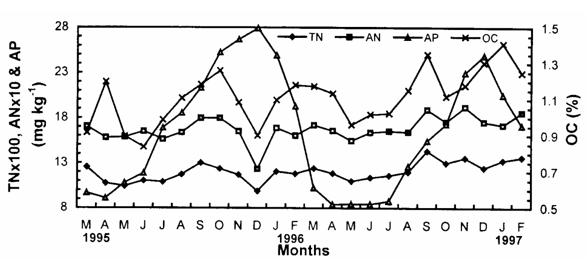

Fig. 2. Monthly variations in some chemical characteristics of sediment of Jagannath canal. OC, organic carbon; TN, total nitrogen; AN, available nitrogen; AP, available phosphorus.

The monthly variation in concentrations of different heavy metals *viz*, Cu, Zn, Fe, Mn, Pb and Cd are reflected in Fig. 3. ANOVA reveals that both spatial and temporal variations of all metals were significant. The concentration of total Cu, Zn, Fe, Mn, Pb and Cd was 43.61-79.87 mg kg^{-1}, 197.22-347.63 mg kg^{-1}, 19100.00-25800.00 mg kg^{-1}, 200.70-445.85 mg kg^{-1}, 36.81-61.38 mg kg^{-1} and 2.84-5.78 mg kg^{-1}, respectively. The magnitude of different trace metals followed the hierarchy: Fe>Mn>Zn>Cu>Pb>Cd. The interaction of trace metals showed positive correlation between Cu and Zn ($r = 0.7553$; $p<0.01$) and Fe and Mn ($r = 0.4933$; $p<0.05$). The seasonal variations reflect that concentration of total Fe, Mn and Pb were

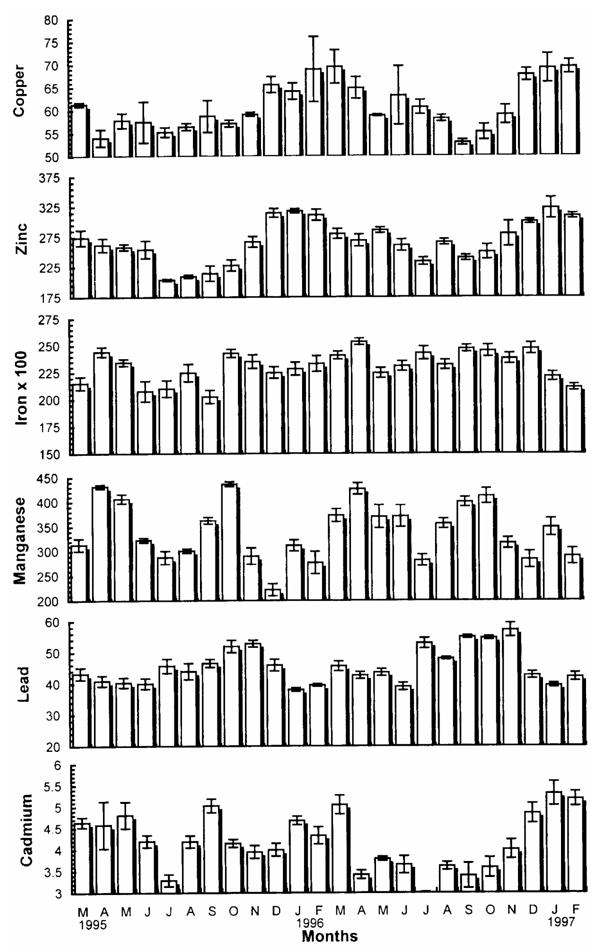

Fig. 3. Monthly variations in different total trace metals (mean ± SE, mg kg^{-1}) of sediment of Jagannath canal.

highest and that of Cu, Zn and Cd were lowest during monsoon season (July-October). Less dilution of overlying sewage mixed brackishwater due to less precipitation should increase the concentration of different metals during postmonsoon season (November to February). But it is seen from the Fig. 3 that out of six metals, concentrations of Cu, Zn and Cd were highest during this period. This may be due to the complex interaction of pH and dissolved oxygen of water and pH of soil, which control the solubility of different metals as opined by Ahrland (1975). Among the studied metals, concentrations of Cu, Zn, Mn and Pb were observed to be higher than the highly metal concentrated area of Hugli estuary (Ghosh & Choudhury 1989; Mitra *et al.* 1996). High concentration of trace metals in the sediment of Jagannath canal indicates metal pollution stress possibly due to large flux of metals is being brought to the canal by the sewage of Calcutta metropolis. This has undergone complexation with large amount of particles carried by the water and deposited to the bottom (Bender *et al.* 1970; Trefry & Presley 1976). The extent of pollution by metals has been assessed by employing the method based on pollution load index (PLI) as developed by Tomlinson *et al.* (1980), which is as follows:

$$PLI = \sqrt[n]{\text{Product of n number of CF values}}$$

Where, CF = contamination factor and n = number of metals.

$$CF = \frac{\text{Concentation of metal}}{\text{Background value of metal}}$$

The world average concentration of Cu (45 mg kg^{-1}), Zn (95 mg kg^{-1}), Fe (46,000 mg kg^{-1}), Mn (800 mg kg^{-1}), Pb (20 mg kg^{-1}), and Cd (0.3 mg kg^{-1}) reported for shale (Turkian & Wedephol 1961) were considered as the background value. The variations in CF values (average of three stations) of the above mentioned heavy metals were 1.177-1.545, 2.143-3.393, 0.457-0.551, 0.233-0.545, 1.905-2.858 and 9.778-17.716, respectively (Fig. 4) indicating that contamination with Cd in the soil was highest in comparison to other metals. The mean PLI values of station 1, 2 and 3 (Fig. 5) were 1.63 ± 0.10, 1.70 ± 0.09 and 1.79 ± 0.10, respectively, suggesting that station 3 was highly polluted with trace metals, which was due to its location nearest to the sewage outfall point of Calcutta metropolis. The strong positive correlation of PLI with organic carbon ($r = 0.544$; $p<0.01$) indicates the metal accumulation ability of organic matter. Shokkovitz & Copeland (1981) reported that the increased organic carbon in the fine particles catalyze the metal scavenging ability of sediment. Comparing the PLI values of some polluted tidal ecosystems, *viz.*, Vishakhapatnam coast (91.45-1.78), Paradip estuary (0.95) and Digha estuary (0.98) (Panigrahy *et al.* 1997), it can be contended that the canal soil was considerably polluted with the metals.

Principal component (PC) analysis have been employed to find out the possible linear combination of the original variables of trace metals, which could account for the largest part (>80%) of the total variance. Reduction in number of variables during future monitoring of the system without significant loss of information can be done by this technique (Pavoni *et al.* 1987). The analysis was performed using the "MSTATC" software package. It is evident from the Table 1 that the 1st PC accounts for 46.38% of the total variance and is made up of Zn, Cu and Cd and in contrast Pb, Mn and Fe. The 2nd PC which contributes 19.95% of the total variance highly weighs Fe, then Mn, Cu and Cd. The 3rd PC (16.52%) is contributed by Pb, Cu, Zn and Fe, and in contrast by Mn and Cd. The remaining PCs have less importance on the entire

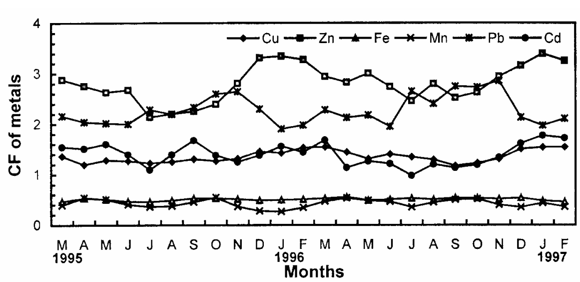

Fig. 4. Monthly variations in contamination factor (CF) values of different heavy metals of sediment of Jagannath canal.

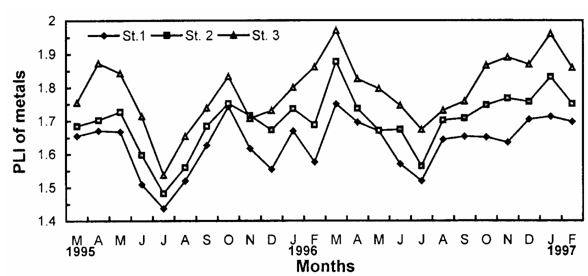

Fig. 5. Monthly variations in pollution load index (PLI) of heavy metals of sediment of Jagannath canal.

Table 1. Principal component (PC) analysis of correlation matrix of total heavy metals of sediment of Jagannath canal.

PC	Latent roots	Variance (%)	Cumulative variance (%)	PC score coefficinets					
				Cu	Zn	Fe	Mn	Pb	Cd
PC1	2.783	46.38	46.38	0.460	0.490	-0.302	-0.331	-0.422	0.412
PC2	1.197	19.95	66.33	0.299	0.211	0.670	0.570	-0.062	0.299
PC3	0.991	16.52	82.85	0.404	0.329	0.308	-0.424	0.536	-0.408
PC4	0.448	7.46	90.31	-0.115	-0.157	-0.003	-0.208	0.593	0.753
PC5	0.322	5.36	95.67	-0.095	0.377	-0.576	0.557	0.422	-0.083
PC6	0.260	4.33	100.00	-0.716	0.664	0.184	-0.104	-0.033	0.028

variance accounted for. Iles (1993) indicates the collinearity among the variables from the condition number (CN) which is calculated by the square root of the ratio of largest and smallest latent roots. He mentioned that only if the CN exceeds the critical value of 10, there is indication of possible collinearity among the variables. As the CN is very low (3.27) than the critical value and the contribution of all the metals are more or less same in the total variance, the observed simple correlation between Cu and Zn, and Fe and Mn can not be considered as collinear. However, considerable weight imparted by Cd in the total variance and its high CF value warrants frequent monitoring of this metal in order to preserve the ecosystem unimpaired.

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