DISTRIBUTION OF SOME TRACE METALS IN THE MANDOVI ESTUARY OF GOA, WEST COAST OF INDIA

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ABSTRACT

Both surface and bottom water samples were collected from ten sampling stations located along the Mandovi estuary in Goa. These water samples were analyzed for some trace metal contents viz. Zinc, Iron, Cadmium, Cobalt and Copper. The samplings were carried out during three seasons viz. pre-monsoon (February-May), monsoon (June-September), post-monsoon (October-January). The general distribution of Zinc (g/l) varied from 19.05 to 187.25 during pre-monsoon, 14.7 to 30.75 during monsoon and 3.25 to 23.65 during post-monsoon while Iron (g/l) concentration varied from 20.95 to 269.65 during pre-monsoon, 8.8 to 114.55 during monsoon and 34.10 to 125.45 during post-monsoon. Cadmium (g/l) concentrations varied from 0.35 to 2.8 during pre-monsoon, from 0.23 to 1.05 during monsoon and from 0.45 to 1.75 during post-monsoon while Cobalt (g/l) concentrations varied from 0.1 to 1.10 during pre-monsoon, from 0.30 to 1.05 during monsoon and from 0.32 to 0.70 during post-monsoon. Copper (g/l) concentrations varied from 0.45 to 0.65 during pre-monsoon, from 0.2 to 5.74 during monsoon and from 0.45 to 5.5 during post-monsoon.

Keywords : ***Mandovi, Estuary, West coast, Trace metals, Industrial effluents.***

INTRODUCTION

Metals are introduced into the aquatic environment from different sources like geological weathering, industrial processing of ores and metals, the use of metals and metal components, leaching of metals from garbage and solid waste dumps as well as animal and human excretions which contain heavy metals (Forster and Wittmann, 1979). It is expected that in areas characterized by metal-bearing formations, these metals will occur at elevated levels in the water and bottom sediments of the particular area. The intensive mining activities in mineralized zones leads to disposal of tailings and the discharge of effluents. Almost all metals, including the essential micronutrients, are toxic to aquatic organisms as well as humans if exposure levels are sufficiently high.

Trace metals introduced into the aquatic systems from different sources enter the aquatic food chain and are at times accumulated in significant quantities (Horne, 1969). Metal ions in solution can be absorbed into aquatic plants and animals and can cause toxicity if concentration is sufficiently high (Alloway and Ayres, 1993). Metal concentrations in aquatic organisms are typically of higher magnitude as compared to the concentrations of the same metals in water. This has led to some speculation that metals may become progressively concentrated at higher trophic levels in aquatic food chains due to biological magnification (Laws, 1981). They not only affect the life cycle of various aquatic organisms but also may eventually cause hazards to human beings consuming them. Their presence in the environment has increased in some areas to levels which threatens the health of aquatic and terrestrial organisms.Therefore an attempt has been made to assess the distribution of some trace metals in the of Mandovi estuary of Goa, west coast of India.

MATERIALS AND METHODS

The Mandovi river originates from the Parwa ghat of the Karnataka part of the Sahyadri Hills and after transversing a stretch of about 70 kms joins the Arabian Sea through the Aguada bay near Panaji. Its width at the mouth of the estuary is 3.2 km while in upstream it narrows down to 0.25 km. It is fed by monsoon precipitation, and discharges from a catchment area of about 1150 km^2 of which 435 km^2 are forest land. Its basins cover an area of about 1530 km^2 and constitute 42 % of the total land area of Goa. Its post-monsoon and pre-monsoon flow is mainly dominated by the semi diurnal tides having a maximum range of 2.3 m. It has a large tributary system and has a number of islands, sharp turns and shallow depths along its course.

The station locations in the study area is given. The area of investigation covers the Mandovi estuary in Goa (west coast of India). It comprises ten sampling stations viz. ME1 to ME10. These stations cover the entire course of the river i.e. from the head to the mouth region. Water samples for the study were collected in three seasons viz. pre-monsoon (May), monsoon (July) and Post-monsoon (November). Surface and bottom water samples were collected using GO-FLOW Niskin water sampler fastened to a plastic rope and was triggered by a messenger.

For trace metal analysis an aliquot (800 ml) of the water sample was filtered soon after its collection through a 0.45 um filter (millipore HA) and collected into a precleaned polyethylene bottle and acdified with HCl to pH of 2-3. The acidified filtered water samples were used for determination of concentration of trace metals viz. Zinc, Iron. Cadmium, Cobalt and Copper (Brooks *et al.*, 1967 and Tsukaijan and Young, 1978). The trace metals were analysed from the water samples using Atomic Absorption Spectrophotometer (AAS).

RESULTS AND DISCUSSION

The trace metal concentrations of the water samples in the Mandovi estuary in the different seasons are furnished in Table 1.

Table 1. Data on seasonal variation of trace metals in estuarine waters of the Mandovi river of Goa.

		Premonsoon (μg l^{-1})					Monsoon (μg l^{-1})					Post monsoon (μg l^{-1})				
Station	Depth.	Zn	Fe	Cd	Co	Cu	Zn	Fe	Cd	Co	Cu	Zn	Fe	Cd	Co	Cu
ME1	S	NA	NA	NA	NA	NA	30.75	26.00	0.23	0.45	3.05	23.65	95.90	1.55	0.55	4.05
	B	NA	NA	NA	NA	NA	25.90	114.55	0.35	0.85	3.55	16.80	65.95	1.25	ND	2.75
ME 2	S	21.75	31.30	0.35	0.85	3.95	20.15	19.95	ND	ND	4.62	10.70	35.75	1.40	0.35	2.20
	B	27.66	226.80	1.10	0.70	3.70	17.50	59.70	ND	0.55	5.74	13.50	91.00	1.75	0.45	2.95
ME3	S	34.55	118.05	2.80	0.95	4.25	14.90	11.90	0.55	0.45	2.90	6.40	62.10	1.30	0.65	1.90
	B	24.15	55.70	2.35	0.50	4.60	16.55	11.75	0.65	ND	2.65	9.40	62.15	1.60	0.60	2.45
ME 4	S	26.65	269.65	1.85	0.65	4.75	18.05	8.80	ND	0.55	3.83	18.40	23.60	1.10	ND	2.75
	B	28.80	76.80	1.70	ND	4.55	14.70	12.90	0.45	0.60	4.05	19.85	11.90	1.35	0.70	5.50
ME 5	S	19.20	72.90	1.80	0.55	1.25	18.20	51.30	ND	ND	2.75	3.85	23.60	1.70	ND	1.65
	B	21.20	28.110	1.35	ND	2.35	16.30	13.85	0.65	ND	2.80	6.65	40.05	1.50	0.65	1.50
ME 6	S	21.50	65.35	1.45	ND	3.55	18.40	46.95	0.75	ND	1.35	7.35	4.10	1.65	0.40	1.75
	B	26.45	99.25	1.30	0.70	1.60	23.30	56.05	ND	1.10	0.65	6.65	19.65	1.45	0.70	1.95
ME 7	S	27.85	39.25	0.50	1.10	6.50	21.65	64.80	0.95	1.05	0.75	3.25	8.70	1.20	ND	1.05
	B	19.05	32.15	0.55	ND	2.35	19.15	13.85	0.45	0.85	0.55	25.40	69.25	1.35	0.32	1.45
ME 8	S	187.25	35.55	0.55	0.60	1.55	15.55	23.70	ND	ND	0.55	19.60	125.45	1.70	ND	0.55
	B	33.05	29.85	1.15	0.85	0.95	18.20	68.10	0.65	0.60	0.40	8.80	92.10	1.05	ND	0.75
ME 9	S	32.10	38.15	0.75	ND	0.75	18.95	56.10	0.45	0.95	0.70	3.80	24.05	1.55	0.43	0.45
	B	25.70	27.65	0.35	0.80	0.80	22.25	51.60	0.50	0.70	2.25	10.50	53.40	0.45	0.58	0.65
ME 9a	S	39.05	65.75	0.70	0.10	0.55	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	B	57.90	124.10	0.75	0.90	1.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ME 10	S	22.70	20.95	0.85	0.70	0.45	15.95	37.05	1.05	0.45	0.20	14.95	50.35	0.85	0.65	0.85
	B	24.75	65.00	0.45	0.45	0.85	17.25	38.45	0.50	0.30	0.45	23.50	71.30	1.70	0.42	0.60

(Keys : M. E. = Mandovi Estuary; S = Surface; B = Bottom; ND = Non Detectable; NA = Not analysed).

Zinc: Concentrations of zinc (μg l^{-1}) in the Mandovi estuary in surface waters varied from 19.2 to 187.25 and 19.05 to 57.9 in bottom waters during pre-monsoon, from 14.9 to 30.75 in surface and 14.7 to 25.9 in bottom waters during monsoon and from 3.8 to 23.05 in surface and 6.65 to 25.4 in bottom waters during post-monsoon period. However, the general distribution of zinc varied from 19.05 to 187.25 during pre-monsoon, from 14.7 to 30.75 during monsoon and 3.25 to 23.65 during post-monsoon (Table 1).

In general, surface waters recorded lower values of zinc compared to bottom waters. These variations can be explained in terms of phytoplankton productivity and decomposition of organic matter at the bottom waters. Zinc could get strongly depleted from the surface waters as it has a nutrient type of distribution in seawater (Pragatheeswaran *et al.*, 1988).

The range and average of zinc obtained in the present study (Table 2) broadly agree with those reported earlier from estuarine waters of Goa (Zingde *et al.*, 1978), Pondicherry coast (Govindasamy et al., 1998), Coromandal coast (Govindasamy and Azariah, 1999) and Arabian Sea (Sen Gupta *et al.*, 1978). The study revealed slightly higher concentration when compared with those reported earlier from inshore and coastal waters of Bay of Bengal (Qasim and Sen Gupta, 1980), Laccadive sea (Sanzgiri and Moroes, 1979), Andaman sea (Sanzgiri and Braganca, 1981), Bay of Bengal (Branganca and Sanzgiri, 1980), Indian Ocean waters (Danielsson *et al.*, 1980) and Mindhola river estuary (Zingde *et* *al.*, 1988). The concentrations were found lower when compared with those reported earlier from Bombay Harbour (Patel *et al.*, 1985), Madras coast (Daniel, 1987), Cochin estuary (Ouseph, 1992) and coastal regions of Visakhapatnam (Satyanarayana *et al.*, 1985).

Table 2. **Comparison of range and average concentrations of trace metals in estuarine waters of Mandovi river of Goa with other regions.**

Location	Zn	Fe	Cd	Co	Cu	References
Average sea water composition	4.9	02	0.1	0.05	0.5	Peter G. Brewer, 1975.
Mandovi estuary	3.25-187.25 (18.2)	4.10-269.65 (55.667)	0.23-2.8 (0.966)	0.10-1.10 (0.455)	0.2 - 6.5 (2.198)	Present study
Zuari estuary	4.65-208.0 (22.78)	10.8-239.80 (48.96)	0.20-5.75 (0.89)	0.20-1.47 (0.39)	0.3 - 7.95 (2.24)	Singh. Khelchandra, 2000
Mandovi estuary	6.2-28.1	165.0-850.0	---	---	2.5 - 5.8	A - Zingde *et al.*, 1978 and B - Kamat and Sankarnarayanan, 1974.
Zuari estuary	5.2-35.5	174.0-900.0	---	---	2.6 - 6.8	A - Zingde *et al.*, 1979 and B - Kamt and Sankarnarayanan, 1975.
Mandovi estuary	---	---	---	---	1.97 - 43.5	Sankarnarayanan and Reddy, 1973.
Zuari estuary	---	---	---	---	4.8 - 67.27	Sankarnarayanan and Reddy, 1973.
Bombay harbour	27	---	0.1	0.5	16.0	Patel *et al.*, 1985.
Madras coast	15.0-290.0	---	1.0 - 4.0	---	6.0 - 170.0	Daniel, 1987
Pondicherry coast	16.70-135.70	---	3.2-69.0	ND - 9.50	0.7 - 61.5	Govindasamy *et al.*, 1998
Coramandel coast	9.0-130.60	---	0.30-66.80	ND - 9.60	0.31 - 50.70	Govindasamy and Azariah, 1999.
Cochin estuary	105.0-385.0	0.2-0.8	1.8-4.2	---	2.2 - 22.20	Ouseph, 1992.
Tutocorin coast	---	4.5-130.25 (29.95)	---	---	---	Ganesan and Kannan, 1995
Inshore and coastal waters of Bay of Bengal	2.6-15.30 (9.0)	6.5-131.5 (69.0)	---	ND	2.7 - 6.80 (4.7)	Qasim and Sen Gupta, 1980.
Coastal Region of Visakhapatnam	2.9-39.5 (23.7)	6.0-44.1 (15.1)	0.5-1.9 (1.0)	ND	0.5 - 6.2 (2.21)	Satyanarayana *et al.*, 1985.
Arabian Sea	0.5-42.40 (19.209)	7.2-66.9 (20.148)	---	ND - 6.6 (1.569)	1.7 - 7.9 (4.85)	Sen Gupta *et al.*, 1978.
Laccadive Sea	1.2-29.7	8.5-96.0	---	ND - 6.7	1.9 - 19.9	Sanzgiri and Moroes, 1979.
Andaman Sea	1.2 - 12.80	2.0 - 21.70	0.15 - 1.90	ND - 1.0	1.0 - 5.0	Sanzgiri and Braganca, 1981.
Bay of Bengal	2.40-20.0	6.2 - 131.5	---	ND - 7.9	22.0 - 37.20	Braganca and Sanzgiri, 1980.
Indian Ocean waters	0.6-13.80	0.15-10.0	0.01 - 0.16	ND - 0.02	0.08 - 0.48	Dinielsson, 1980
Mindhola river estuary	3.0 - 48.0	---	---	---	2.6 - 15.90	Zingde *et al.*, 1988.

Values in parentheses are average values; ND - Non detectable; All values in $\mu g\ l^{-1}$.

Seasonal variation of zinc registered highest values during pre-monsoon followed by monsoon and post-monsoon seasons (Fig. 1) During pre-monsoon period mining activities are very intensive. A large number of barges transport iron and manganese ores to the adjoining Mormugao harbour along the Mandovi river. In addition to these, high temperature favours decomposition of organic matter, by setting the trace metals in the bottom sediments which can be resuspended by tides (Martin and Whitfield, 1983). All these factors must have kept the concentration higher in pre-monsoon period. High concentration of zinc during monsoon compared to post-monsoon is perhaps due to large amount of land and river drainage during monsoon. Similar higher values of zinc during premonsoon were reported by Govindasamy and Azariah (1999) at Mahabalipuram and Pondicherry, Senapati and Sahu (1996) at Subernarekha river and Ouseph (1992) in Cochin estuarine waters.

Iron: During the pre-monsoon the concentrations of iron (g l^{-1}) varied from 20.95 to 269.7 in surface waters and 27.65 to 226.8 in bottom waters, from 8.8 to 64.8 in surface and 11.75 to 114.6 in bottom waters during monsoon and from 4.10 to 125.5 in surface and 8.65 to 25.4 in bottom waters during post-monsoon. However, the general distribution of iron varied from 20.95 to 269.65 during pre-monsoon, from 8.8 to 114.55 during monsoon and 4.10 to 125.45 during post-monsoon (Table 1).

The range and average of iron obtained in the present study (Table 2) revealed slightly higher concentration when compared with those reported earlier from Arabian sea (Sen Gupta *et al.*, 1978), Laccadive sea (Sanzgiri and Moroes, 1979), Andaman sea (Sanzgiri and Braganca, 1981), Bay of Bengal (Branganca and Sanzgiri, 1980), Indian Ocean waters (Danielsson *et al.*, 1980), Cochin estuary (Ouseph, 1992) and coastal regions of Visakhapatnam (Satyanarayana *et al.*, 1985) and Tuticorin coast (Ganesan and Kannan, 1995). The study revealed lower concentration when compared with those of earlier reports from, coastal waters of Bay of Bengal (Qasim and Sen Gupta, 1980). However, it revealed lower concentrations when compared with earlier reported from estuarine waters of Goa (Kamat and Sankaranarayanan, 1975). Concentrations of iron registered highest values during the pre-monsoon period followed by post-monsoon and monsoon in the Mandovi (Fig. 2).

Like zinc bottom waters registered higher values of iron compared to surface waters. The higher concentration of iron in bottom waters has been attributed to the release of iron from the bottom deposits due to turbulence (Kamat and Sankaranarayanan, 1975). Presence of considerable amounts of organic matter with which Fe forms both soluble and insoluble metal chelates (Sen Gupta et al., 1978) may also be responsible for higher concentration in bottom waters.

Relatively higher concentration during pre-monsoon can be attributed to intensive mining activities and transportation of iron ores through these rivers by barges. This could have contributed to substantial amount of iron inputs in the water, which kept the concentration high during the pre-monsoon.Iron ore deposits in this region appear to be influencing the concentration levels of iron of these waters to a greater extent (Kamat and Sankaranarayanan, 1975). No plausible explanation can be offered for high concentrations during post-monsoon compared to monsoon in the Mandovi estuary. Similar higher values of iron during pre-monsoon were recorded from Cochin estuary (Ouseph, 1992) and Subernarekha river (Senapati and Sahu, 1996). However, Ganesan and Kannan (1995) reported higher concentrations from Tuticorin coast during the monsoon season.

Cadmium: In the Mandovi estuary, concentrations of cadmium (g l^{-1}) during pre-monsoon in surface waters varied from 0.35 to 2.8 and 0.35 to 2.35 in bottom waters. During monsoon concentrations varied from 0.23 to 1.05 in surface and 0.35 to 0.65 in bottom waters and from 0.85 to 1.7 in surface and 0.15 to 1.75 in bottom waters during post-monsoon. However, the general distribution of cadmium varied from 0.35 to 2.8 during the pre-monsoon, from 0.23 to 1.05 during monsoon and from 0.45 to 1.75 during post-monsoon (Table 1). The concentrations of cadmium in water of a few stations were out of detectable range during monsoon season.

Unlike Zn and Fe, cadmium recorded higher concentrations in surface than bottom waters in both the estuaries. High concentrations in the surface waters strongly suggest anthropogenic inputs injected by industrial activities along these two rivers.

The range and average of cadmium obtained in the present study (Table 2) generally agree with those reported earlier from coastal regions of Visakhapatnam (Satyanarayana *et al.*, 1985) and Andaman sea (Sanzgiri and Braganca, 1981). It revealed slightly higher concentration when compared with those reported earlier from Indian Ocean (Danielsson et al., 1980) and Bombay harbour (Patel *et al.*, 1985). Lower concentrations were revealed when compared with those of earlier reports from Madras coast (Daniel, 1987), Pondicherry coast (Govindasamy *et al.*, 1998), Coromandel coast (Govindasamy and Azariah, 1999) and Cochin estuary (Ouseph, 1992).

Relatively higher concentrations during post-monsoon and pre-monsoon can be attributed to increased number of barges traffic along the Mandovi river. According to Paul and Pillai (1983) increased concentrations of Cu and Cd during nonmonsoon period was due to evaporation and increased dissolution from sediments due to higher summer temperature and larger contact time. Similar high concentrations of Cd during postmonsoon were reported from Mahabalipuram and Pondicherry (Govindasamy and Azariah, 1999).

Cobalt: Concentrations of Cobalt (g l^{-1}) in surface waters varied from 0.10 to 1.1 and 0.45 to 0.9 in bottom waters during the pre-monsoon, from 0.45 to 1.05 in surface and 0.30 to 1.10 in bottom waters during monsoon and from 0.35 to 0.65 in surface and 0.32 to 0.7 in bottom waters during post-monsoon. However, the general distribution of cobalt varied from 0.10 to 1.10 during the pre-monsoon, from 0.30 to 1.10 during monsoon and from 0.32 to 0.70 during the post-monsoon (Table 1).The concentrations of cobalt in water of a few stations were out of detectable range in all the three seasons.

Like Zn and Fe surface waters registered lower values of Co compared to bottom waters in both the estuaries. Lower values in surface waters are due to removel of a substantial amount of Co from surface waters by phytoplanktons (Bruland and Franks, 1983).

The range and average of Co obtained in the present study (Table 2) broadly agree with those reported earlier from Bombay harbour (Patel *et al.*, 1985), Andaman Sea (Sangziri and Braganca, 1981). But it revealed lower concentration when compared with those reported earlier from Pondicherry coast (Govindasamy *et al.*, 1998), Coromandal coast (Govindasamy and Azariah, 1999), Arabian Sea (Sen Gupta *et al.*, 1978), Laccadive Sea (Sangziri and Moroes, 1979) and Bay of Bengal (Braganca and Sangziri, 1980). But it revealed higher concentrations when compared with those reported earlier from water samples of Indian Ocean (Danielsson *et al.*, 1980).

Seasonal variation of Co in Mandovi estuary registered highest values during pre-monsoon period closely followed by those in monsoon and post-monsoon periods (Fig. 2). High concentrations may be due to intensive mining activities and transport of iron ores along these rivers by barges. Govindasamy and Azariah (1999) reported high concentrations of Co during the pre-monsoon at Mahabalipuram and Pondicherry.

Copper: The concentrations of Copper (g l^{-1}) in surface waters varied from 0.45 to 6.5 and 0.8 to 4.6 in bottom waters during pre-monsoon, from 0.2 to 4.62 in surface and 0.45 to 5.74 in bottom waters during monsoon and from 0.45 to 4.05 in surface and 0.65 to 5.5 in bottom waters during post-monsoon. However, the general distribution of copper varied from 0.45 to 6.5 during the pre-monsoon, from 0.2 to 5.74 during monsoon and from 0.45 to 5.5 during the post-monsoon (Table 1).

Like Zn, Fe and Co surface waters registered lower values of Cu compared to bottom waters in both the estuaries. Presence of high organic matter with which copper forms soluble and insoluble metal chelates may be resposible for the high concentrations in bottom waters (Raman and Ganapathi, 1983).

In general, the range and average of Cu obtained in the present study (Table 2) broadly agree with those reported earlier from estuarine waters of Goa (Zingde *et al.*, 1978) coastal region of Visakhapatnam (Satyanarayana *et al.*, 1985) and Andaman Sea (Sangziri and Braganca, 1981). But it revealed lower concentration when compared with those reported earlier from estuarine waters of Goa (Sankaranarayana and Reddy, 1973) Bombay harbour (Patel *et al.*, 1985), Madras coast (Daniel, 1987), Pondicherry coast (Govindasamy *et al.*, 1998), Coromandal coast (Govindasamy and Azariah, 1999), Inshore and Coastal waters of Bay of Bengal (Qasim and Sen Gupta *et al.*, 1980), Arabian Sea (Sen Gupta *et al.*, 1978), Laccadive Sea (Sangziri and Moroes, 1979), Mindhola estuary (Zingde *et al.*, 1988). The study revealed higher concentrations when compared with those reported earlier from water samples of Indian Ocean (Danielsson *et al.*, 1980).

It is evident from Fig 2. that the concentration of Cu is found to be highest during pre-monsoon followed by those in monsoon and post-monsoon in both the estuaries. According to Osterroht, (1988) dissolved organic copper exists in two forms, i.e., one probably originating from humic acid being responsible for the constant background level of dissoved organic copper, while the other is formed from materials produced recently by the phytoplanktons resulting to the additional peak concentration of dissolved organic copper. The amount of this additional organic copper depends on the productivity and varies from region to region and is also subject to rapid changes. Because of the high productivity in Mandovi estuary during the pre-monsoon (Dehadrai and Bhargava, 1972), the organic matter available for decomposition is much more than those in monsoon season. The decomposition products of the organic matter are brought to the water by different mechanisms like current, tidal cycle (Duinker, 1982) and diffusion (Gobiel et al., 1987). Besides, mining and barges activities are found to be very rapid. Due to all these factors , concentration is found to be higher in pre-monsoon period. Ouseph (1992) has also reported high copper content during the pre-monsoon from Cochin estuary. High concentration of copper during the pre-monsoon at Mahabalipuram and during post-monsoon at Pondicherry were reported by Govindasamy and Azariah (1999). These variations were attributed to the major sources of metal pollution, intensive human activity, discharge of domestic waste and land run-off reaching the coastal area at Mahabalipuram and also discharge of industrial effluents, sewage outlet and municipal wastes at Pondicherry.

The range and average values obtained for the trace metals in the present study are in broad agreement with the findings in some Indian estuarine and coastal waters. But the concentrations are found higher than the Indian Ocean waters and average seawater composition. In general, all metals showed higher concentration during pre-monsoon followed by monsoon and post-monsoon seasons. During pre-monsoon, there is little or negligible precipitation and runoff is almost absent. A good steady weather prevails, which increases the barge traffic along the river transporting iron ores to adjoining Mormugao harbour. Mining activities are also intensive during this period. Factors like high temperature, light penetration, high nutrient availability are common during pre-monsoon season. High temperature favours decomposition of organic matter in releasing trace metals on the surface sediments, which can be resuspended by tides, currents and dredging. These combined effects might have resulted in higher concentrations of metals during pre-monsoon period. Lower concentrations observed during monsoon period may be due to the reduced mining and shipping activity. During monsoon, river discharge is very high and shipping while mining activities are very less compared to other seasons. Because of the rough weather at the mouth of the estuary, loading of iron ore is at its minimum. The dilution due to precipitation and reduced shipping and mining activities could have kept the concentrations of all the metals at a lower level during monsoon season.

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