Indian Journal of Geo-Marine Sciences
Vol. 44(10), October 2015, pp. 1613-1621

Impact of Thane cyclone on the heavy metal distribution in water, sediment, plankton and fish (*Mugil cephalus*) in selected areas along the Tamil Nadu, Southeast coast of India

Chinnaraja, V., P. Santhanam* and S. Dinesh Kumar

Marine Planktonology & Aquaculture Lab., Department of Marine Science, School of Marine Sciences, Bharathidasan University, Tiruchirappalli-620 024, Tamil Nadu, India.
*[E-mail: sanplankton@yahoo.co.in; santhanamcopepod@gmail.com]

Received 19 March 2014; revised 12 May 2014

Investigations on distribution of heavy metals in water, sediment, plankton and fish (*Mugil cephalus*) was studied in Thane cyclone affected areas (Pondicherry, Cuddalore, Nagappattinam) and un-affected area (Mimisal). Accumulation rate of heavy metals was noticed in the order of Sediment > Water > Plankton > Fish. In water, the metal distribution order was found to be high in the order of Nagapattinam > Mimisal > Cuddalore > Pondicherry. Iron as dominant metal (28.91µg/l) at Mimisal and cadmium as least recorded metal (0.75µg/l). In sediments, the order was Cuddalore > Pondicherry > Nagappattinam > Mimisal. The zinc noticed as a dominant metal with 10.79µg/g at Cuddalore and cadmium minimum (0.59µg/g) found in Pondicherry. The area wise metal distribution in plankton were Pondicherry > Nagappattinam > Cuddalore > Mimisal with cadmium minimum (0.79µg/g) recorded at Pondicherry and zinc maximum (58.54µg/g) at Cuddalore. While for fish the order of metal accumulation was Mimisal > Pondicherry > Nagappattinam > Cuddalore with a maximum accumulation (23.02µg/g) of zinc at Mimisal and minimum (0.70µg/g) of cadmium at Cuddalore.

[**Keywords:** Thane cyclone, Metal, Plankton, Fish, South east coast of India]

Introduction

Marine fishes are serving as chief protein sources which need to be protected from smear by heavy metals which are potentially toxic to the consumer. Numbers of studies illuminating the bioaccumulation of heavy metals by oysters, clams, crabs, shrimps, fish and plankton in near-shore environments have been studied by several workers[1-9]. The metal contaminants in aquatic systems usually remain either in soluble or suspension form and finally tend to settle down to the bottom and are taken up by all the organisms. The progressive and irreversible accumulation of these metals in various organs of marine creatures leads to various diseases in the long run because of their toxicity, thereby endangering the aquatic biota and other organisms[10, 11]. Fishes being one of the main aquatic organisms in the food chain may often accumulate large amounts of certain metals such as zinc, cadmium, copper, lead, nickel, cobalt and sodium dichromate[12]**.** Directly acting or synergistically acting metals like Iron (Fe), Zinc (Zn), Lead (Pb), Cadmium (Cd) and Copper (Cu) are common toxic pollutants for fish[9]**.** Normally, fishes assimilate these heavy metals through ingestion of suspended particulates, food materials and /or by constant ion-exchange process of dissolved metals across lipophilic membranes like the gills/adsorption of dissolved metals on tissue and membrane surfaces. Some of these metals, such as Cd and Pb, are toxic to living organisms even at quite low concentrations, whereas others, such as Zn and Cu, are biologically essential and natural constituents of aquatic ecosystems, and generally become toxic at very high concentrations viz., Zn -60 µg/g and Cu – 10 µg/g[13]. Being non biodegradable like many organic pollutants, metals can be concentrated along the food chain, producing their toxic effects at points often far away from the source of the pollution[14]. Accumulation of heavy metals in the food web can occur either by accumulation from the surrounding medium, such as water or sediment, or by bioaccumulation from the food source[15]. Aquatic organisms have been widely used in biological monitoring and assessment of safe environmental levels of heavy metals. Further, the Thane cyclone that struck the Indian coasts on 29th December 2011 with the speed of more than 165 km/hr has caused considerable changes in the marine ecosystem by polluting the environment with high turbidity and also breaken the coastal vegetations[16]. With this view, the present study is aimed to determine the impact of Thane cyclone on the distribution of heavy metals in water, sediment, plankton and fishes (*Mugil cephalus*) in selected affected areas such as Pondicherry, Cuddalore and Nagapattinam and compared the data's with Thane cyclone non affected area Mimisal which is located in the eastern zone of the Bay of Bengal during January to June 2012. Mimisal located at Palk Bay region of the Southeast coast of India. No Thane cyclone struck the Mimisal coastal zone[17].

Materials and Methods

The sampling sites are shown in the Fig. 1. The study area's are Pondicherry [Lat. 11°55'N; Long. 79°50'E], Cuddalore [Lat. 11°43' N; Long. 79°49' E], Nagapattinam [10°45' N; Long. 79°51' E] and Mimisal [Lat. 9° 51' N Long. 79° 7' E]. Among these four sampling areas, Pondicherry, Cuddalore and Nagapattinam are severely affected by Thane cyclone on 29th December 2011 where as Mimisal was unaffected area.

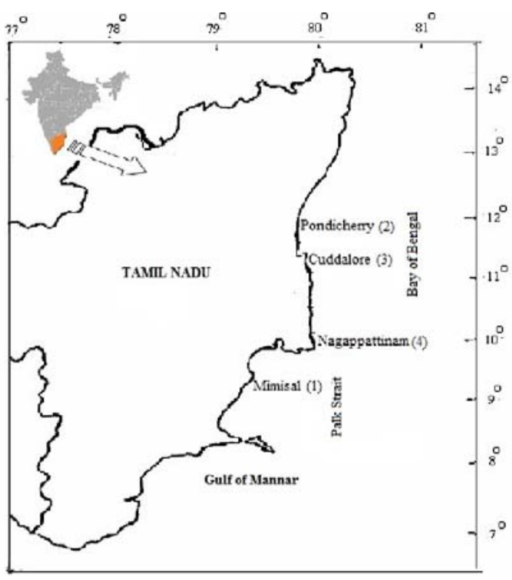

Fig.1. Study area

The water, sediment, plankton and fish samples were collected from the 4 sampling stations (Pondicherry, Cuddalore, Nagapattinam and Mimisal) for the period of six months from January to June 2012. Two litre of surface water samples were collected in pre cleaned and acid washed polypropylene bottles and they were filtered through GF/C filter paper [mesh size 0.45μm] using Millipore filtering apparatus. The samples were pre-concentrated with APDC – MIBK extraction procedure[18]. The physico-chemical and nutrients were estimated following the method of Strickland and Parsons[19].

Sediment samples were collected in pre cleaned, acid washed PVC corer, transferred to clean polythene bags and transported to the laboratory. These samples were then washed with metal free double distilled water and oven dried at 150ºC for 5-6 hr. The dried sample was ground to powder in a glass mortar and stored in pre-cleaned polythene bags. Analyses of metals was continued by digesting the 250 mg of sediment samples with a mixture of 1 ml of Sulphuric acid (H_2SO_4), 5 ml conc. Nitric acid (HNO_3) and 2 ml of conc. Perchloric acid ($HClO_4$). 2 ml of Hydrofluoric acid (HF) were added in order to achieve complete dissolution of the materials. The mixture was boiled, evaporated to near dryness and the resuspended in 10 ml 2 N HCl. This was passed through a filter paper and made up to 25 ml with metal free double distilled water. The resulting solution was then stored in polypropylene containers. Concentrations of Cu, Zn, Pb, Fe and Cd in the solution were determined by aspirating the solution to a standard Flame Atomic Absorption Spectrophotometer[20].

Heavy metals from plankton were extracted following the method of Ibrahim *et al.*, [21]. Plankton samples were collected with the aid of a plankton net (mesh size: 48μm) through horizontal hauls. The plankton samples were filtered through pre-weighed Whatman GF/C filter paper (1 μm) under mild vacuum. The filter paper was dried in desiccators, to constant weight and weight of the filter paper was determined using a balance with an accuracy of 0.01 mg. Dry weight of the plankton was determined by subtracting the initial weight of filter paper from the final weight. Samples were heated in a mixture of concentrated sulfuric and nitric acid (1: 10, V/V) under reflux. After about 4 h of reflux the solution was cleared by the addition of 4 ml of hydrogen peroxide. The acidified samples were kept for analyses.

Fresh specimens of fish (*Mugil cephalus*) were collected using cast and gill net in the respected study areas. The fish samples (90-270 mm total length) were washed and dissected using a stainless steel scalpel and the body muscle below the first dorsal fin was removed for the analysis of Zn, Cu, Fe, Pb and Cd[22]. The dissected portion of body muscle tissues was dried in an oven at 110°C for 24 h. It was then weighed and subjected to acid digestion with conc. HNO_3 and $HClO_4$ (3:1 v/v) on a hot plate until a clear solution was obtained. The digested sample was then made up to 25 ml with metal free doubled distilled water and subjected to analysis.

Statistical analyses

Two-way ANOVA (Graphpad Prism-Ver 5.0) was employed to find the significant differences of heavy metal concentrations in water, sediment, plankton, and fish with regard to sites and seasons.

Results and Discussion

Water

Variation in the accumulation of Zn, Cu, Fe, Pb and Cd in water were recorded for four stations during January to June 2012 are shown in Table 1. In water, the accumulation of heavy metals among the four stations was observed in the order of Fe > Pb >Cu > Cd >Zn. Highest recorded value among heavy metals was obtained for Fe which varied from 7µg/l to 99.5µg/l with an average value of 23.75µg/l and the lowest recorded value was seen in Zn which varied from 1.25µg/l to 5.25µg/l with an average value of 3.14µg/l. The minimum concentrations of Fe were observed during April 2012 at Mimisal, Pondicherry and Cuddalore whereas at Nagappattinam it was noticed during February 2012. The maximum concentrations of Fe were observed during January 2012 at Mimisal and Pondicherry and in May-2012 at Cuddalore and Nagappattinam. This variation in metal concentrations might be due to the presence of major sources of metal pollutants discharged from industries, intensive human activity and discharge of municipal waste [23]. Among the metals analysed in water, Fe concentration showed elevated levels in all the stations with maximum at station 4 (Mimisal) which is non cyclone affected area (Fig 2). This may be due to river inflow which might have carried metal pollutant from the catchment areas during the sampling time. However, after Thane cyclone (December-2011), the affected area have recorded high metal concentration (except copper) compared to Mimisal (Non-affected area). After January, the heavy metal concentration was found to decrease in the cyclone affected area which did not showed any significant variation ($P > 0.05$). This may be because of dilution of river water. Except zinc, all other metals (Cu, Fe, Pb and Cd) were recorded high in three stations (Thane hited areas) than non affected area (Mimisal). Decomposition of the organic matter remains is found to release heavy metals back to sediments; and this process might be responsible for the strong association of Zn and Cu with organic carbon[24]. Moreover, the variation in the metal concentration is due to the impact of natural disasters that caused large scale seawater inundation and the receding tidal waves carried into the sea, debris, anthropogenic wastes, adjacent terrestrial parts including plastic materials and domestic disposals from the near lands[25].

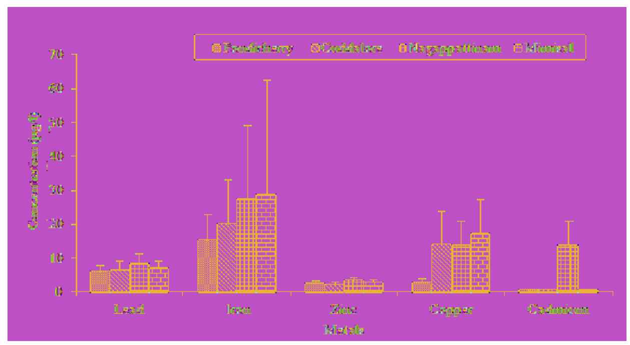

Fig.2. Heavy metal concentrations (µg/l) recorded in water samples along the Tamil Nadu coast

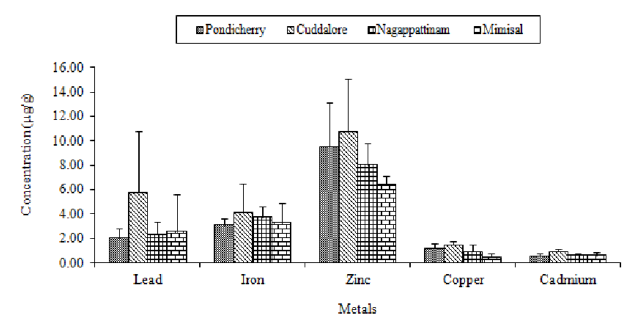

Fig.3. Heavy metal concentrations (µg/g) recorded in sediment samples along the Tamil Nadu coast

Sediment

In sediments, the distribution of heavy metals was found in the order of Zn (8.85 µg/g) > Fe (3.62 µg/g) > Pb (3.19 µg/g) > Cu (1.01 µg/g) > Cd (0.7 µg/g). Among the metals studied, the zinc was almost high and cadmium being the lowest in all the stations. Lowest concentration of zinc (4.75µg/g) was noticed during January, 2012 in Pondicherry and highest concentration was observed (19.5µg/g) during February, 2012 at Cuddalore with an average value of 8.85µg/g. The cadmium values were ranged from 0.25 to 1.13µg/g with an average value of 0.7µg/g.

The lowest concentration was recorded at Pondicherry (June-2012) and Mimisal (February-2012). The heavy metal was found high in cyclone affected area than non affected area could be attributed to the continuous stirring of sediments by the high speed of natural tidal actions[26].

Plankton

Assessment of heavy metal concentrations in plankton is very important because plankton is often the main diet for many predators and may contribute to the transfer of heavy metals to higher tropic levels[27]. Mean concentrations of heavy metals in plankton are shown in Fig. 4.

Fig.4. Heavy metal concentrations (µg/g) recorded in plankton samples along the Tamil Nadu coast

The distribution of heavy metals (mean values) in plankton sample with respect to areas were found in the following order. Lead: Pondicherry > Mimisal > Cuddalore > Nagappattinam; Iron: Nagappattinam > Mimisal > Pondicherry > Cuddalore; Zinc: Cuddalore > Nagappattinam > Pondicherry > Mimisal; Copper: Pondicherry > Mimisal > Cuddalore > Nagappattinam; Cadmium: Cuddalore > Nagappattinam > Mimisal > Pondicherry. From these results, it is clear that the highest metal concentration of 58.54µg/g was contributed by zinc recorded from the Cuddalore. Whereas the, lowest metal concentration was 0.79µg/g contributed by cadmium from the Pondicherry. The results were explained that the Thane affected area showed higher metal distribution compared to non-affected area (Mimisal).

The results indicated that Cu, Cd, Fe and Pb concentrations in plankton were much lower than those of water and higher than the sediments. But Zn concentration was noticed enormously in plankton compared to water and sediment.

This may be related to the large surface area of planktonic organisms (phyto- and zooplankton) in relation to their mass unit, and their active metabolism leading to rapid adsorption of metals like zinc. The previous worker is reported some algal species protect themselves by trapping and accumulating pollutants (e.g. metals) in their polysaccharide cell walls[28]. The order of abundance of metals in plankton was Zn > Pb > Fe > Cu > Cd. This corresponds to the same order of abundance of these metals in sediment, which supports the hypothesis that sediment is an important source of plankton contamination. Bhanasway *et al.,*[27] have reported that the water is a main source of plankton contamination. But, in the present investigation, sediment reported higher metals in cyclone hitted areas which maybe turbulated due to high wave and current action during the cyclone. The concentration of heavy metals in plankton has been reported to depend leading several factors, such as the productivity of the body of water, the physico-chemical properties of the water, quantitative and qualitative composition of phyto and zooplankton, the capacity of heavy metal absorbance, and the season[29].The recorded concentrations of heavy metals in plankton are shown in Table 3.

Fish:

The accumulation of heavy metals was found high in cyclone struck area except zinc and copper, which followed the accumulation order of Zn > Fe > Pb > Cu > Cd. The distribution order was found similar in non-affected area too. But, variation in metals concentration between four stations is differing from metals to metals. Among the metals analysed, the lead and cadmium were high in cyclone affected areas whereas the iron, zinc and copper was high in non affected area (Mimisal). The highest concentration was contributed by Pb (7.75µg/g) followed by Fe (22.58µg/g), Zn (23.21µg/g), Cu (2.63µg/g) and Cd (1.04µg/g).

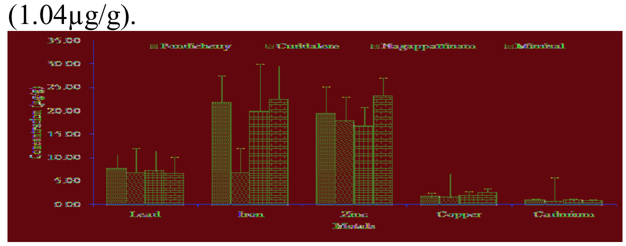

Fig.5. Heavy metal concentrations (µg/g) recorded in fish samples along the Tamil Nadu coast

Table 1: Heavy metals concentration (µg/l) in water samples collected from Thane cyclone affected and non-affected areas from January – June 2012.

	Metals	Lead				Iron				Zinc				Copper				Cadmium			
	Stations	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Months	January	6.2	11.7	13.7	8.5	30.2	47.2	18.2	11.2	3.5	2.7	3.5	3.2	3.0	22.7	23.0	23.5	1.0	1.0	23.0	1.00
	February	2.7	5.0	8.2	9.2	12.2	13.7	34.7	9.25	2.2	3.5	3.2	2.7	4.5	25.2	12.5	5.50	0.7	1.0	12.5	1.05
	March	6.0	7.5	8.0	7.0	15.5	20.0	22.2	28.7	2.7	2.5	3.5	3.0	4.0	14.0	15.0	17.2	1.0	0.7	15.0	0.75
	April	8.0	4.5	7.5	9.0	13.5	11.5	7.00	9.50	3.2	1.7	2.2	2.0	2.7	19.0	21.5	32.0	0.5	0.7	21.5	0.75
	May	8.2	4.0	3.2	3.0	7.00	16.0	69.7	99.5	2.2	1.2	5.2	3.7	1.2	1.25	5.00	21.0	0.5	0.5	5.00	0.75
	June	5.7	5.5	9.7	6.0	14.2	12.5	14.2	15.2	3.2	2.5	4.2	4.0	3.2	2.25	7.00	4.75	0.7	0.5	7.00	0.50
ANOVA	Factor	Month		Stations		Month		Stations		Month		Stations		Month		Stations		Month		Stations	
	df	4		2		4		2		4		2		4		2		4		2	
	F- Value	3.08		2.09		3.38		1.16		1.55		3.32		2.67		0.40		1.08		15.57	
	Significance	0.05		0.18		0.06		0.36		1.55		3.32		0.11		0.68		0.42		0.001	

Table 2: Heavy metals concentration (µg/g) in sediment samples collected from Thane cyclone affected and non-affected areas from January – June 2012.

	Metals	Lead				Iron				Zinc				Copper				Cadmium			
	Stations	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Months	January	1.7	3.00	3.2	0.2	2.5	2.7	4.7	4.5	06.5	19.5	11.0	5.7	1.5	1.2	1.7	0.2	0.7	1.1	0.8	1.0
	February	1.0	0.20	1.5	1.2	3.2	8.2	3.5	4.5	04.7	7.00	7.7	6.7	1.2	1.7	1.0	0.7	0.5	1.0	0.7	0.2
	March	2.5	05.7	2.5	5.0	3.2	4.0	3.2	3.2	09.5	07.5	8.0	6.5	0.7	1.5	0.9	0.5	0.8	1.0	0.7	0.7
	April	2.2	03.5	3.7	8.0	3.0	5.5	3.7	0.2	08.0	8.75	7.7	5.7	1.0	1.2	0.7	0.7	0.7	1.0	0.7	0.5
	May	3.2	06.7	1.0	0.5	2.7	1.2	2.5	3.0	13.0	9.75	6.5	7.0	1.0	1.5	1.0	0.5	0.5	0.7	0.6	0.7
	June	1.5	15.5	2.0	0.5	4.0	3.2	4.7	4.5	15.2	12.2	6.5	7.2	1.7	1.7	00	00	0.2	0.5	0.5	0.5
ANOVA	Factor	Month		Stations		Month		Stations		Month		Stations		Month		Stations		Month		Stations	
	df	4		2		4		2		4		2		4		2		4		2	
	F- Value	0.72		1.47		1.31		0.74		0.51		3.70		1.54		17.15		1.48		3.71	
	Significance	0.59		0.28		0.34		0.50		0.72		0.07		0.27		0.001		0.29		0.07	

Table 3: Heavy metals concentration (µg/g) in plankton samples collected from Thane cyclone affected and non-affected areas from January – June 2012.

	Metals	Lead				Iron				Zinc				Copper				Cadmium			
	Stations	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Months	January	18	0.7	3.5	3.5	1.7	0.7	37.5	23	53.7	64.0	56.2	50.0	25.5	5.5	3.5	24.7	1.0	1.1	1.0	1.0
	February	10	3.2	1.5	5.7	2.2	3.2	5.5	03	52.0	61.2	55.0	49.5	10.2	4.2	1.7	0.7	1.0	1.0	1.0	0.7
	March	03	2.5	2.0	5.0	2.7	2.5	5.5	03	50.7	58.5	54.5	47.7	08.7	2.5	1.5	6.0	1.0	0.8	1.0	0.7
	April	50.	0.7	2.2	5.5	2.5	0.7	4.2	03	50.0	58.7	53.7	47.2	07.5	0.0	1.2	2.7	0.7	0.7	1.0	0.7
	May	08	4.7	1.5	3.0	3.0	4.7	2.7	06	49.5	55.0	52.2	45.0	05.0	3.0	1.2	1.0	0.5	0.7	0.5	1.0
	June	01	3.7	1.2	7.5	4.2	3.7	3.5	05	46.2	53.7	51.2	37.5	01.7	0.5	0.0	0.0	0.5	0.7	0.5	0.7
ANOVA	Factor	Month		Stations		Month		Stations		Month		Stations		Month		Stations		Month		Stations	
	df	4		2		4		2		4		2		4		2		4		2	
	F- Value	0.37		8.08		0.73		1.27		8.46		58.1		1.54		0.54		0.89		0.03	
	Significance P< 0.05	0.81		0.01		0.59		0.32		0.00		1.71		0.27		0.60		0.51		0.96	

	Metals	Lead				Iron				Zinc				Copper				Cadmium			
	Stations	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Months	January	08.2	5.5	9.5	8.5	22.2	5.5	31.0	18.5	23.5	07.0	21.7	21.2	2.0	0.7	2.5	3.0	1.2	1.2	1.5	1.0
	February	13.2	9.0	7.5	12	32.2	9.0	22.2	37.0	27.5	26.2	17.5	25.2	2.7	2.2	2.7	3.2	1.2	0.7	1.0	1.0
	March	07.7	6.7	6.5	7.5	21.7	6.7	19.7	23.0	23.0	17.7	18.0	25.0	2.2	2.0	2.0	3.5	1.0	0.7	1.1	1.0
	April	07.5	9.5	13	2.0	22.5	9.5	14.5	19.7	15.0	16.5	18.2	26.0	1.2	1.5	2.2	1.5	1.0	0.5	0.7	1.0
	May	05.0	5.7	6.0	4.5	14.5	5.7	2.50	21.0	14.7	22.5	15.7	25.7	1.0	1.2	2.2	2.5	1.0	0.5	0.7	0.7
	June	04.7	5.0	0.0	5.5	18.2	5.0	29.0	16.2	13.7	17.5	09.5	16.0	1.0	1.7	0.5	2.0	0.7	0.5	0.5	0.5
ANOVA	Factor	Month		Stations		Month		Stations		Month		Stations		Month		Stations		Month		Stations	
	df	4		2		4		2		4		2		4		2		4		2	
	F- Value	1.32		0.06		1.27		6.53		3.87		9.18		2.58		2.48		9.18		8.27	
	Significance P< 0.05	0.33		0.93		0.35		0.02		0.04		0.00		0.11		0.14		0.00		0.01	

Table 4: Heavy metals concentration (µg/g) in fish (*Mugil cephalus*) collected from Thane cyclone affected and non-affected areas from January –June 2012

1. Mimisal 2. Pondicherry 3. Cuddalore 4. Nagappattinam (Station -1 Represented Non affected area; Stations – 2, 3 and 4 Represented Thane cyclone affected coastal areas).

The high concentration of Zn and Fe in the fish could be associated with the fact that these metals are naturally abundant in Indian coastal soils and since the source of metal depositories is the aquatic system[30]. In comparison to the affected area, higher metal concentration of Cu, Zn and Fe recorded at non-affected area (Mimisal). The observed variability ofmetal levels depends on feeding habits[31], ecological needs, metabolism[32], age, size and length of the fish[33] and their habitats[34] and natural activity like Tsunami, cyclone etc.,[26]. The recorded mean Zn concentration was ranged from 16.80µg/g to 23.21µg/g in tissues of *M. cephalus*. These values are similar to those reported previously[35-37]. The concentrations of heavy metals in fish are shown in Table 4.

In the present study, physico-chemical and nutrients characteristics of sea surface water were analysed and the results were given in the Table. 5 and 6. The maximum concentration of water temperature (32ºC), dissolved oxygen (8.79 mg/l), biological oxygen demand (6.37 mg/l) were recorded in Cuddalore and maximum concentrations of phosphate (5.63µmol/l), nitrite (14.65µmol/l), nitrate (20.92µmol/l) and ammonia (30.58µmol/l) were noticed in Nagapattinam. The reason behind this is rich discharges of agricultural and industrial wastes[38]. The maximum pH (8.20) and salinity (34 psu) was noticed in Mimisal and Pondicherry respectively. This might be due to high solar radiation, evaporation and less water mixing[39].

Table 5: Monthly variations in physico-chemical parameters of the selected study areas.

	Temperature (ºC)				pH				Salinity (psu)				DO (mg/l)				BOD (mg/l)			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Mean	29.6	29.5	29.3	29.8	7.77	7.73	7.38	7.73	30.1	30.1	29.3	30.3	5.14	7.11	7.31	5.98	3.28	4.89	4.98	3.68
Median	29.5	29.5	29.0	30.0	7.80	7.80	7.50	7.75	30.0	29.5	29.5	30.5	5.69	6.89	7.11	5.80	3.37	4.69	4.78	3.44
Range	5.00	3.00	2.00	2.00	0.90	1.00	1.50	0.40	4.00	5.00	2.00	3.0	6.99	2.39	3.10	1.48	5.31	2.22	3.03	1.26
Minimum	28.0	28.0	28.0	29.0	7.30	7.10	6.50	7.50	28.0	29.0	28.0	29.0	0.43	6.15	5.69	5.35	0.19	4.05	3.34	3.15
Maximum	33.0	31.0	32.0	31.0	8.20	8.10	8.00	7.90	32.0	34.0	30.0	32.0	7.42	8.54	8.79	6.83	5.50	6.27	6.37	4.41
Standard error	0.76	0.43	0.61	0.30	0.14	0.15	0.23	0.07	0.54	0.79	0.33	0.49	0.99	0.41	0.52	0.22	0.71	0.36	0.49	0.22
99% confidence interval	3.06	1.73	2.48	1.20	0.55	0.60	0.91	0.27	2.19	3.19	1.34	1.99	3.98	1.65	2.09	0.88	2.88	1.45	1.99	0.88
Variance	3.47	1.1	2.27	0.50	0.11	0.13	0.31	0.03	1.77	3.77	0.67	1.47	5.86	1.01	1.61	0.29	3.05	0.78	1.47	0.28
Standard deviation	1.86	1.05	1.51	0.70	0.33	0.36	0.55	0.16	1.33	1.94	0.82	1.21	2.42	1.00	1.27	0.54	1.75	0.88	1.21	0.53
Coefficient of variation	0.06	0.04	0.05	0.03	0.04	0.05	0.07	0.02	0.04	0.06	0.03	0.04	0.47	0.14	0.17	0.09	0.53	0.18	0.24	0.15
Skew	1.28	000	1.27	0.31	-0.20	-1.17	-0.76	-0.38	-0.44	2.12	-0.86	0.08	-1.92	0.47	0.18	0.76	-1.02	0.72	0.04	0.77
Kurtosis	1.85	-0.25	1.53	-0.10	-1.05	1.34	-0.20	-1.48	1.34	4.68	-0.30	-1.55	4.36	-1.89	-1.66	-0.19	2.49	-0.89	-1.44	-1.73
Kolmogorov-Smirnov stat	0.26	0.18	0.25	0.25	0.16	0.19	0.18	0.18	0.28	0.37	0.29	0.21	0.37	0.27	0.21	0.21	0.30	0.26	0.20	0.27
Critical K-S stat, alpha=.01	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62

Table 6: Monthly variations in inorganic nutrients of selected areas.

	Phosphate (µ/mol/l)				Nitrite (µ/mol/l)				Nitrate (µ/mol/l)				Silicate (µ/mol/l)				Ammonia (µ/mol/l)			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Mean	0.51	1.11	0.71	2.20	0.81	7.54	1.49	6.19	1.15	0.69	0.75	6.15	29.3	27.1	24.2	23.8	2.68	6.10	9.82	18.7
Median	0.47	0.95	0.59	1.49	0.64	9.05	0.92	5.44	0.80	0.51	0.75	1.23	29.7	22.4	27.3	24.8	1.81	4.39	11.6	14.6
Range	0.95	2.03	1.31	4.73	1.41	13.1	4.18	13.16	3.28	1.58	0.56	20.7	20.4	59.4	45.6	42.6	7.43	10.9	11.0	19.1
Minimum	0.05	0.32	0.27	0.90	0.32	0.89	0.45	1.49	0.19	0.15	0.46	0.19	19.2	4.32	3.86	1.93	0.82	3.45	2.75	11.4
Maximum	0.99	2.34	1.58	5.63	1.73	14.0	4.63	14.65	3.48	1.73	1.02	20.9	39.6	63.8	49.5	44.5	8.25	14.3	13.8	30.5
Standard error	0.14	0.28	0.21	0.74	0.22	2.23	0.64	1.82	0.49	0.22	0.08	3.57	3.66	9.18	7.21	8.30	1.14	1.69	1.85	3.46
99% confidence interval	0.55	1.14	0.84	2.97	0.91	9.01	2.57	7.34	1.97	0.90	0.34	14.3	14.7	37.0	29.0	33.4	4.58	6.82	7.45	13.9
Variance	0.11	0.48	0.26	3.25	0.30	29.9	2.43	19.8	1.43	0.30	0.04	76.3	80.5	506	311	412	7.75	17.15	20.4	71.77
Standard deviation	0.33	0.70	0.51	1.80	0.55	5.47	1.56	4.46	1.20	0.54	0.21	8.74	8.98	22.5	17.6	20.3	2.78	4.14	4.52	8.47
Coefficient of variation	0.65	0.63	0.72	0.82	0.68	0.73	1.05	0.72	1.04	0.79	0.28	1.42	0.31	0.83	0.73	0.85	1.04	0.68	0.46	0.45
Coefficient of Skewness	0.16	1.17	1.11	1.83	1.08	-0.40	2.31	1.66	1.99	1.78	-0.07	1.30	-0.01	0.87	0.06	-0.07	2.23	2.25	-0.96	0.85
Coefficient of Kurtosis	-0.22	1.91	0.69	3.31	0.24	-1.81	5.49	3.72	4.29	3.89	-1.12	0.16	-2.82	-0.03	-0.90	-2.77	5.17	5.17	-0.87	-1.74
Kolmogorov-Smirnov stat	0.18	0.20	0.22	0.28	0.20	0.21	0.40	0.34	0.32	0.30	0.20	0.36	0.26	0.19	0.20	0.23	0.39	0.35	0.25	0.28
Critical K-S stat, alpha=.01	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62

1.Mimisal 2. Pondicherry 3. Cuddalore 4. Ngappattinam

Table7: Inter-relation between physico-chemical variables and heavy metals distribution in water, sediment, plankton and fish at Mimisal, Pondicherry, Cuddalore and Nagappattinam

	Mimisal		Pondicherry		Cuddalore		Nagappattinam	
Combination	**‘r' value**	**Significance**	**‘r' value**	**Significance**	**‘r' value**	**Significance**	**‘r' value**	**Significance**
pH × Temperature	-	-	0.74	0.10	-	-	-	-
Salinity × Temperature	0.83	0.03	0.82	0.00	0.70	0.11		
BOD × pH	-	-	0.63	0.20	-	-	-	-
BOD × Salinity	-	-	0.81	0.10	-	-	-	-
DO × BOD	-	-	0.81	0.00	-	-	-	-
BOD × DO	0.97	7.88	-0.73	0.15	0.99	3.09	0.97	0.00
DO × Nitrite	-	-	-0.90	0.03	-	-	-	-
Nitrite × Temperature	-0.55	0.25	-	-	-	-	0.82	0.04
Nitrite × Salinity	-0.88	0.01	-	-	-	-	0.72	0.10
Nitrite × pH	-	-	-0.74	0.15	-	-	-	-
Phosphate × Temperature	-0.57	0.23	-	-	-	-	-	-
Phosphate × pH	-0.52	0.28	-0.63	0.25	-	-	-0.69	0.12
Silicate × Temperature	-	-	-	-	-0.71	0.11	-	-
Silicate × Salinity	-	-	-	-	-0.90	0.01	0.63	0.17
BOD × Nitrite	-	-	-0.76	0.13	-	-	-	-
Nitrate × Temperature	-	-	-	-	-	-	0.54	0.25
Nitrate × Salinity	-	-	-	-	-	-	0.61	0.19
Nitrate × Phosphate	-	-	-	-	-0.75	0.08	-	
Nitrate × Silicate	-	-	0.84	0.06	-	-	0.60	0.19
Ammonia × Temperature	-	-	0.90	0.03	-	-	0.60	0.20
Ammonia × pH	0.61	0.19	0.76	0.12	-	-	-	-
Ammonia × Salinity	-	-	0.94	0.02	-	-	-	-
Ammonia × DO	-	-	0.76	0.12	-	-	-	-
Ammonia × Nitrite	-	-	0.99	8.53	-0.67	0.13	0.53	0.27
Ammonia × Phosphate	-0.69	0.12	-	-	0.56	0.24	-	-
WHM × pH	-0.67	0.14	-	-	-	-	-	-
WHM × Salinity	-0.59	0.21	-	-	-	-	-	-
WHM × Nitrite	0.50	0.30	-0.64	0.23	-	-	-	-
WHM × Silicate	-0.62	0.18	-	-	-	-	-	-
WHM × Ammonia	-	-	-	-	-0.79	0.06	-	-
SHM × pH	0.55	0.25	0.59	0.28	-	-	-	-
SHM × Salinity	0.59	0.20	-	-	0.62	0.18	0.87	0.02
SHM × Temperature	0.87	0.02	-	-	-	-	-	-
SHM × Phosphate	-0.74	0.08	-	-	-	-	-	-
SHM × Nitrite	-	-	-	-	0.90	0.01	-	-
SHM × Silicate	-	-	-	-	-0.73	0.09	0.73	0.09
SHM × WHM	-	-	-0.64	0.24	-	-	-	-
PHM × pH	-	-	-	-	-	-	-0.62	0.18
PHM × Temperature	-0.58	0.22	-	-	-	-	-	-
PHM × Salinity	-0.80	0.02	-	-	-	-	-	-
PHM × Phosphate	-	-	-	-	-	-	0.97	8.73
PHM × Nitrite	0.79	0.06	-0.84	0.06	0.78	0.06	-	-
PHM × Nitrate	-	-	-	-	-0.66	0.15	-	-
PHM × Silicate	-	-	-0.80	0.09	-0.61	0.19	-	-
PHM × Ammonia	-	-	0.82	0.08	-	-	0.68	0.13
PHM × WHM	0.90	0.01	-	-	-	-	-	-
PHM × SHM	-	-	-	-	0.93	0.00	-	-
PHM × FHM	-	-	-	-	0.82	0.04	-	-
FHM ×Temperature	-0.75	0.08	-	-	-	-	-	-
FHM × pH	-0.62	0.18	-0.88	0.04	-	-	-	-
FHM × DO	-	-	-	-	-	-	-0.74	0.09
FHM × BOD	-	-	-	-	-	-	-0.63	0.17
FHM × Phosphate	0.92	0.00	0.69	0.19	-	-	-	-
FHM × Nitrite	-	-	-	-	0.96	0.00	-	-
FHM × Nitrate	-	-	-0.69	0.18	-	-	-	-
FHM × Silicate	-	-	-	-	-0.62	0.18	-	-
FHM × Ammonia	-0.50	0.30	-	-	-0.71	0.10	-	-
FHM × SHM	-0.88	0.01	-0.89	0.04	0.92	0.00	-	-

Note: SHM – Sediment Heavy Metals; WHM – Water Heavy Metals; PHM – Plankton Heavy Metals; FHM – Fish Heavy Metals

The significant negative correlations between dissolved metals in water and surface sediments in Pondicherry, WHM X SHM = -0.64, $_{sig}$ 0.24 rise as proof of transaction or substitute process. The significant negative correlations between salinity, pH and dissolved metals in water (Table 7) declare the role of aquatic salinity and pH in the process of conclusion. This role is confirmed by the significant positive correlation values between salinity, pH and sediment metals (Table 7). Hence, in the present geographical locale, aquatic salinity and pH have a regulatory role in the exchange of heavy metals between the aquatic phase and underlying surface sediment through dissolution-precipitation phenomenon as agreed by Chakraborty *et al.*[40].

This study clearly explained the considerable variations in the distribution of heavy metals in water, sediment, plankton and fish (*Mugil Cephalus)* with emphasis on Thane cyclone. These variations in the marine environment are unquestionably brought about by the cyclone as agreed by Martin Deva Prasath and Hidayathulla Khan[26]. The similar type of variations in the physico chemical characters were observed in the coastal water quality of southeast coast of India[26]. Many of the earlier works revealed that heavy metals were more concentrated in the tissues of marine animals than in seawater due to biomagnification[25, 27]. Similar trend also reflected in the present attempt. It is understood that the high concentration of metals in water can be gradually accumulated on the sediments, plankton and in due course it may get transferred to fish. This study was on the monthly variation of metals in the respective study areas after Thane cyclone, which clearly explained the effect of cyclone in these areas can be ascertained.

Acknowledgements

Authors are thanks the Head, Department of Marine Science and authorities of Bharathidasan University for the facilities provided. One of the author (SDK) thank the DBT, Govt. of India for Junior Research Fellowship.

References

1 Ruangsomboon, S., Wongrat, L., Bioaccumulation of cadmium in an experimental aquatic food chain involving phytoplankton (*Chlorella vulgaris*), zooplankton (*Moina macrocopa*), and the predatory catfish *Clarias macrocephalus* × *C. Gariepinus*. *Aquat. Toxicol*., 78 (2006) 15–20.

2 Zhang, Z., He, L., Li, J., Wu, Z., Analysis of heavy metals of muscle and intestine tissue in fish – in banan section of chongqing from three gorges reservoir, China. *Polish J. of Environ. Stud.,* 16 (6) (2007) 949-958.

3 Demirak, A., Balci, A., Investigation of some chemical properties of rain water near Yatagan (Mugla) and nearby. In: XV National Chemistry Congress, Abstracts Book, CK-(Istanbul, Turkey) 2001, pp. 7,

4 Raja, P., Veerasingam, S., Suresh, G., Marichamy, G., Venkatachalapathy, R., Heavy metals concentration in four commercially valuable marine edible fish species from Parangipettai Coast, South East coast of India. *Int. J. of Anim. Vet. Adv.,* 1 (1) (2009) 10-14.

5 Lakshmanan, R., Kesavan, K., Vijayanand, P., Rajaram, V., Rajagopal, S., Heavy metals accumulation in five commercially important fishes of Parangipettai, Southeast coast of India. *Adv. J. Food Sci. Tech.,* 1 (1) (2009) 63-65.

6 Begum, A., Hari Krishna, S., Khan, I., Analysis of heavy metals in water, sediments and fish samples of madivala lakes of Bangalore, Karnataka. *Int. J. Chem. Tech. Res.,* 1 (2) (2009) 245-249.

7 Akan, J. C., Abdulrahman, F. I., Sodipo, O. A., Ochanya, A. E., Askira, Y. K., Heavy metals in sediments from river Ngada, Maiduguri Metropolis, Borno State, Nigeria. *J. Environ. Chem. Ecotox.,* 2 (9) (2010) 131-140.

8 Kamaruzzaman, B.Y., Ong, M.C., Rina, S. Z., Concentration of Zn, Cu and Pb in some selected marine fishes of the Pahang coastal waters, Malaysia. *Am. J. App. Sci.,* 7 (3) (2010) 309-314.

9 Chinnaraja, V., Santhanam, P., Balaji Prasath, B., Dinesh Kumar, S., Jothiraj, K., An investigation on heavy metals accumulation in water, sediment and small marine food chain (Plankton and Fish) from Coromandel Coast, Southeast coast of India. *Indian J. Nat. Sci*., 11 (2011) 532-540.

10 Watling, H. R., Accumulation of seven metals by *Crassostrea gigas, Crassostrea margaritacea, Perna perna*, and *Choromytilus meridionalis*. *Bull. Environ. Contam. Toxicol*., **30** (1983) 317-322.

11 Melville, F., Burchett, M., Genetic variation in *Avicennia marina* in three estuaries of Sydney (Australia) and implications for rehabilitation and management. *Mar. Pollut. Bull*., 44 **(**2002**)** 469 - 479.

12 Baby, J., Justin S.R., Biby, E. T., Sankarganesh, S., Jeevitha, M. V., Ajisha, S. U., Sheeja, R., Toxic effect of heavy metals on aquatic environment. *Int. J. Biol. Chem. Sci*. 4(4) (2010) 939-952.

13 FAO; WHO., Effect of green seaweeds (*Ulva* sp.) as feed supplements in Red tilapia (*Oreochromis* sp) diet on growth performance, feed utilization and body composition. *J. of Arab. Aqu. Cult. Soc*. 5 (2) (1984) 179 - 194.

14 Fernandez, M., Cuesta, S., Jimene, O., Garcia, M. A., Hernandez, L. M., Marina, M. L., Gonzalez, M. J., Organochlorine and heavy metal residues in the water/sediment system of the Southeast Regional Park in Madrid, Spain. *Chemosphere* 41 (2000) 801-812.

15 Tulonen, T., Pihlstrom, M., Arvola, L. Rask, M., Concentrations of heavy metals in food web components of small, boreal lakes. *Boreal Environ. Res*., 11 (2006) 185-194.

16 Joint Typhoon Warning Center (2012-05-05). Tropical Cyclone 06B (Thane) Best Track Analysis. United States Navy, United States Air Force. Retrieved 2012-05-05.
17 Punithavathi, J., Tamilenthi, S., Baskaran, R., A study of thane cyclone and its impacts in Tamil Nadu, India using geographic information system. *Arch. Appl. Sci. Res*., 4 (1) (2012) 685-695.
18 Brooks, R.R., Presley, B. J., Kaplax, I. R., Determination of copper in saline waters by atomic absorption spectrophotometry combined with APDC-MIBK extraction. *Anal. Chim. Acta*., 38 (1967) 321-326.
19 Strickland, S.C., Parsons, T.R., *A practical handbook of seawater analyses*. (Bulletin of Fisheries Research Board of Canada, Ottawa) 1972, pp. 185.
20 Sankar. R., Ramkumar, L., Rajkumar, M., Jun Sun., Anantha n, G., Seasonal variations in physico-chemical parameters an d heavy metals in water and sediments of Uppanar estuary, N agapattinam, India. *J. Environ. Biol*., 31 (5) (2010) 681-686.
21 Ibrahim, A., Al-Tisan., Joseph, P., Chandy., Distribution of heavy metals in plankton collected during the umitaka maru cruise (ii) in The ropme sea area, Umitaka Maru symposium, Tokyo, Japan, December, (1995) pp. 1-8.
22 Tabari, S., Saravi, S. S. S., Bandany, G. A., Dehghan, A., Shokrzadeh, M., Heavy metals (Zn, Pb, Cd and Cr) in fish, water and sediments sampled form Southern Caspian Sea, Iran.*Toxicol. Ind. Health*. 1 (30) (2014) 64-72.
23 Govindasamy, C., Azariah, J., Seasonal variation of heavy metals in coastal water of the Coromandel coast Bay of Bengal, India. *Ind. J. Mar. Sci.* 28 (1999) 249-256.
24 Bardarudeen, T., Damodaran, K.T., Sajan, K., Padmalal, D., Texture and geochemistry of the sediments of a tropical mangrove ecosystem, southwest coast of India. *Environ. Geol*., 27 (1996) 164-169.
25 Martin Deva Prasath, P., Vijayakumar, R., Kulathooran, S., Bioaccumulation of Trace Metals on the Clam Meretrix casta, before and After Tsunami in Tharangampadi Estuary, Southeast Coast of India. *The Ekologia*, 5 (1-2) (2006) 75-80.
26 Martin Deva Prasath, P., Hidayathulla Khan, T., Impact of Tsunami on the heavy metal accumulation in water, sediments and fish at Poompuhar coast, Southeast Coast of India. *E-J. Chem.,* 5 (1) (2008) 16-22.
27 Bahnasawy, M., Khidr, A. A., Dheina, N., Assessment of heavy metal concentrations in water, plankton, and fish of Lake Manzala. *Egypt. Turk. J. Zool.,* 35 (2) (2011) 271-280.
28 Ravera, O., Monitoring of the aquatic environment by species accumulator of pollutants: A review. *J. Limnol*. 60 (2001) 63-78.
29 Elmacı, A., Teksoy, A., Olcay Topaç, F., Özengin, N., Kurtoğlu, S., Savaş Başkaya, H., Assessment of heavy metals in lake Uluabat, Turkey. *Afr. J. Biotech*., 6 (2007) 2236-2244.
30 Raja, P., Sahul Hameed, P., study on the distribution and bioaccumulation of natural radionuclides, ^{210}Po and ^{210}Pb in Parangipettai coast, South East coast of India. *Ind. J. Mar. Sci.*, 39, (2010) 449-455.
31 Watanabe, K.H., Desimone, F.W., Thiyagarajah, A., Hartley, W.R., Hindrichs, A.E., Fish tissue quality in the lower Mississippi River and health risks from fish consumption. *Sci. Total Environ.,* 302 (1–3) (2003) 109–126.
32 Canli, M., Kalay, M., Levels of heavy metals (Cd, Pb, Cu, Cr and Ni) in tissue of *Cyprinus carpio, Barbus capito* and *Chondrostoma regium* from the Seyhan River, *Turkey. Tr. J. Zool.,* 22 (1998) 149–157.
33 Al-Yousuf, M.H., El-Shahawi, M.S., Al-Ghais, S.M., 2000. Trace metals in liver, skin and muscle of *Lethrinus lentjan* fish species in relation to body length and sex. *Sci. Total Environ.* 256 -287.
34 Canli, M., Atli, G., The relationships between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. *Environ. Pollut.,* 121 (1) (2003) 129– 136.
35 Karadede, H., Oymak, S.A., Unlu, E., Heavy metals in mullet, *Liza abu* and catfish, *Silurus triostegus*, from the Ataturk Dam Lake (Euphrates), *Turkey. Environ. Int.* 30 (2004) 183–188.
36 Mendil, D., Uluozlu, O.D., Hasdemir, E., Tuzen, M., Sari, H., Suicmez, M., 2005. Determination of trace metal levels in seven fish species in lakes in Tokat, *Turkey. Food Chem.* 90, 175–179.
37 Demirak, A., Yilmaz., F., Tuna, A. L., Ozdemir, N., Heavy metals in water, sediment and tissues of *Leuciscus cephalus* from a stream in southwestern. *Turkey Chemosphere.* 63 (2006) 1451–1458.
38 Saravanakumar, A., Rajkumar, M., Sesh Serebiah, J., Thivakaran, G.A., Seasonal variations in physico-chemical characteristics of water, sediment and soil texture in arid zone mangroves of Kachchh-Gujarat. *J. Environ. Biol*., 29 (2008) 725-732.
39 Perumal, N.V., Rajkumar, M., Perumal, P., Thillai Rajasekar, K., Seasonal variations of plankton diversity in the Kaduviyar estuary, Nagapattinam, Southeast Coast of India. *J. Environ. Biol*., 30 (2009) 1035-1046.
40 Chakraborty, R., Zaman, S., Mukhopadhyay, N., Banerjee, K., Mitra, A., Seasonal variation of Zn, Cu and Pb in the estuarine stretch of West Bengal. *Ind. J. Mar. Sci.*, 38 (2009) 104-109.