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Bioaccumulation of Zinc, Copper and Lead in Upper Stretch of Gangetic West Bengal

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Abstract: Concentration of zinc, copper and lead were investigated in the gill, gonads, skin and muscle tissues of six commercially edible fishes from upper stretch of the Ganga River at West Bengal, India. The study area receives a wide variety of wastes generated by municipalities and the industries like paints and pigments, metal processing industries, thermal power plants, electro-processing industries etc. situated on the both side of the river Ganga. Simultaneous analysis of the metals was also carried out in the sediment and aquatic phases to monitor the degree of contamination. Although in the study area, the availability of heavy metals is still below alarming level (the acceptable limit for human consumption of the heavy metals are copper 10 μg g^{-1}, zinc 150 μg g^{-1} and lead 1.5 μg g^{-1}) but if the present trend continues, the level might get elevated and the consumption of the contaminated fishes might pose severe health hazards to human beings in times to come. The results of this study indicated that the six commercially edible fishes through food, water and sediment leading thereby to bioaccumulation took the metals present in the river ecosystem. The degree of bioaccumulation was directly proportional to the concentration of heavy metals in water phase and found to follow the order pre-monsoon<post-monsoon<monsoon. Muscle tissues and gill showed higher concentration of zinc, copper and lead than gonads and skin. Highest concentration of zinc, copper and lead were detected in gill tissues. Lowest concentration observed in gonads of fish sampled from upper course of the River Ganga. Further, metal accumulation showed high degree of species specificity, where the order of accumulation of heavy metals was zinc>copper>lead.

Key words: Edible fish, heavy metals, bioaccumulation, Ganga river, West Bengal, India

INTRODUCTION

The presence of heavy metals in the aquatic environment is a major concern because of their toxicity and threat to plant and animal life disturbing the natural ecological balance. The specific problem associated with the heavy metals in the environment is their accumulation through food chain and persistent in nature. Uptake of heavy metals like zinc, copper and lead through food chain in human being may cause various physiological disorders like hypertension, sporadic fever, nausea, renal damage, cramps etc.

Other toxic responses include irritability, less appetite, damage to nervous system and kidneys, anemia and gastrointestinal problems (NRC, 1977). In fact, heavy metal pollution and its management has been a major global concern for environmentalists due to their non-biodegradable and hazardous nature.

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The Hooghly estuarine ecosystem is one of the most productive estuaries of the world (Nath, 1998) and the backbone of capture fishery. The fishery resources of this important estuary have tremendous economical and nutritional importance (Hassan *et al*., 1998). But the declining trend of the commercial fishes in the recent past is a matter of concern for the fishery scientists. One of the technological progress and industrial revolution has been the release of a large number of chemicals into the environment (Yazdandoost and Katdare, 1999). The study area, which is an important part of Hooghly estuarine ecosystem situated on the upper stretch of Gangetic West Bengal. The area receives a wide variety of industrial and municipal wastes from industries. The wastes generated from industries include fertilizer, paints and pigments, dye-manufacturing units, electroplating units, thermal power plants etc. These industrial effluents contaminated the river water with a variety of heavy metals acting as point sources. Some of the metals are important for the growth, development and health of living organisms. But the same metal may be considered toxic one as its concentration exceeds to the normal permissible limit. The adverse effect due to non-degradation of metals leading to accumulation in tissues followed by changes in physiological and metabolic processes and hence become bio-accumulated (Giesy *et al*., 1998). The bioaccumulation through food chain leads to bio-magnification, which causes severe physiological abnormalities (Anderson and McFarlane, 1988). The level of pollutants detected in the tissues of organisms is the only direct measure of the proportion of the total toxicant delivery to biota and therefore indicates the fraction that is likely to enter and affect aquatic ecosystem (Phillips, 1978; Mount, 1998). With the advent of agricultural and industrial revolution, most of the water sources are becoming contaminated (Khare and Singh, 2002). Industrial discharges containing toxic and hazardous substances, including heavy metals (Gbem *et al*., 2001; Woodling *et al*., 2001) contribute tremendously to the pollution of aquatic ecosystems. Concentrations of both Mn and Co in gonads, Cr in branchial hearts and Zn in both gills and mantle increased linearly with animal weight (Ramzy and Rafik, 2003). Heavy metal levels were found generally higher in the liver and gill than the gonad and muscle tissues in three species *Dicentrarchus labrax* L., *Sparus aurata* L. and *Mugli cephalus* L., the levels of all metals in a given tissue were generally higher in *Mugil cephalus* (Meltem *et al*., 2005). The muller fish, Liza Klunzingeri, commercially important and widely relished by Kumaiti residents and the stressed ecosystem in Kuwait Bay instigated us to conduct toxicity and bioaccumulation tests on heavy metals (Pb, Ni, V, Cu and Fe). Among five metals, Pb had the lowest observed effect concentration at 1 $\mu g\ L^{-1}$ (Bu-olayan *et al*., 2005). The pattern of accumulation of cadmium and its affinity to selected tissues-gills, kidneys, liver, skin and muscle-of Clarias batrachus exposed to sublethal concentration (7 ppm) of cadmium chloride was investigated and the mean rate of accumulation of exposure was in order gills> kidneys> liver> skin> muscle (Jayakumar and Paul, 2006). Bhattacharya *et al*. (2006) observed that chromium and cadmium in the muscles tissues and gill of six commercially edible fishes is higher than gonads and skin in upper course of gangetic West Bengal, India

In the present study, an attempt has been made to study the seasonal bioaccumulation of zinc, copper and lead in gills, gonads, skin and the muscle tissues of commercially edible six different fishes *Apocryptes bato*, *Glossogobius guris*, *Gudusia chapra*, *Mastacembelus armatusy*, *Eutropiichthys vacha*, *Cynoglossus punticeps* of pre-monsoon, monsoon and post-monsoon seasons from sampled from upper stretch of Gangetic West Bengal which flows through important town and industrial agglomerations. Heavy metals concentrations in water and sediment phase were also investigated simultaneously to assess the degree of bioaccumulation. The pH, alkalinity and temperature of the ambient aquatic medium were determined to find out if they influenced the zinc, copper and lead concentrations in the gills, gonads, skin and the muscle tissues of selected fish species.

MATERIALS AND METHODS

The study was carried out at Uttar Para-Bally region situated at the upper stretch of Gangetic West Bengal during 2006-2007. The area received wide variety of wastes that arise due to various anthropogenic activities from both sides on the bank of river Ganga. The entire network comprised the seasonal sampling of water, sediment and fish samples for detecting the concentration of zinc, copper and lead in water sediment and muscle tissues of fish samples. The seasonal sampling was carried out during the time of pre-monsoon (March, 2006-Mid May, 2006), monsoon (August, 2006-September, 2006) and post-monsoon (December, 2006-January, 2007).

Water samples were collected in TARSON makes PVC bottles and passed through 0.45-micron millipore membrane. The filtered sample was treated with diethyl-dithio-carbamate and extracted in carbon tetrachloride. The extract was evaporated to dryness and the residue was mineralized with 0.1 mL of concentrated HNO_3 described by Chakraborty *et al*. (1987). Analytical blanks were prepared and treated with same reagents. All analysis was done in triplicate by direct aspiration to German make GBC-Atomic Absorption Spectrophotometer Model 902 fitted with a deuterium background corrector. The result obtained for dissolved heavy metals were expressed in $\mu g\ L^{-1}$.

The analytical procedure for the metal analysis in the sediment sample was the dilute (0.5 N HCl) acid treatment of Malo (1997) for the determination of biological fraction of total trace elements and the concentrated HNO_3, $HClO_4$ and HF digestion, Ageman and Chau (1976) for the determination of total metal concentrations. All analysis was done in duplicate by direct aspiration into air-acetylene flame of GBC Atomic Absorption Spectrophotometer Model 902 equipped with a simultaneous background corrector. The results obtained were expressed in $\mu g\ g^{-1}$.

For all fish samples, specimens of uniform size were collected each season in order to avoid the possible error due to size differences soft parts was carefully dissected after quick rinse with double distilled water and oven dried at 110°C. The heavy metal concentrations in the dried samples were estimated after acid digestion following standard method as laid down in APHA, AWWA (1998). Harper *et al*. (1989) using the same atomic absorption spectrophotometer as used for water and sediment analysis. The results were expressed in $\mu g\ g^{-1}$ metal per dry weight.

The physico-chemical parameters (Table 2), pH and temperature were recorded at site with a pre calibrated portable pH meter (sensitivity ±0.01) of Cyberscan pH 110 and a standard RTD thermometer, Eutech, Singapore make. Turbidity and total dissolved solids were determined at site with a pre-calibrated portable Nephelometric turbidity meter of waterproof TN 110 and Ecoscan Palmtop TDS meter, Eutech, Singapore make. The total alkalinity was determined by standard method as laid down in APHA, AWWA (1998). All analysis was carried in duplicate to avoid any conspiracy in experimental results.

RESULTS AND DISCUSSION

The level of heavy metal concentrations in ambient media (water, sediment) as well as in different muscle tissues of commercially edible fish samples during the period of study exhibited a unique seasonal oscillation. The concentration of heavy metals follow the trend: zinc>copper>lead. The seasonal variation of different metals considered for the study in water and sediment phase at sampling station Bally, Uttarpara, West Bengal in the upper stretch of Ganga River is shown in the Table 1. The concentrations of zinc, copper and lead in water phase were found to be maximum during monsoon period which may be characterized by extremely low alkalinity and pH of the aquatic medium (Table 2). During the pre-monsoon period the concentration of metals attained it's minimum value with high surface water temperature. The parameters like pH, alkalinity, TDS and turbidity value also reached to their highest values during the pre-monsoon period. The resulting effect was observed in sediment phase with highest heavy metal concentration in pre-monsoon period followed by post monsoon and monsoon period.

The above fact was supported by Mitra *et al*. (1994), Laksmann and Nambisan (1983). A change from sediment phase to the water phase due to influence of physicochemical parameters (Table 2) could be the only reason. Heavy metals observed to undergone compartmentation process resulting in the increase of dissolved heavy metals in water phase and decrease of biologically available heavy metals in sediment compartment during monsoon. High concentrations of heavy metals during monsoon period have been recorded very recently in the coastal zone of West Bengal and in the present situation, their is a keen relationship of the urban and suburb run off that responsible for maximum load of heavy metal during monsoon from several paint and pigment unit, electroplating units, thermal power plants and fertilizer industries situated in the nearby areas of estuarine environment.

The concentrations of heavy metals in different tissues of fish samples from upper course of River Ganga were shown in Table 3-6, the monsoon period got the highest concentration of heavy metals followed by post-monsoon period and pre-monsoon period. Muscle tissues and gill showed higher concentration of zinc, copper and lead than gonads and skin. Zinc and copper accumulation are much higher than lead of different fish species. Gonads showed the lowest concentration of heavy metals compare to the any other tissues of the fish samples studied at the sampling station during the period. Metal accumulation was found to be the function of their respective membrane permeability and enzyme system. This is why different degree of zinc, copper and lead accumulation has been observed in different tissues. Metal accumulation follows the same trends as observed in water phase. Therefore, heavy metal concentration showed a sharp seasonal oscillation.

Table 1: Heavy metal distribution in water and sediment phase

		Water phase ($\mu g\ L^{-1}$)			Sediment (Total) ($\mu g\ g^{-1}$)			Sediments (Biologically available) ($\mu g\ g^{-1}$)		
Station	Season	Zn	Cu	Pb	Zn	Cu	Pb	Zn	Cu	Pb
Bally Uttar Para,	Pre-monsoon	0.546	0.122	0.042	11.870	5.780	0.115	5.305	3.045	0.032
West Bengal,	Monsoon	0.681	0.181	0.048	10.543	2.180	0.097	4.781	1.416	0.025
India	Post-monsoon	0.612	0.151	0.045	10.910	3.460	0.104	5.068	2.212	0.036

Table 2: Environmental characteristics of the investigated course of the Ganga river

Season	Temperature (°C)	pH	Total alkalinity ($CaCO_3$) (mg L^{-1})	Total dissolved solids (mg L^{-1})	Turbidity (NTU)
Pre-monsoon	30	8.1	142	270	38
Monsoon	25	7.2	90	193	346
Post-monsoon	17	7.9	120	238	29

Table 3: Concentrations of analyzed heavy metals (in $\mu g\ g^{-1}$ dry weight) in the muscle of fish of the Ganga river

Metal	*Apocryptes bato*	*Glossogobius guris*	*Gudusia chapra*	*Mastacembelus armatus*	*Eutropiichthys vacha*	*Cynoglossus punticeps*
Pre-monsoon						
Zn	11.741	10.142	7.662	4.836	4.543	4.441
Cu	4.641	0.582	4.538	1.098	0.547	BDL
Pb	0.008	0.012	0.014	0.006	0.005	0.008
Monsoon						
Zn	12.101	11.311	8.115	5.680	5.156	4.992
Cu	5.142	1.907	4.734	1.126	1.041	1.066
Pb	0.009	0.013	0.016	0.007	0.009	0.011
Post-monsoon						
Zn	11.821	10.679	7.921	4.935	4.757	4.727
Cu	4.792	0.632	4.602	1.117	0.754	0.485
Pb	0.008	0.012	BDL	BDL	0.008	0.007

BDL = Below Detection Limit

Table 4: Concentrations of analyzed heavy metals (in µg g^{-1} dry weight) in the gonads of fish of the Ganga river

Metal	*Apocryptes bato*	*Glossogobius guris*	*Gudusia chapra*	*Mastacembelus armatus*	*Eutropiichthys vacha*	*Cynoglossus punticeps*
Pre-monsoon						
Zn	6.253	5.469	3.987	2.432	2.292	2.291
Cu	2.269	0.242	2.269	0.586	0.234	BDL
Pb	0.003	0.005	0.006	0.003	0.002	0.004
Monsoon						
Zn	6.129	5.531	4.231	2.983	2.536	2.447
Cu	2.501	0.987	2.352	0.601	0.504	0.509
Pb	0.004	0.006	0.008	0.003	0.004	0.006
Post-monsoon						
Zn	6.413	5.387	3.421	2.453	2.327	2.302
Cu	2.343	0.315	2.301	2.521	0.321	0.240
Pb	0.003	0.005	0.001	BDL	0.004	0.003

BDL = Below Detection Limit

Table 5: Concentrations of analyzed heavy metals (in µg g^{-1} dry weight) in the skin of fish of the Ganga river

Metal	*Apocryptes bato*	*Glossogobius guris*	*Gudusia chapra*	*Mastacembelus armatus*	*Eutropiichthys vacha*	*Cynoglossus punticeps*
Pre-monsoon						
Zn	12.136	10.229	9.016	7.602	5.996	5.012
Cu	7.013	1.001	7.013	2.001	1.139	1.006
Pb	0.016	0.019	0.025	0.010	0.012	0.015
Monsoon						
Zn	13.998	12.023	11.012	10.069	10.023	7.987
Cu	9.964	2.136	7.898	2.013	1.878	1.948
Pb	0.016	0.024	0.032	0.011	0.017	0.021
Post-monsoon						
Zn	12.002	10.024	9.221	7.891	6.312	5.491
Cu	7.540	1.189	7.379	2.214	1.460	0.769
Pb	0.015	0.021	0.002	BDL	0.013	0.010

BDL = Below Detection Limit

Table 6: Concentrations of analyzed heavy metals (in µg g^{-1} dry weight) in the gill of fish of the Ganga river

Metal	*Apocryptes bato*	*Glossogobius guris*	*Gudusia chapra*	*Mastacembelus armatus*	*Eutropiichthys vacha*	*Cynoglossus punticeps*
Pre-monsoon						
Zn	12.291	10.921	9.291	7.831	6.231	5.291
Cu	7.338	1.023	7.210	2.021	1.326	1.012
Pb	0.017	0.021	0.027	0.013	0.012	0.016
Monsoon						
Zn	13.239	12.623	11.321	10.643	10.213	8.007
Cu	10.121	2.264	8.439	2.016	1.987	1.998
Pb	0.018	0.026	0.033	0.013	0.019	0.022
Post-monsoon						
Zn	12.129	10.432	9.669	7.931	6.332	5.529
Cu	7.589	1.198	7.739	2.248	1.469	0.849
Pb	0.017	0.023	0.001	BDL	0.004	0.003

BDL = Below Detection Limit

Therefore, it may be said that aquatic life is more prone to heavy metal contamination in monsoon period while comparing with the other two period of the season. In fact, the level of heavy metals in the body of the fish depending upon their chemical environment in which they exist (Yazdandoost and Katdare, 1999).

Further, the metal accumulation was not same in all edible fishes, which may be due to difference in the degree of membrane permeability (Bhattacharya *et al*., 2001, 2006) for each metal. Membrane permeability depends on a particular fish species and therefore, metal accumulation in of fish species were varied from zinc, copper and lead.

Results of analysis showed the order of accumulation of zinc is:

Apocryptes bato > *Glossogobius guris* > *Gudusia chapra* > *Mastacembelus armatus* >*Eutropiichthys vacha* > *Cynoglossus punticeps*

The level of copper accumulation is:

Apocryptes bato> *Gudusia chapra* >*Mastacembelus armatus* > *Glossogobius guris* *Eutropiichthys vacha* > *Cynoglossus punticeps*

In case of lead the trend is:

Glossogobius guris> *Cynoglossus punticeps* > *Mastacembelus armatus* > *Eutropiichthys vacha* > *Apocryptes bato*> *Gudusia chapra*

It has been suggested that fish may accumulate large amounts of heavy metals though ingestion or direct uptake from polluted water (Gras *et al*., 1992). However, significantly high positive correlation between the tissue metal concentrations and dissolved metal of the ambient water is a pathway to detect kind and degree of pollution at different fishing sites (Ramakrishna *et al*., 1997).

CONCLUSIONS

The phenomenon of bioaccumulation and bio-magnification intensified with concentration of heavy metals at different tropic levels. In aquatic ecosystem the primary producers absorb the metallic ions, which in turn pass to the consumer level through predictions. The degree of bio-magnification of heavy metals at different levels depends upon the bioaccumulation capacity of the flora and fauna. In water they occur as complex and diverse mixtures of soluble and insoluble forms such as ionic species, inorganic and organic complexes and/or associated with colloids and suspended particulate matter (Pani *et al*., 2002).

Today, fishes have become the major diet and there have been attempts to devise ways to enhance fish production. The bioaccumulation of zinc, copper and lead in edible part of the fishes indicates the extent of stress posed on this highly productive ecosystem. Muscle tissues and gill showed higher concentration of zinc, copper and lead than gonads and skin. In fact, lowest concentration of heavy metals was observed in tissue of gonads for all the different fish species from the upper course (Bally, Uttar Para region) of Ganga River. The metal accumulation trend was observed to zinc > copper > lead.

Also the major findings of the study reveals that heavy metal concentrations in muscle, gonads, skin and gill of *Apocryptes bato*, *Glossogobius guris*, *Gudusia chapra*, *Mastacembelus armatus*, *Eutropiichthys vacha* and *Cynoglossus punticeps* from the river Ganga were significantly alarming and in general exhibited a unique seasonal variation. The highest metal accumulation was observed during the monsoon.

Carnivores at the top of the food chain such as birds and mammals including humans, obtain most of their pollutant burden from aquatic ecosystems by way of their food especially fish (Mason, 1990). People who eat contaminated fish regularly, therefore, are most exposed to the risk of chronic poisoning (Milagros, 1996). Although in the study area, the availability of heavy metals is still below alarming level (the acceptable limit for human consumption of the heavy metals are copper 10 $\mu g\ g^{-1}$, zinc 150 $\mu g\ g^{-1}$ and lead 1.5 $\mu g\ g^{-1}$ dry weight (Nair *et al*., 1997) but if the present trend continues, the level might get elevated and the consumption of the contaminated fishes might being severe health hazards to human beings in longer duration. Therefore, proper monitoring and control is utmost important to keep the health of this highly productive ecosystem intact.

REFERENCES

Ageman, A. and S.Y. Chau, 1976. Evaluation of extraction techniques for the determination of metals in aquatic sediments. Analyst, 101: 761-767.

Anderson, E.T., J.M. McFarland, 1988. Community as Client. J.B. Lippincott Company, Philadelphia, pp: 482.

Bhattacharya, A.K., A. Chowdhury and A. Mitra, 2001. Accumulation of heavy metals in commercially edible fishes of gangetic West Bengal. Res. J. Chem. Environ., 5: 27-28.

Bhattacharya, A.K., S.N. Mandal and S.K. Das, 2006. Bioaccumulation of chromium and cadmium in commercially edible fishes of gangetic West Bengal. Trends Applied Sci. Res., 1: 511-517.

Bu-olayan, A.H. and B.V. Thomas, 2005. Toxicity and bioaccumulation of heavy metals in mullet fish Liza Klunzingeri (Mugilidae: Perciformes). Chem. Ecol., 21: 191-197.

Chakraborty, D., F. Adams, W. Van Mol and J.K. Irgolic, 1987. Determination of trace metals in natural waters at nanogram per liter levels by electrochemical atomic absorption spectrometry after extraction with sodium diethyl dithio carbamate. Anal. Chem. Acta, 196: 23-31.

Gbem, T.T., J.K. Balogun, F.A. Lawal and P.A. Annune, 2001. Trace metal accumulation in *Clarias gariepinus* teugules exposed to sunlethal levels of tannery effluent. Sci. Total Environ., 271: 1-9.

Giesy, J.P., D.J. Versteeg and R.I. Graney, 1988. A Review of Selected Clinical Indicators of Stress Induced Changes in Aquatic Organisms in Toxic Contaminants and Ecosystem Health: A Great Lake Focus. Vol. 21. Evans, M.S. (Ed.), John Wiley and Sons, New York, pp: 169-200.

Gras, N., L. Munoz, N. Thieck and S. Hurtadeo, 1992. Seasonal and geographical variability in some trace elements of pacific oysters (*Crassostrea gigas*) cultured in two different bays of Northern Chile. J. Radio Anal. Nucl. Chem., 161: 135-139.

Harper, D.J., C.F. Fileman, P.V. May and J.F. Postmann, 1989. Aquatic environmental protocols analytical methods. MAFE. Direct. Fish Res. Lowestoff, UK.

Hassan, S.S., R.K. Sinha, S.N. Ahsan and N. Hassan, 1998. Impact of fishing operations and hydro-biological factors on recent fish catch in Ganga near Patna, India. J. Inland Fish. Soc. India, 30: 1-12.

Jayakumar, P. and V.I. Paul, 2006. Patterns of Cadmium accumulation in selected tissues of the catfish *Clarias batrachus* (Linn.) exposed to sublethal concentration of cadmium chloride. Vet. Arhiv., 76: 167-177.

Khare, S. and S. Singh, 2002. Histopathological lesions induced by copper sulphate and lead nitrate in the gills of fresh water fish Nandus. J. Ecotoxicol. Environ. Monit., 12: 105-111.

Laksmann, P.T. and P.N.K. Nambisan, 1983. Seasonal variations in trace metal content in bivale mollusks. *Villorita cyprinoids*, *Meretrix costa* and *Perna virdis*. Indian J. Mar. Sci., 12: 100-103.

Malo, B.A., 1997. Partial extraction of metals from aquatic sediments. Environ. Sci. Technol., 11: 277-288.

Mason, C.F., 1990. Biological Aspects of Freshwater Pollution. In: Pollution: Causes, Effects and Control. Harrison, R.M. (Ed.), Cambridge: The Royal Society of Chemistry, pp: 393.

Meltem, D., M.Z. Lugal Goksu, A.A. Ozak and B. Derici, 2005. Bioaccumulation of some heavy metals in different tissues of *Dicentrarchus labrax* L., 1758, *Sparus aurata* L., 158 and *Mugli cephalus* L., 1758 from the camliklagoon of the Eastern Cost of Mediterranean (Turkey). Water, Air Soil Pollu., 176: 1573-2932.

Milagros, L.R., 1996. Total mercury of selected fish species from Laguna DE Bay. Philippines J. Sci., 125: 305-316.

Mitra, A., S. Trivedi and A. Chudhury, 1994. Interrelationship between trace metal pollution and physio-chemical variables in the framework of Hooghly Estuary. Indian Ports, 10: 27-35.

Mount, D.I., 1998. Ambient Toxicity to Assess Biological Impact. In: Toxic Contaminants and Ecosystem Health: A Great Lake Focus. Evans, M.S. (Ed.), John Wiley and Sons. New York, pp: 237-245.

Nair, M., K.K. Balachandra, V.N. Sankaranayan and T. Joseph, 1997. Heavy metals in fishes from Coastal Waters of Cochin, South West Coast of India, India. J. Mar. Sci., 26: 98-100.

Nath, D., 1998. Zonal Distribution of Nutrients and their bearing on primary production in Hooghly Estuary. J. Inland Fish. Soc. India, 30: 64-74.

NRC (National Research Council), Drinking Water and Public Health, 1977. Safe Drinking Water Committee, National Academy Press, Washington, pp: 1.

Pani, S., A. Bajpai and S.M. Misra, 2002. Studies on bioaccumulation of selective heavy metals in a tropical ecosystem. Res. J. Chem. Environ., 6: 67-68.

Phillips, D.J., 1978. Use of biological inductor organisms to quantitative organo-chlorine pollutants in aquatic environments. A Rev. Environ. Poll., 16: 167-229.

Ramakrishna, V.V.S., M.N. Ambullcar and A.M. Learg, 1997. Multi-Elemental Neutron Activation Analysis of Nutrients and Pollutants in Marine Fish from East Coast of India in Advances on Environmental Science. Piyer, C.S. (Ed.), Educational Book Publishers and Distributors, New Delhi, pp: 247-251.

Ramzy, N.B. and R. Rafik, 2003. Bioaccumulation of heavy metals in octopus vulgaris from coastal waters of alexandria (Eastern Mediterranean). Chem. Ecol., 19: 275-281.

Woodling, J.D., S.F. Brinkman and B.J. Horn, 2001. Non-uniform accumulation of cadmium and copper in kidney's of wild brown trout Salmo trutta populations. Arch. Environ. Contam. Toxicol., 40: 318-385.

Yazdandoost, M.Y. and M.S. Katdare, 1999. Study of heavy metal accumulation in the tissues of fish from pune-rivers India. Asian J. Microbiol. Biotechnol. Environ. Sci., 1: 115-118.