ASSESSMENT OF SEASONAL VARIATION OF TRACE METALS IN SOME COMMERCIAL FISH AND CRUSTACEAN IN THE COASTAL AREA OF BANGLADESH

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Abstract

This study was conducted to determine the seasonal variation of Cr, Ni, Cu, Zn, As, Cd and Pb concentration in some commercial fishes and crustacean from four coastal sites of Bangladesh. The summer and the winter samples were collected from August to September, 2013 and January to early February, 2014 respectively. The fish of Cox's Bazar site showed the highest levels of Zn (138), As (13), Cd (0.075) and Pb (0.63 mg/kg ww) in summer season. The mean concentration in fish followed a decreasing order of Zn > Cu > As > Cr > Pb >Ni > Cd in summer and Zn > Cu > As > Cr >Ni > Pb > Cd in winter. The elevated concentration of Cu (400), Zn (1480), As (53) and Cd (8.27 mg/kg ww) was observed in the crabs of Cox's Bazar in summer. Some metals in fish and crustacean exceeded the international quality guidelines.

Key words: Bangladesh, coastal pollution, trace metals, fish, seafood.

INTRODUCTION

Over the last few decades, trace metal contamination has been identified as a great concern in coastal environment. The accumulation of trace metals in the coastal environment has become a vital problem throughout the world (Gupta *et al*. 2009, Wang *et al*. 2010). Trace metals discharged into the marine environment can damage marine species diversity as well as ecosystems, due to their toxicity, long persistence, bio-accumulation and bio-magnification in the food chain (Eisler 1993, Rahman and Islam 2010, Ebrahimpour *et al*. 2011). Considering coastal region, substantial unplanned development in the industrialization, huge urbanization, population growth, agricultural expansion, transboundary political issues, different types of anthropogenic activities and overall man's greed accelerate the trace metals inclusion into the estuarine and coastal environment through rivers discharge, oceanic dumping and Aeolian processes (Tarras-Wahlberg *et al*. 2001, Jordao *et al*. 2002).

Fishes are often at the top of the aquatic food chain and may concentrate large amounts of some metals from the water and sediment (Mansour and Sidky 2002). Among the bio-indicators of aquatic ecosystem, fishes are often deemed as the most suitable objects because they occupy high trophic level and are important food source of human population (Abdel-Baki *et al*. 2011). Although, the consumption of fish has been increased in importance among the health conscious people due to their high protein supply, low saturated fat and omega fatty acids content that are known to contribute to good health (Copat *et al*. 2012). Thus, trace metals pollution in fish has become an important worldwide concern, not only because of the threat to fish, but also due to the health risks associated with fish consumption.

Bangladesh is a low-lying country having large marshy jungle coastline of 580 km on the northern littoral of the Bay of Bengal. A network of 230 rivers with their tributaries and distributaries crisscross the country. The Padma and the Jamuna have been one of the major recipients of industrial effluents from its neighboring country, like India, entering in to Bangladesh which dumping unknown quantities of poisonous residues from agricultural, chemical, industrial, farm effluents, solid waste, sewage disposal through Bhola estuary into the the Bay of Bengal (BOBLME 2011) . The waste materials coming through these rivers pollute the coastal environment that might contaminate the water, sediment specially fish, crustacean and others aquatic biota. In Bangladesh, a large number of peoples is engaged in coastal fishing. Fish and crustacean are the major protein source and second earning foreign exchange (http://www.fao.org/fishery/countrysector/naso_bangladesh/en). The Hilsa (*Tenualosa ilisha*), Rupchanda (*Pampus argentius*) and Loitta-Bombay duck (*Harpadon nehereus*), Long Tongue Sole (*Cynoglossus lingua*), Indian Shrimp (*Penaeus indicus*) and Mud crab (*Scylla serrata*) are commercially important edible fish and crustacean which are consumed by the people. But, trace metals contamination has been paid less attention.

In Bangladesh aspect, seasons are very important for the fisheries, agriculture expansion, industrial activities and above all anthropogenic inputs along with the coastal area. Interestingly, this coastal environment especially the biological and geochemical conditions have been contaminated and influenced by seasonal vagaries which might have played a vital role in the variation of metal distribution in aquatic animals in this tropical estuarine system. So, this study was assigned to provide base line information on the seasonal variation of some toxic trace metals concentration in some commercial fish and crustaceans. Although, there have been few studies (Hossain and Khan 2001) on the monitoring of trace metals in fish and crustacean, but no detail studies have been carried out. So, it is high time to concentrate our views to this problem with integrated approaches and try to monitor possible pollution sources of the toxic trace elements and factors that influence impending risks of the study area.

MATERIAL AND METHODS

Study area and sampling location

Four sampling sites (Cox's Bazar, Chittagong, Meghna Estuary and Sundarbans) with three different locations of each were investigated in the southeast and southwest coastal area of Bangladesh (Fig. 1**)**. The first site (St. 1) was located at the southeast coastal area in Cox's Bazaar which lies between latitudes 21°27′02″N to 21°26′33″N and longitudes 91°58′16″E to 91°57′01″E. Cox's Bazar was a seaside tourist town having two diverse ecological sub sites like, Bakkhali estuary and hatchery site.

The second site (St. 2) was located near the Chittagong port and ship breaking area which lies between latitudes 22°13′27″N to 22°38′22″N and longitudes 91°48′14″E to 91°32′45″E. This was the southeastern principal seaport region of the country, straddling the hills at the estuary of the Karnaphuli River which regarded as industrial and commercial hubs having more than 8,00 industrials establishments which are adjacent to the sampling sites (BOBLME 2011). Besides, Chittagong ship breaking yard is world's second largest ship breaking area confined to 18 km^2 area along the coast of Sitakund Upazilla specially Bhatiary to Kumira.

The third site (St. 3) was located near the Meghna Estuary in Bhola which lies between latitudes 22°28′07″N to 22°20′39″N and longitudes 90°49′41″E to 90°50′31″E. This is an estuarine area where the main rivers mix together to the Bay of Bengal containing the industrial effluents through inland rivers from country and trans-boundary countries.

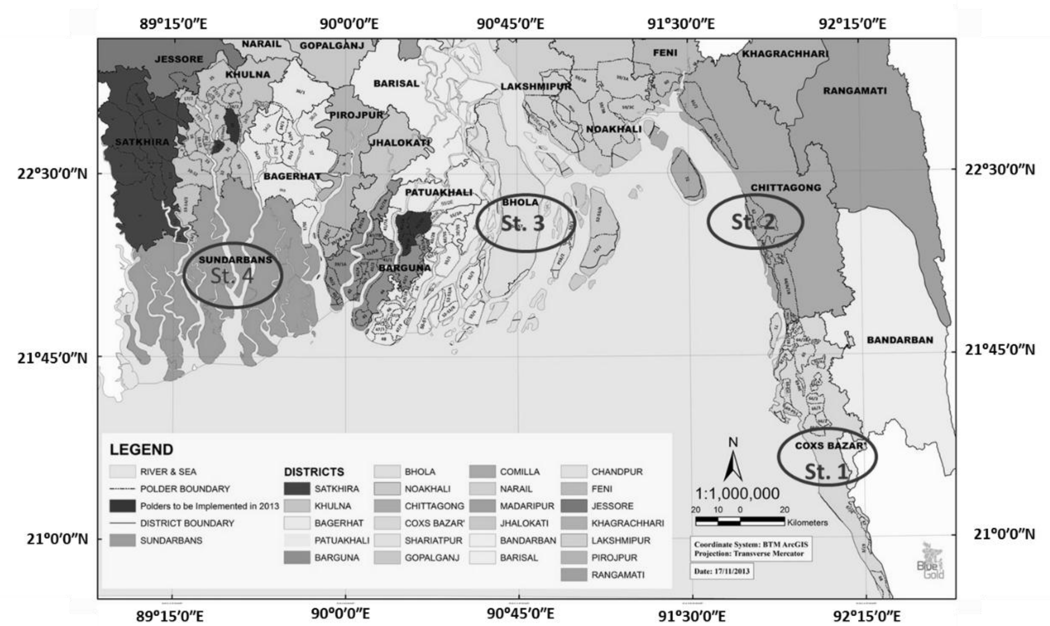

Fig. 1. Map showing sampling sites in the coastal area of Bangladesh.

The last site (St. 4) was located near the southwest part of coastal area of Sundarbans that is regarded as a large mangrove ecosystem in Bangladesh which lies between latitudes 22°34′43″N to 22°18′02″N and longitudes 89°32′48″E to 89°36′26″E. This sampling area was also mostly influenced by different anthropogenic and industrial activities of Khulna and Mongla area.

Sample collection and preparation

The sampling was conducted in two distinct seasons, summer (S) and winter (W). The summer samples were collected during the transition of summer and rainy season starting from early August to early September in 2013 and the winter samples were collected on early January to early February, 2014. Three mostly consumed fish viz. Hilsa (*Tenualosa ilisha*), Rupchanda (*Pampus argentius*) and Long tongue sole (*Cynoglossus lingua*); Indian shrimp (*Penaeus indicus*) and Mud crab (*Scylla serrata*) were collected from the local fishermen and markets at adjacent sampling sites. The fish and crustacean were identified in the laboratory by referring standard books and manuals (Shafi and Quddus 1982, Chowdhury and Hafizuddin, 1991). Immediately after collection, fish and crustaceans samples were kept in airtight insulating box and were transported to the laboratory of Department of Fisheries, University of Dhaka. After transportation, fish and crustaceans samples were rinsed in deionized water to remove surface adherents. Non-edible parts were removed with the help of a stainless steel knife. The edible portion of the samples was cut into small pieces. A composite of at least nine samples of each fish and crabs, and 18 samples for shrimps was prepared and homogenized in a food processor and 100 g test portions were stored at −20°C in the Laboratory. Then all samples were freeze dried for 48 h until the constant weight was attained. The all processed samples were brought to Yokohama National University, Japan, for chemical analysis under the permission of Yokohama Plant Protection Station.

Sample digestion and metal extraction

A microwave digestion (Raknuzzaman *et al*. 2016) was used to digest the samples for analysis. All chemicals were analytical grade reagents and Milli-Q water was used for each solution preparation. The PTFE (polytetrafluoro ethylene) digestion vessels and polypropylene containers were cleaned, soaked in 5% HNO_3 for more than 24 h, then rinsed with Milli-Q water and dried. For metal analysis, 0.2 g of fish and crustacean samples were treated with 5 mL 69% HNO_3 acid and 2 mL 30% H_2O_2 in the digestion vessels. By stirring carefully with a teflon bar, the vessels containing mixtures were kept undisturbed for 20 minutes in the draft chamber. Then the vessels were placed in a microwave digestion system. The following microwave program was applied: 10 min at 180 ºC with 800 W, 10 min at 190 ºC with 900 W, and as a last step 10 min at 100 ºC with 400 W. After digestion, acid solutions with samples were transferred into a Teflon graduated cylinder and total volume was made up to 50 mL with Milli-Q water. The digested acid solutions were then filtered by using syringe filter and stored in 50 mL polypropylene tubes.

Table 1. Operating conditions for ICP-MS and parameters for metal analysis (Raknuzzaman *et al.* 2016).

Operating conditions	
Nebulizer pump (rps)	0.1
RF power (W)	1550
Rf frequency	27.12MH_Z
Sample depth (mm)	9 mm from load coil
Plasma gas flow rate (L/min)	15
Make up gas flow rate	Ar 0 L/min
Carrier gas (Ar) flow rate (L/min)	1.0 (optimized daily)
Collision gas mode	He 4.0 mL/min
Measurement parameters	
Scanning mode	Peak hop
Resolution (amu)	0.7
Readings/replicate	1
No. of replicates	3
Correction equations for interferences	Li [6] : [6]*1- [7]*0.082
	In [115] : (115)*1-[118]*0.014
	Pb [208] : [208]*1 + [206]*1+ [207]*1
Isotopes	^{52}Cr, ^{60}Ni, ^{63}Cu, ^{65}Zn, ^{75}As, ^{111}Cd, ^{208}Pb

Instrumental analysis

For trace metals, samples were analyzed using inductively coupled plasma mass spectrometer (ICP-MS, Agilent 7700 series, USA) (Table 1). Multi-element Standard XSTC-13 (SPEX CertiPrep®, USA) solutions was used to prepare calibration curve. The calibration curves with R^2 >0.999 were accepted for concentration calculation. Before starting the sequence, relative standard deviation (RSD<5%) was checked by using tuning solution (1 μg/L each of Li, Y, Ce, Tl, Mg and Co in 2 wt % HNO_3) purchased from Agilent Technologies.

Table 2. Analysis of trace metals from certified reference materials (fish) by ICP-MS (Mean ± SD, mg/kg-dw).

Certified reference material	Metal	Certified value (mg/kg-dw)	Measured value (mg/kg-dw) (n=3)	Average recovery (%)
NMIJ CRM 7402-a cod fish tissue	Cr	0.72 ± 0.09	0.76 ± 0.08	106
	Ni	0.38 ± 0.05	0.40 ± 0.02	105
	Cu	1.25 ± 0.07	1.14± 0.05	91
	Zn	21.3 ± 1.50	20.5 ± 1.94	96
	As	36.7 ± 1.80	38.3 ± 1.73	104

Internal calibration standard solution containing 1.0 mg/L each of Beryllium (Be) and Tellurium (Te), and 0.5 mg/L each of Indium (In), Yttrium (Y), Cobalt (Co) and Thallium (TI) was purchased from SPEX CertiPrep®, USA and it was added into each sample. Working standards (0, 10, 20, 50 and 100 μg/L) were prepared by dilution of a multi-element stock solution (Custom Assurance Standard, SPEX CertiPrep®, USA), then the concentrations of trace metals were determined by an internal standard method. All test batches were evaluated using an internal quality approach and validated if they satisfied the defined Internal Quality Controls (IQCs). For each batch experiment, one blank, one certified reference material (CRM) and several samples were analyzed in duplicate to eliminate any batch-specific error. Finally, the concentration of trace metals were quantified by calibration based on internal standards.

Quality control and quality assurance

The quality of total acid digestion of the fish and crustacean were checked by using the certified reference material, NMIJ CRM 7402-a, Cod fish tissue which was purchased from the National Institute of Advanced Industrial Science and Technology (AIST), and yielded good accuracy of analysis. Comparison is made with the certified values, which in both cases confirmed that the sample preparation and instrumentation conditions provided good levels of accuracy and precision (Table 2). In the present study, the trace metal concentrations were determined on a wet weight (ww) basis in the composite commercially important fishes and crustacean's species. Mean metal concentrations in fishes and crustaceans are shown in Table 3.

RESULTS AND DISCUSSION

Concentration of trace metals in fish

A wide range of metal concentrations were observed among the sampling sites. The concentration of investigated trace metals in fish samples were found to be in the range of 0.15−2.2 for Cr, 0.1−0.56 for Ni, 1.3−4 for Cu, 31−138 for Zn, 0.76−3 for As, 0.033−0.075 for Cd and 0.07−0.63 for Pb mg/kg ww in summer season and 0.4−0.8 for Cr, 0.2− 0.5 for Ni, 1.6−4.6 for Cu, 12.8−24.8 for Zn, 1.0−2.5 for As, 0.077−0.134 for Cd and 0.15−0.25 for Pb mg/kg ww in winter season respectively. The mean concentration of studied metals in fish followed a decreasing order of Zn > Cu > As > Cr > Pb >Ni > Cd in summer and Zn > Cu > As > Cr >Ni > Pb > Cd in winter. Considering summer, most of the studied metals in fish showed the highest mean concentration at Cox's Bazar site while the samples of Sundarbans and Bhola showed the lowest concentration. The high concentration in this particular period due to the huge activities and discharges of different salts and chemicals from hatcheries, fish processing aqua farms and different industries. Conversely, considering winter, most of the studied metals showed the highest mean concentration at Meghna estuary, Bhola site while the samples of and Sundarbans showed the lowest concentration. It might be caused due to less rain fall and high input of effluents from whole country through the Meghna estuary to the sea.

Among the sites, fish of Cox's Bazar showed the remarkable high concentration of Zn (138.2), Cu (13.9), As (12.5), Cr (2.2) and Pb (0.6 mg/kg ww) in summer and Cd (0.13 mg/kg ww) in winter season (Table 3). Zinc is known to be involved in most metabolic pathways in humans (Tuzen 2009). Zinc contents in the literature have been reported in the range of 42.8–418 (mg/kg-dw) in some edible fishes in Bangladesh (Rahman *et al.* 2012) and 38.8–93.4 (mg/kg-ww) in some fish species from the Black Sea, Turkey (Tuzen 2009).

The high Zn concentration might be attributed due to discharged of different salts and chemicals from hatcheries, fish processing industries where zinc oxide (ZnO) is broadly used for the oxygen supply to fry and fingerlings (Shamsuzzaman and Biswas 2012). ZnO and ZnS have long been used in paints as anticorrosive coatings in boats, fishing trawlers and ships in Cos'x Bazar area. Most of the domestic, municipal and industrial sewages of Cox's Bazar city were incorporated to the Bakkhali River through different uncontrolled canals to the Sea. Waste discharge and chemical spills were represented an additional source of pollutants in this area which might have possibility to be higher bioavailability in fish.

The highest concentration of copper was found as 13.9 (mg/kg-ww) at Cox's Bazar site in summer season. During this period, Cu has been used as disinfectant chemical in hatcheries, aquatic farms and aquaculture operations in Cox's Bazar. It is also broadly used as an effective algaecide and in some parasites treatment. Copper levels in the literatures have been reported in the range of 5.17–9.45 (mg/kg-ww) in fish from Dhaleshwari river, Bangladesh (Ahmed *et al.* 2009). In this study, in comparison to international guideline, the concentration of copper is within the safe limits Table 4.

The highest concentration of arsenic in fish was observed as 12.5 (mg/kg-ww) in summer samples which exceeded the international quality guideline values Table 4. In some literatures, the arsenic concentrations have been reported in the range of 1.01-15.2 (mg/kg-ww) in Bangladeshi fresh water fish species (Shah *et al*. 2009). Comparing with published data, Delgado-Andrade *et al*. (2003) reported total As in fish from south-east Spain and found total As in muscles ranging from 0.39 to 12.58 (mg/kg-ww) which concentration was similar to our present study. Seafood contains a high concentration of organic arsenic (arsenobetaine, arsenocholine, and organoarsenicals) which is less toxic than inorganic arsenic (Han *et al*. 1998). It is suspected that inorganic As present in fish consumed by humans is carcinogenic (Han *et al*. 1998). However, as only about 10% of the As present in fish is in inorganic form only this percentage was used to calculate hazard (Buchet *et al*. 1996). High As concentration might be attributed to the anthropogenic activities such as treatment of agricultural land with ground water for irrigation, fertilizers and arsenical pesticides in the crop land for paddy production in this area (Renner 2004, Neumann *et al*. 2011, Fu *et al*. 2014).

Table 3. Mean metal concentrations (mg/kg wet-weight) in fish and crustaceans (*composite samples) collected from Bangladeshi coast.

Sampling sites	Species	Cr		Ni		Cu		Zn		As		Cd		Pb	
		S	W	S	W	S	W	S	W	S	W	S	W	S	W
Cox,s Bazar	Fish	2.2	0.6	0.6	0.4	13.9	1.6	138	14.8	12.5	2.5	0.07	0.13	0.6	0.2
	Shrimp	1.1	0.3	1.3	0.6	13.1	3.3	131	18.6	2.5	0.6	0.09	0.05	0.4	0.05
	Crab	29	0.5	43	0.9	400	48.5	1480	39.0	52.5	7.9	8.27	1.70	67.8	0.2
Chittagong port	Fish	1.1	0.5	0.5	0.3	5.9	1.8	53.0	12.8	2.7	1.9	0.06	0.08	0.5	0.2
	Shrimp	1.0	0.4	1.4	0.3	22	3.6	107	17.4	2.0	0.6	0.12	0.05	0.3	0.1
	Crab	14.0	0.7	34	0.8	305	77.8	902	86	33.5	20.1	4.21	5.34	78.5	0.2
Sundarbans	Fish	0.1	0.4	0.1	0.2	1.3	2.6	31	21.5	1.1	1.0	0.03	0.10	0.1	0.2
	Shrimp	0.3	0.2	0.5	0.3	63	11.8	53.	14.4	0.9	0.2	0.02	0.01	0.1	0.05
	Crab	0.5	1.7	1.4	1.9	80	22.9	157	94	1.3	3.5	0.09	0.25	0.5	1.7
Meghna estuary, Bhola	Fish	0.3	0.8	0.3	0.5	1.6	4.6	35	24.8	0.8	2.3	0.05	0.10	0.2	0.3
	Shrimp	0.3	0.2	0.8	0.3	52	11	114	13	0.3	0.3	0.10	0.05	0.1	0.1
	Crab	0.3	0.7	0.8	0.9	111	54	137	88	1.5	1.3	0.19	0.17	0.2	0.3

* Composite samples: For each site, 9 samples of each fish and crabs, and 18 for shrimps were homogenized in a food processor to prepare composite samples having 3 replicates of each.

Table 4. Standard levels of metals in fish in (mg/kg ww) described in the literature and range of concentrations found in fishes and crustaceans in coastal area of Bangladesh.

	Species/ Country	Cr		Ni		Cu		Zn		As		Cd		Pb		References
		S	W	S	W	S	W	S	W	S	W	S	W	S	W	
Bangladesh coast	Fish	0.15-2.2	0.4-0.8	0.1-0.6	0.2-0.5	1.3-14	1.0-4.6	31-138	12.8-24.8	0.8-13	1.0-2.5	0.03-0.07	0.08-0.13	0.07-0.63	0.2-0.3	Present study
	Shrimp	0.32-1.1	0.2-0.4	0.28-1.4	0.3-0.6	13-63	3.3-11.8	53-131	13.2-18.6	0.3-2.5	0.2-0.6	0.02-0.12	0.01-0.1	0.1-0.38	0.05-0.1	Present study
	Crab	0.29-29	0.5-1.7	0.49-43	0.8-1.9	80-400	22.9-77.8	137-1480	39.0-94.1	1.3-53	1.3-20.1	0.09-8.3	0.2-5.3	0.24-79	0.2-1.7	Present study
Guidelines	New Zealand	--	--	--	--	30	--	40	--	1	--	1	--	2	--	*CEPA,1995-97
	Hong Kong	--	--	--	--	--	--	--	--	1.4	--	2	--	6	--	*CEPA,1995-97
	Zambia	--	--	--	--	100	--	100		5	--	--	--	10	--	*CEPA,1995-97
	Tolerance level in fish	--	--	--	--	--	--	50	--	--	--	0.1	--	0.5	--	FAO/WHO, 1989
	Turkish	--	--	--	--	20	--	50	--	--	--	0.1	--	0.3	--	Turkish Food Codex (Anonymous, 2008)

*California Environmental Protection Agency, State Water Resources Control

Maximum Pb concentration was found as 0.63 (mg/kg-ww) which is close to the literature reported concentrations of 0.026–0.481 mg/kg-ww (Morgano *et al*. 2011). Considering Pb, European Community (EC) regulates 0.2 (mg/kg-ww) as the maximum limit in fish (European Commission 2002). The high concentration of Pb in this site might be attributed to the acid drainage from the industrial wastes and different chemical activities of hatcheries, fish processing, paint and ship repairing industries.

Metal accumulation in fish was evidenced to be pretentious by several factors, e.g. metabolic activities, swimming patterns, ecological needs and living environments. Besides, bioaccumulation patterns of contaminants in fish also depend both on uptake and elimination rates (Hakanson 1980, Guven *et al*. 1999). Among these factors metabolic and swimming activities were frequently considered to be more important. The high concentration of trace metals in fish was found in summer than in winter season because, during the summer, naturally the metabolic and swimming activities in water increased vigorously which led to more bioaccumulation and biotransformation of trace metals into the body of fish.

Concentration of trace metals in crustaceans

The concentration ranges of trace metals in crustaceans (shrimp) were as follows: Cr: 3.2–1.1; Ni: 0.28–1.4; Cu: 13–63; Zn: 53–131; As: 0.3–2.5; Cd: 0.02–0.12; Pb: 0.1–0.38 mg/kg ww in summer and Cr: 0.2–0.4; Ni: 0.3–0.6; Cu: 3.3–11.8; Zn: 13.2–18.6; As: 0.2–0.6; Cd: 0.01–0.1; Pb: 0.05–0.1 mg/kg-ww in winter Table 3. The mean concentrations of studied metals in shrimp followed a decreasing order of Zn > Cu>As >Ni > Cr > Cd >Pb in both season. Otherwise, trace metals in crustaceans (crabs) ranged over following intervals: Cr: 0.29–29; Ni: 0.49–43; Cu: 80–400; Zn: 137–1480; As: 1.3–53; Cd: 0.084–8.3; Pb: 0.24–79 mg/kg ww. in summer and Cr: 0.5–1.7; Ni: 0.8–1.9; Cu: 22.9–77.8; Zn: 39.0–94.1; As: 1.3–20.1; Cd: 0.2–5.3; Pb: 0.2–1.7 mg/kg ww in winter. The mean concentrations of studied metals in crabs followed a decreasing order of Zn > Cu > Pb >As >Ni > Cr > Cd in summer and Zn > Cu >As> Cd > Ni > Cr>Pb in winter. Compared with fishes and other crustaceans, the elevated level of metals concentration was observed in crabs. Remarkably, most of the studied metals specially, Cu, Zn, As and Cd in crabs showed the highest mean metal concentration at Cox's Bazar site in summer season. Considering winter, high concentration of Cr, Ni, Zn and Pb were found in Sundarbans site while As, Cd and Cu was found higher in crabs at Chittagong site. In both season, most of the metal concentrations were exceeded the international quality guideline **(**Table 4**).** However, crabs were regarded as typical benthic organisms residing above or in the sediment that might be good indicators reflecting the contamination levels in surface sediment (Ololade *et al*. 2011).

Unlike fish skin, crab legs were often buried in surficial sediments and might adsorb metals from sediment more easily. Thus, it was more susceptible to sediment and was expected to possess high metal levels (Zhao *et al*. 2012). Perceptibly elevated levels of Zn (1480 mg/kg ww) and Cu (400 mg/kg ww) were found in crabs (Table 3) in summer season which could be explained by the facts that the two metals were necessary elements to meet crab's physiological needs as metabolic activities were tremendously raised during summer for their movement to collect their foods (e.g. debris or small benthic organism). Interestingly, most of crab's food had high accumulation of these metals that might be stimulated higher bioavailability in their body.

Among the four sites studied, considering fish and crabs, higher metal concentration was observed in summer than in winter samples at Cox's Bazar site. Remarkable concentration of As, Zn, Cu and Cd was observed in crabs collecting from Cox's Bazar in summer season. Crabs were more susceptible to possess the high metal accumulation than other fishes due to its absolute different bioaccumulation pattern (Zhao *et al*. 2012). Some metals in fish and crustaceans exceeded the international quality guidelines. Factors such as rainfall, terrestrial runoff, anthropogenic inputs (e.g. fisheries, agricultural and industrial etc.) and above all geomorphological setup were influenced by seasonal vagaries which might have played a vital role in the variation of metal distribution in this tropical estuarine system.

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