Research Journal of Environmental Sciences, 2011
ISSN 1819-3412 / DOI: 10.3923/rjes.2011.

Heavy Metal Accumulation in Commercially Important Fishes of South West Malaysian Coast

B.Y. Kamaruzzaman, Z. Rina, B. Akbar John and K.C.A. Jalal
Institute of Oceanography and Maritime Studies (INOCEM), Kulliyyah of Science, International Islamic University Malaysia, Jalan Sultan Ahmad Shah, Bandar Indera Mahkota, 25200, Kuantan Pahang, Malaysia

Corresponding Author: B.Y. Kamaruzzaman, Institute of Oceanography and Maritime Studies (INOCEM), Kulliyyah of Science, International Islamic University Malaysia, Jalan Sultan Ahmad Shah, Bandar Indera Mahkota, 25200, Kuantan Pahang, Malaysia

ABSTRACT
Now-a-days, bioaccumulation of toxic metals in aquatic animals causes serious threats to the human health when they are consumed. Thus the detection of toxic elemental concentration in aquatic flora and fauna has attracted various researches to determine their toxic levels in organism's edible parts. Upon considering this issue, the accumulation of some heavy metals such as Mercury (Hg), Arsenic (As), Lead (Pb) and Zinc (Zn) in Muscle and gill tissues were determined in commercially important fishes. Five species (*Nemipterus japonicas, Chirocentrus dorab, Lutjanus sebae, Otolithes ruber* and *Pampus argenteus*) were collected from south west coast of Malaysia, covering 3 states (Johor, Melaka and Negeri Sembilan). Metal concentration was determined using Inductively Coupled Plasma Mass Spectrometer (ICP-MS). In general, higher metal accumulation was detected in gill tissues than the muscle tissue of selected fishes while Hg concentration was higher in muscle tissues except in *Pampus argenteus*. Similar observation was noted in As and Pb accumulation in *N. japonicus* and *L. sebae*, respectively. Hg and As concentration was higher in *P. argenteus* muscle and gill tissues on the other hand higher Pb and Zn level was noted in Muscle tissues *L. sebae*. Higher concentration of Pb and Zn were detected in gill tissues of *L. sebae* and *O. ruber*, respectively. There was no species specific differences in metal accumulation were noted ($p<0.05$). It was also observed that essential metal level in fish samples were greater than non-essential toxic metals. The metal concentrations found in this study were lower than the national and international standard maximum permissible limits for human consumption. Therefore, no public health problem would be raised in the consumption of these fishes.

Key words: Metal accumulation, biomagnification, mercury concentration, ICP-MS analysis, estimation of weekly intake (EWI)

INTRODUCTION
The contamination of fresh and marine waters with a wide range of pollutants has become a matter of concern over the last few decades (Vutukuru, 2005; Dirilgen, 2001). The natural aquatic systems may extensively be contaminated with heavy metals released form domestic, industrial and other anthropogenic activities (Velez and Montoro, 1998; Mohammad and Hossam, 2007). It is well documented that heavy metal contamination could have devastating effects on the ecological balance of the recipient environment via altering the diversity of aquatic organisms

(Farombi *et al.*, 2007; Vosyliene and Jankaite, 2006; Ashraf, 2005; Javed, 2005) especially to the fish community (Olaifa *et al.*, 2004). These metals could reach food chain through various biochemical processes such as bioconcentration, bioaccumulation and ultimately biomagnified in various trophic levels and eventually threaten the health of humans by seafood consumption (Etesin and Benson, 2007; Kudirat, 2008; Lakshmanan *et al.*, 2009).

The natural concentrations of these metals in sea water are very low and hence the risk of contamination in living tissue is high, when the organisms started accumulating more amount of metals than the level of its excretion. These heavy metals, being conservative in nature have the maximum probability of biomagnification, when they are transferred to the human beings through the various members of different trophic levels in the marine food chain (Giarratano *et al.*, 2007; Adefemi *et al.*, 2008). The studies carried out on various fishes have shown that heavy metals may alter the physiological activities and biochemical parameters both in tissues and in blood (Basha and Rani, 2003).

Fisheries is one of the most important food production sectors in supplying protein to the human population. According to Food and Agriculture Organisation (FAO), world fisheries production in 2008 touched 146 million tonnes and a record value of 103 billion USD. Due to the increasing health consciousness of the consumers, seafood demands increase drastically during the past decade. The ever growing human population has pressurized on the sustainability of the fish population in the sea. The issues of over harvesting, global warming, pollution and fisheries stock management continue haunting the industry. FAO (2008) reported that if the present situation does not improved, 40 million tonnes of seafood shortage would be expected in 2030. Upon considering these issues, present research was initiated to determine the bioaccumulation level of hazardous metals in some commercially important fishes from South West coast of Peninsular Malaysia.

MATERIALS AND METHODS

Five fish species were purchased from local fish markets (LKIM) from 3 states (Johor, Melaka and Negeri sembilan) during 2008 (Fig. 1). Prior to the sampling, information on the fishing ground, time of fishing and the type of fishing gears and crafts used were noted from fisher men to make sure that the samples were collected from the respective sampling sites. Standard length and weight of the fishes documented prior to freezing. Fish samples were identified taxonomically using standard reference sources (www.fishbase.org).

Prior to analysis, fish samples were cleaned with running tape water and thawed at room temperature and gill and dorsal muscle tissues of selected fishes were excised using sterile scissors and transferred to the clean petridish. The tissues were dried in oven for three days at 60°C. The desired constant dry weight (0.5 g) of each sample was obtained after three days of drying process.

Acid digestion and ICP-MS analysis: Acid digestion method was performed to digest the samples which involved heating of 0.5 g of dried tissues of crabs in Teflon beaker with mixed concentrated acids (Hydrogen Peroxide (H_2O_2), Nitric acid (HNO_3), hydrochloric acid (HCl)) and sulphuric acid (H_2SO_4) in the ratio of 1:1 (Kamaruzzaman *et al.*, 2007). After the digestion process hundred times dilution was performed using Mili-Q water then the samples were analyzed using Inductively Coupled Plasma Spectrophotometer (ICP-MS). The values of the heavy metal concentrations in the tissues were calculated based on dry weights as this discounts the variability due to inner parts differences in the moisture content of organisms. International certified standards (DORM-2) by National Research Council of Canada and a blank in replicates were used to control the accurateness of this procedure and percentage of recovery was between 95-105%.

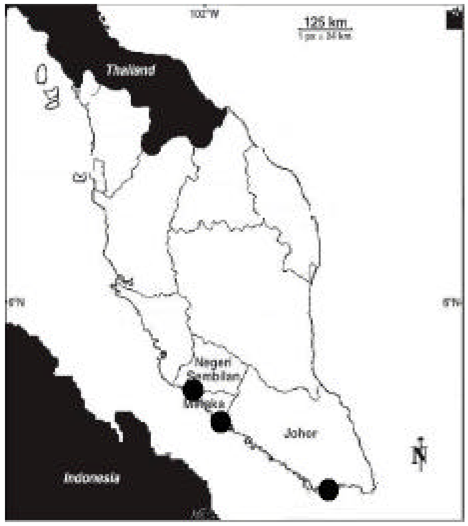

Fig. 1: Location of sampling sites (Kamaruzzaman *et al*., 2010)

Data analysis: Analysis of Variance (ANOVA) statistical test was performed to check the significance in bioaccumulation of metals in different body parts. Weekly intake of metal level in fishes was determined using formula by Cardoso *et al*. (2010).

RESULTS AND DISCUSSION

The data obtained from the present study revealed that higher metal accumulation occurs in gill tissues compared to the muscle tissues of fishes (Table 1). This observation might be directly due to the respiratory mechanisms of fishes. Similar observation was noted by Playle (1998) who reported that during the respiratory process, the constant exposure of gills to the ambient water and the consecutive filtering action for oxygen intake might have enhanced the metal concentration in gill tissues. It was also reported that in general, the metal concentrations were lowest in muscle and did not exceed the established quality standards for fish (Alam *et al*., 2002). Present study also showed that the concentration of essential metal (Zn) level in fish samples were greater than non-essential toxic metals (Pb, As and Hg) (Table 1). Similar observation was reported by various studies (Kamaruzzaman *et al*., 2008, 2010). Due to the crucial role played by the essential metals (Fe, Zn and Cu) as precursors in most of the enzymatic activities, they are carefully regulated by the physiological mechanisms in most organisms and thus the knowledge of their concentrations in fish is important in terms of their management and for human consumption. *Otolithes ruber* accumulated higher amount of Zn in gills (10.517±1.273 $\mu g\ g^{-1}$) and tissues (5.870±1.967 $\mu g\ g^{-1}$) followed by *Lutjanus sebae* (Gill = 10.296±1.605 $\mu g\ g^{-1}$, tissue = 5.518±1.318 $\mu g\ g^{-1}$) and *Chirocentrus dorab* (gills = 10.212±3.578 $\mu g\ g^{-1}$). The lowest concentration of Zn was detected in *Pampus argenteus* (gill = 9.854±2.317 $\mu g\ g^{-1}$, muscle = 3.752±0.373 $\mu g\ g^{-1}$) followed by *Nemipterus japonicus* (gill = 8.722±1.663 $\mu g\ g^{-1}$, muscle = 2.327±1.066 $\mu g\ g^{-1}$) (Table 1). Similar observation was reported by Lakshmanan *et al*. (2009) who postulated that accumulation of metal in different species is the function of their respective membrane permeability and enzyme system which is highly species specifics and because of this fact different metals accumulated in different orders in different fish samples. The high Zn concentration in fishes in

Table 1: Trace metal concentrations and related statistical parameter for various samples of fish

Metal concentration (DW µg g^{-1})	Certified value	Analysis value	Recovery percentage	Tissue sample	*Nemipterus japonicus*	*Chirocentrus dorab*	*Lutjanus sebae*	*Otolithes ruber*	*Pampus argenteus*
Hg	4.64±0.26	4.59±0.11	98.92	Muscle	0.012±0.008	0.017±0.015	0.015±0.001	0.017±0.003	0.019±0.007
				Gill	0.006±0.003	0.016±0.009	0.011±0.005	0.007±0.002	0.033±0.014
As	18±1.1	18.68±0.37	103.78	Muscle	0.014±0.005	0.006±0.001	0.011±0.003	0.004±0.001	0.025±0.009
				Gill	0.013±0.002	0.017±0.003	0.023±0.005	0.013±0.004	0.035±0.007
Pb	0.065±0.007	0.062±0.039	95.38	Muscle	0.055±0.053	0.037±0.026	0.263±0.072	0.036±0.046	0.17±0.087
				Gill	0.119±0.066	0.106±0.063	0.193±0.067	0.101±0.04	0.192±0.054
Zn	25.6±2.3	24.73±0.4	96.6%	Muscle	2.327±1.066	3.316±1.283	5.518±1.318	5.870±1.967	3.752±0.373
				Gill	8.722±1.663	10.212±3.578	10.296±1.605	10.517±1.273	9.854±2.317
No. of samples					37	25	35	30	35
Length range (cm)					28.1-31.4	44-54.5	23-24.5	33.3-42.6	17.5-25.2
Weight range (g)					244-281	588-592	135-137	420-531	277-279

Value are Mean±SD. Recovery test results of the analysis of standard reference material Dog fish muscle (DORM-2) at 95% confident limit

the present study might also because Zn is a necessary element for embryo development and is important to reproductive organs as reported by Carpene *et al.* (1994) and El-Sherif *et al.* (2009).

L. sebae accumulated higher amount of Pb in gills (0.193±0.067 µg g^{-1}) and tissues (0.263±0.072 µg g^{-1}) followed by *P. argenteus* (Gill = 0.192±0.054 µg g^{-1}, tissue = 0.17±0.087 µg g^{-1}) and *N. japonicus* (gills = 0.119±0.066 µg g^{-1}, tissues = 0.055±0.053 µg g^{-1}). The lowest concentration of Pb was detected in *C. dorab* (gill = 0.106±0.063 µg g^{-1}, muscle = 0.037±0.026 µg g^{-1}) followed by *O. ruber* (gill = 0.101±0.04 µg g^{-1}, muscle = 0.036±0.046 µg g^{-1}) (Table 1). It was reported that Pb is a cumulative toxin. In human beings, it binds with SH group of proteins, apart from that, Pb damages blood circulation, central nervous system, liver and kidneys (Ekong *et al.*, 2006). Hence, knowledge on Pb accumulation is highly essential for the utilization of fishes for safer human consumption. Even though, the bioavailability of Pb in marine environment is low, their constant bioaccumulation by aquatic organisms especially fishes would cause serious threats to human health when they are consumed.

P. argenteus accumulated higher amount of As in gills (0.035±0.007 µg g^{-1}) followed by *L. sebae* (0.023±0.005 µg g^{-1}) and *C. dorab* (0.017±0.003 µg g^{-1}). The lowest concentration of As was detected in *N. japonicas* and *O. ruber* gills (0.013±0.004 µg g^{-1}). Higher concentration of As in muscle tissue was detected in *P. argenteus* (0.025±0.009 µg g^{-1}) followed by *N. japonicas* (0.014±0.005 µg g^{-1}), *L. sebae* (0.011±0.003 µg g^{-1}), *C. dorab* (0.006±0.001 µg g^{-1}) and *O. ruber* (0.004±0.001 µg g^{-1}) (Table 1). It is evident from previous study that long term exposure to As would cause lesions and gill damage (Bols *et al.*, 2001). It is known that As tend to accumulate in different body organs and are dangerous to fishes (Celino *et al.*, 2008) and hence detailed investigation would reveal their rate of bioaccumulation in fish samples.

P. argenteus accumulated higher amount of Hg in gills (0.033±0.014 µg g^{-1}) followed by *C. dorab* (0.016±0.009 µg g^{-1}) and *L. sebae* (0.011±0.005 µg g^{-1}). The lowest concentration of Hg was detected in *O. ruber* (0.007±0.002 µg g^{-1}) and *N. japonicus* gills (0.006±0.003 µg g^{-1}). Higher concentration of Hg in muscle tissue was detected in *P. argenteus* (0.019±0.007 µg g^{-1}) followed by *O. ruber* (0.017±0.003 µg g^{-1}), *C. dorab* (0.017±0.015 µg g^{-1}), *L. sebae* (0.015±0.001 µg g^{-1}) and *N. japonicus* (0.012±0.008 µg g^{-1}) (Table 1). The observed different concentrations of mercury in fishes might be due to the nature of fish habitats. As the species studied were all demersal fishes, various agricultural and industrial activities near by the fishing ground would have enhanced Hg levels in sediments which inturn expressed in tissue samples. Similar observation was reported by

Table 2: Estimated Weekly Intake (EWI) of metals such as Zn, Pb, As and Hg from sampled fishes with reference to international standards

	Heavy metal concentration in selected fishes (μg)			
Samples	Zn	Pb	As	Hg
Nemipterus japonicus	3.618	0.069	0.001	0.021
Chirocentrus dorab	5.061	0.035	0.001	0.013
Lutjanus sebae	6.104	0.05	<0.001	0.013
Otolithes ruber	5.590	0.24	0.016	0.018
Pampus argenteus	4.445	0.152	0.061	0.024
Tolerable weekly intake (μg) by WHO/FAO	25	50.00	0.015	0.043

Table 3: Mean concentration of metals in fishes from South West Zone and comparison with national and International standards

Metals	Hg	As	Pb	Zn	References
Present study	0.031±0.019	0.032±0.007	0.256±0.004	14.077±1.121	
Malaysia	0.5	0.5	2	100	MRF (1985)
Singapore	0.5	2	2	-	FRS (1990)
Australia	2	0.5	0.5	-	FSA (2002)
WHO	0.14	0.5	1.5	150	WHO (1990)

Lawrence and Mason (2001) and Mason *et al.* (2000). The detected significant relationship between fish size and Hg bioaccumulation ($p<0.05$) demonstrated the positive linear relationship between total Hg concentration and fish length. Khaniki *et al.* (2005) suggested that mercury concentration in fish ultimately determined by methyl mercury accumulation at the base of the food chain. World Health Organization (1990) reported that methyl mercury concentration in fish can be up to 100000 higher than its water concentration level. Upon considering the lethal effects of mercury on the normal physiologic condition of the fishes, its route of exposure to the aquatic organisms should be noted. The source of the mercury in the sampling sites might be from the industrial discharges from nearby area. Similar observation was noted by Lindeberg *et al.* (2007) who reported that Hg enters surface waters via industrial waste discharges and atmospheric route. Except with food, Hg might have entered fish body directly through skin and gills in the present study. Similar observation was also reported by Celechovska *et al.* (2007) who observed a part of Hg builds itself into a feeding chain and ultimately reach the higher trophic level and can also enter the fish body via skin and gills tissues during respiration.

Heavy metals have the tendency to accumulate in various organs of marine organisms, especially fish which in turn may enter into the human metabolism through consumption causing serious health hazards (Bravo *et al.*, 2010). Thus weekly intake of selected metals were calculated which showed all the metals gets accumulated by selected fishes lower than the international standard levels ($p<0.05$) except Arsenic (As) intake by *P. argenteus* (0.061) (Table 2). The detected concentration of Zn, Pb and Hg in the selected commercial fishes probably may not cause serious ill effects in human when the fishes are consumed. However, the slight increase in As level in *P. argenteus* should be revalidated with species specific study for the proper managemental steps. It was also observed that *P. argenteus* accumulated more amount of toxic metals than the selected fishes which was probably due to its feeding behaviour.

Significantly the detected mean concentration of metals in fishes were lower than the maximum permissible limits ($p<0.05$) of national and international standards and thus the selected commercial fishes from south west coast of peninsular malaysia could be used for human consumption (Table 3).

CONCLUSION

Present study clearly showed the lower toxicity of various metal concentrations in commercially important fishes from SW Malaysian coast. Hence it is evident that the fishes caught from south west Malaysian coast would not cause acute toxicity in human when it is consumed. But the long term monitoring program of metal bioaccumulation in fishes would be valuable and provide useful information for the assessment of the potential health risks of metals in Malaysian residents. Calculation of Permissible Tolerable Weekly Intake (PTWI) of the heavy metal concentration in the fish demonstrated that among all the heavy metal tested, Arsenic (As) was predicted to exceed the Malaysian permissible concentration limit. Due to the letahal toxic nature of Arsenic in human detailed study should be initiated to validate this observation which could ultimately helpful in utilization of commercial fishes from South west Malaysian coast for human consumption.

ACKNOWLEDGMENT

Authors express their sincere gratitude to the International Islamic University Malaysia for providing infrastructure facilities.

REFERENCES

Adefemi, S.O., S.S Asaolu and O. Olaofe, 2008. Major elements in fish (*Illisha africana*), sediments and water from selected dams in Ekiti state. Res. J. Environ. Sci., 2: 63-67.

Alam, M., A. Tanaka, G. Allinson, L. Laurenson, F. Stagnitti and E. Snow, 2002. A comparison of trace element concentrations in cultured and wild carp (*Cyprinus carpio*) of Lake Kasumigaura, Japan. Ecotoxicol. Environ. Saf., 53: 348-354.

Ashraf, W., 2005. Accumulation of heavy metals in kidney and heart tissues of *Epinephelus microdon* fish from the Arabian Gulf. Environ. Monit. Assess., 101: 311-316.

Basha, P.S. and A.U. Rani, 2003. Cadmium induced antioxidant defense mechanism in freshwater teleost *Oreochromis mossambicus* (Tilapia). Ecotoxicol. Environ. Saf., 56: 218-221.

Bols, N.C., J.L. Brubacher, R.C. Ganassin and L.E.J. Lee, 2001. Ecotoxicology and innate immunity in fish. Dev. Comp. Immunol., 25: 853-873.

Bravo, A.G., J.L. Loizeau, S. Bouchet, A. Richard and J.F. Rubin *et al.*, 2010. Mercury human exposure through fish consumption in a reservoir contaminated by a chlor-alkali plant: Babeni reservoir (Romania). Environ. Sci. Pollut. Res. Int., 17: 1422-1432.

Cardoso, C., I. Farias, V. Costa, M. Nunes and L. Gordo, 2010. Estimation of risk assessment of some heavy metals intake through black scabbardfish (*Aphanopus carbo*) consumption in Portugal. Risk Anal., 30: 952-961.

Carpene, E., B. Gumiero, G. Fedrizzi and R. Serra, 1994. Trace elements (Zn, Cu, Cd) in fish from rearingponds of Emilia-Romagna region (Italy). Sci. Total Environ., 141: 139-146.

Celechovska, O., Z. Svobodova, V. Zlabek and B. Macharackova, 2007. Distribution of metals in tissues of the common carp (*Cyprinus carpio* L.). Acta Vet. Brno, 76: 93-100.

Celino, F.T., S. Yamaguchi, C. Miura and T. Miura, 2008. Testicular Toxicity of Arsenic on Spermatogenesis in Fish. In: Interdisciplinary Studies on Environmental Chemistry-Biological Responses to Chemical Pollutants, Murakami, Y., K. Nakayama, S.I. Kitamura, H. Iwata and S. Tanabe (Eds.). Terra Publishers, Tokyo, pp: 55-60.

Dirilgen, N., 2001. Accumulation of heavy metals in freshwater organisms assessment of toxic interactions. Turk. J. Chem., 25: 173-179.

Ekong, E.B., B.G. Jaar and V.M. Weaver, 2006. Lead-related nephrotoxicity: A review of the epidemiologic evidence. Kidney Int., 70: 2074-2084.

El-Sherif, M.S., M.T. Ahmed, M.A. El-Danasoury and N.H.K. El-Nwishy, 2009. Effects of pollutants on some aquatic organisms in Temsah Lake in Egypt. J. Fish. Aquatic Sci., 4: 150-160.

Etesin, U.M. and U.N. Benson, 2007. Cadmium, copper, lead and zinc tissue levels in Bonga Shad (*Ethmalosa fimbriata*) and Tilapia (*Tilapia guineensis*) Caught from Imo River, Nigeria. Am. J. Food Technol., 2: 48-54.

FAO, 2008. Fisheries Management. No. 3. Managing Fishing Capacity. FAO Technical Guidelines for Responsible Fisheries. No. 4. Suppl. 3, FAO., Rome, Italy, pp: 104.

FRS, 1990. Singapore's food regulation: Coconut oil. The Sale of Food Act (Chapter 283, 1990 Ed.). National Printers Ltd., Singapore.

FSA, 2002. Australia New Zealand food standards code part 1.4.1-1.4.2 contaminants and residues. Australia New Zealand Food Authority. http://www.foodstandards.gov.au/foodstandards/foodstandardscode.cfm.

Farombi, E.O., O.A. Adelowo and Y.R. Ajimoko, 2007. Biomarkers of oxidative stress and heavy metal levels as indicators of environmental pollution in African cat fish (*Clarias gariepinus*) from Nigeria Ogun River. Int. J. Environ. Res. Public Health, 4: 158-165.

Giarratano, E., L. Comoglio and O. Amin, 2007. Heavy metal toxicity in *Exosphaeroma gigas* (Crustacea, Isopoda) from the coastal zone of Beagle Channel. Ecotoxicol. Environ. Safety, 68: 451-462.

Javed, M., 2005. Growth responses of *Catla catla, Labeo rohita* and *Cirrhina mrigala* for bio-accumulation of zinc during chronic exposure. Pak. J. Biol. Sci., 8: 1357-1360.

Kamaruzzaman, B.Y., K. Zaleha, M.C. Ong and K.Y.S. Willison, 2007. Copper and zinc in three dominant brackish water fish species from paka estuary, terengganu, Malaysia. Malaysia J. Sci., 26: 65-70.

Kamaruzzaman, B.Y., M.C. Ong and K.C.A. Jalal, 2008. Levels of copper, zinc and lead in fishes of mengabang Telipot River, terengganu, Malaysia. J. Boil. Sci., 8: 1181-1186.

Kamaruzzaman, B.Y., M.C. Ong, S.Z. Rina and B. Joseph, 2010. Levels of some heavy metals in fishes from pahang river estuary, Pahang, Malaysia. J. Biol. Sci., 10: 157-161.

Khaniki, G.R.J., A. Inteaz, E. Nowroozi and R. Nabizadeh, 2005. Mercury contamination in fish and public health aspects: A review. Pak. J. Nutr., 4: 276-281.

Kudirat, A.O., 2008. Bioconcentration of lead in the tissues of feral and laboratory exposed *Clarias gariepinus*. J. Medical Sci., 8: 281-286.

Lakshmanan, R., K. Kesavan, P. Vijayanand, V. Rajaram and S. Rajagopal, 2009. Heavy metals accumulation in five commercially important fishes of parangipettai, southeast coast of India. Adv. J. Food Sci. Technol., 1: 63-65.

Lawrence, A.L. and R.P. Mason, 2001. Factors controlling the bioaccumulation of mercury and methyl mercury by the estuarine amphipod *Leptocheirus plumulosus*. Environ. Pollut., 111: 217-231.

Lindeberg, C., R. Bindler, C. Bigler, P. Rosen and I. Renberg, 2007. Mercury pollution trends in subarctic lakes in the northern Swedish mountains. Ambio, 36: 401-405.

MRF, 1985. Food regulations (Food regulations amendments) from January 1987. 4th Edn., Malaysian National Printers Berhad, Kuala Lumpur.

Mason, R.P., J.M. Laporte and S. Andres, 2000. Factors controlling the bioaccumulation of mercury, methylmercury, arsenic, selenium and cadmium by fresh water invertebrates and fish. Arch. Environ. Contam. Toxicol., 38: 283-297.

Mohammad, H.N.A. and H.H.A. Hossam, 2007. Accumulation and distribution of copper and zinc in both water and some vital tissues of two fish species (*Tilapia zillii and Mugil cephalus*) of lake Qarun, Fayoum Province, Egypt. Pak. J. Biol. Sci., 10: 2106-2122.

Olaifa, F.G., A.K. Olaifa and T. E. Onwude, 2004. Lethal and sublethal effects of copper to the African Cat fish (Clariasgariepnus). Afr. J. Biomed. Res., 7: 65-70.

Playle, R.C., 1998. Modelling metal interactions at fish gills. Sci. Total Environ., 219: 147-163.

Velez, D. and R. Montoro, 1998. Arsenic speciation in manufactured seafood products: A review. J. Food Protect., 61: 1240-1245.

Vosyliene, M.Z. and A. Jankaite, 2006. Effect of heavy metal model mixture on rainbow trout biological parameters. Ekologija, 4: 12-17.

Vutukuru, S.S., 2005. Acute effects of hexavalent chromium on survival, oxygen consumption, hematological parameters and some biochemical profiles of the Indian major carp, *Labeo rohita*. Int. J. Environ. Res. Public Health, 2: 456-462.

World Health Organization, 1990. Environmental Health Criteria 101: Methyl Mercury. WHO/IPCS, Geneva, Switzerland.