

**Original Article****Heavy Metals Concentrations and Human Health Risk Assessment for Three Common Species of Fish from Karkheh River, Iran**Habib Janadeleh<sup>\*1</sup>, Masoumeh Kardani<sup>2</sup>

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**ABSTRACT**

**Background:** The concentrations of heavy metals in the tissues and organs of fishes indicate the concentrations of heavy metals in water and their accumulation in food chains. In the present study, the concentrations of Zn, Cu, Cd, Ni, V and Pb in three common species of fish and the potential health risks to local residents via consumption of the fishes were estimated.

**Methods:** The concentrations of heavy metals (Zn, Cu, Cd, Ni, V and Pb) in the muscles, heart, liver, and gills of *Liza abu*, *Barbus grypus* and *Cyprinus carpio*, collected from Karkheh River, Southern Iran were measured. Associated human health risk was also evaluated by hazard quotient (HQ) and hazard index (HI) of muscle tissues.

**Results:** Bioaccumulation of heavy metals was the highest in the livers followed by gills, heart and muscle. Zn was the most accumulated metal in liver of *C. Carpio* while Cd had the lowest concentration in the muscle of *L. abu*. There were significant differences in metal concentration among different fish and different tissues ( $P < 0.05$ ). Zinc showed the highest concentrations in different tissues of all analyzed fish, while Cd had the lowest concentration in all tissue samples. The hazard quotients from consumption of the collected fish did not exceed the limit of 1.0.

**Conclusion:** The present study was a large-scale investigation of heavy metals in three common species of fish in Karkheh River. Occasional consumption of these fish is not likely to cause adverse effects. However, hazard indices for *C. carpio* and *Liza abu* were 1.751 and 1.21, respectively, which implies that continuous and excessive intake of these fish could result in chronic non-carcinogenic adverse effects.

**Keywords:** Chemical Water Pollutants, Fishes, Heavy Metals, Iran.

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**INTRODUCTION**

Heavy metals are of increasing global concern because of their persistence in the environment, effects on biogeochemical recycling, and ecological risks, their potential toxic effects and ability to bioaccumulate in aquatic ecosystems [1,2]. Heavy metals are categorized as potentially toxic agents (e.g. Cd, Pb, Ni) but some of them are essential elements for normal metabolism (e.g. Cu and Zn). Even at low concentrations, toxic metals can become harmful for human health when ingested over long periods. Essential metals can also produce toxic effects with excessive intake [3-5]. Elevated levels of heavy metals in aquatic ecosystems have raised serious public concerns around the world, due to their high potential to enter and accumulate in food chains and the correlation between heavy metals exposure and

cancer in human [6]. The toxicity of these chemicals is highly influenced by geochemical factors that influence their bioavailability [7,8].

Fish is widely consumed by humans in the world due to their high protein supply and omega-3 fatty acids that help reduce the risk of certain types of cancer and cardiovascular diseases [9]. However, fish can accumulate high levels of metals through water and their food [10-12]. Fishes are widely used as bioindicators for the determination of heavy metal pollution in aquatic ecosystems [13,14]. Approximately 90% of human health risks related to fish consumption are associated with metal-contaminated fish [15]. The concentrations of heavy metals in tissues and organs of fishes could indicate their concentrations in water and their accumulation in the food chain [16].

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Recently, numerous investigations and monitoring programs have been carried out on heavy metal concentrations in different fishes [17-19]. They are largely based on measuring accumulated heavy metals in different tissues of the fish, such as liver, gills, muscle and heart. Gills and liver are mostly chosen as target organs for assessing metal accumulation. Concentrations of metals in gills reflect their water levels where the fish live, whereas concentrations in the liver represent storage of metals [20]. Increased metal concentrations in the liver may represent storage of sequestered products in this organ. Muscle is not an active tissue in accumulating heavy metals [4, 15, 20, 21].

Karkheh River originates in the Zagros Mountains and, after entering the northwest plains of Iran, crosses Ahwaz anticline near Hamidiya Village. A little further, downstream, the river turns into two parallel channels, both ending in Hawzah marshes near the Iraq-Iran border. About 10%–11% of Iran's wheat production comes from Karkheh River basin [22]. Therefore, assessing heavy metals levels in fishes for possible contamination is of utmost importance. The objective of the present study was to determine the concentrations of Zn, Cu, Cd, Ni, V and Pb in the muscles, heart, liver and gills of three common species of fish collected from Karkheh River and their potential health risk.

## MATERIAL AND METHODS

### *Sample Collection and Preparation*

The fish species were *Cyprinus carpio*, *Liza abu*, and *Barbus grypus*. Samples were collected from local anglers. In total, 120 fish samples were collected in the winter of 2014 from Karkheh River. Fish samples were put in zip-lock polyethylene bags and then were transferred to lab within 3 h. The gill, muscle, liver and heart were immediately separated in the lab, and stored at -20 °C until processing for analysis.

### *Sample Analysis*

All freeze-dried muscles, gills, heart, and liver samples were crushed, sieved, grinded, and homogenized. The tissues were dissected in sterile conditions and were used to determine the levels of Zn, Cu, Cd, Ni, V and Pb. First, 0.5 g of homogenized sample was mixed with 0.5 ml magnesium acetate and was dried at 100 °C for 3–4 h. The samples were extracted with 2 N nitric acid (HNO<sub>3</sub>) after being washed at 600 °C (8 h)

and diluted to 15 ml. All containers used in the study were washed in HNO<sub>3</sub> (10%) to prevent contamination. The Pb, Cd, Cu and Zn contents of the filtrates were analyzed using an inductively coupled plasma-optic emission spectrophotometer [23, 24].

### *Statistical Analysis*

Statistical analysis was performed using SPSS version 16; SPSS, Chicago, IL, USA). Student's *t*-test and one-way analysis of variance (ANOVA) were used to verify significant differences in organ metal concentrations between fish species. Values are given as means ± standard deviation (SD).

### *Health Risk Assessment*

The potential non-cancer risk for individual heavy metals is expressed as the hazard quotient (HQ) [25, 26] and can be calculated as follows:

$$HQ = ADD / RfD \quad (1)$$

$$ADD = C \times IR / BW \quad (2)$$

where RfD is the daily intake reference dose ( $\mu\text{g kg}^{-1} \text{day}^{-1}$ ), ADD is the average daily intake of heavy metals ( $\mu\text{g kg}^{-1} \text{day}^{-1}$ ), C is the mean concentrations of heavy metals in fish ( $\mu\text{g/kg}$ ), IR is the consumption rate of fish ( $63 \text{g person}^{-1} \text{day}^{-1}$ ), and BW is the average adult body weight (70 kg). The RfD values were 300, 40, 20, 1, 9, and 4  $\mu\text{g kg}^{-1} \text{day}^{-1}$  for zinc, copper, nickel, cadmium, vanadium and lead, respectively. If the HQ exceeds one, there might be concerns for potential non-cancer effects. As a rule, the greater the value of HQ, the higher level of concern. A hazard index (HI) approach was used to assess the overall potential non-carcinogenic health risk posed by more than one heavy metal. HI is equal to the sum of the HQs, as described in Eq. (3) [26].

$$HI = HQ_1 + HQ_2 + \dots + HQ_n \quad (3)$$

## RESULTS

### *Concentration of Heavy Metals in Fish*

The concentrations of heavy metals in the three studied fish species are demonstrated in Tables 1, 2 and 3. All metals concentrations were determined on a wet weight basis. Among all metals, Zn and Pb had the highest and lowest concentrations, respectively. The hazard quotients and hazard indices of Zn, Cu, Cd, Ni, V and Pb through consuming these fishes for adults are

listed in Table 4. Since muscles constitute the main part of the fish consumed by humans, we only investigated hazard quotients and hazard indices in the muscles of the specimens. Among the studied metals, Cd presented the highest HQ (0.70) and the lowest HQ was for Zn (0.038).

*C. carpio* showed the highest health risk among three fish species. The HI for *C. carpio* was 1.751 while it was 1.21 and 0.76 for *Liza abu* and *Barbus grypus*, respectively.

The results of one-way ANOVA are presented in Table 5. Analysis of muscles and gills tissues revealed no significant differences for Cu, Cd, Ni, V and Pb in the three fish species ( $P>0.05$ ). However, zinc content of the livers of *L. abu* and *B. grypus* were significantly different ( $P<0.05$ ). Heart tissues also showed significant differences for Zn, Pb and Cd ( $P<0.05$ ) in all fish species. Metals concentrations differed significantly among liver, gills, heart, and muscles in *C. carpio*, *L. abu* and *B. grypus* (Table 5).

## DISCUSSION

In all fishes, HQs of individual metals were below one, which means that the daily intake of these metals would be unlikely to cause adverse health effects for local residents. The results of this research showed that continuous and excessive intake of fishes studied, especially *C. carpio* and *B. grypus*, could cause adverse health effects. Generally, *C. carpio* consumption had the highest health risk for the investigated exposure groups, while *L. abu* consumption had the lowest health risk. The highest Zn concentration was observed in liver of *C. carpio* (27.11  $\mu\text{g/g}$ ). This result was partly similar to another report [27]. The lowest Zn concentration was in muscles of *Liza abu* (12.75  $\mu\text{g/g}$ ). The FAO guideline for maximum Zn content is 30 mg/kg [28]. The concentrations of Zn in the present study were lower than the guideline's values. Our analyzed fish species had a tendency to accumulate Zn in the liver as was also reported earlier [27, 28]. Zn is known to be involved in most metabolic pathways in humans, and Zn deficiency can lead to loss of appetite, growth retardation, skin changes, and immunological abnormalities. The concentrations of Zn in all the fish samples were lower than the FAO standard of 30 mg/g [29] and MAFF limit of 50 mg/g [30]. Zn, has a tendency to get bio-accumulated in fatty tissues of aquatic organisms, including the fish, and affects reproductive physiology in fishes [31].

In the present investigation, Cd had the lowest concentrations of all metals in all tissues that were analyzed. The lowest concentration of Cd was in muscles of *L. abu* (0.24 $\pm$ 0.1  $\mu\text{g/g}$ ) and the highest was in the liver of *C. carpio* (1.14 $\pm$ 0.55). The bioaccumulation of Cd in liver is in accordance with previous studies [32, 33]. Maximum Cd concentration detected in the liver of *C. carpio* was 0.75 mg/kg [27]. Cd can accumulate in human body and may cause kidney dysfunction, skeletal damage, and reproductive impairment [5]. The concentrations of Cd in all fish samples were far below the Western Australian authorities' proposed level of 5.5  $\mu\text{g/g}$  [34], and FAO standard of 2.0  $\mu\text{g/g}$  [28]. Cd occurs naturally in the environment in low levels. It is also used in batteries, pigments, and metal coatings [35].

The concentrations of Cu in the samples analyzed ranged from 3.22 $\pm$ 1.45 to 8.89 $\pm$ 1.57  $\mu\text{g/g}$ , with the highest concentration of 8.89 $\pm$ 1.57  $\mu\text{g/g}$ , in the gills of *C. carpio*. However, the lowest concentration of 3.22 $\pm$ 1.45  $\mu\text{g/g}$  was in the muscle of *L. abu*, which was far below the FAO guideline of 30 mg/kg [28]. Thus, the concentrations of Cu in the fish samples analyzed were all below the recommended limits [28]. Ahmed et al. [35] reported the highest concentration of 575.34 $\pm$ 61.86 mg/kg, in prawn and the lowest concentration of 4.39 $\pm$ 0.49 mg/kg in *Gagatayoussoufi*. Cu is an essential trace element, but in high concentrations can cause adverse health problems such as liver and kidney damage [36]. According to UK Food Standards Committee Report, Cu concentration in food should not exceed 20 mg/kg of wet weight [37, 38]. Spanish legislation also proposed 20 mg/kg of wet weight as the permissible level [15], but Australian Food Standard Code accepted 10 mg/kg wet weight as the maximum safe concentration of Cu [10].

Major sources of Ni in humans are processed food and uptake from natural resources [37, 38]. The concentrations of Ni in the samples ranged from 2.31 $\pm$ 1.52 to 6.91 $\pm$ 1.34 mg/kg. Maximum Ni levels were in the livers (6.91 $\pm$ 1.34) of *C. carpio* and the minimum was in the muscles of *L. abu* (2.31 $\pm$ 1.52  $\mu\text{g/g}$ ). Ni is normally found at very low concentrations in the environment, and at high levels can result in a variety of pulmonary adverse effects, such as lung inflammation, fibrosis, emphysema, and tumors [39]. WHO recommends 100–300  $\mu\text{g Ni}$  for daily intake [40]. The concentration of V was higher in

the livers of *C. carpio* ( $6.84 \pm 2.21$ ). The lowest V accumulation was in the muscles of *L. Abu* ( $2.54 \pm 1.38$ ). The highest concentration of V was detected in the gills of big-head carps ( $167.83 \pm 38.11$ ) [41].

Ahmed et al. [35] reported the highest concentration of V was  $1.84 \pm 0.11$  mg/kg in *M. pancalus* and the lowest V accumulation ( $0.17 \pm 0.04$  mg/kg) was in *M. rosenbergii*. V is an essential element for normal cell growth and some enzymes, particularly the V nitrogenase used by some nitrogen-fixing microorganisms. V complexes can reduce growth of cancer cells and improve human diabetes mellitus but can be toxic when presented at higher concentrations [42]. V content in the literature has been reported in the range of 0.047–1.310 mg/kg in dietary fish [43,44].

In our study, maximum concentration of Pb observed was  $1.52 \pm 0.37$   $\mu\text{g/g}$  in the livers of

*Barbusgrypus* and the lowest was  $0.37 \pm 0.1$   $\mu\text{g/g}$  in the muscles of *L*. The highest Pb concentration was detected in *R. decussates* [20]. Ahmed et al. [35] stated the highest concentration of Pb was in *Indoplanorbis exustus*, and the lowest was measured in *A. coila*. Gu et al. [2] reported the maximum concentration of Pb observed was 27.31 ng/g in *Siganus oramin*. Petkovšek et al. [27] found the maximum concentration of Pb in the gills of *A. alburnus alburnus* (0.88 mg/kg) and *C. auratus gibelio* (0.48 mg/kg). Pb poisoning can cause reduced cognitive development and intellectual performance in children, increased blood pressure and cardiovascular diseases in adults [45]. Pb is a non-essential element and it is well documented that Pb can cause neurotoxicity, nephrotoxicity, and many others adverse health effects [46]. The maximum permitted lead level is 2.0  $\mu\text{g/g}$  [30, 47]. Lead levels in our investigated fish tissue samples were lower than the standard.

**Table 1.** Mean heavy metals concentrations ( $\mu\text{g/kg}$ , wet weight) in the muscle, heart, liver and gills of *Liza abu* from Karkheh River.

Element	Muscle	Heart	Liver	Gill
Zn ( $\mu\text{g/kg}$ )	$12.75 \pm 2.25c$	$15.91 \pm 2.28c$	$21.13 \pm 2.5d$	$20.87 \pm 3.7d$
Cu ( $\mu\text{g/kg}$ )	$3.22 \pm 1.45b$	$3.24 \pm 1.22b$	$4.35 \pm 1.70c$	$4.29 \pm 1.7c$
Cd ( $\mu\text{g/kg}$ )	$0.24 \pm 0.1a$	$0.31 \pm 0.1a$	$0.43 \pm 0.21a$	$0.37 \pm 0.19a$
Ni ( $\mu\text{g/kg}$ )	$2.31 \pm 1.52b$	$4.43 \pm 1.37b$	$5.55 \pm 1.65c$	$5.51 \pm 0.25c$
V ( $\mu\text{g/kg}$ )	$2.54 \pm 1.38b$	$3.02 \pm 1.33b$	$3.76 \pm 1.25c$	$3.22 \pm 0.25c$
Pb ( $\mu\text{g/kg}$ )	$0.37 \pm 0.1a$	$0.58 \pm 0.21$	$1.21 \pm 0.28b$	$0.95 \pm 0.25c$

Values within the same row with different letters are significantly different ( $p < 0.05$ )

**Table 2.** Mean heavy metal concentrations ( $\mu\text{g/kg}$ , wet weight) in the muscle, heart, liver and gills of *Barbus grypus* from Karkheh River.

Element	Muscle	Heart	Liver	Gill
Zn	$15.32 \pm 2.5c$	$19.58 \pm 2.67d$	$22.21 \pm 2.25d$	$20.51 \pm 2.4d$
Cu	$4.48 \pm 1.55$	$4.56 \pm 0.64c$	$5.69 \pm 2.2c$	$5.51 \pm 1.4c$
Cd	$0.42 \pm 0.2a$	$0.63 \pm 0.1a$	$0.88 \pm 0.18a$	$0.71 \pm 0.11a$
Ni	$3.69 \pm 0.87b$	$3.75 \pm 1.19c$	$4.23 \pm 1.22c$	$3.79 \pm 0.99c$
V	$3.68 \pm 1.84$	$4.85 \pm 1.64c$	$5.96 \pm 2.25c$	$5.12 \pm 0.37c$
Pb	$0.68 \pm 0.2a$	$1.10 \pm 0.18b$	$1.52 \pm 0.37b$	$1.35 \pm 0.25b$

Values within the same row with different letters are significantly different ( $p < 0.05$ )

**Table 3.** Mean heavy metal concentrations ( $\mu\text{g/kg}$ , wet weight) in the muscle, heart, liver and gills issues of *Cyprinus Carpio* from Karkheh River.

Element	Muscle	Heart	Liver	Gill
Zn	$22.85 \pm 4.69c$	$24.51 \pm 3.69c$	$27.11 \pm 3.96c$	$25.89 \pm 2.5c$
Cu	$6.55 \pm 1.67b$	$7.65 \pm 0.69b$	$8.23 \pm 2.02b$	$8.89 \pm 1.57b$
Cd	$0.78 \pm 1.5a$	$0.87 \pm 0.11a$	$1.14 \pm 0.55a$	$0.93 \pm 0.1a$
Ni	$5.53 \pm 1.28b$	$6.83 \pm 1.57b$	$6.91 \pm 1.34b$	$6.18 \pm 1.1b$
V	$4.17 \pm 1.37b$	$5.21 \pm 1.67b$	$6.84 \pm 2.21b$	$6.53 \pm 0.55b$
Pb	$0.75 \pm 0.2a$	$0.85 \pm 0.1a$	$1.50 \pm 0.62a$	$1.01 \pm 0.25a$

Values within the same row with different letters are significantly different ( $p < 0.05$ )

**Table 4.** Hazard quotient (HQ) and hazard index (HI) of heavy metals from consumption of three fish species collected from the Karkheh River.

Heavy metals	Hazard quotient (HQ)		
	<i>Liza abu</i>	<i>Barbus grypus</i>	<i>Cyprinus Carpio</i>
Zn	0.038	0.045	0.068
Cu	0.072	0.100	0.147
Cd	0.216	0.378	0.703
Ni	0.103	0.166	0.248
V	0.254	0.368	0.417
Pb	0.083	0.153	0.168
<b>Hazard index (HI)</b>	0.766	1.21	1.751

**Table 5.** Statistical Analysis of metal concentrations in the muscle, heart, liver, and gills of *Liza abu*, *Barbus grypus* and *Cyprinus carpio*.

Fish species	Zn		Cu		Cd		Ni		V		Pb	
	One-way	ANO										
	Fval	Pvalue	Fval	Pvalue	Fval	Pvalue	Fvalue	Pval	Fvalu	Pval	Fval	Pvalue
<i>L. abu</i>	126.25	<0.001	12.27	<0.001	14.88	<0.001	123.46	<0.002	37.14	<0.001	299.79	<0.001
<i>B.grypus</i>	99.58	<0.001	452.48	<0.002	49.69	<0.001	13.44	<0.002	240.11	<0.001	63.74	<0.001
<i>C. Carpio</i>	41.80	<0.001	212.85	<0.001	54.77	<0.001	26.88	<0.001	280.14	<0.001	65.52	<0.001

## CONCLUSION

The present study was a large-scale investigation of heavy metals (Zn, Cu, Cd, Ni, V and Pb) in three common species of fish in Karkheh River in South of Iran. Occasional consumption of these fish is not likely to cause adverse effects. However, hazard indices for *C. carpio* and *Liza abu* were 1.751 and 1.21, respectively. This indicated that continuous and excessive intake of these fish could result in chronic non-carcinogenic adverse effects.

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## REFERENCES

- David IG, Matache ML, Tudorache A, Chisamera G, Rozylowicz L, Radu GL. Food chain biomagnification of heavy metals in samples from the Lower Prut Floodplain Natural Park. *Environ Eng Manag J* 2012;11(1):69-73.
- Gu Y-G, Lin Q, Wang X-H, Du F-Y, Yu Z-L, Huang H-H. Heavy metal concentrations in wild fishes captured from the South China Sea and associated health risks. *Mar Pollut Bull* 2015;96(1):508-12.
- Ashraf W, Seddigi Z, Abulkibash A, Khalid M. Levels of selected metals in canned fish consumed in Kingdom of Saudi Arabia. *Environ Monit Assess* 2006;117(1-3):271-9.
- Tuzen M. Toxic and essential trace elemental contents in fish species from the Black Sea, Turkey. *Food Chem Toxicol* 2009;47(8):1785-90.
- Uluozlu OD, Tuzen M, Mendil D, Soylak M. Trace metal content in nine species of fish from the Black and Aegean Seas, Turkey. *Food Chem* 2007;104(2):835-40.
- Zhang X, Wiseman S, Yu H, Liu H, Giesy JP, Hecker M. Assessing the toxicity of naphthenic acids using a microbial genome wide live cell reporter array system. *Environ Sci Tech* 2011;45(5):1984-91.
- Janadeleh H, Hosseini Alhashemi A, Nabavi S. Investigation on concentration of elements in wetland sediments and aquatic plants. *Global J Environ Sci Manage* 2016;2(1):81-93.
- Fairbrother A, Wenstel R, Sappington K, Wood W. Framework for metals risk assessment. *Ecotoxicol Environ Saf* 2007;68(2):145-227.
- Storelli M. Potential human health risks from metals (Hg, Cd, and Pb) and polychlorinated biphenyls (PCBs) via seafood consumption:

- estimation of target hazard quotients (THQs) and toxic equivalents (TEQs). *Food Chem Toxicol* 2008;46(8):2782-8.
10. Alam M, Tanaka A, Allinson G, Laurenson L, Stagnitti F, Snow E. A comparison of trace element concentrations in cultured and wild carp (*Cyprinus carpio*) of Lake Kasumigaura, Japan. *Ecotoxicol Environ Saf* 2002;53(3):348-54.
  11. Hodson PV. The effect of metal metabolism on uptake, disposition and toxicity in fish. *Aqua Toxicol* 1988;11(1-2):3-18.
  12. Mansour S, Sidky M. Ecotoxicological studies. Heavy metals contaminating water and fish from Fayoum Governorate, Egypt. *Food Chem* 2002;78(1):15-22.
  13. Ahmad A, Shuhaimi-Othman M. Heavy Metal Concentrations in Sediments and Fishes from Lake Chini, Pahang, Malaysia. *J Biol Sci* 2010;10(2):93-100.
  14. Alibabić V, Vahčić N, Bajramović M. Bioaccumulation of metals in fish of Salmonidae family and the impact on fish meat quality. *Environ Monit Assess* 2007;131(1-3):349-64.
  15. Demirak A, Yilmaz F, Tuna AL, Ozdemir N. Heavy metals in water, sediment and tissues of *Leuciscus cephalus* from a stream in southwestern Turkey. *Chemos* 2006;63(9):1451-8.
  16. Pintaeva ET, Bazarsadueva S, Radnaeva L, Petrov E, Smirnova O. Content and character of metal accumulation in fish of the Kichera River (a tributary of Lake Baikal). *Contemp Probl Ecol* 2011;4(1):64-8.
  17. Mendil D, Uluözülü ÖD, Hasdemir E, Tüzen M, Sari H, Suicmez M. Determination of trace metal levels in seven fish species in lakes in Tokat, Turkey. *Food Chem* 2005;90(1):175-9.
  18. Reynders H, Bervoets L, Gelders M, De Coen W, Blust R. Accumulation and effects of metals in caged carp and resident roach along a metal pollution gradient. *Sci Total Environ* 2008;391(1):82-95.
  19. Yi Y, Yang Z, Zhang S. Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin. *Environ Pollut* 2011;159(10):2575-85.
  20. Abdallah MAM. Bioaccumulation of heavy metals in mollusca species and assessment of potential risks to human health. *B Environ Contam Tox* 2013;90(5):552-7.
  21. Sankar T, Zynudheen A, Anandan R, Nair PV. Distribution of organochlorine pesticides and heavy metal residues in fish and shellfish from Calicut region, Kerala, India. *Chemos* 2006;65(4):583-90.
  22. Marjanizadeh S, de Fraiture C, Loiskandl W. Food and water scenarios for the Karkheh River Basin, Iran. *Wat Intern* 2010;35(4):409-24.
  23. Telliard W, Martin T. Trace elements in water, solids and biosolids by inductively coupled plasma-atomic emission spectrometry. Washington, DC: US Environmental Protection Agency; 2001.
  24. USEPA. Guidelines for exposure assessment, environmental protection agency, risk assessment forum. Washington: DC; 1992.
  25. USEPA. Guidance for performing aggregate exposure and risk assessments, environmental protection agency. Office of pesticide programs. Washington: DC; 1999.
  26. USEPA. Risk assessment guidance for superfund. Human health evaluation manual (part A) Interim final, Washington (DC): United States Environmental Protection Agency; 1989.
  27. Petkovšek SAS, Grudnik ZM, Pokorny B. Heavy metals and arsenic concentrations in ten fish species from the Šalek lakes (Slovenia): assessment of potential human health risk due to fish consumption. *Environ Monit Assess* 2012;184(5):2647-62.
  28. Nauen C. Compilation of legal limits for hazardous substances in fish and fishery products. FAO, Rome, Italy; 1983.
  29. Jabeen F, Chaudhry AS. Environmental impacts of anthropogenic activities on the mineral uptake in *Oreochromis mossambicus* from Indus River in Pakistan. *Environ Monit Assess* 2010;166(1-4):641-51.
  30. MAFF. Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1993. *Aquatic Environment Monitoring Report No. 44*. Directorate of Fisheries Research, Lowestoft; 1995.
  31. Ghosh BB, K MM, Bagchi MM. Proc. National Seminar on Pollution Control and Environ Manag. 1985, p. 194-9.
  32. Ikem A, Egiebor N, Nyavor K. Trace elements in water, fish and sediment from Tuskegee Lake, Southeastern USA. *Water, Air, & Soil Pollution* 2003;149(1-4):51-75.
  33. Yilmaz F, Özdemir N, Demirak A, Tuna AL. Heavy metal levels in two fish species *Leuciscus cephalus* and *Lepomis gibbosus*. *Food Chem* 2007;100(2):830-5.
  34. Plaskett D, Potter I. Heavy metal concentrations in the muscle tissue of 12 species of teleost from Cockburn Sound, Western Australia. *Mar Freshwater Res* 1979;30(5):607-16.
  35. Ahmed MK, Baki MA, Islam MS, Kundu GK, Habibullah-Al-Mamun M, Sarkar SK, et al. Human health risk assessment of heavy metals in

- tropical fish and shellfish collected from the river Buriganga, Bangladesh. *Environ Sci Pollut Res* 2015;22(20):15880-90.
36. Ikem A, Egiebor NO. Assessment of trace elements in canned fishes (mackerel, tuna, salmon, sardines and herrings) marketed in Georgia and Alabama (United States of America). *J Food Compos Anal* 2005;18(8):771-87.
  37. Cronin M, Davies IM, Newton A, Pirie JM, Topping G, Swan S. Trace metal concentrations in deep sea fish from the North Atlantic. *Marine Mar Environ Res* 1998;45(3):225-38.
  38. NAS-NRC. Division of medical sciences, medical and environmental effects of pollutants nickel. National Academic Press, Washington .1975.
  39. Forti E, Salovaara S, Cetin Y, Bulgheroni A, Tessadri R, Jennings P, et al. In vitro evaluation of the toxicity induced by nickel soluble and particulate forms in human airway epithelial cells. *Toxicol Vit* 2011;25(2):454-61.
  40. WHO. Quality directive of potable water. WHO, Geneva;1994.p.197-8.
  41. Jiang D, Hu Z, Liu F, Zhang R, Duo B, Fu J, et al. Heavy metals levels in fish from aquaculture farms and risk assessment in Lhasa, Tibetan Autonomous Region of China. *Ecotoxic* 2014;23(4):577-83.
  42. USEPA. Regional screening level (RSL) summary table. 2013.
  43. Millour S, Noël L, Chekri R, Vastel C, Kadar A, Sirot V, et al. Strontium, silver, tin, iron, tellurium, gallium, germanium, barium and vanadium levels in foodstuffs from the Second French Total Diet Study. *J Food Compos Anal*2012;25(2):108-29.
  44. Guérin T, Chekri R, Vastel C, Sirot V, Volatier J-L, Leblanc J-C, et al. Determination of 20 trace elements in fish and other seafood from the French market. *Food Chem* 2011;127(3):934-42.
  45. Canfield RL, Henderson Jr CR, Cory-Slechta DA, Cox C, Jusko TA, Lanphear BP. Intellectual impairment in children with blood lead concentrations below 10 µg per deciliter. *New Engl J Med* 2003;348(16):1517-26.
  46. García-Lestón J, Méndez J, Pásaro E, Laffon B. Genotoxic effects of lead: an updated review. *Environ Int* 2010;36(6):623-36.
  47. WHO. Health criteria other supporting information. In:Guidelines for Drinking Water Quality; 1996.p. 31–388.