Marine Pollution Bulletin xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Baseline

Determination of mercury and vanadium concentration in *Johnius belangerii* (*C*) fish in Musa estuary in Persian Gulf

Neamat Jaafarzadeh Haghighi Fard [a,b], Maryam Ravanbakhsh [b,g,*], Zahra Ramezani [c,d], Mehdi Ahmadi [a,b], Kambiz Ahmadi Angali [e], Ahmad Zare Javid [f]

[a] Environmental Technology Research Center, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran
[b] Department of Environmental Health Engineering, School of Public Health, Ahvaz Jundishapur University of Medical Sciences, Ahvaz 15794-61357, Iran
[c] Nanotechnology Research Center, Faculty of Pharmacy, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran
[d] Department of Medicinal Chemistry, Faculty of Pharmacy, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran
[e] Department of Biostatistics, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran
[f] Nutrition and Metabolic Diseases Research Center, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran
[g] Student Research Committee, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran

ARTICLE INFO

Article history:
Received 27 January 2015
Revised 5 May 2015
Accepted 13 May 2015
Available online xxxx

Keywords:
Mercury
Vanadium
Johnius belangerii (*C*) fish
Persian Gulf
Musa estuary

ABSTRACT

The main aim of this study was to determine the concentrations of mercury and vanadium in *Johnius belangerii* (*C*) fish in the Musa estuary. A total of 67 fishes were caught from the Musa estuary during five intervals of 15 days in the summer of 2013. After biometric measurements were conducted, the concentrations of mercury and vanadium were measured in the muscle tissue of fish using a direct method analyzer (DMA) and a graphite furnace atomic absorption spectrophotometer, respectively. The mean concentration of mercury and vanadium in the muscle tissue of fish was 3.154 ± 1.981 and 2.921 ± 0.873 mg/kg w.w, respectively. The generalized linear model (GLM) analysis showed a significantly positive relationship among mercury concentration, length, and weight ($P = 0.000$). In addition, there was a significantly negative relationship between vanadium concentration and fish length ($P = 0.000$). A reverse association was found between concentrations of mercury and vanadium. Mercury concentration exceeded the allowable standards of the Environmental Protection Agency (EPA), the World Health Organization (WHO), and the Food and Drug Administration (FDA) in *J. belangerii* (*C*).

The Persian Gulf is a shallow basin area spanning 240,000 km^2 with an average depth of 35–40 m (Mortazavi and Sharifian, 2011b), located to the south of Iran (Elahi et al., 2012). It joins free international waters via the Hormuz Strait. Pollutants may persist longer in the Persian Gulf due to factors such as low turnover and flushing time (3–5 years), shallow depth, limited circulation, high salinity, high temperature, and evaporation. Therefore, their effects on the marine environment may be considerable. The Musa estuary (with several branches) is one of the largest estuaries, located in the northern coastal area of the Persian Gulf (latitude of 30°15′–30°32′ and longitude of 49°–49°20′). It is a coastal ecosystem hosting various unique marine fauna and flora. The self-purification capacity of the Musa estuary is low, and the concentrations of suspended solids are high. A massive volume of contaminants is transferred into this estuary from the Persian Gulf. In addition, because of its geographical position, many tankers and ships use the Musa estuary as a waterway. The Musa estuary receives a huge quantity of effluents from urban and agricultural resources, petrochemical plants, and large ports (Malmasi et al., 2010).

Heavy metals with high bioaccumulation ability are abundant and persistent contaminants, therefore probably existing at high concentrations in both the environment and biota samples. Species found at the top of a food chain can accumulate such environmental pollutants in high concentrations. Heavy metals can originate from natural and anthropogenic sources (Jaafarzadeh et al., 2011).

The heavy metal concentration in fish is important with regard to the management of nature and human consumption (Karadede et al., 2004). Heavy metal accumulation in fish depends on many factors including several chemical interactions (Wang et al., 2005), their bioavailability and possible pollutant source (Abdolahpur

* Corresponding author.
E-mail addresses: Jaafarzadeh-n@ajums.ac.ir (N.J.H. Fard), mapseh@gmail.com (M. Ravanbakhsh), zramezani@ajums.ac.ir (Z. Ramezani), ahmadi241@gmail.com (M. Ahmadi), kzfir@yahoo.com (K.A. Angali), ahmaddjavid@gmail.com (A.Z. Javid).

http://dx.doi.org/10.1016/j.marpolbul.2015.05.036
0025-326X/

Monikh et al., 2013), the region and time of fishing, the requirements, gender, size, species, nutrition, their concentration in water, exposure time with heavy metals, and other environmental factors such as salinity, pH, and water temperature (Zhang and Wong, 2007).

The evaluation of the chemical quality of water and aquatic organisms is important for human life (Fletcher et al., 2014; Mendil et al., 2010). Several studies selected fishes to assess heavy metal bioaccumulation (Agah et al., 2012; Fletcher et al., 2014; Guérin et al., 2011; Hosseini Alhashemi et al., 2012; Jaafarzadeh et al., 2011; Love et al., 2013; Mohammadnabizadeh et al., 2013; Mortazavi and Sharifian, 2012; Shreadah et al., 2015). Zhou and Wong (2000) studied mercury accumulation in freshwater fish collected from the Pearl River Delta in Hong Kong. Papagiannis et al. (2004) measured the concentration of copper and zinc in freshwater fish species from Lake Pamvotis in Greece. Ikem and Egiebor (2005) assessed trace elements in canned fishes marketed in Georgia and Alabama in the USA. Dural et al. (2007) investigated heavy metal levels in economically important fish species captured from the Tuzla lagoon. Hakeri et al. evaluated potentially toxic elements in water and fish at the Shahid Rajaei Dam in the north of Iran.

Mercury (Hg) is a globally distributed toxic pollutant in the environment, and it can bioaccumulate and biomagnify in food webs (Clarkson and Magos, 2006). Humans are exposed to high levels of Hg through the consumption of mercury-containing fish and fish products, in turn being subject to potential adverse health effects related to Hg exposure (Clarkson and Magos, 2006). Hg is released into the Musa estuary through sewage outflow from the chlor-alkali unit of the Bandar Imam Petrochemical Complex (BIPC) (Godarzi Nik et al., 2012), leading to contamination of sediments and organisms such as fishes. Before the activity of BIPC, seaside sediments were free of mercury contaminations. Therefore, the presence of any mercury contamination in this region can be attributed to BIPC activities (Aghanabati, 2004; Godarzi Nik et al., 2012).

Vanadium in trace amounts is beneficial to normal cell growth, and it is an essential element. However, toxicity arises when vanadium concentrations are increased to a higher level. The concentration of vanadium in natural waters is very low, usually ranging from 0.5 to 2.5 μg/L (ATSDR, 2012). The vanadium concentrations reported in sediments from the Musa estuary vary between 8125 and 14,129 ng/g (dry weight) with an average concentration of 11,141 ± 625 ng/g (dry weight) (Khademi et al., 2014). Vanadium porphyrin is found in the petroleum and bitumen extracted from shales (Colina et al., 2005), and it can be considered as an indicator of marine oil pollution (Khoshnood et al., 2011). Oil pollution is one of the major concerns in the Persian Gulf (Sheppard et al., 2010). The findings of one study showed that the concentrations of vanadium in sediments from the northern coastline of the Persian Gulf were higher than the global baseline values (Rezaie-Atagholipour et al., 2012).

In Iran, the total fish catch in 2009 was 378,947 *t*, of which 341,980 *t* were only caught from the Persian Gulf. According to the statistics (Annual Fishery Statistics of Iran, 2010) in Iran, the consumption of fish has been increasing in the last decade. The per-capita consumption of fish was about 1 kg per person in 1980, whereas it increased to 7.62 kg per person in 2009. The fishes caught in this estuary are considered as the main sources of animal protein in the diet of local residents (Mortazavi, 2011).

Johnius belangerii (*C*) is a benthopelagic fish (Sciaenidae family) living near sediments. It is a carnivorous fish, with a diet of shellfish, mollusks, shrimp, and smaller fishes (Abdolahpur Monikh et al., 2011). It is widely consumed in the Musa estuary.

This study is inevitably important as it highlights the important pollutant sources in the Musa estuary that release mercury and vanadium into the marine environment, as well as their use as indicators of marine pollution. The main aim of this study was to determine the concentrations of mercury and vanadium in the muscle tissue of *J. belangerii* (*C*) fish from the Musa estuary, in the Persian Gulf. The other aims of the current study were as follows: (a) to evaluate the relationship between metal concentration and the length and weight of fish samples and (b) to determine the relationships between two metals.

The present study was carried out in the Musa estuary, one of the biggest estuaries in the Persian Gulf located northwest of the Persian Gulf (latitude of 30°15′–30°32′ and longitude of 49°–49°2 0′ (Fig. 1).

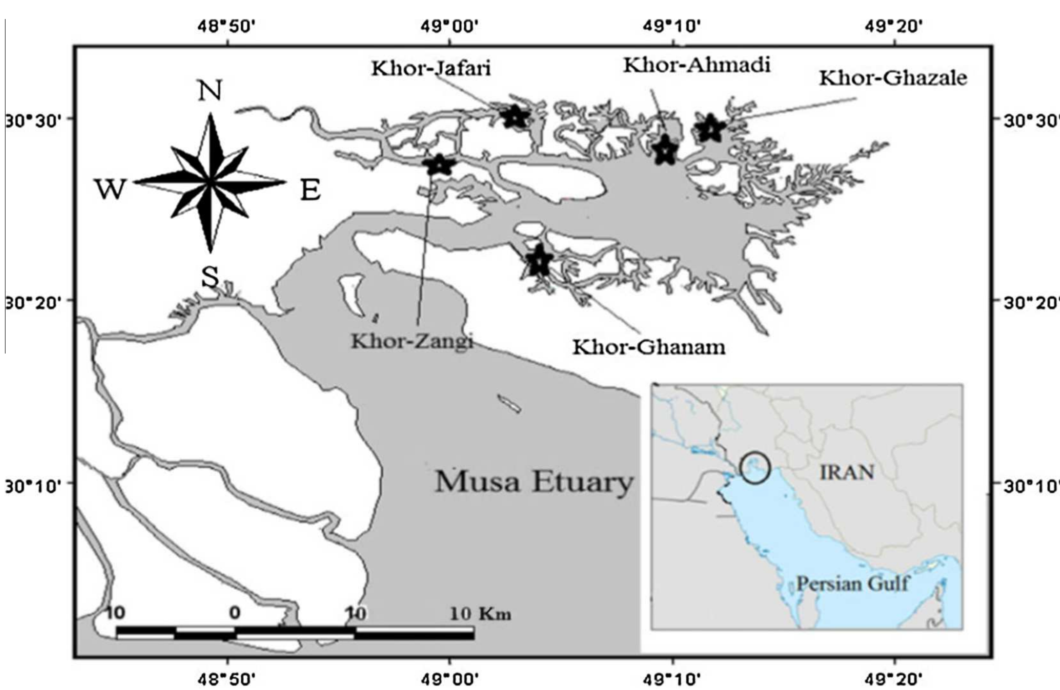

Fig. 1. Musa estuary and its branches (Abdolahpur Monikh et al., 2013).

Table 1
Time and temperature plan of DMA-80.

Temperature program	Maximum start temperature	Drying 1 (combustion)	Drying 2 (catalyst)	Drying 3 (amalgamator)
Temperature (°C)	200	160	650	650
Holding time (s)	120	60	120	60

A total of 67 *J. belangerii* (*C*) fish samples were collected from Musa estuary waters during 2 months (five times with 15-day intervals) in the summer of 2013 (from 22 May until 22 July 2014). Usually, summer is the most optimal time for fishing of *J. belangerii* (*C*) in this estuary.

All caught fish were transferred to the laboratory in a cool box. The biometric measurements including weight and length were conducted using a biometric board and a digital scale. In order to prevent any possible pollution during analysis of the sample, the extra parts and skin of fish samples were dispatched using a stainless steel knife. Then, the muscle fillet (without any bone) was dissected and maintained in a freezer at −70 °C.

The mercury concentration of samples was directly (without any sample preparation) determined using a direct method analyzer (DMA 80). The time planning of this device is shown in Table 1. The fish samples were weighed using a digital scale and recorded to the nearest 0.0001 g. The device boat was washed with detergent and maintained in an electric oven at 500 °C for 60 min. Then, the homogenized fish samples were placed in the boat individually for measuring the mercury concentration. All measurements were carried out in triplicate.

All containers were rinsed with a diluted nitric acid solution and dried in an oven at 105 °C. Nitric acid (65% (v/v)) was added to 2.5 g of wet muscle sample and maintained at room temperature for 24 h. Then 30% hydrogen peroxide (v/v) was added. Following this, the samples were placed in a high-pressure microwave (Milestone Ethos 900), equipped with a probe section to control the pressure and temperature. The digested samples were diluted with deionized distilled water (Milli-Q Millipore, 18.2 MΩ/cm) and brought to the volume of 100 ml.

The vanadium concentration was measured using an atomic absorption spectrophotometer, Carl Zeiss Jena GmbH – AAS 5 EA (Germany), equipped with a graphite oven and an automatic sampler. After the device was calibrated, the vanadium concentration was measured at a wavelength of 318.4 nm (the condition of the device is shown in Table 2). The slit width of the monochromator was 0.8 nm. Matrix correction was not required. In each step, 20 μl of the digested samples were injected into the device. The recovery percentage of added vanadium to the digested samples is shown in Table 3. The standard addition method was also used in the procedure.

The statistics analysis was performed using SPSS software (version 16). In this study, the "generalized linear model" (GLM) was used for analyzing the effect of an independent variable on a dependent variable. GLMs are mathematical extensions of linear models that do not force data into unnatural scales, thereby allowing for nonlinearity and nonconstant variance structures in the data. They are based on an assumed relationship (called a link function) between the mean of the response variable and the linear combination of the explanatory variables. Data may be assumed to be from several families of probability distributions, including the normal, binomial, Poisson, negative binomial, or gamma distribution, many of which better fit the non-normal error structures of most ecological data. Thus, GLMs are more flexible and better suited for the analysis of ecological relationships, which can be poorly represented by classical Gaussian distributions (Zeger and Karim, 1991). The predictor data were entered into the model, and the linear models were calculated. Moreover, regression and correlation analyses were used to investigate the relationship and correlation between metal concentration and fish length and weight.

The biometric measurements are shown in Table 6. The total mean weight of fish samples was 71.418 ± 23.580 g with a maximum and minimum of 160.00 and 29.00 g, respectively. The total mean length was 17.515 ± 1.879 cm with a maximum and minimum of 22.00 and 13.00 cm, respectively.

The mean concentration of mercury was 3.451 ± 1.981 mg/kg w.w with a maximum and minimum of 17.199 and 1.308 mg/kg w.w. The mean concentration of vanadium in muscle samples

Table 2
The condition used in atomic absorption spectrophotometer for determination of vanadium.

Step	Temperature (°C)	Ramp (°C/s)	Hold (s)
Drying	90	5	20
Drying	105	3	20
Drying	110	2	10
Pyrolysis	1300	250	10
Az	1300	0	6
Atomization	2550	1500	5
Cleanout	2600	500	4

Table 3
The recovery percentage of added vanadium to digested samples.

Sample	Absorption (μm)	Concentration (ppb)	RSD (%)	Recovery (%)
Real sample 1	0.0437	49.889	1.7	
Sample 1 (100 ppb)	0.125	140.222	1.7	90.3
Real sample 2	0.0227	26.556	2.5	
Sample 2 (100 ppb)	0.112	125.778	4.4	99.2
Real sample 3	0.052	50.2	0.8	
Sample 3 (100 ppb)	0.1823	137.1	0.6	86.87
Real sample 4	0.203	20.07	1	
Sample 4 (100 ppb)	0.1656	125.9	4	96.87
Real sample 5	0.0423	43.73	1.5	
Sample 5 (100 ppb)	0.0.186	139.5	3.9	95.8
Real sample 6	0.056	48.867	1.1	
Sample 6 (100 ppb)	0.196	146.2	0.5	97.333

Please cite this article in press as: Fard, N.J.H., et al. Determination of mercury and vanadium concentration in *Johnius belangerii* (*C*) fish in Musa estuary in Persian Gulf. Mar. Pollut. Bull. (2015), http://dx.doi.org/10.1016/j.marpolbul.2015.05.036

Table 4
The GLM analysis: vanadium and Hg as dependent variables.

Dependent variable	Parameter	B	Std. error	95% Wald confidence interval		Hypothesis test			Exp (B)	95% Wald confidence interval for Exp (B)	
				Lower	Upper	Wald Chi-square	*df*	Sig.		Lower	Upper
Mercury	(Intercept)	483.76	2.5639	478.735	488.786	35599.702	1	.000	1.243E21	8.168E207	1.892E212
	Vanadium	−0.143	0.0002	−0.143	−0.143	862627.782	1	.000	0.867	0.867	0.867
	Weight	0.821	0.0156	0.791	0.852	2789.995	1	.000	2.274	2.206	2.344
	Length	182.09	0.1948	181.710	182.473	874152.790	1	.000	1.206E79	8.231E78	1.766E79
Vanadium	(Intercept)	2.56E4	2.5335	2556.609	2566.541	1022261.237	1	.000	.[a]	.[a]	.[a]
	Mercury	−0.024	6.3555E−5	−0.025	−0.024	147126.680	1	.000	0.976	0.976	0.976
	Weight	12.78	.0154	12.747	12.808	685992.153	1	.000	3.541E5	343552.998	364969.577
	Length	−32.23	0.1950	−32.613	−31.848	27308.260	1	.000	1.006E−14	6.861E−15	1.474E−14

[a] Set to zero because this parameter is redundant.

Table 5
The correlation between variables.

		Vanadium	Mercury	Weight	Length
Vanadium	Pearson correlation	1	−0.034	0.283*	0.245*
	Sig. (two-tailed)		0.783	0.020	0.046
	N	67	67	67	67
Mercury	Pearson correlation	−0.034	1	0.106	0.128
	Sig. (two-tailed)	0.783		0.392	0.304
	N	67	67	67	67
Weight	Pearson correlation	0.283*	0.106	1	0.937**
	Sig. (two-tailed)	0.020	0.392		0.000
	N	67	67	67	67
Length	Pearson correlation	0.245*	0.128	0.937**	1
	Sig. (two-tailed)	0.046	0.304	0.000	
	N	67	67	67	67

* Significant with P<0.01.
** Significant with P < 0.05.

Table 6
The biometric measurements and concentrations of mercury and vanadium in *Johnius belangerii* (*C*) fish.

Variable	Sampling time	*N*	Mean ± Std. deviation	Minimum	Maximum
Weight (g)	Day 1	13	85.15 ± 14.56	61.00	116.00
	Day 15	13	80.15 ± 27.046	52.00	160.00
	Day 30	13	61.15 ± 18.037	41.00	107.00
	Day 45	14	58.93 ± 24.333	29.00	126.00
	Day 60	14	74.64 ± 23.277	32.00	105.00
	Total	67	71.851 ± 23.71	29.00	160.00
Length (cm)	Day 1	13	18.692 ± 1.011	17.00	20.00
	Day 15	13	18.0385 ± 1.49	17.00	22.00
	Day 30	13	16.577 ± 1.669	15.00	21.00
	Day 45	14	16.6786 ± 2.025	13.00	21.00
	Day 60	14	17.643 ± 2.226	13.50	21.00
	Total	67	17.515 ± 1.879	13.00	22.00
Mercury (mg/kg w.w)	Day 1	13	3.131 ± 0.825	1.873	4.422
	Day 15	13	2.9148 ± 0.732	1.701	4.025
	Day 30	13	2.9445 ± 1.053	1.740.	5.039
	Day 45	14	3.5762 ± 4.028	1.308	17.199
	Day 60	14	3.1678 ± 1.122	1.778	5.160
	Total	67	3.1536 ± 1.981	1.308	17.199
Vanadium (mg/kg w.w)	Day 1	13	2.949 ± 1.348	1.133	5.947
	Day 15	13	3.0318 ± 0.640	2.160	4.517
	Day 30	13	2.5583 ± 0.596	0.907	3.397
	Day 45	14	2.782 ± 0.382	2.216	3.791
	Day 60	14	3.268 ± 1.024	2.285	5.516
	Total	67	2.921 ± 0.873	0.907	5.947

was 2.921 ± 0.873 mg/kg w.w with a maximum and minimum of 5.947 and 0.907 mg/kg w.w.

According to the GLM analysis in Table 4, with mercury concentration as a dependent variable, and vanadium concentration, length, and weight as independent variables, there was a significant reverse relationship observed between the concentrations of mercury and vanadium ($\beta = -0.143$; $P = 0.00$). Furthermore, weight and length showed a significant direct relationship with the concentration of mercury (with $\beta = 0.821$ and 182.091, respectively; $P = 0.00$). It was also shown that the length had the greatest relationship with mercury concentration compared with weight and vanadium concentration (Table 4).

Furthermore, considering the concentration of vanadium to be a dependent variable and mercury concentration, weight, and length to be independent variables in the GLM analysis, there was a significant reverse relationship between the concentrations of vanadium and mercury ($\beta = -0.024$; $P = 0.00$). The length also had a significant reverse relationship with vanadium concentration ($\beta = -32.231$; $P = 0.00$). By contrast, the weight had a significant direct relationship with vanadium concentration ($\beta = 12.777$; $P = 0.00$). It was found that the length had the greatest direct relationship with vanadium concentration compared with the other variables.

There was a significantly positive correlation observed between vanadium concentration and weight ($P = 0.02$), and a significantly negative correlation seen with length ($P = 0.046$) (Table 5).

Furthermore, according to the regression analysis, there was a significant relationship (equation as below) between length and weight ($r = 0.937$; $P = 0.00$).

$$\text{Length (cm)} = 12.179 + 0.074 \text{ Weight (g)}$$

Mercury can accumulate in an organism via the bioaccumulation process (Arnot and Gobas, 2006). The main biological factors involved in the accumulation of mercury include age, length, weight, and diet. According to several studies, the concentration of total mercury in fish is positively associated with age, length, and weight (Al-Majed and Preston, 2000; Leah et al., 1992). Storelli et al. (2007) found that the mercury levels increased with length in seven species of marine fish from the Adriatic Sea. Moreover, a positive correlation was observed between length and mercury levels in 11 species of marine fish collected from the western Aleutians (Bering Sea/North Pacific Ocean) (Burger and Gochfeld, 2007). On the other hand, large and old fishes may exhibit a higher bioaccumulation of mercury as they may be exposed to pollution sources longer than small and young fishes are. It is indicated that usually the length is used as an alternate factor for age (Elahi et al., 2012). Moreover, many factors are involved in the relationship between metal concentration and length. These include the specific metabolism of metal in the fish body, the tissue type, the competition between diverse effects of aging and tissue growth, and the availability of metal in the environment (Evans et al., 1993). The mercury concentration in the muscle sample measured in this study showed a significant relationship with fish length and weight. However, it was greatest with length. This finding is in concordance with the results of several studies (Sackett et al., 2010; Sager, 2002). It is indicated that such a relationship depends on the differences in growth rate and mercury assimilation/depuration efficiencies (Trudel and Rasmussen, 2006). The growth rate used in some studies explains the changes in mercury concentrations (Lavigne et al., 2010; Simoneau et al., 2005). Generally, the lower growth rate is linked to increased muscle mercury concentrations in fishes of certain length (Cossa et al., 2012; Lavigne et al., 2010). Accordingly, the mercury intake may be diluted in rapidly growing fish of large size (Simoneau et al., 2005). In the present study, we selected *J. belangerii* (*C*) fish as a model of a fish with a low growth rate. Therefore, it is suggested that the low growth rate in this fish may be the cause of a high mercury concentration in muscle tissue. In addition, it is suggested that larger specimens are more dependent on the bed (benthic) and less on the surface (pelagic) compared with smaller specimens; thus, they are exposed to polluted sediment as a source of mercury for a longer duration (Holthuis, 1980; Lavalli and Spanier, 2007).

In this study, the muscle tissue was selected for analysis, as it is the main part consumed by humans and it is involved in health risk. According to the Environmental Protection Agency (EPA) (USEPA, 2002), the World Health Organization (WHO, 1989), and the Food and Drug Administration (FDA) (Askary Sary and Beheshti, 2012), the threshold limit values for mercury are 0.3, 0.5, and 0.5–1.0 (expressed as µg/g wet weight), respectively. In comparison, in the present study, it was found that the total mercury concentration in the muscle tissues of samples was higher than the threshold values. Moreover, the mercury concentration of samples in this study was greater than those reported by previous studies of the coastal waters and estuary areas of the Persian Gulf. Mortazavi and Sharifian (2011a) found that the mercury concentration in *Liza abu*, *Sparidentex hasta*, *Acanthopagrus latus*, *Thunnus tonggol*, and *Fenneropenaeus indicus* fish was, respectively, 0.373, 1.172, 0.445, 0.390 and 0.360 µg/g dry weight, which all values were lower than those found in this study. Moreover, Rahimi and Behzadnia (2011) found that the Hg concentration in *Otolithes ruber* ranged between 0.017 and 0.394 mg/kg w.w, which was also lower than that reported in this study. Furthermore, according to the study of the Musa estuary (Imam Khomeini port) by Askary Sary et al. (2010), the mercury concentration in *Periophthalmus waltoni* and *Cynoglossus arel* fish was, respectively, 0.81 ± 0.11 and 0.68 ± 0.1 mg/kg w.w. Several other studies carried out in different seas with different fish species also found lower concentrations of Hg compared with the present study (Ikem et al., 2003; Ikemoto et al., 2008; Mohammadnabizadeh et al., 2013; Nakao et al., 2007; Parvaneh et al., 2011; Sabzalizadeh and Dehghan Madise, 2010; Saei-Dehkordi et al., 2010a,b; Türkmen et al., 2009; Tuzen, 2009).

The natural sources that release vanadium into water include wet and dry deposition, soil erosion, and leaching from rocks and soils (ATSDR, 2012). Vanadium is one of the main ingredients of coal and crude oil. It is a heavy metal, and it is used as porphyrins in crude oil and an indicator of oil pollution (Khoshnood et al., 2011).

The mean values of vanadium concentration in the muscle samples of *J. belangerii* (*C*) fish found in the present study were higher than those reported in the previous studies carried out in the northern coastal waters of the Persian Gulf (Mashinchian Moradi et al., 2011; Sarmadian et al., 2013; Yazdanabad et al., 2014). Agah et al. (2009) reported that the vanadium concentration in five species of fishes in the Persian Gulf ranges between 0.16 and 0.71 mg/kg w.w, which was approximately half of that found in the present study. Furthermore, in the other studies by Pourang et al. (2004, 2005), the vanadium concentrations in four species of fishes in the Persian Gulf were 0.177, 0.216, 0.265, and 0.011 mg/kg w.w, all of which were about five times lower than the findings of this study. Similarly, other studies (Ikem et al., 2003; Ikem and Egilla, 2008) have reported lower vanadium concentrations compared with our study. On the other hand, an increasing trend in the vanadium concentration in different fishes in the Musa estuary was observed during the last decade. This may have resulted from an increase in the bioavailability of metals in the estuary.

The high vanadium accumulation observed in samples in the present study may have resulted primarily from the pollution caused by petrochemical industrial plants and crude oil transportation activities in this region. In addition, Abdolahpur Monikh et al. (2011) suggested that the combustion of fossil fuels and the residual fuel oil contributes to the vanadium accumulation in sediments and fish in the Musa estuary. The pollution arising from the petrochemical industries around the Musa estuary may affect its ecosystem and biodiversity (Jafarian et al., 2012). Therefore, because the water and sediments in the Musa estuary is polluted with vanadium, its accumulation in fish species is expected. In their study, Jafarian et al. (2012) indicated that the estuaries in the region were highly influenced by petrochemical activities affecting different species of fishes and benthic communities (Jafarian et al., 2012). Some other studies carried out in the

Persian Gulf (Alireza Safahieh et al., 2011; Haidari et al., 2013) and worldwide (Ikem and Egiebor, 2005; Nakao et al., 2007) concur with our suggestions.

In the present study, the vanadium concentration had a significantly negative relationship with the length of samples (in contrast to mercury). Some possible reasons include possible feeding habits, different habitat, and physiological changes of skin during the life span of *J. belangerii* (*C*) fish. This finding does not agree with the findings of other studies (Khoshnood et al., 2010; Yazdanabad et al., 2014) showing a positive correlation with the length of samples. The species of fishes investigated in these studies may be a possible reason for this diverse result. For example, the samples selected in one study (Khoshnood et al., 2010) were benthic fish, but benthopelagic fish were selected in the present study.

Furthermore, in this study, the mercury and vanadium concentration had a significant reverse relationship. It is suggested that the mercury concentration may accumulate in muscle tissue as the fish grows, whereas the vanadium concentration may be biodiluted. Additionally, the pattern of metal content of samples in this study showed that the mercury concentration was greater than the vanadium concentration (Hg > V). Therefore, it is assumed that fish samples eaten by consumers may have a higher content of mercury. However, it is emphasized that both metal concentrations are high in *J. belangerii* (*C*) fish.

Only few studies on the vanadium concentration in fish in the Persian Gulf have been carried out. Therefore, considering several pollutant sources in this region, further studies are needed to evaluate the vanadium concentration in fish.

It is concluded that the concentrations of two heavy metals, mercury and vanadium, were higher than the threshold limits for *J. belangerii* (*C*) fish in the Musa estuary. Therefore, to control the high consumption of seafood in this region, nutritionist guidance is recommended especially in vulnerable groups such as children and pregnant and breast-feeding women. Moreover, with the increase in the concentration of these two metals in fishes during the last decade, the elimination of pollutant release by petrochemical plants and transportation of crude oil would be necessary. Reducing the pollutant load in the region appears to be the best approach to decreasing the availability of heavy metals and consequently reducing their accumulation in fish tissues.

Acknowledgments

This research was financially supported by the Deputy of Research and Technology, Ahvaz Jundishapur University of Medical Sciences, Iran (No. of project: ETRC-9310). The authors hereby express their gratitude.

References

Abdolahpur Monikh, F., Hosseini, M., Peery, S., Maryamabadi, A., Ghanemi, K., Bastami, A.A., Karami, O., 2011. Heavy metals levels in sediment and Ray fish (*Dasyatis bennettii*) from Musa Estuary and Selech Estuary, Persian Gulf. Am.–Eurasian J. Toxicol. Sci.

Abdolahpur Monikh, F., Safahieh, A., Savari, A., Doraghi, A., 2013. Heavy metal concentration in sediment, benthic, benthopelagic, and pelagic fish species from Musa Estuary (Persian Gulf). Environ. Monit. Assess. 185, 215–222.

Agah, H., Fatemi, S., Hashtroudi, M.S., Baeyens, W., 2012. A survey on the accumulation of trace metals in local fishermen hair from the Northern Persian Gulf. J. Persian Gulf 3, 1–12.

Agah, H., Leermakers, M., Elskens, M., Fatemi, S.M., Baeyens, W., 2009. Accumulation of trace metals in the muscle and liver tissues of five fish species from the Persian Gulf. Environ. Monit. Assess. 157, 499–514.

Aghanabati, A., 2004. Geology of Iran. Geological Survey of Iran (in Persian).

Al-Majed, N., Preston, M., 2000. Factors influencing the total mercury and methyl mercury in the hair of the fishermen of Kuwait. Environ. Pollut. 109, 239–250.

Alireza Safahieh, F.A.M., Savari, Ahmad, Doraghi, Abdolmajid, 2011. Heavy metals concentration in Mullet Fish, *Liza abu* from petrochemical waste receiving creeks, Musa Estuary (Persian Gulf). J. Environ. Protect. 02, 1218–1226.

Annual Fishery Statistics of Iran, 2010. Consumption of Fish in Iran. Ministry of Agriculture, pp. 36–40.

Arnot, J., Gobas, F., 2006. A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. Environ. Rev. 14, 257–297.

Askary Sary, A., Beheshti, M., 2012. Cadmium, iron, lead and mercury bioaccumulation in Abu Mullet, *Liza abu*, different tissues from Karoun and Karkheh Rivers, Khozestan, Iran. Bull. Environ. Contam. Toxicol. 88, 158–161.

Askary Sary, A., Velayatzadeh, M., Mohammadi, M., 2010. Mercury concentration in mudskipper (Periophthalmus waltoni) and flat Fish (Cynoglossus arel) in Bandar-e-Emam and Bandar Abbas. J. Fish. 4, 51–57 (in Persian).

ATSDR, 2012. Agency for Toxic Substances and Disease Registry – Toxicological Profile for Vanadium.

Burger, J., Gochfeld, M., 2007. Risk to consumers from mercury in Pacific cod (*Gadus macrocephalus*) from the Aleutians: fish age and size effects. Environ. Res. 105, 276–284.

Clarkson, T.W., Magos, L., 2006. The toxicology of mercury and its chemical compounds. CRC Crit. Rev. Toxicol. 36, 609–662.

Colina, M., Gardiner, P., Rivas, Z., Troncone, F., 2005. Determination of vanadium species in sediment, mussel and fish muscle tissue samples by liquid chromatography–inductively coupled plasma-mass spectrometry. Anal. Chim. Acta 538, 107–115.

Cossa, D., Harmelin-Vivien, M., Mellon-Duval, C., Loizeau, V., Averty, B., Crochet, S., Chou, L., Cadiou, J.-F., 2012. Influences of bioavailability, trophic position, and growth on methylmercury in hakes (*Merluccius merluccius*) from northwestern Mediterranean and northeastern Atlantic. Environ. Sci. Technol. 46, 4885–4893.

Dural, M., Göksu, M., Özak, A.A., 2007. Investigation of heavy metal levels in economically important fish species captured from the Tuzla lagoon. Food Chem. 102, 415–421.

Elahi, M., Esmaili-Sari, A., Bahramifar, N., 2012. Total mercury levels in selected tissues of some marine crustaceans from Persian Gulf, Iran: variations related to length, weight and sex. Bull. Environ. Contam. Toxicol. 88, 60–64.

Evans, D.W., Dodoo, D.K., Hanson, P.J., 1993. Trace element concentrations in fish livers: implications of variations with fish size in pollution monitoring. Mar. Pollut. Bull. 26, 329–334.

Fletcher, D.E., Lindell, A.H., Stillings, G.K., Mills, G.L., Blas, S.A., McArthur, J.V., 2014. Variation in trace-element accumulation in predatory fishes from a stream contaminated by coal combustion waste. Arch. Environ. Contam. Toxicol.

Godarzi Nik, M., Shahbazi, B., Grigoryan, K., 2012. The study of mercury pollution distribution around a chlor-alkali petrochemical complex, Bandar Imam, southern Iran. Environ. Earth Sci. 67, 1485–1492.

Guérin, R.C., Vastel, C., Sirot, V., Volatier, J., Leblanc, J., Noël, L., 2011. Determination of 20 trace elements in fish and other seafood from the French market. Food Chem. 127.

Haidari, B., Bakhtiari, A.R., Yavari, V., Kazemi, A., Shirneshan, G., 2013. Biomonitoring of Ni and V contamination using Oysters (*Saccostrea cucullata*) at Lengeh Port, Persian Gulf, Iran. CLEAN–Soil, Air, Water 41, 166–173.

Holthuis, L.B., 1980. FAO Species Catalogue. Shrimps and Prawns of the world. An Annotated Catalogue of Species of Interest to Fisheries.

Hosseini Alhashemi, A., Sekhavatjou, M.S., Hassanzadeh Kiabi, B., Karbassi, A.R., 2012. Bioaccumulation of trace elements in water, sediment, and six fish species from a freshwater wetland, Iran. Microchem. J. 104, 1–6.

Ikem, A., Egiebor, N., Nyavor, K., 2003. Trace elements in water, fish and sediment from Tuskegee Lake, Southeastern USA. Water Air Soil Pollut. 149, 51–75.

Ikem, A., Egiebor, N.O., 2005. 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. 18, 771–787.

Ikem, A., Egilla, J., 2008. Trace element content of fish feed and bluegill sunfish (Lepomis macrochirus) from aquaculture and wild source in Missouri. Food Chem. 110, 301–309.

Ikemoto, T., Tu, N.P.C., Okuda, N., Iwata, A., Omori, K., Tanabe, S., Tuyen, B.C., Takeuchi, I., 2008. Biomagnification of trace elements in the aquatic food web in the Mekong Delta, South Vietnam using stable carbon and nitrogen isotope analysis. Arch. Environ. Contam. Toxicol. 54, 504–515.

Jaafarzadeh, H.F., Khoshnood, R., Khoshnood, Z., 2011. Cadmium determination in two flat fishes from two fishery regions in north of the Persian Gulf. Iran. J. Fish. Sci. 10, 537–540.

Jafarian, M.E., Malmasi, S., Monavari, A., Juzi, S., 2012. Assessing the environmental impacts of Mahshahr petrochemical special economic zone using AHP. Environ. Sci. 8, 145–156 (in Persian).

Karadede, H., Oymak, S.A., Ünlü, E., 2004. Heavy metals in mullet, *Liza abu*, and catfish, Silurus triostegus, from the Atatürk Dam Lake (Euphrates), Turkey. Environ. Int. 30, 183–188.

Khademi, N., Riyahi-Bakhtiari, A., Sobhanardakani, S., Rezaie-Atagholipour, M., Burger, J., 2014. Developing a bioindicator in the Northwestern Persian Gulf, Iran: trace elements in bird eggs and in coastal sediments. Arch. Environ. Contam. Toxicol., 1–9

Khoshnood, Z., Khoshnood, R., Afkhami, M., Khzaal, A., 2011. Effects of oil pollution on EURYGLOSSA ORIENTALIS and PSETTODES ERUMEI in the Persian Gulf 1. Rom. J. Biol. 2, Pak. J. Anal. Environ. Chem. – ZOOL.

Khoshnood, Z., Mokhlesi, A., Khoshnood, R., 2010. Bioaccumulation of some heavy metals and histopathological alterations in liver of Euryglossa orientalis and Psettodes erumei along North Coast of the Persian Gulf. Afr. J. Biotechnol. 9, 6966–6972.

Lavalli, K.L., Spanier, E., 2007. The Biology and Fisheries of the Slipper Lobster. CRC Press.

Lavigne, M., Lucotte, M., Paquet, S., 2010. Relationship between mercury concentration and growth rates for walleyes, northern pike, and lake trout from Quebec lakes. North Am. J. Fish. Manag. 30, 1221–1237.

Leah, R., Evans, S., Johnson, M., 1992. Mercury in flounder (*Platichthys flesus* L) from estuaries and coastal waters of the north-east Irish Sea. Environ. Pollut. 75, 317–322.

Love, M.S., Saiki, M.K., May, T.W., Yee, J.L., 2013. Whole-body concentrations of elements in three fish species from offshore oil platforms and natural areas in the southern California bight, USA. Bull. Mar. Sci. 89, 717–734.

Malmasi, S., Jozi, S., Monavari, S., Jafarian, M., 2010. Ecological impact analysis on Mahshahr petrochemical industries using analytic hierarchy process method. Int. J. Environ. Res. 4, 725–734.

Mashinchian Moradi, A., Jalali Mosallam, M., Fatemi, M., 2011. A survey on the accumulation of heavy metals as indicator of oil pollution index (vanadium and nickel) in bivalve rock oyster (*Saccostrea cucullata*) in Qeshm Island coasts. Int. J. Mar. Sci. Eng. 1, 51–58.

Mendil, D., Unal, O.F., Tuzen, M., Soylak, M., 2010. Determination of trace metals in different fish species and sediments from the River Yesilirmak in Tokat, Turkey. Food Chem. toxicol.: Int. J. Publ. British Ind. Biol. Res. Assoc. 48, 1383–1392.

Mohammadnabizadeh, S., Afshari, R., Pourkhabbaz, A., 2013. Metal concentrations in marine fishes collected from Hara biosphere in Iran. Bull. Environ. Contam. Toxicol. 90, 188–193.

Mortazavi, M., Sharifian, S., 2011a. Mercury bioaccumulation in some commercially valuable marine organisms from Mosa Bay, Persian Gulf. Int. J. Environ. Res. 5.

Mortazavi, M.S., Sharifian, S., 2011b. Mercury bioaccumulation in some commercially valuable marine organisms. Int. J. Environ. Res. 5, 757–762.

Mortazavi, M.S., Sharifian, S., 2012. Metal concentrations in two commercial fish from Persian Gulf, in relation to body length and sex. Bull. Environ. Contam. Toxicol. 89, 450–454.

Mortazavi, M.S.A.S., 2011. Mercury bioaccumulation in some commercially valuable marine organisms. Int. J. Environ. Res. 5, 757–762.

Nakao, M., Seoka, M., Tsukamasa, Y., Kawasaki, K.I., Ando, M., 2007. Possibility for decreasing of mercury content in bluefin tuna Thunnus orientalis by fish culture. Fish. Sci. 73, 724–731.

Papagiannis, I., Kagalou, I., Leonardos, J., Petridis, D., Kalfakakou, V., 2004. Copper and zinc in four freshwater fish species from Lake Pamvotis (Greece). Environ. Int. 30, 357–362.

Parvaneh, M., Khaivar, N., Nikpour, Y., Nabavi, S.M., 2011. Heavy metals (Hg, Cd, Pb, Ni, Cu) concentrations in Euryglossa orientalis and sediments from Khur-e-Musa Creek in Khuzestan Province. Iran. Sci. Fish. J. 20, 17–26 (in Persian).

Pourang, N., Dennis, J., Ghourchian, H., 2004. Tissue distribution and redistribution of trace elements in shrimp species with the emphasis on the roles of metallothionein. Ecotoxicology 13, 519–533.

Pourang, N., Nikouyan, A., Dennis, J.H., 2005. Trace element concentrations in fish, surficial sediments and water from northern part of the Persian Gulf. Environ. Monit. Assess. 109, 293–316.

Rahimi, E., Behzadnia, A., 2011. Determination of Mercury in Fish (*Otollithes ruber*) and Canned Tuna Fish in Khuzestan and Shiraz. Iran. World Appl. Sci. J. 15, 1553–1556.

Rezaie-Atagholipour, M., Riyahi-Bakhtiari, A., Sajjadi, M., Yap, C.K., Ghaffari, S., Ebrahimi-Sirizi, Z., Ghezellou, P., 2012. Metal concentrations in selected tissues and main prey species of the annulated sea snake (*Hydrophis cyanocinctus*) in the Hara Protected Area, northeastern coast of the Persian Gulf. Iran. Mar. Pollut. Bull. 64, 416–421.

Sabzalizadeh, S., Dehghan Madise, S., 2010. Assessment of heavy metals pollution in the sediments of Lifeh Busaf (northwest of Persian Gulf) using Geo-accumulation Index. Iran. Sci. Fish. J. 19, 51–60.

Sackett, D., Aday, D.D., Rice, J., Cope, W.G., Buchwalter, D., 2010. Does proximity to coal-fired power plants influence fish tissue mercury? Ecotoxicology 19, 1601–1611.

Saei-Dehkordi, S., Fallah, A.A., Nematollahi, A., 2010a. Arsenic and mercury in commercially valuable fish species from the Persian Gulf: influence of season and habitat. Food Chem. Toxicol.: Int. J. Publ. Brit. Ind. Biol. Res. Assoc. 48, 2945–2950.

Saei-Dehkordi, S.S., Fallah, A.A., Nematollahi, A., 2010b. Arsenic and mercury in commercially valuable fish species from the Persian Gulf: influence of season and habitat. Food Chem. Toxicol. 48, 2945–2950.

Sager, D.R., 2002. Long-term variation in mercury concentrations in estuarine organisms with changes in releases into Lavaca Bay, Texas. Mar. Pollut. Bull. 44, 807–815.

Sarmadian, S., Safahieh, A., Zolgharnein, H., Archangi, B., Tabar, M.H., 2013. Spatial Variation of Fe, Mn and Ni concentrations in sediment and water of Musa Estuary, Persian Gulf. World J. Fish Mar. Sci. 5, 571–574.

Sheppard, C., Al-Husiani, M., Al-Jamali, F., Al-Yamani, F., Baldwin, R., Bishop, J., Benzoni, F., Dutrieux, E., Dulvy, N.K., Durvasula, S.R., Jones, D.A., Loughland, R., Medio, D., Nithyanandan, M., Pilling, G.M., Polikarpov, I., Price, A.R., Purkis, S., Riegl, B., Saburova, M., Namin, K.S., Taylor, O., Wilson, S., Zainal, K., 2010. The Gulf: a young sea in decline. Mar. Pollut. Bull. 60, 13–38.

Shreadah, M.A., Fattah, L.M.A., Fahmy, M.A., 2015. Heavy metals in some fish species and bivalves from the mediterranean coast of Egypt. J. Environ. Protect. 6, 1.

Simoneau, M., Lucotte, M., Garceau, S., Laliberté, D., 2005. Fish growth rates modulate mercury concentrations in walleye (*Sander vitreus*) from eastern Canadian lakes. Environ. Res. 98, 73–82.

Storelli, M.M., Barone, G., Piscitelli, G., Marcotrigiano, G., 2007. Mercury in fish: concentration vs. fish size and estimates of mercury intake. Food Addit. Contam. 24, 1353–1357.

Trudel, M., Rasmussen, J.B., 2006. Bioenergetics and mercury dynamics in fish: a modelling perspective. Can. J. Fish. Aquat. Sci. 63, 1890–1902.

Türkmen, M., Türkmen, A., Tepe, Y., Töre, Y., Ates, A., 2009. Determination of metals in fish species from Aegean and Mediterranean Seas. Food Chem. 113, 233–237.

Tuzen, M., 2009. Toxic and essential trace elemental contents in fish species from the Black Sea, Turkey. Food Chem. Toxicol. 47, 1785–1790.

USEPA, 2002. Mercury Update: Impact on Fish Advisories. EPA Office of Water, Washington, DC.

Wang, X., Sato, T., Xing, B., Tao, S., 2005. Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. Sci. Total Environ. 350, 28–37.

WHO, 1989. Evaluation of Certain Food Additives and the Contaminants Mercury, Lead and Cadmium., WHO. Technical Report Series.

Yazdanabad, T.E., Emtyazjoo, M., Mostafavi, P.G., Sahebi, Z., 2014. Evaluation of copper and vanadium concentration in the soft tissue of *Tylosurus crocodilus* in Bahregan region, Persian Gulf. Chem. Speciat. Bioavailab. 26.

Zeger, S.L., Karim, M.R., 1991. Generalized linear models with random effects; a Gibbs sampling approach. J. Am. Stat. Assoc. 86, 79–86.

Zhang, I., Wong, M.H., 2007. Environmental mercury contamination in China: sources and impacts. Environ. Int. 33.

Zhou, H.Y., Wong, M.H., 2000. Mercury accumulation in freshwater fish with emphasis on the dietary influence. Water Res. 34, 4234–4242.