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| 6 | | Particle | |
| 7 | | Given Name | **Shirin** |
| 8 | | Suffix | |
| 9 | | Organization | Iranian National Institute for Oceanography (INIO) |
| 10 | | Division | |
| 11 | | Address | Tehran, Iran |
| 12 | | e-mail | hugan.chinho@gmail.com |
| 13 | Author | Family Name | **Ghorghani** |
| 14 | | Particle | |
| 15 | | Given Name | **Nasrin Farzaneh** |
| 16 | | Suffix | |
| 17 | | Organization | Islamic Azad University |
| 18 | | Division | Department of Marine Science and Technology |
| 19 | | Address | North Branch, Tehran, Iran |
| 20 | | e-mail | |
| 21 | Author | Family Name | **Ashtiyani** |
| 22 | | Particle | |
| 23 | | Given Name | **Seyede Masoumeh Lotfi** |
| 24 | | Suffix | |
| 25 | | Organization | Islamic Azad University |
| 26 | | Division | Department of Marine Science and Technology |
| 27 | | Address | North Branch, Tehran, Iran |
| 28 | | e-mail | |
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Abstract

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Keywords separated by ' - '

Coral reef - Rocky shore - Mangrove forest - Muddy habitat - Intertidal ecosystem

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# Heavy metal in water and aquatic organisms from different intertidal ecosystems, Persian Gulf

Shirin Rahmanpour · Nasrin Farzaneh Ghorghani · Seyede Masoumeh Lotfi Ashtiyani

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**Abstract** Intertidal ecosystems are being damaged by anthropogenic activities, particularly in the developing countries. In this study, the load of heavy metals was determined in water, fish, shrimp, and crab collected from four intertidal ecosystems, including coral reef, rocky shore, mangrove forest, and muddy habitat along the Persian Gulf coasts. Generally, the sequence of metal accumulation in the water of coral reef and mangrove forest was Ni > Pb > V > Cd > As > Hg, whereas in muddy habitats and rocky shores, the sequence was Ni > Pb > V > Cd > Hg > As and Ni > V > Pb > As > Hg > Cd, respectively. Water of the coral reef had the highest level of Ni (97.44 μg $l^{-1}$), Pb (3.92 μg $l^{-1}$), V (10.42 μg $l^{-1}$), Cd (3.92 μg $l^{-1}$), As (1.87 μg $l^{-1}$), and Hg (0.74 μg $l^{-1}$). For the most part, the highest concentrations of the studied metals were found in the liver and the gills of *Johnius belangerii* and the hepatopancreas of *Portunus pelagicus* and *Metapenaus affinis* collected from the coral reef ecosystem.

**Keywords** Coral reef · Rocky shore · Mangrove forest · Muddy habitat · Intertidal ecosystem

S. Rahmanpour (✉)
Iranian National Institute for Oceanography (INIO),
Tehran, Iran
e-mail: hugan.chinho@gmail.com

N. F. Ghorghani · S. M. L. Ashtiyani
Department of Marine Science and Technology, Islamic Azad University,
North Branch, Tehran, Iran

## Introduction

Although intertidal ecosystems encompass relatively the smallest area of the world's oceans environment, they contain a tremendous diversity of life. For example, the high stocks of primary productivity and secondary productivity, which provide essential food sources for higher trophic levels of organisms such as crustaceans, fishes, and birds (Wolff 1987), are within these areas and is one of the reasons why intertidal habitats are of high conservation values. These littoral areas are considered among the most stressful of all marine environments, because the daily exposure at low tide results in a daily fluctuation in temperature, humidity, salinity, wave exposure, sediment transportation, and light (Wright et al. 2004; Chapman and Reed 2006). In comparison to oceanic habitats, restoration of the intertidal habitats may, as a result, be more challenging.

During the last few decades, these areas have been largely disturbed and damaged by human activities, perhaps more than any other marine ecosystems (Milazzo et al. 2002). Previous studies have shown that different anthropogenic activities such as coastal development, tourism (Hanna 1991), phosphate mining (Hanna and Ormond 1982), agriculture, petrochemical, and oil-related activities (Hashim et al. 1995) can reduce the environmental health of this zone including species richness (Huang et al. 2006; Prescott 2006).

The Persian Gulf is a shallow area with depths ranging between 10 and 100 m. The salinity and the surface temperature of this sea range between 37–41 % and 10–36°, respectively. It is an elongated, semi-enclosed

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subtropical marginal sea and connected to the Oman Sea at its southeastern end by the Straits of Hormuz. The Persian Gulf receives fresh water through the Arvand River at its northwestern extremity and through several streams and seasonal rivers along its northern coasts (Sheppard et al. 2010). This sea has a wide variety of intertidal and coastal zones such as mangrove forests of Qeshm, muddy and sandy coasts of Khozestan, rocky shores of Qeshm, and coral reefs of Khark Island. However, like other intertidal zones in the world, this sea is also exploited by the surrounding developing countries including, the Kingdom of Bahrain, Islamic Republic of Iran, Republic of Iraq, State of Kuwait, Sultanate of Oman, State of Qatar, the Kingdom of Saudi Arabia, and the United Arab Emirates. There is an urgent need to adopt an environmentally maintainable management system to ensure protection of the resources of the Persian Gulf coastal zone. To meet this need, it is important to recognize and assess the behavior and interactions of contaminants, particularly non-biodegradable pollutants, in different intertidal ecosystems.

The main aim of this study was to evaluate the load and bioaccumulation patterns of heavy metals in water and organisms of different intertidal ecosystems in the Persian Gulf including, the mangrove ecosystem, coral reefs, rocky shores, and muddy habitats.

## Material and methods

The present study was carried out in the Qeshm mangrove forest, rocky shores of Qeshm Island, muddy habitats in Khozestan province, and the coral reef structures of Khark Island. Qeshm, the biggest island in the Persian Gulf, is located in the western part of the Strait of Hormuz. It is 120-km long and up to 30-km wide. The largest mangrove forest of Iran and the Persian Gulf is located on this island, covering approximately 20 km×20 km. Only two species of mangrove are found within Iranian mangrove forests, *Avicennia marina* and *Rhizophora macrunata*. Qeshm has many different intertidal zones, sandy, mixed and muddy, and in the south, rocky ecosystems. Many rocky shores are found along the southeast shoreline of Qeshm Island. Khark Island is located in the northwest Persian Gulf with an area of 38 km2, and is renowned for its diverse and spectacular coral reefs. Khozestan province is situated on the northern part of the Persian Gulf. It has different intertidal areas such as Musa estuary, Arvand River, Hendigan coasts, and more than 37 other outlying islands. Grain size analysis showed that muddy sediments are more abundant in the Khozestan province coasts (Abdolahpur Monikh et al. 2012a, b). Q2

Water, fish (*Johnius belangerii*, $n$=20), shrimp (*Metapenaus affinis*, $n$=30), and crab (*Portunus pelagicus* $n$=40) were collected from each ecosystem (Fig. 1). Water samples were collected by Nansen Sampler, 0.5 m below the water surface, kept in bottles (precleaned with polyethylene), acidified by adding 0.5 % concentrated nitric acid (65 %) and filtered through a 0.45-μm micropore membrane filter. The biota samples were caught by trawl from each ecosystem. The samples were placed on ice and brought daily to the laboratory then frozen at −20 °C until analysis.

Each fish sample was dissected for its gill and liver, while each shrimp and crab was dissected for its hepatopancreas using a stainless steel scalpel. One gram of the sample was digested with 6 ml of concentrated $HNO_3$ (65 %) and 2 ml of concentrated $H_2O_2$ in microwave digestion system, diluted to 10 ml with double deionized water (Milli-Q Millipore 18.2 M cm1 resistivity) and filtered through a 0.45-μm nitrocellulose membrane filter.

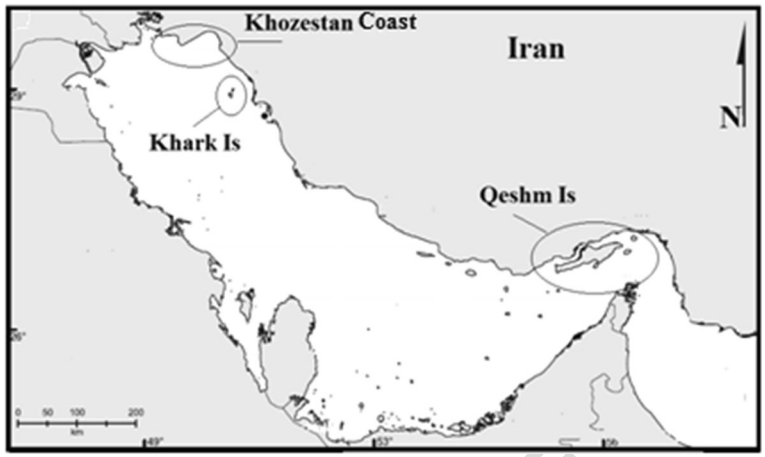
All reagents were of analytical reagent grade, and all chemicals and standard solutions were obtained from Merck. All plastic and glassware were soaked in nitric acid (10 %) and rinsed with distilled water before use. Standard reference material DORM-2 (muscle of Dogfish, National Research Council of Canada), and SRM-143d (National Institute of Standards and Technology) were used to check the analysis accuracy of the organisms and water, respectively. The result showed good agreement with the certified values. The recovery values were between 92 and 110 %. The blanks were prepared in a similar manner. Determination of the elements in all samples was carried out by ICP–AES (Opt. 2000, PerkinElmer). Detection limits were between 0.001 and 0.042. Mercury was determined by the cold vapor technique using an atomic absorption spectrometer (Unicam model 919). Arsenic metal was analyzed with graphite furnace atomic absorption (GFAA).

All data were tested for normal distribution with Shapiro-wilk normality test. Significant differences between heavy metal concentrations in the samples of various ecosystems were determined using one-way analysis of variance (ANOVA) followed by Duncan post hoc test. The linear regression analyses were used

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Q3 **Fig. 1** A map showing the Persian Gulf and the studied ecosystems

to find the relationships between metal concentration in water and tissues. The level of significance was set at $\alpha$=0.05.

## Results and discussion

### Heavy metals in the coral reefs

The mean and standard deviation of heavy metal concentrations in the water and the organisms of the different ecosystems were given in Table 1. In general, the order of metal accumulation in water of coral reef was Ni > Pb > V > Cd > As > Hg. The concentration of Ni and V indicates that heavy metals in this ecosystem could originate from oil pollution (Pourang et al. 2005). In fact, heavy metals in Khark Island originate from oil and non-oil industries including desalination plants, oil refineries, and petrochemical plants. However, oil contamination effects are likely in the area, as the island is considered as the main Iranian oil terminal in the Persian Gulf (ROPME 1999). About 1 million barrels of oil are spilled in the area annually from the routine discharge of dirty ballast waters and tank washing, partly due to the lack of shore reception facilities (ROPME 1999). There have been very few studies on trace elements in seawater of coral ecosystems. Ali et al. (2011) reported concentrations of heavy metals (Cu, Zn, Pb, Cd, Ni, Co and Fe) in seawater collected from seven reef sites in the Northern Red Sea. The concentrations of Cd, Ni, and Pb in coral reef seawater of Khark Island were higher than those reported by Ali et al. (2011). In comparison with guidelines, the results showed that the concentrations of Cd and Pb were below the maximum permissible levels for aquatic life (MPL, Cd: 5 $\mu g\ l^{-1}$; Pb: 25 $\mu g\ l^{-1}$) (Pourang et al. 2005). The observed level for V was also below the protection of saltwater life (V: 100 $\mu g\ l^{-1}$) (Anon 2001). Whereas, the levels of Cd, Pb, and Ni in this ecosystem were higher than those reported in Australian and New Zealand Environment and Conservation Council (ANZECC, Cd: 2 $\mu g\ l^{-1}$; Pb: 5 $\mu g\ l^{-1}$, Ni: 15 $\mu g\ l^{-1}$) (ANZECC 1992).

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t1.1 **Table 1** Level and standard deviation of heavy metals in seawater from different marine ecosystems in the Persian Gulf (in micrograms per liter)

| t1.2 Location | Hg | Cd | Ni | Pb | V | As |
|---|---|---|---|---|---|---|
| t1.3 MF, Qeshm Is | 0.35±0.02b | 1.62±0.1b | 41.0±7.63a | 2.47±0.9b | 2.34±0.4a | 0.57±0.2b |
| t1.4 RS, Qeshm Is | 0.15±0.01a | NDa | 43.2±4.21a | 0.5±0.03a | 2.61±0.28a | 0.23±0.1a |
| t1.5 CR, Khark Is | 0.74±0.06d | 3.92±0.3d | 97.44±3.05b | 8.3±0.9c | 10.42±0.71b | 1.87±0.37c |
| t1.6 MH, Khozestan Pr | 0.51±0.04c | 2.72±0.25c | 41.3±11.0a | 3.07±0.6b | 2.84±0.1a | 0.48±0.22b |

*MF* mangrove forest, *RS* rocky shore, *CR* coral Reef, *MH* muddy habitat. Different letters show significant differences of metal concentration between ecosystems

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## Heavy metal in muddy habitats

The results indicated that the order of metal concentrations in the water of muddy habitats was Ni > Pb > V > Cd > Hg > As (Table 1). With the exception of the level of Hg and As, this order was relatively similar to that recorded in coral reefs. From the mid- 1950s to the present, manufacturing industries, particularly petrochemical industries, population expansion, and rapid urban development have resulted in industrial and municipal wastewater discharges in the area (Abdolahpur Monikh et al. 2012a). For example, the PETZONE (Petrochemical Special Economic Zone) industrial complex is one of the largest in the Persian Gulf. This complex includes a large oil refinery and terminal, three fertilizer plants, some chemical manufacturing plants, 19 petrochemical units, a paper products factory, and power plant (Abdolahpur Monikh et al. 2012a; Safahieh et al. 2011). Enrichment in Hg, observed in the water of Khozestan's muddy habitats, may be brought about by petrochemical activities such as chlor-alkali in the area. Demirak et al. (2006) studied the concentrations of metals in water from muddy habitats in southwestern Turkey. The findings from the present work generally were higher for Cd and Pb than those. Pourang et al. (2005) studied metal concentrations in seawater of muddy habitats from the north Persian Gulf. Compared to the results of Pourang et al. (2005), the concentrations of Cd and Ni in the present study were higher than their findings, while the level of Pb in this study was lower than their study. Similarly, the concentration of V in seawater collected from the north Persian Gulf (Pourang et al. 2005) agreed well with the current results. The levels of Cd, Pb, and V metals in seawater of this ecosystem did not exceed the permissible limits proposed by MPL (Pourang et al. 2005) and the protection of saltwater life (Anon 2001). The concentration of Cd and Ni was higher than the limits proposed by ANZECC (ANZECC 1992).

## Heavy metal in rocky shore

As shown in Table 1, in the rocky shore, the concentrations of the selected elements decreased in the sequence Ni > V > Pb > As > Hg > Cd. Cadmium was below the limits of detection in seawater of this ecosystem. According to previous studies, petrochemical activities are the main sources of Cd, As, and Hg in intertidal ecosystems (Safahieh et al. 2011; Abdolahpur Monikh et al. 2012a). Qeshm Island is the largest island in the Persian Gulf and receives a large number of visitors to its intertidal rocky shores. Yet, there are no defined standards or program for the protection of rocky shore along the Iranian marine coastal areas. Direct removal along with physical disturbances caused by trampling, driving, and costal developments are likely to impact the biodiversity, and contaminate the rocky intertidal shores of Qeshm Island. However, the visitors' are likely not a main source for metal contamination. In addition, the absence of industrial activities in the area can also explain the observed sequence and levels of Cd, Hg, and As in seawater of this ecosystems. Total levels of Cd, Pb, and V were below the limits proposed by MPL (Pourang et al. 2005) for the protection of saltwater life (Anon 2001) and ANZECC (ANZECC 1992), whereas the concentration of Ni exceeded the limits proposed by ANZECC (ANZECC 1992).

## Heavy metal in mangrove forests

Table 1 also provides data on the level of selected metals in the seawater of mangrove forests of Qeshm Island. The levels of the studied heavy metals decreased in the sequence Ni > Pb > V > Cd > As > Hg, which is similar to that reported for seawater in the coral reefs of Khark Island. The area surrounding the Qeshm mangrove is currently being developed as the northernmost suburb of the city of Qeshm. Several hotels and some industries are located in the proximity of Qeshm's mangroves forest (Aghajan Pour et al. 2012; Ebrahimi-Sirizi and Riyahi-Bakhtiyari 2012). This forest is located in the north of Qeshm Island, between Boshehr and Qeshm cities, and close to the South Pars Special Economic Energy Zone (SPSEEZ) and represents a noteworthy accumulative area for several heavy metals (Ebrahimi-Sirizi and Riyahi-Bakhtiyari 2012). The South Pars Special Economic Energy Zone was established in 1998 for the utilization of South Pars oil and gas resources and to encourage commercial activities in the fields of oil, gas, and petrochemical industries in the Boshehr coasts. In addition to receiving pollutants from the Persian Gulf, this ecosystem receives considerable amount of contaminations from Boshehr and Qeshm industrial and shipping activities.

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## Variation of heavy metals among ecosystems

Regional differences in metal concentrations were examined for water and each species (Tables 1, 2, and 3). Regarding seawater, the data show that the highest average concentration of Hg, Cd, Ni, Pb, V, and As was found in the coral reefs followed by muddy habitats and mangrove forest. The concentrations of all the studied metals in the liver and gills of *J. belangerii* and the hepatopancreas of *P. pelagicus* from the reef structure were significantly higher than those in the other intertidal ecosystems. The concentrations of Hg and Cd in the hepatopancreas of *M. affinis* from muddy habitats of Khozestan province were higher than those in the same species from the other ecosystems; however, the concentrations of the other metals were similar to their distribution in the liver and gills of *J. belangerii* and the hepatopancreas of *P. pelagicus*. Variations of heavy metals in different ecosystems are attributed to local contamination, biological activities, environmental factors, sedimentation regimes, and marine currents of each ecosystem (Komastu et al. 1999).

Oil pollution has a very long history in the Persian Gulf. In recent years, the level of oil contamination has decreased due to the role of the Regional Organization for Protection of Marine Environment (ROPME) and other local environmental protection agencies (Al-Arfaj and Alam 1993). Thus, the average content of oil-related heavy metals such as V and Ni in the Persian Gulf has decreased by several times over the last two and three decades. However, the levels of these metals are still higher than the maximum permissible pollutant levels set up in the ROPME (ROPME 1999). Hence, it is expected that V and Ni concentration in the water and organisms of all the studied ecosystems would be high and with no significant variation, except for reef structure of Khark Island. Khar Island is the biggest oil terminal in the Persian Gulf, thus, it is not surprising that its water and organisms have the highest levels of oil-related metals. During the present study, we found that, in addition to oil related metals, the concentration of the other metals in coral reef seawater was higher than those in seawater of the other ecosystems. Reef structures of Khark Island are situated in clear water where there are no fluvial sedimentation processes. In this ecosystem, heavy metals are hardly removed from water column by fine sediment, thus, these contaminants remain for a long time in the dissolved phase (ROPME 1999). Besides, the amount of carbon dioxide in the atmosphere of Khark Island is relatively high, and this enrichment is known to be due to petroleum and petrochemical activities, primarily the combustion of fossil fuels and removal of forests (ROPME 1999). Microalgae have attracted a great deal of attention for $CO_2$ fixation because they can convert $CO_2$ into biomass via photosynthesis. However, oil pollution in Khark Island has degraded and killed microalgae and subsequently led to a rise in dissolved $CO_2$. Higher

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**Table 2** Level and standard deviation of heavy metals in liver of fish and hepatopancreas of crab and shrimp from different marine ecosystems in the Persian Gulf (in micrograms per gram wet weight)

| Species | Location | Hg | Cd | Ni | Pb | V | AS |
|---|---|---|---|---|---|---|---|
| *J. belangerii* | MF, Qeshm Is | 4.32±0.6b | 12.06±3.85b | 95.27±16.44a | 5.64±1.23b | 4.75±1.16b | 2.68±0.7b |
| | RS, Qeshm Is | 0.81±0.2a | 1.21±0.32 b | 93.15±10.32a | 1.24±0.73a | 1.33±0.37a | 0.77±0.31a |
| | CR, Khark Is | 7.32±1.77c | 19.52±3.85d | 286.42±29.65b | 17.33±6.53d | 17.93±3.26c | 4.43±1.17d |
| | MH, Khozestan Pr | 3.65±1.03b | 15.18±4.82c | 99.37±16.47a | 11.07±3.75c | 5.07±1.44b | 3.92±1.26cd |
| *M. affinis* | MF, Qeshm Is | 1.32±0.21c | 1.43±0.54b | 51.92±7.83a | 3.05±0.7b | 0.76±0.25b | 0.43±0.11b |
| | RS, Qeshm Is | 0.21±0.01a | 0.11±0.02a | 52.15±13.47a | 0.76±0.31a | 0.32±0.08a | 0.14±0.03a |
| | CR, Khark Is | 0.62±0.16b | 4.92±1.05c | 89.32±18.61b | 3.94±0.63b | 2.85±0.64d | 1.06±0.34d |
| | MH, Khozestan Pr | 3.64±0.42d | 5.15±2.28c | 53.75±9.23a | 3.16±0.85b | 0.97±0.12c | 0.76±0.15c |
| *P. pelagicus* | MF, Qeshm Is | 2.84±0.73b | 6.93±0.78b | 332.21±61.13b | 4.67±0.75 b | 0.83±0.27b | 4.83±1.29c |
| | RS, Qeshm Is | 0.65±0.1a | 0.54±0.25a | 214±34.9a | 1.78±0.36a | 0.11±0.02a | 0.95±0.44a |
| | CR, Khark Is | 5.11±0.8d | 9.4±2.76c | 674.28±82.94d | 8.94±2.17c | 1.75±0.23b | 8.63±2.82d |
| | MH, Khozestan Pr | 4±0.62c | 7.12±3.02b | 352.44±42.19c | 5.43±2.06b | 0.85±0.1a | 3.92±0.71bc |

*MF* mangrove forest, *RS* rocky shore, *CR* coral Reef, *MH* muddy habitat. Different letters show significant differences of metal concentration between ecosystems

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t3.1 **Table 3** Level and standard deviation of heavy metals in gills of fish from different marine ecosystems in the Persian Gulf (in micrograms per gram wet weight)

| t3.2 Species, gills | Location | Hg | Cd | Ni | Pb | V | As |
|---|---|---|---|---|---|---|---|
| t3.3 *J. belangerii* | MF, Qeshm Is | 2.17±0.64b | 7.86±2.66b | 102.32±38.91a | 3.57±1.13b | 3.74±0.97a | 2.13±0.75b |
| t3.4 | RS, Qeshm Is | 0.86±0.22a | 2.17±0.12a | 107.14±41a | 0.64±0.21a | 3.41±1.04a | 1.93±0.55a |
| t3.5 | CR, Khark Is | 4.97±1.74c | 13.49±4.56d | 212.93±52.16b | 28.25±5.09d | 19.33±3.86c | 8.14±3.64d |
| t3.6 | MH, Khozestan Pr | 2.16±0.58c | 10.27±3.41c | 106.22±24.16a | 13.43±3.77c | 12.71±2.96b | 5.03±1.21c |

*MF* mangrove forest, *RS* rocky shore, *CR* coral Reef, *MH* muddy habitat. Different letters show significant differences of metal concentration between ecosystems

dissolved $CO_2$ increases water acidity and lowers the concentration of carbonate that corals use, in the form of calcium carbonate, to build their skeletons (Connell 1978). It is well documented that in acidic and carbonate-free conditions, heavy metals tend to be in dissolved and bioavailable phases (Peng et al. 2009).

Large amounts of fine sediments, nutrients, and organic matter are washed into the Qeshm mangrove forest by the tidal currents and some seasonal rivers and into muddy habitats of Khozestan province by Arvand River. Environmental factors of sediment are important to understand metal concentrations in seawater. Sediment particulates are divided according to size. Heavy metal pollution is generally more of a problem in sediment with a high percentage of clay, because these fractions are more chemically active than the other sediment components (Peng et al. 2009). In the marine environment, heavy metals are rapidly removed from the water column and transported to bottom sediments, particularly in places that receive fine sediments (Abdolahpur Monikh et al. 2012b). The input of nutrients, such as nitrogen, and organic matter in the mangrove ecosystem of Qeshm Island enhances the net primary productivity in the water column and subsequently enhance fish communities in the area (Aghajan Pour et al. 2012; Ebrahimi-Sirizi and Riyahi-Bakhtiyari 2012). The primary producers and other organisms result in heavy metal uptake and consequently a decrease of the metal in seawater. Organic compounds in sediment of mangrove ecosystem play a significant role in heavy metal transformation. The reaction between heavy metals and organic matter is usually recognized as the most important reaction pathway. This phenomenon can strongly lower the mobility, bioavailability, and the concentration of metals in natural waters (Rae 1997). Two groups of sediments can be characterized in the Arvand River. The first group is abundant in the coarse-grained and carbonate-rich sediments; the other is associated with the finer and detritus-rich sediments (Milliman and Meade 1983). In sediments, metals can be bound to various fractions in different ways: adsorbed on clay surfaces or Fe- and Mn-oxyhydroxides; present in a lattice of secondary minerals like carbonates, sulfates or oxides; absorbed to organic matter or lattice of primary minerals such as silicates (Peng et al. 2009). It is well known that fine sediments and carbonates have a high potential for absorbing heavy metals (Peng et al. 2009). Therefore, despite receiving huge amounts of petrochemical wastewaters, the adsorption of heavy metals by the fine sediments and carbonate rich sediment, which enter the region by the Arvand River, and phenomena like flocculation due to the salinity increase, are some important reasons for the low concentrations of metals in seawater of the muddy habitats of Khozestan province.

Regarding the organisms, significant differences were observed among the ecosystems. Generally, the accumulation of heavy metals in the fish, crab, and shrimp was ranked as follows: rocky shore < mangrove forests < muddy habitats < coral reef ecosystem, except for Hg in liver of *J. belangerii*, As in *P. pelagicus* and Hg and Cd in *M. affinis*. Heavy metals, in company with other essential nutrients, are taken up by fish from food and water and eventually accumulated in target organs such as liver and gills (Abdolahpur Monikh et al. 2012a, b). The low levels of the studied metals in the gills of the fish in comparison to their liver may be attributed to the content of metallothionein protein in liver tissue (Al-Yousuf et al. 2000). According to Abdolahpur Monikh et al. (2012a), gills usually reflect the content of metals in seawater, because this organ is directly in contact with water, while liver and hepatopancreas reflect the level of heavy metals in water and food.

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Due to the variation of characteristics among marine ecosystems such as ecosystem size, complexity, community diversity, and level of primary production, fish of the same species and different ecosystems may be positioned in different trophic levels. For example, Post et al. (2000) and Doi et al. (2009) examined the importance of size, primary production and resource availability (microalgal carbon) in driving food chain in different marine ecosystems. Their results indicated that a combination of ecosystem size, primary production, and resource availability mainly control food chain length. Heavy metals bioaccumulation in aquatic systems varies considerably with food-chain structure and length (Misztal-Szkudli et al. 2011). There are two basic types of food chains: the grazing food chain (green plants to grazing herbivores to carnivores) and the detritus food chain (dead organic matter to detritus-feeding organisms to predators of detritivores). Coral reefs represent some of the most biologically diverse ecosystems on Earth, providing critical habitat to approximately 25 % of marine species (Connell 1978). Almost a third of the world's marine fish species are found on coral reefs (McAllister 1991). More than 99 % of coral reef food chains are based on the grazing food chain (McAllister 1991). Khozestan intertidal mudflats are considered as among the most biologically productive areas in the Persian Gulf (Sheppard et al. 2010). Most of food chains in Khozestan muddy habitats are also based on the grazing food chain (ROPME 1999). In mangrove intertidal benthic communities, usually three to four trophic levels food chains were distinguished (Abrantes and Sheaves 2009). Mangrove's unique features such as high productivity, abundant detritus, and rich organic carbon may make it an advantageous site for bacteria and detritus-feeding organisms. The grazing pathway is considered to be unimportant in mangrove ecosystems, since it has been estimated that only below 5 % of the leaf material is removed by grazing organisms before leaf abscission (Middleton and McKee 2001). *J. belangerii* lives in close association with sediment and feeds mainly on crustaceans, molluscs, and shrimp; however, its feeding habits change in different ecosystems (Fishbase www.fishbase.org). This changing in the feeding habits, position of the fish in food chain, type of food chains, and trophic levels has significant effects on the accumulation of heavy metals by the fish. As an example, Abdolahpur Monikh et al. (2013) studied the biomagnification of heavy metals in experimental aquatic food chains involving three species of phytoplankton, one species of zooplankton and one species of fish. They concluded that the primary producers could strongly control the biomagnification and accumulation of metal in different food chains even though the primary and second consumer in the chains is from the same species.

We found that the concentrations of Hg and Cd in *M. affinis* of muddy habitats were higher than those from the other ecosystems, which could be attributed to the load of these metals in the sediment of the Khozestan province. The Arvand River is the major source of fresh water entering the Persian Gulf (ROPME 1999; Sheppard et al. 2010). The freshwater appreciably dilutes the high salinity of the seawater in the area and leads to sediment deposition. According to Kishe and Machiwa (2003) and Sekhar et al. (2003), because of the strong adsorption capability of fine sediments, they act as a trap for heavy metals. Thus, it is quite possible that the high concentration of Hg and Cd observed in *M. affinis*, which are sediment-associated species, could be related to the Hg- and Cd-bound sediments deposition in the area.

## Conclusion

As we expected, significant differences were found in different ecosystems in view of the accumulation of the selected metals. The somewhat high concentrations of Ni, Pb, Hg, Cd, V, and As in water at the ecosystems of the Persian Gulf appear to be the result of anthropogenic influence. The results obtained from this study indicated that heavy metals in the same species from different ecosystems have different accumulation patterns. This variation could be explained by the differences in environmental and biological factors. Coral reefs of Khark Island were the most contaminated ecosystem among the studied ecosystems followed by muddy habitats of Khuzestan province and mangrove forests of Qeshm Island.

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Q4. The sentence starting with “Whereas, the concentration of Ni” was merged with the sentence starting with “Total levels of Cd, Pb, and V” for consistency and clarity. Please check.
Q5. “Rae 1997” is cited in text but not given in the reference list. Please provide details in the list or delete the citation from the text.
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