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Bioaccumulation of Heavy Metals in Sediment and Crab, *Portunus pelagicus* From Persian Gulf, Iran

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Abstract: Persian Gulf supports diverse ecosystems and biota in need of remediation and protection and metal data from this region is needed. The levels of heavy metal in tissues (hepatopancreas, muscle and exoskeleton) of blue swimming crab, *Portunus pelagicus* and sediments in the Persian Gulf coasts, south Iran were investigated. Heavy metals analysis was performed by Atomic Absorption Spectrophotometer. The results showed that variable levels of some of the metals in the sediments and crab samples. Some of the metals were higher than others, in some stations and on the different body components. The distribution pattern of heavy metals in the tissues of crab and sediments was as follows: sediment > hepatopancreasn > muscle > exoskeleton. The most concentrated was Cu (64.89±01.46 µg/g) while the least concentration was obtained in Pb (0.08±0.02 µg/g). Maximum concentration of the total heavy metal in sediments and all tissues of *P.pelagicus* observes in Bahrekan station ($P<0.05$). There was no significant difference ($P<0.05$) between the level of heavy metals in the tissues of the crab *P.pelagicus*. Differences in heavy metal among waders could have resulted from diverse feeding habitats and dissimilar foraging stations.

Key words: Heavy Metal · *Portunus pelagicus* · Sediment · Persian Gulf

INTRODUCTION

The Persian Gulf is a body of water in the Middle East between the Arabian Peninsula and Iran. This inland sea is connected to the Gulf of Oman by the Strait of Hormuz [1]. Persian Gulf is a semi-enclosed formation and heavy discharges of the surrounding industries have been ongoing for many decades. Other sources of Persian Gulf pollution include invasions and bombardments that have been staggering in the recent years and are yet to be fully investigated. Although heavy metals are very toxic to both humans and the wildlife, limited research is available on heavy metals pollution in the Persian Gulf area. Aquatic environments, such as Persian Gulf, are especially at high risk for heavy metals contamination since much of the atmospheric deposition and all of the industrial water-runoffs culminate in these ecosystems. Large areas of agricultural lands, local fisheries, oil export facilities and a petrochemical plant operate in the general area. Trace elements are found in natural water bodies at varying concentrations. The most potentially dangerous of these elements are heavy metals. Body levels of essential metals such as copper, chromium, nickel and zinc can be regulated by some decapod crustacean at concentrations below a threshold level. Accumulation of these metals only begins after the organisms are faced with high concentration in the surrounding medium [2], but body levels of nonessential metals such as cadmium and lead were not found to be regulated by crustacean [3]. Heavy metals concentrations in aquatic ecosystems are usually monitored by measuring its concentration in water, sediments and biota [4]. Sediments are important sinks for various pollutants such as heavy metals [5-7] and also play a useful role in the assessment of heavy metal contamination [8].Crabs belong to a group of animals knows as decapods crustaceans. Most of the

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marine crabs occurring along the Persian Gulf coasts belong to the family Portunidae. The blue swimming crab, *P. pelagicus* is widely distributed throughout the coastal and estuarine areas of the tropical western Pacific and Indian oceans [9]. *P. pelagicus* is one of the important representatives of decapod crustacean and a species commonly found in Persian Gulf coasts, Iran. Crabs has the capability of accumulating heavy metals [9] and is thus a suitable biondicator for environmental contamination with these agents hepatopancreas, the key site of heavy metal accumulation in Crustacean [10], is one of the most important organs that play important roles in metal detoxification [11]. Therefore, it is of great interest to investigate the toxicity of heavy metal on hepatopancreas in blue swimming crabs. Crabs are an excellent bioindicator of metal contamination and can be used to effectively and accurately monitor metal level for several reasons. Anthropogenic pollutants such as industrial, municipal and agricultural wastes finally end up in wetlands; exposing waterfowl to a variety of environmental pollutants.

Heavy metal used a widely in modern industry. Heavy metals including both essential and non-essential elements have a particular significance in ecotoxicology, since they are highly persistent and all have the potential to be toxic to living organisms [12]. Heavy metals do not exist in soluble forms for a long time in waters. They are present mainly as suspended colloids or are fixed by organic and mineral substances [13]. Several factors such as size, nature of the environment, seasonal variation and variability in species have been identified as important independent variable influencing metal levels in marine organisms [14]. Over the past century, heavy metals have been discharged into the world rivers and estuaries as a result of the rapid industrialization [15, 16]. Anthropogenic activities are the determining ecological factors in cities and industrial regions [17].

Metals that are naturally introduced into the river come primarily from sources such as rock weathering, soil erosion, or the dissolution of the water-soluble salts. Depending on physicochemical conditions, the pollutants in dissolved form can later be precipitated [18]. The deposition of metals in sediments occurs through an interaction between sediment and water, whereby variations of metal contents of sediment and water depend on variation of water chemistry, for example temperature, pH and solute concentration [19]. Sediments, particularly surficial sediments, may serve as a metal pool that can release metals to the overlaying water via natural anthropogenic processes, causing potential adverse health effects to the ecosystems because of their serious toxicity and persistence [20, 21]. In order to differentiate human impact from natural variability, knowledge of background concentrations of metals and their fluctuations in biomonitor organisms is essential as well as a thorough understanding of accumulation and detoxification strategies. These depend on various aspects, including the biological species and element considered, the applied exposure regime, cation homeostasis mechanisms, life-history status, spatial and temporal scales and other factors [22, 23]. This study was to determine the distribution and concentration of heavy metals (Cu, Cd, Ni, Co and Pb) in sediments and tissues (hepatopancreas, muscle, exoskeleton) of species *Portunus pelagicus* from Persian Gulf coasts located in south Iran.

MATERIAL AND METHODS

Study Area: The study was carried out in the several adjoining coasts in the Persian Gulf such as Khuzestan province (including coasts Abadan and Bahrekan), Boushehr province (including coasts Boushehr and Khark) and Hormozgan province including coasts Bandar Abbas and Jask (Figure 1). The Persian Gulf lies on the South Iran, between longitudes 48°25' and 56°25" East and latitudes 24°30" and30°30' North. It has an estimated area of 260Km2 and extends 600Km offshore to a depth average of about 30-40 meter [1].

Samples of surficial sediments and available species of blue swimming crabs were collected between July and September 2011 from 6 coastal localities in Persian Gulf coasts a distance of about 909 kilometers. Sampling covered areas of the direct or indirect influence of urban and industrial releases, those located near the mouth of the tributary rivers which carry industrial discharges of pollutants to the offshore waters and a locality not under the influence of industrial or urban releases. The sampling stations were selected to reflect progression of pollution, ecological particularity, vegetation and human activities in the area.

Sampling was performed in Persian Gulf coasts including six stations. Sediment Sampling was performed with Van Veen grab from the bottom at all stations. In each station Sediments samples were collected at 4 random locations. After sampling, the samples were packed in plastic bags, preserved and transferred to laboratory for analysis. All equipment and containers were soaked in 10% HNO3 and rinsed thoroughly with deionized distilled water before use.

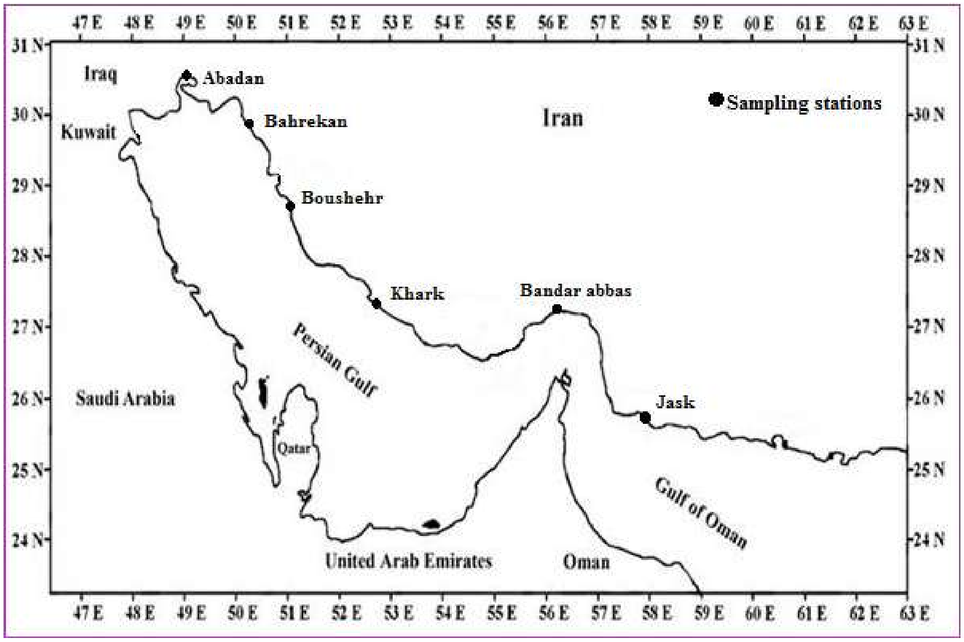

Fig. 1: Map of Persian Gulf coasts showing Sampling stations and the Study Site.

Then samples were digested by adding HCL, Nitric and Sulfuric acid. The standard solution of the elements Cu, Cd, Ni, Co and Pb were prepared by pipetting the required amount of the solution from the stock solution, manufactured by Fisher-Scientific Company, New Jersey, USA. The standard solution was prepared before every determination of the analysis of the present work. Samples of sediments were oven dried, sieved through a 63 µm mesh and weight to 10 g. The pH of the sediments was measured in distilled water with a 1: 2.5 sediment/solution ratio [24, 25]. The content of organic matter in each sample was determined using loss on ignition. Portions of 5.0 g oven dried sediment from each site were heated at 450°C for 20 h [26, 27]. Each sample was re-weighted after being cooled to determine level of organic content by the loss in weight of dry sediment.

Crabs sampling was performed with shrimp trawl. After sampling, samples were transferred to the laboratory in a cooler and stored in a deep freezer for further analysis. Each crab was properly cleaned by rinsing with distilled water to remove debris, planktons and other external adherent and then they were dissected for collect tissues hepatopancreas, muscle and exoskeleton. It was then drained under folds of filter, weighed, wrapped in aluminum foil and then frozen at 10ºC prior to analysis. The tissues were placed in clean watch glasses and were oven dried at 105°C for 1 hour and later cooled in the desiccators.

The analysis of total heavy metal were done by the cold vapor method using a Perkin-Elmer Atomic Absorption System AA-2380 with automatic background correction and a Perkin-Elmer Mercury Analysis System 303-0830. Replicate (3 to 5) measurements were made on each sample. All the reagents used were of spectroscopic grade and ultra-high purity (99.9 %). In all experiences several blanks were performed with the reagents used, in order to check for possible contamination. The data obtained were statistically analyzed for confirmation of the results. Metal toxicity from different tissues and sediments was calculated by using regression equation and results were expressed in µg /gm dry weight.

Statistical Analyses: Data were analyzed using the one-way analysis of variance (ANOVA) and group means were compared using Duncans multiple range test. P values < 0.05 were considered significant.

RESULTS

The concentrations of the heavy metals in the sediments from different stations are presented in Table 1. The results showed that the heavy metal concentration in sediments at all sampling stations occurs in descending order of Cu > Cd > Ni > Co > Pb. The highest concentrations of the heavy metal in sediment were recorded in Bahrekan station and the least was in Boushehr station. The present study recorded that

Table 1: Concentration of heavy metal (µ g/g dry weight) in sediments from different stations along Persian Gulf coasts

Stations	Pb	Cd	Ni	Cu	Co
Abadan	1.49 ± 0.04	21.83 ± 0.40	19.5 ± 1.22	45.19 ± 1.46	4.70 ± 0.59
Bahrekan	3.85±0.04	29.63 ± 0.40	24.7 ± 1.22	64.89 ± 1.46	6.70 ± 0.59
Boushehr	0.26 ± 0.02	17.34 ± 0.65	9.93 ± 0.58	21.22 ± 0.46	2.50 ± 0.33
Khark	0.55 ± 0.03	21.55 ± 0.54	17.01 ± 0.86	43.86 ± 2.29	3.60 ± 0.44
Bandar Abbas	1.32 ± 0.03	23.34 ± 0.33	14.46 ± 0.30	51.18 ± 1.57	3.89 ± 0.40
Jask	0.42 ± 0.03	21.34 ± 1.14	11.24 ± 1.96	23.96 ± 0.49	2.59 ± 0.25

Table 2: Concentration of heavy metal (µ g/g dry weight) in hepatopancreas of crab, *P. pelagicus* from different stations along Persian Gulf coasts

Stations	Pb	Cd	Ni	Co	Co
Abadan	1.04 ± 0.02	20.10 ± 0.40	18.70 ± 1.12	44.89 ± 1.46	4.10 ± 0.50
Bahrekan	2.85 ± 0.04	26.30 ± 0.40	22.10 ± 0.20	61.80 ± 1.46	5.20 ± 0.25
Boushehr	0.16 ± 0.02	16.34 ± 0.60	8.30 ± 1.58	20.40 ± 0.46	2.10± 0.20
Khark	0.75 ± 0.03	20.55 ± 1.50	16.01 ± 1.10	41.86 ± 1.20	3.16 ± 0.14
Bandar Abbas	0.62 ± 0.03	22.14 ± 0.44	13.60 ± 0.25	50.28 ± 1.57	3.41 ± 0.20
Jask	0.22 ± 0.03	20.24 ± 1.30	11.01 ± 0.10	18.96 ± 0.49	2.19 ± 0.15

Table 3: Concentration of heavy metal (µ g/g dry weight) in muscle of crab, *P. pelagicus* from different stations along Persian Gulf coasts

Stations	Pb	Cd	Ni	Cu	Co
Abadan	0.98 ± 0.10	18.30 ± 0.20	17.50 ± 0.20	40.89 ± 1.46	3.20 ± 0.50
Bahrekan	2.40 ± 0.20	22.60 ± 0.40	20.80 ± 1.22	60.90 ± 1.20	4.70 ± 0.50
Boushehr	0.15± 0.02	14.34 ± 0.65	7.93 ± 0.50	18.22 ± 0.66	1.59 ± 0.30
Khark	0.55 ± 0.03	19.55 ± 0.54	16.01 ± 0.86	40.16 ± 1.30	2.50 ± 0.44
Bandar Abaas	0.58 ± 0.03	19.34 ± 0.33	12.46 ± 0.30	45.20 ± 0.50	2.81 ± 0.40
Jask	0.20 ± 0.03	17.24 ± 1.14	10.24 ± 1.96	16.70 ± 0.40	2.01 ± 1.25

Table 4: Concentration of heavy metal (µ g/g dry weight) in exoskeleton of crab, *P. pelagicus* from different stations along Persian Gulf coasts

Stations	Pb	Cd	Ni	Cu	Co
Abadan	0.40 ± 0.05	16.60 ± 0.40	15.7 0± 1.22	35.89 ± 1.50	2.70 ± 0.59
Bahrekan	1.90 ± 0.04	20.30 ± 0.40	19.10 ± 0.10	57.89 ± 1.40	3.70 ± 0.59
Boushehr	0.08 ± 0.02	12.34 ± 0.35	6.90± 0.50	16.20 ± 0.06	1.59 ± 0.33
Khark	0.40 ± 0.03	17.55 ± 0.54	15.01 ± 0.60	36.80 ± 1.04	2.16 ± 0.30
Bandar Abaas	0.45 ± 0.05	16.34 ± 0.30	11.40 ± 0.30	40.30 ± 1.50	1.90 ± 0.40
Jask	0.15 ± 0.05	15.20 ± 1.10	9.20± 1.30	15.50 ± 0.40	1.10 ± 0.20

Cu forms the most abundant element in the sediment (64.89 ± 1.46 µg/g) and lead had concentration least (0.26 ± 0.02µg/g).There was significant difference ($p<0.05$) between the level of heavy metals in the different stations.

The concentrations of the heavy metals in the hepatopancreas of crab, *P. pelagicus* from different stations along Persian Gulf coasts presented in Table 2. Results showed that the highest concentrations of the heavy metal in hepatopancreas were Copper (61.80 ± 1.46 µg/g) and lead was least (0.16 ± 0.02 µg/g). Generally our results showed that concentrations of the heavy metals in the sediments were higher than hepatopancreas tissue, muscle tissue and exoskeleton. Table 3 shows the concentration of heavy metals in the muscle tissue of crab *P. pelagicus*. The highest concentrations of the heavy metal in muscle tissue were Copper (60.90 ± 1.20 µg/g) and lead was minimum (0.15± 0.02 µg/g).The concentrations of the heavy metals in the exoskeleton of crab presented in Table 4. The highest concentrations of the heavy metal in exoskeleton was Copper (57.89 ± 1.40 µg/g) and lead was minimum (0.08 ± 0.02 µg/g). The comparison on heavy metal accumulation between hepatopancreas tissue, muscle tissue and exoskeleton showed that bioaccumulation in the exoskeleton was less than hepatopancreas and muscle tissue. The data shown that for crab samples (hepatopancreas, muscle and exoskeleton), Cu were the highest concentration, followed by Cd, Ni, Co and least was Pb. There was no significant difference ($p<0.05$) between the level of heavy metals in the tissues of *P.pelagicus*.

In the present study, results showed that concentrations of the heavy metals in the sediments and crabs in Bahrekan station were significantly higher (P < 0.05) than the other stations. There is a growing concern about the physiological and behavioral effects of environmental trace metals in human population and probably due to nearby to petrochemical industries and a high amount wastewaters containing heavy metal always dumped at this station.

DISCUSSION

The contamination of soils, sediments, water resources and biota by heavy metals is of major concern especially in many industrialized countries because of their toxicity, persistence and bioaccumulative nature [5]. Sequential extraction results can provide information on possible chemical forms of heavy metals in sediments [28]. Levels of contaminants in marine animals are of particular interest because of the potential risk to humans who consume them. In particular, the tendency of heavy metals to accumulate in various organs of crustacean, which in turn may enter the human metabolism through consumption causing serious health hazards. Accumulation of metals in marine animals is the function of their respective membrane permeability and enzyme system, which is highly species specifics and because this fact different metals accumulated in different orders in the studied *P. pelagicus* samples. The effects of heavy metals in the environment depend to a large extent on whether they occur in forms that can be taken up by plants or animals. Therefore, the present study was undertaken to evaluate the heavy metals accumulation of Cu, Cd, Ni, Co and Pb in the sediments and tissues (hepatopancreasn, muscle, exoskeleton) of the crab *P. pelagicus*. A wide range of values for heavy metal concentrations was observed for the sediments. The heavy metal concentration in sediments at all sampling stations occurs in descending order of Cu > Cd > Ni > Co > Pb, except for Bahrekan station where heavy metal concentration was higher than the other stations. Results showed that concentrations of the heavy metals in the sediments in Bahrekan station were significantly higher (P < 0.05) than the other stations. There is a growing concern about the physiological and behavioral effects of environmental trace metals in human population and probably due to nearby to petrochemical industries and a high amount wastewaters containing heavy metal always dumped at this station. The present study recorded that Cu forms the most abundant element in the sediment and lead had concentration least. The higher concentrations of copper were in sediments of Bahrakan station and the least concentrations of copper were in sediments of Boushehr station. In *P.pelagicus* the distribution pattern of heavy metals was in the increasing order of hepatopancreasn > muscle > exoskeleton. Results showed that Cu had the higher concentrations in the tissues of crab and Pb element had concentrations least. This observation may be due to the major functional differences in their body. The research same, the comparison on heavy metal accumulation between all tissues crustaceans show that bioaccumulation of heavy metals was more in hepatopancreasn than other tissues [29, 30]. The variation is also an indication of the degree to which particular species pick up particulate matter from surrounding water and in particular sediments while feeding. Crabs are bottom feeder and are generally expected to concentrate more metals than surface feeders like prawn which is in agreement with earlier report. There was no significant difference (p<0.05) between the level of heavy metals in the tissues of the crab *P.pelagicus* but there was a significant difference (P< 0.05) between sediments and tissues of crab *P.pelagicus.* The concentrations of Cu were higher than the other metals, suggesting that there is an influence of the industrial activities in surroundings of the sampled stations. Research same showed that the highest concentrations of copper in water were found in lakes which had the lowest water pH and the lowest sediment pH [31]. The low value of Pb concentration in the present study may indicates that the tissues of *P. pelagicus* is not the target organs for Pb accumulation. The absence or low value of lead in the crab may be due to the activities around the location of the Gulf. The area consist mainly farmland and few residential houses. There are few or no industrial activities around the location. This may agree to the study of Craig and Overnell (2003). They concluded that Pb concentration in the tissues of crustacean is low than other metals [32]. Research same showed that the highest concentration of lead was found in the Turlok Lake when there were high boating activities [33]. The result of the analysis has shown that crab *portunus pelagicus* can be used as bio-indicator as it contains variable levels of the metals analyzed with high enrichment of Cd, Co, Cu, Ni and Pb observed. As far as the crabs consume organic substances present in the bottom of sediments of aquatic systems, they are good biomonitors for pollutants presents in the ecosystems. It is also important the fact that this species represents both source of income and nourishment for the marginal populations effects. The high concentrations of heavy metals in commercially important crustaceans sampled from Persian Gulf (Bahrekan station) is a cause of concern and requires regular monitoring of water quality around the point sources present opposite to the Northwestern part of the Persian Gulf, in combination with the fact that crab consumption is the main source of heavy metal intake in people not occupationally exposed, amplifies the need for preventive measures to safeguard public health. The heavy metal accumulation in the different tissues and sediments increased as the exposure time increased. So, heavy metal will reach the tissues of human beings through the food chain. Therefore, it should be mentioned by industrialists and they should take steps to reduce the aquatic pollution.

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REFERENCES

1. ROPME, 1999. Overview on Land-based Sources and Activities Affecting the Marine Environment in the ROPME Sea Area. UNEP/GPA Coordination Office and ROPME, pp: 127.
2. Rainbow, P.S. and S.L. White, 1989. Comparative strategies of heavy metal accumulation by crustaceans: Zinc, copper and cadmium in a decapod, an amphipod and a barnacle. Hydrobiologia, 174: 245-262.
3. Pastor, A., J. Medina, J. Del Ramo, A. Torreblanca, J. Diaz-Mayans and F. Hernandez, 1988. Determination in different tissues. Bull Environ Contam Toxicol., 41: 412-8.
4. Camusso, M., L. Vigano and R. Baitstrini, 1995. Bioaccumulation of trace metals in rainbow trout. Ecotoxicology and Environmental Safety, 31: 133-141.
5. Ikem, A., N.O. Egiebor and K. Nyavor, 2003. Trace elements in water, fish and sediment from Tuskegee Lake, Southeastern USA. Water, Air and Soil Pollution, 149: 51-75.
6. Eimers, M.C., R.D. Evans and P.M. Welbourn, 2001. Cadmium accumulation in the freshwater isopod Asellus racovitzai: The relative importance of solute and particulate sources at trace concentrations. Environmental Pollution, 111: 247-253.
7. Ho, S.T., L.J. Tsai and K.C. Yu, 2003. Correlations among aqua-regia extractable heavy metals in vertical river sediments. Diffuse Pollution Conference, Dublin, 1: 12.
8. Clements, W. and M. Newman, 2002. Community ecotoxicology. New York: Wiley.
9. Kumar, M., G. Ferguson, Y. Xiao, G. Hooper and S. Venema, 2000. Studies on reproductive biology and distribution of blue swimmer crab (*Portunus pelagicus*) in South Australian Waters. Research report series, 47: 1324-2083.
10. Reinecke, A.J., R.G. Snyman and J.A.J. Nel, 2003. Uptake and distribution of lead (Pb) and cadmium (Cd) in the freshwater crab, *Potamonautes perlatus* (Crustacea) in the Eerste River, South Africa. Water Air Soil Pollution, 145: 395-408.
11. Wang, L., X.Q. Yang, Q. Wang and D.X. Wang, 2001. The accumulation of Cd and the effect of EST in five tissues and organs of *Eriocheir sinensis*. Acta Zoologica Sinica, 47(Suppl.): 96-100.
12. Gibson, R. and P.L. Barker, 1979. The Decapoda hepatopancreas. Oceanography and Marine Biology, 17: 285-346.
13. Storelli, M.M., A.D. Storelli, R. ddabbo, C. Marano, R. Bruno and G.O. Marcotrigiano, 2005. Trace elements in loggerhead turtles (*Caretta caretta*) from the eastern Mediterranean Sea: Overview and evaluation. Environmental Pollution, 135: 163-170.
14. Kabata-Pendias, A. and H. Pendias, 2001. Trace elements in soils and plants (3rd ed.). Boca Raton, FL: CRC Press.
15. Baldantoni, D., A. Alfani and P.D. Tommasi, 2004. Assessment of macro and microelement accumulation capability of two aquatic plants. Environmental Pollution, 130: 149-156.
16. Chen, M.H., 2002. Baseline metal concentrations in sediments and fishes and the determination of bioindicators in the subtropical Chi-ku Lagoon, S.W. Taiwan. Marine Pollution Bulletin, 44: 703-714.
17. Tam, N.F.Y. and Y.S. Wong, 2000. Spatial variation of heavy metals in surface sediments of Hong Kong mangrove swamps. Environmental Pollution, 110: 195-205.
18. Birke, M. and U. Rauch, 2000. Urban geochemistry: Investigation in the Berlin metropolitan area. Environmental Geochemistry and Health, 22: 233-248.
19. Jain, C.K., D.C. Singhal and M.K. Sharma, 2005. Metal pollution assessment of sediment and water in the river Hindon, India. Environmental Monitoring and Assessment, 105: 193-207.

20. Davies, P.J., 1974. Arsenic in sediments on the continental shelf of southeast Australia. Searchs, 5: 394-397.
21. McCready, S., G.F. Birch and E.R. Long, 2006. Metallic and organic contaminants in sediments of Sydney Harbour, Australia and vicinity-a chemical dataset for evaluating sediment quality guidelines. Environment International, 32: 455-465.
22. Huang, J.F., H.P. Yu and M. Takeda, 1992. A review of the Ocypodid and Mictyrid crabs (Crustacea: Decapoda: Brachyura) in Taiwan. Bulletin of the Institute of Zoology, Academia Sinica, 31: 141-161.
23. Zauke, G.P. and G. Petri, 1993. Metal concentrations in Antarctic Crustacea. The problem of background levels. In: R. Dallinger and P.S. Rainbow (eds.), Ecotoxicology of metals in invertebrates, pp: 73-101. Lewis Publishers, Boca Raton, USA.
24. Madejon, P., J.M. Murillo, T. Maranon, T.F. Cabrera and F. Lopez, 2002. Bioaccumulation of As, Cd, Cu, Fe and Pb in wild grasses affected by the Aznalcollar mine spill (SW Spain). Science of the Total Environment, 290: 105-120.
25. Guevara-Riba, A., A. Sahuquillo, R. Rubio and G. Rauret, 2004. Assessment of metal mobility in dredged harbor sediments from Barcelona, Spain. Science of the Total Environment, 321: 241-255.
26. Manta, D.S., M. Angelone, A. Bellanca, R. Neri and M. Sprovieri, 2002. Heavy metals in urban soils: A case study from the city of Palermo (Sicily), Italy. Science of the Total Environment, 300: 229-243.
27. Andrews, S. and R.A. Sutherland, 2004. Cu, Pb and Zn contamination in Nuuanu watershed, Oahu, Hawaii. Science of the Total Environment, 324: 173-182.
28. Xiangdong, L., S. Zhenguo, W.H.W. Onyx and L. Yok-sheung, 2000. Chemical partitioning of heavy metal contaminants in sediments of the Pearl River Estuary. Chemical Speciation and Bioavailability, 12: 17-25.
29. Bunt, A.H., 1986. An ultrastructural study of the hepatopancreas of *Procambarus clarkia* (Girard) (Decapoda: Astacides). Crustaceana, 15: 282-288.
30. Vijayaraman, K., G. John, P. Sivakumar and R.R. Mohamed, 1999. Uptake and less of heavy metal by the freshwater prawn, Macrobrachium malcolmsonii. Journal of Enviromental Biological, 20(3): 217-222.
31. Samecka-Cymerman, A. and A.J. Kempers, 2001. Concentrations of heavy metals and plant nutrients in water, sediments and aquatic macrophytes of anthropogenic lakes former open cut brown coal/mines differing in stage of acidification. Science of the Total Environment, 281: 87-98.
32. Craig, S. and J. Overnell, 2003. Metals in squid, *Loligo forbesi*, adults, eggs and hatchlings. No evidence for a role for Cu-or Zn-metallothionein. Comparative Biochemistry and Physiology, 134: 311-317.
33. Byrd, J.E. and M.J. Perona, 1980. The temporal variations of the lead concentration in a freshwater lake. Water, Air and Soil Pollution, 13: 207-220.
34. Schuwerack, P.M.M., J.W. Lewis and P. Jones, 2001. The potential use of the South African river crab, *Potamonautes warreni*, as a bioindicator species for heavy metal contamination. Ecotoxicology, 10: 159-166.
35. Pekey, H., 2006. The distribution and sources of heavy metals in Izmir Bay surface sediments affected by a polluted stream. Marine Pollution Bulletin, 52: 1197-1208.
36. Chen, Z., Y. Saito, Y. Kanai, T. Wei, L. Li, H. Yao, *et al.* 2004. Low concentration of heavy metals in the Yangtze estuarine sediments, China: A diluting setting. Estuarine, Coastal and Shelf Science, 60: 91-100.
37. Wang, S., Z. Cao, D. Lan, Z. Zheng and G. Li, 2007. Concentration distribution and assessment of several heavy metals in sediments of west-four Pearl River estuary. Environmental Geology, 55(5): 963-975.