Chapter

# Assessment of Metal Accumulation and Bioaccumulation Factor of Some Trace and Heavy Metals in Freshwater Prawn and Crab

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## Abstract

Globally, freshwater decapods have been one of the major food delicacies because of their rich deposits of minerals. High metals are usually accumulated in the body tissues of these organisms because of their lifestyle. Metal accumulation in freshwater decapods has been acclaimed and perceived to cause serious health concerns when transferred to humans along the food chain. A recent study has shown that freshwater biota, prawn (*Macrobrachium rosenbergii*), showed significant differences ($p < 0.05$) in Mn, Cu, Pb and Cr and no significant difference ($p > 0.05$) in Fe, Zn and Cd. In contrast, the freshwater biota, crab (*Sudanonautes africanus*), showed significant differences ($p < 0.05$) in Fe, Zn and Mn and no significant differences ($p > 0.05$) in Pb, Cr and Cd. A high accumulation of Fe in the whole tissues of *Macrobrachium rosenbergii* and *Sudanonautes africanus* was also established. This is because Fe in the Nigerian soil and sediment is naturally very high beyond slated thresholds and tend to accumulate and transcend or magnify in benthic. It was noticed that Zn (2.68) and Cr (4.52) had the highest bioaccumulation factors in prawn and crab, respectively. Chromium has been observed to be carcinogenic. The consumption of Cr in the muscles of crab might constitute probable serious health risk.

**Keywords:** accumulation, biomagnification, decapods, risk, carcinogenicity

## 1. Introduction

Globally, freshwater decapods have been one of the major food delicacies because of their rich deposits of minerals, metals; calcium (Ca), iron (Fe), zinc (Zn) and copper (Cu), Nickel (Ni), Vanadium (V) and Cadmium (Cd) as well as nutrients; protein, fibers and cellulose. High levels of mineral contents like metals are usually accumulated in the body tissues of these organisms because of their lifestyle. This has necessitated the increased rate of human consumption in recent times [1].

It has been documented that freshwater crab (*Sudanonautes africanus*) and prawn (*Macrobrachium rosenbergii*) have high deposits of Fe, Zn and Mn, with few traces of Cu, Pb, Cr, Cd, Ni and V [1–4].

Metal accumulation in freshwater decapods has been acclaimed and perceived to cause serious health concerns when transferred to humans along the food chain. Environmental valuation of the noxiousness of metals in the freshwater *Sudanonautes africanus* and *Macrobrachium rosenbergii* had been shown to have probable human health hazard effect concomitant by way of ingestion [1].

Health risks associated with heavy metals such as renal failure, skeletal deformation, and hepatic failure have been linked to their non-decomposable and persistence nature in the visceral organ-parts of humans [5]. This can lead to severe maladies like dysentery, stomach aches, head-tremor, anemia, paralysis, nausea, paroxysm, melancholy and even respiratory disorders [6], which can be either acute or chronic forms; neuron toxicity, oncogenic, genetic alteration or teratogenicity [7].

High levels of bio-accumulated heavy metals in freshwater decapods have been identified in these ranks; Fe > Zn > Mn > Cu > Pb > Cr [1] as interconnected with their sediment background levels [8].

## 2. Methodology

### 2.1 Sampling technique

Samples of freshwater prawns and crabs (*Macrobrachium rosenbergii* and *Sudanonautes africanus*) were captured and collected monthly from March 2015 to August 2016 at designated stations by some fishermen, using local-hand nets enticed with ox-heart, set at the river bank of each station 24 hours before capturing. The prawns and crabs were collected and kept in different labeled plastic rubbers according to the stations, filled with the river water and immediately taken to the laboratory for heavy metal analysis and identifications.

### 2.2 Extraction and determination of heavy metals in freshwater decapods

Employing the methods of [1], the freshwater biota was oven dried at 105°C. About 2 g of a dried up standardized sample of each tissue were digested and sample was made up to about 50 ml of purified water. Samples of the biota were analyzed for iron, manganese, zinc, copper, chromium, cadmium, nickel, lead, and vanadium with an AAS (atomic absorption spectrophotometer; SOLAAR 969AA UNICAM, Spectronic Unicam, Cambridge, UK) [1].

### 2.3 Data analysis

Simple descriptive analysis, ANOVA (Analysis of variance), was employed using SPSS version 20.0.

To determine the accumulation rate of heavy metals in the freshwater biota, the bio-indices; bioaccumulation factor was employed with Micro Excel version 2013. Bioaccumulation factor (BAF) is the concentration of metals in sediment or water over the concentration of metals in the biota in mg kg$^{-1}$ [8]. This can be represented in the equation below:

$$\text{BAF} = \frac{\text{concentration of metals in sediment/water (mg/kg)}}{\text{concentration of metals in Crab/prawn (mg/kg)}} \tag{1}$$

## 3. Assessment of metal contents in freshwater decapods

The assessment of metal contents in freshwater decapods is suitable for both water and terrestrial life forms. This is based on their significance as water indicators of pollutants via monitoring in spatial or temporal, in order to quantify their ecological role in the ecosystem. Even though the dangers of water pollution by metals are fully acknowledged, it is still a subject of discussing in line with the over increasing anthropogenic activities [9] and as well as the lithogenic activities [1].

Freshwater prawn and shrimp (Macroinvertebrates) are commonly recommended as fauna-indicators for evaluating the fluctuation of aquatic disorders in the region of probable pollution [3]. In general, decapods are of certain prominence for bio-monitoring survey [10], as the bedrock species in most aquatic systems [11], as well as the most tolerated species against water pollution. This shows their pollution status as regards to the buildup of the corresponding components of metals in their muscles [12].

### 3.1 Accumulation of metals in *Sudanonautes africanus* and *Macrobrachium rosenbergii*

Metal contamination in freshwater ecosystem is of utmost worry everywhere in the biosphere [13–15]. This might be as a result of their persistence noxious special effects and accumulation features in the aquatic system and fauna respectively [16–22].

Metals go in into freshwater ecosystem via lithogenic and human activities [18, 22–24]. Benthic region is a key sink and a basis for metal pollution [25]. Built-up substances such as metals can be a sign of macrobenthic fauna-accumulation severity, ill health or death as the case may arise [24]. Certain residential chemicals in the sediment can exterminate benthic macroinvertebrates, thus plummeting the food chain structure [26].

However, a recent study has shown that freshwater biota; prawn (*Macrobrachium rosenbergii*) showed significant differences ($p < 0.05$) in Mn, Cu, Pb and Cr and no significant difference ($p > 0.05$) in Fe, Zn and Cd. No observable p-values were noticed for Ni and V respectively (**Table 1**). In contrast, the freshwater biota; crab (*Sudanonautes africanus*) showed significant differences ($p < 0.05$) in Fe, Zn and Mn and no significant difference ($p > 0.05$) was observed in Pb, Cr and Cd. There was also no observed p-values in Ni and V (**Table 2**) [28]. It was noticed that the ranks of heavy metals and their spatial variability in the shrimps and crabs were Fe > Zn > Cu > Pb = Cd > Cr = Ni = V and Fe > Zn > Mn > Cu > Pb > Cr = Cd > Ni = V respectively.

### 3.2 Bioaccumulation

The food chain structure has served as a pointer where metals are streamed along. Freshwater ecosystem pollution by metals, especially the heavy ones is on the increase daily around the world, causing several problems globally. Consequent of the buildup effect of certain heavy metals, particularly via the food chain, their bio-availability needs to be examined. This can be done via investigation of metal contents in biota in order to gather and predict its bioavailability and subsequent accumulation in the organism(s).

Generally, freshwater decapods freely accumulate metals in their muscles in order to meet their basic metabolic needs. This makes them appropriate as bio-indicators of metals in the ecosystem. For example, freshwater *Sudanonautes africanus* and *Macrobrachium rosenbergii* accumulate high levels of Fe, Zn and Mn in their muscles [28] based on the facts that these metals play vital role in the respiratory pigment

| Parameters | Units | Station 1 | Station 2 | Station 3 | Station 4 | p-values | Significant | [27] limits |
|---|---|---|---|---|---|---|---|---|
| | | Mean ± SD | Mean ± SD | Mean ± SD | Mean ± SD | | | |
| Fe | mg $kg^{-1}$ | 120.99 ± 43.95 | 150.45 ± 71.66 | 148.48 ± 86.88 | 119.16 ± 49.36 | 0.25 | $p > 0.05$ | 100 |
| Zn | mg $kg^{-1}$ | 45.82 ± 22.46 | 52.13 ± 23.26 | 57.79 ± 21.14 | 53.06 ± 18.55 | 0.32 | $p > 0.05$ | 100 |
| Mn | mg $kg^{-1}$ | 1.61 ± 1.41 | 1.94 ± 1.16 | 2.08 ± 1.68 | 1.13 ± 0.46 | 0.04 | $p < 0.05$ | 1.0 |
| Cu | mg $kg^{-1}$ | 0.39 ± 0.32 | 0.73 ± 0.48 | 0.72 ± 0.57 | 0.66 ± 0.32 | 0.04 | $p < 0.05$ | 30 |
| Pb | mg $kg^{-1}$ | 0.01 ± 0.01 | 0.02 ± 0.02 | 0.01 ± 0.01 | 0.01 ± 0.01 | 0.02 | $p < 0.05$ | 0.5 |
| Cr | mg $kg^{-1}$ | 0.00 ± 0.00 | 0.01 ± 0.02 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.05 | $p < 0.05$ | NS |
| Cd | mg $kg^{-1}$ | 0.01 ± 0.02 | 0.02 ± 0.02 | 0.02 ± 0.02 | 0.01 ± 0.01 | 0.62 | $p > 0.05$ | 0.5 |
| Ni | mg $kg^{-1}$ | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 | — | NS |
| V | mg $kg^{-1}$ | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 | — | NS |

*Most of the parameters were measured in mg/kg; $p < 0.05$, significant difference; $p > 0.05$, no significant difference. NS, not specified; FAO, Food and Agriculture Organization; WHO, World Health Organization.*

**Table 1.**
*Summary of the accumulation of heavy metals in prawns from Ossiomo River collected from designated stations from March 2015 to August 2016.*

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| Parameters | Units | Station 1 | Station 2 | Station 3 | Station 4 | p-values | Significance | [27] limits |
|---|---|---|---|---|---|---|---|---|
| | | Mean ± SD | Mean ± SD | Mean ± SD | Mean ± SD | | | |
| Fe | mg $kg^{-1}$ | 154.55 ± 41.40 | 203.42 ± 76.29 | 167.86 ± 118.00 | 170.28 ± 113.14 | 0.02 | $p < 0.05$ | 100 |
| Zn | mg $kg^{-1}$ | 66.59 ± 21.15 | 92.99 ± 31.40 | 66.80 ± 51.76 | 69.73 ± 50.92 | 0.02 | $p < 0.05$ | 100 |
| Mn | mg $kg^{-1}$ | 1.98 ± 1.60 | 3.68 ± 2.59 | 3.31 ± 2.95 | 3.57 ± 3.11 | 0.02 | $p < 0.05$ | 1.0 |
| Cu | mg $kg^{-1}$ | 0.64 ± 0.27 | 1.13 ± 0.74 | 0.88 ± 0.78 | 0.95 ± 0.81 | 0.03 | $p < 0.05$ | 30 |
| Pb | mg $kg^{-1}$ | 0.01 ± 0.02 | 0.03 ± 0.04 | 0.03 ± 0.04 | 0.04 ± 0.04 | 0.19 | $p > 0.05$ | 0.5 |
| Cr | mg $kg^{-1}$ | 0.01 ± 0.01 | 0.02 ± 0.02 | 0.02 ± 0.02 | 0.02 ± 0.03 | 0.34 | $p > 0.05$ | NS |
| Cd | mg $kg^{-1}$ | 0.00 ± 0.01 | 0.02 ± 0.03 | 0.02 ± 0.03 | 0.02 ± 0.03 | 0.23 | $p > 0.05$ | 0.5 |
| Ni | mg $kg^{-1}$ | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 | — | NS |
| V | mg $kg^{-1}$ | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 | — | NS |

*Most of the parameters were measured in mg/kg; $p < 0.05$, significant difference; $p > 0.05$, no significant difference. NS, not specified; FAO, Food and Agriculture Organization; WHO, World Health Organization.*

**Table 2.**
*Summary of the accumulation of heavy metals in crab from Ossiomo River collected from designated stations from March 2015 to August 2016.*

hemocyanin [29] and metalloenzymes [30] respectively. An appreciable increase in the values of Mn in the whole tissue of freshwater decapods has been associated with a combination of factors such as co-factor [1, 30–32]. More so, high concentration of iron in the sediment and decapods can possibly be related to its presence in cytochromes and proteins [28, 32].

A high accumulation of Fe in the whole tissues of *Macrobrachium rosenbergii* and *Sudanonautes africanus* has been established by [28]. This is because Fe in the Nigerian soil and sediment is naturally very high beyond slated thresholds and tends to accumulate and transcend or magnify in benthic macroinvertebrates [24, 33–35].

Freshwater fauna are well known to be discriminatory in metal accumulation [36]. Antón et al. and Hopkin [37, 38], stated that decapods regulate their net assimilation of metals, which need about 0.07 mg $kg^{-1}$ of Zn and 0.08 mg $kg^{-1}$ of Cu to trigger the enzymes and respiratory proteins. The high levels of heavy metals in aquatic biotas are of particular interest because of the potential risk to humans who consume them [1, 36]. The effects of metals in the surroundings, rest on to a great magnitude on whether they exist in forms that can be assimilated by plants or animals [36]. Some freshwater decapods are bottom feeders and are generally expected to concentrate more metals than surface feeders like shrimp. The accumulation of metals in their muscles may be either dosage or time-reliant. This may therefore be contemplative of the amount of metals in the ecosystem [37–41].

### 3.3 Bioaccumulation factor: designated trace and heavy metals and impact in freshwater *Macrobrachium rosenbergii* and *Sudanonautes africanus*

**Table 3** shows the computed bioaccumulation factor for the different trace and heavy metals in the whole body tissue of freshwater prawn and crab. It was observed that the concentration of the BAFs of heavy metals of prawn as compared with that of crab was distinct with varied increase in values greater than 1 (BAFs > 1) Fe (2.68) in prawn and Fe, Zn, Mn, Cu, Pb and Cr (1.30, 1.45, 1.77, 1.41, 1.81, and 4.52) in crab as related to their sediment concentrations. It was noticed that Cr had the highest value of accumulation in crab.

| Trace and heavy metal in $mgkg^{-1}$ | Mean Trace and heavy metal in Sediment | Mean Trace and heavy metal in Shrimps | Mean Trace and heavy metal in Crabs | BAF in Shrimps | BAF in Crabs |
|---|---|---|---|---|---|
| Fe | 249.11 | 134.77 | 175.27 | **0.54** | 1.30 |
| Zn | 19.46 | 52.20 | 75.46 | 2.68 | 1.45 |
| Mn | 36.53 | 1.69 | 2.99 | **0.05** | 1.77 |
| Cu | 8.07 | 0.63 | 0.88 | **0.08** | 1.41 |
| Pb | 3.48 | 0.01 | 0.02 | **0.00** | 1.81 |
| Cr | 4.05 | 0.00 | 0.01 | **0.00** | 4.52 |
| Cd | 3.93 | 0.01 | 0.01 | **0.00** | 1.06 |
| Ni | 1.98 | 0.00 | 0.00 | **0.00** | **0.00** |
| V | 1.72 | 0.00 | 0.00 | **0.00** | **0.00** |

NB: Values in red; means BAF > 1, an indication of increase level beyond threshold. Black bolded values; means BAF < 1, an indication of safe limit.

**Table 3.**
*Results of bioaccumulation factors (BAFs) of trace and heavy metals in freshwater prawn (Macrobrachium rosenbergii) and crab (Sudanonautes africanus) in Ossiomo River.*

### *3.3.1 Iron (Fe)*

Iron, is the richest element in the Earth's crust [42]. The two oxidation states of Fe; ferrous ($Fe^{2+}$), and ferric ($Fe^{3+}$) account for their Fenton chemical reactions in aquatic fauna via combination with their macromolecules (proteins, nucleic acids, lipids and carbohydrates) [43]. On the other hand, ferric iron is virtually insoluble in aqueous solution and can bioaccumulated in freshwater fauna (decapods) in their tissues [44] and even biomagnified along the food chain thereby impeding the health status of humans.

Iron is very vital to quite a lot of life processes; manufacturing of DNA, the respiratory electron transport chain, as well as oxygen storage and transport. However, level of Fe beyond the threshold in fauna muscles can result to conjunctivitis, choroids, and retinitis [45] pneumoconiosis, called siderosis [46] and the risk of pulmonary cancer when ingested or inhaled by humans [43].

### *3.3.2 Zinc (Zn)*

Zinc is one of the essential trace metals in nature. Aquatic fauna depends on it for their survival. Zinc is made up of about 200 metalloenzymes and other metabolic components guaranteeing permanency of the DNA and its assemblies; nuclear membranes, nucleolus and protein structures (ribosomes) [41]. Excessive consumption of Zn can result to a diverse compulsive health impact on humans [47].

The composition of zinc found in the tissue of decapods has been investigated to be intrinsically high which will possibly biomaginify in tissues at much higher levels [48–52]. Possible impact of Zn toxicity in freshwater decapods is in the gills, and abdominal muscle which has been confirmed in juvenile of decapods [53, 54]. This might be basically linked to the comparatively greater and more pervious body nature of the juveniles [41].

### *3.3.3 Manganese (Mn)*

This is a crucial trace metal which can be seriously noxious upon persistent contact through ingestion above threshold limits. The basic dietary requirements of Mn are fulfilled through food intake [55–57], but with little noxious effects from air and water. This is a great concern to individuals who will consume freshwater of *Macrobrachium rosenbergii* and *Sudanonautes africanus* with elevated amounts of Mn accumulated in them.

Possible conditions linked to Mn toxicity are schizophrenia, dreariness, weak brute force, head tremor and sleeplessness [58, 59]. Chronic impacts of Mn are hepatopancreas, lung, liver and vascular instabilities, deteriorations in body fluid pressure, failure in growth of fauna fetuses and brain impairment.

### *3.3.4 Copper (Cu)*

Like manganese, copper is found naturally in the surroundings and also crucial for normal growth and metabolic rate of all fauna [60] especially the aquatic ones. Copper contributes immensely to the cellular metalloprotein-hemocyanin in freshwater decapods [49, 61]. However, fairly low copper contents are found in the muscles of freshwater *Sudanonautes africanus* and *Macrobrachium rosenbergii* [28].

Freshwater *Sudanonautes africanus* and *Macrobrachium rosenbergii* cannot be compared to their counterpart; crayfish, which is very valuable for evaluating bioavailability of Cu in water environments [62, 63].

#### 3.3.5 Lead (Pb)

This element is neither crucial nor valuable to aquatic fauna and causes series of health conditions in the biota [40, 60] and subsequently probable risk impact to man via the food chain [1]. Pb can be introduced into a freshwater ecosystem via lithogenic form; re-suspension of the bottom sediment by benthic dwellers [1, 24] or via anthropogenic inputs; fertilizers and pesticides.

The amount of lead accumulated in freshwater *Sudanonautes africanus* and *Macrobrachium rosenbergii* has been investigated to be fairly below the benchmark limits of [27]. Previous studies have stated that the amount of Pb found in muscles of decapods were also in line of the benchmark limit [54, 64–67]. Contrary, [68] observed a high concentration (0.15 mg $l^{-1}$) of Pb in the gonads of the freshwater crab, *Potamonautes perlatus*.

At low concentrations, Pb may result to a variety of health effects, including behavioral problems and learning disabilities [58]. Lead affects the central and peripheral nervous systems, eventually causing neurological and behavioral disorders in patients [69]. Lead has been found to be carcinogenic and also a probable enzyme stimulating effect [70], which interferes with fertility and causes renal damage.

#### 3.3.6 Chromium (Cr)

This is a crucial element that has high noxious level [71]. Chromium has been found to be very high in the muscles of certain decapods [41, 54–67, 72]. However, study on freshwater *Sudanonautes africanus* and *Macrobrachium rosenbergii* revealed fairly low amount of Cr in their whole tissue [28].

#### 3.3.7 Cadmium (Cd)

This is not an essential element and has high potential for teratogenicity, cancer-causing, and high latency for kidney toxicity at the chronic stage if ingested via food [72, 73].

Bioaccumulation of residue Cd in aquatic ecosystems and decapods whole tissue have been described to have a positive relationship consequent on the biota closeness to point source [9, 74–78].

#### 3.3.8 Nickel (Ni) and vanadium (V)

Nickel and vanadium are universal elements recognized for their noxiousness, persistence, and likeness for bio-accumulation [60]. However, they were below detectable limits (BDL) in *Sudanonautes africanus* and *Macrobrachium rosenbergii* in this study [28]. This might be as a result of the geo-formation of the ecosystem and lack of the use of Ni and V related materials around the study terrain.

## 4. Conclusions

The assessment of metal accumulation and bioaccumulation factor of some trace and heavy metals in freshwater prawn and crab (*Sudanonautes africanus* and *Macrobrachium rosenbergii*) have shown that the metal accumulation were in this ranks: Fe > Zn > Cu > Pb = Cd > Cr = Ni = V and Fe > Zn > Mn > Cu > Pb > Cr = C d > Ni = V. The BAFs values obtained were observed to be greater than 1 (BAFs > 1) for Fe (2.68) in prawn and also for Fe, Zn, Mn, Cu, Pb and Cr (1.30, 1.45, 1.77, 1.41, 1.81, and 4.52) in crab as related to their sediment concentrations. It was noticed

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that Zn and Cr had the highest bioaccumulation factors in prawn and crab respectively. Chromium has been observed to be carcinogenic. Consumption of Cr in the muscles of crab might constitute probable serious health risk.

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## Conflict of interest

We declare no conflict of interest.

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## References


[1] Anani OA, Olomukoro JO. Health risk from the consumption of freshwater prawn and crab exposed to heavy metals in a Tropical river, Southern Nigeria. Journal of Heavy Metal Toxicity and Diseases. 2018;**3**(2):5. DOI: 10.21767/2473-6457.10024

[2] Storelli MM. Potential human health risks from metals (Hg, Cd, and Pb) and polychlorinated biphenyls (PCBs) via seafood consumption estimation of target hazard quotients (THQs) and toxic equivalents (TEQs). Food and Chemical Toxicology. 2008;**46**:2782-2788

[3] Li XY, Liu LJ, Wang YG, Luo GP, Chen X, et al. Heavy metal contamination of urban soil in an old industrial city (Shenyang) in Northeast China. Geoderma. 2013;**192**:50-58

[4] Bogdanovic T, Ujevic I, Sedak M, Listeš E, Šimat V, et al. As, Cd, Hg and Pb in four edible shellfish species from breeding and harvesting areas along the eastern Adriatic coast, Croatia. Food Chemistry. 2014;**146**:197-203

[5] Duruibe JO, Ogwuegbu MDC, Egwurugwu JN. Heavy metal pollution and human biotoxic effects. International Journal of Physical Science. 2007;**2**:112-118

[6] McCluggage D. Heavy Metal Poisoning. The Bird Hospital, Columbia: NCS Magazine; 1991

[7] European Union. Heavy Metals in Wastes. Brussels: European Commission on Environment; 2002

[8] Demina LL, Galkin SV, Shumilin EN. Bioaccumulation of some trace elements in the biota of hydrothermal fields of the Guaymas Basin (Gulf of California). Boletín de la Sociedad Geológica Mexicana. 2009;**61**(1):31-45

[9] Besser JM, Brumbaugh WG, May TW, Schmitt CJ. Biomonitoring of lead, zinc, and cadmium in streams draining lead-mining and non-mining areas, Southeast Missouri, USA. Environmental Monitoring and Assessment. 2007;**129**(1-3):227-241

[10] Schilderman PAEL, Moonen EJC, Maas LM, Welle I, Kleinjans JCS. Use of crayfish in biomonitoring studies of environmental pollution of the river Meuse. Ecotoxicology and Environmental Safety. 1999;**44**(3):241-252

[11] Holdich DM. Distribution of crayfish in Europe and some adjoining countries. Bulletin Français de la Pêche et de la Pisciculture. 2002;**367**:611-650

[12] Suarez-Serrano AC, Alcaraz C, Ibáñez C, Trobajo R, Barata C. Procambarus clarkii as a bioindicator of heavy metal pollution sources in the lower Ebro River and Delta. Ecotoxicology and Environmental Safety. 2010;**73**(3):280-286

[13] Allen HE. Metal Contaminated Aquatic Sediments. Michigan: Ann Arbor Press; 1995

[14] Guevara R, Rizzo A, Sanchez R. Heavy metal inputs in northern Patagonia lakes from short sediment core analysis. Journal of Radioanalytical and Nuclear Chemistry. 2005;**265**:481-493

[15] Mashal K, Salahat M, Al-Qinna M, Al-Degs Y. Spatial distribution of cadmium concentrations in street dust in an arid environment. Arabian Journal of Geosciences. 2014;**8**(5):3171-3182. DOI: 10.1007/s12517-014-1367-1

[16] Sin SN, Chua H, Lo W, Ng LM. Assessment of heavy metal cations in sediments of Shing Mun River, Hong

Kong. Environment International. 2001;**26**:297-301

[17] Lafabrie C, Pergent G, Kantin R, Pergent-Martini C, Gonzalez JL. Trace metals assessment in water, sediment, mussel and seagrass species-validation of the use of *Posidonia oceanica* as a metal biomonitor. Chemosphere. 2007;**68**:2033-2039

[18] Al-Taani AA, Batayneh A, El-Radaideh N, Al-Momani I, Rawabdeh A. Monitoring of selenium concentrations in major springs of Yarmouk Basin, north Jordan. World Applied Sciences Journal. 2012;**18**:704-714

[19] Barakat A, Baghdadi M, Rais J, Nadem S. Assessment of heavy metals in surface sediments of Day River at Beni-Mellal Region Morocco. Research Journal of Environmental and Earth Sciences. 2012;**4**(8):797-806

[20] Al-Taani AA. Trend analysis in water quality of Al-Wehda Dam, NW Jordan. Environmental Monitoring and Assessment. 2014;**186**:6223-6239

[21] Moosavian SM, Baghernabavi SM, Zallaghi E, Rouzbahani MM, Panah EH, Dashtestani M. Measurement of pollution level caused by heavy metal on vanadium, nickel, lead and copper using bivalves shells of *Timoclea imbricate* species on Bahrakan coast in spring 2013. Jundishapur Journal of Health Sciences. 2014;**6**(4):23473

[22] Al-Taani AA, Batayneh AT, El-Rasaideh N, Ghrefat H, Zumlot T, Al-Rawabdeh AM, et al. Spatial distribution and pollution assessment of trace metal in surface sediments of Ziqlab Reservoir. Environmental Monitoring and Assessment. 2015;**187**:32. DOI: 10.1007/s 10661-015-4289-9

[23] Bai J, Cui B, Chen B, Zhang K, Deng W, Gao H. Spatial distribution and ecological risk assessment of heavy metals in surface sediments from a typical plateau lake wetland, China. Ecological Modelling. 2011;**222**:301-306

[24] Anani OA, JO O. The evaluation of heavy metal load in benthic sediment using some pollution indices in Ossiomo River, Benin City, Nigeria. FUNAI Journal of Science and Technology. 2017;**3**(2):103-119

[25] Li XD, Thornton I. Chemical partitioning of trace and major elements in soils contamination by mining and smelting activities. Applied Geochemistry. 2001;**16**:1693-1706

[26] Pan Y, Brugam RB. Human disturbance and tropic status changes in Crystal Lake, Mc Henry County, Illinois, U.S.A. Journal of Paleolimnology. 1997;**17**:369-376

[27] FAO/WHO. Evaluation of certain food additives and the contaminants mercury, lead and cadmium. In: WHO Technical Report Series. 1989. p. 505

[28] Anani OA. Heavy metal residues and contamination profiles of water, sediment, *Macrobrachium rosenbergii* and *Sudanonautes africanus* in Ossiomo River, Edo State [PhD thesis]. Benin City, Nigeria: University of Benin; 2017. pp. 165-182

[29] Van de Brock WLF. Season levels of chlorinated hydrocarbons and heavy metals in fish and brown shrimps from the Medway Estuary Kent. Environmental Pollution. 1979;**19**:21-28

[30] De Silva SS, Anderson TA. Fish Nutrition in Aquaculture. 1st ed. London: Chapman and Hall; 1995

[31] Murphy PA, Atchison GJ, Mchitosh AW, Kolar DJ. Cadmium and zinc content of fish from an industrially contaminated Lake. Journal of Fish Biology. 1978;**13**:327-335

[32] Enuneku AA, Ezenwa IM, Adeosun S. Bioaccumulation profile of selected heavy metals in whole tissue of *Macrobrachium macrobrachion* and *Macrobrachium vollenhovenii* from Benin River in Delta State, Nigeria. African Scientist. 2016;**17**(1):1-8. Available from: http://www.niseb.org/afs

[33] Kakulu SE. Heavy metals in the Niger Delta: Impact of petroleum industry on the baseline levels [PhD thesis]. Ibadan: University of Ibadan; 1985

[34] Kakulu SE, Osibanjo O, Ajayi SO. Trace metal content of fish and shellfishes of the Niger delta area of Nigeria. Environment International. 1987;**13**:247-251

[35] Edema U, Egborge ABM. Heavy metal content of *Macrobrachim* sp. (Crustacea: Palaemonidae) from Warri River, Nigeria. Tropical Journal of Environmental Science and Health. 1999;**2**(1):65-70

[36] Enuneku AA, Ezemonye LI, Ainerua MO. Human health risk assessment of metal contamination through consumption of *Sesarma angolense* and *Macrobrachium macrobrachion* from Benin River Nigeria. European International Journal of Science and Technology. 1987;**3**:6

[37] Antón A, Serrano T, Angulo E, Ferrero G, Rallo A. The use of two species of crayfish as environmental quality sentinels: The relationship between heavy metal content, cell and tissue biomarkers and physico-chemical characteristics of the environment. The Science of the Total Environment. 2000;**247**:239-251

[38] Hopkin SP. Ecophysiology of Metals in Terrestrial Invertebrates. Pollution Monitoring Series. London: Elsevier Press; 1989

[39] Alcorlo P, Otero M, Crehuet M, Baltanás A, Montes C. The use of the red swamp crayfish (*Procambarus clarkii*, Girard) as indicator of the bioavailability of heavy metals in environmental monitoring in the river Guadiamar (SW, Spain). The Science of the Total Environment. 2006;**366**:380-390

[40] Allert AL, Fairchild JF, DiStefano RJ, Schmitt CJ, Brumbaugh WG, Besser JM. Ecological effects of lead mining on Ozark streams: In-situ toxicity to woodland crayfish (*Orconectes hylas*). Ecotoxicology and Environmental Safety. 2009;**72**:1207-1219

[41] Antonín K, Miloš B, Pavel K. Bioaccumulation and effects of heavy metals in crayfish: A review. Water, Air, and Soil Pollution. 2010;**211**:5-16. DOI: 10.1007/s11270-009-0273-8

[42] Aisen P, Enns C, Wessling-Resnick M. Chemistry and biology of eukaryotic iron metabolism. International Journal of Biochemistry and Cell Biology. 2001;**33**:940-959

[43] Hentze MW, Muckenthaler MU, Andrews NC. Balancing acts: Molecular control of mammalian iron metabolism. Cell. 2004;**117**:285-297

[44] Aisen P, Listowsky I. Iron transport and storage proteins. Annual Review of Biochemistry. 1980;**49**:357-393

[45] Braun V, Killmann H. Bacterial solutions to the iron-supply problem. Trends in Biochemical Sciences. 1999;**24**:104-109

[46] Archibald F. *Lactobacillus Planteruna*, an organism not requiring iron. FEMS Microbiology Letters. 1983;**19**:29-32

[47] Eisler R. Zinc hazards to fish, wildlife, and invertebrates: A synoptic review. In: U.S. Fish and Wildlife Service Biological Report. 1993. p. 10

[48] Bryan GW. Zinc regulation in the freshwater crayfish (including

some comparative copper analyses). The Journal of Experimental Biology. 1967;**46**:281-296

[49] White SL, Rainbow PS. Regulation and accumulation of copper, zinc and cadmium by the shrimp *Palaemon elegans*. Marine Ecology Progress Series. 1982;**8**:95-101

[50] White SL, Rainbow PS. Regulation of zinc concentration by *Palaemon elegans* (Crustacea: Decapoda): Zinc flux and effects of temperature, zinc concentration and moulting. Marine Ecology Progress Series. 1984;**16**:135-147

[51] Bagatto G, Alikhan MA. Zinc, iron, manganese and magnesium accumulation in crayfish populations near copper-nickel smelters at Sudbury, Ontario, Canada. Bulletin of Environmental Contamination and Toxicology. 1987c;**38**:1076-1081

[52] Vijayram K, Geraldine P. Are the heavy metals cadmium and zinc regulated in freshwater prawns? Ecotoxicology and Environmental Safety. 1996;**34**:180-183

[53] Bennet-Chambers MG, Knott B. Does the freshwater crayfish *Cherax tenuimanus* (Smith) [Decapoda: Parastacidae] regulate tissues zinc concentrations? Freshwater Crayfish. 2002;**13**:405-423

[54] Bruno G, Volpe MG, De Luise G, Paolucci M. Detection of heavy metals in farmed *Cherax destructor*. Bulletin Français de la Pêche et de la Pisciculture. 2006;**380-381**:1341-1349

[55] US EPA. Health Assessment Document for Manganese. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office. Research Triangle Park. NC.EPA 600/8-83-013F; 1984

[56] Francis A, Forsyth C. Toxicity Profile of Manganese [Internet]. 2005. Available from: http://rais.ornl.gov/tox/profiles/mn.shtml [Accessed: February 2011]

[57] Hoekman T. Heavy Metal Toxicology [Internet]. 2008. Available from: www.ucs.mun.ca/~thoekman [Accessed: February 2011]

[58] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Cadmium. ATSDR/TP-88/08. Atlanta: ATSDR/U.S. Public Health Service; 1989

[59] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Nickel. US Department of Health and Human Services, Atlanta, GA, USA. Atyaephyra *desomeresti mesopotamica* (Al-Adub, 1987). Marina Mesopotamica. 2005;**17**(2):365-376

[60] Eisler R. Copper hazards to fish, wildlife, and invertebrates: A synoptic review. In: U.S. Geological Survey. Biological Science Report No. USGS/BRD/BSR-1997-0002. 1998

[61] Rainbow PS. Trace metal concentrations in aquatic invertebrates: Why and so what? Environmental Pollution. 2002;**120**:497-507

[62] Naqvi SM, Devalraju I, Naqvi NH. Copper bioaccumulation and depuration by red swamp crayfish, *Procambarus clarkii*. Bulletin of Environmental Contamination and Toxicology. 1998;**61**:65-71

[63] Guner U. Freshwater crayfish *Astacus leptodactylus* (Eschscholtz, 1823) accumulates and depurates copper. Environmental Monitoring and Assessment. 2007;**133**:365-369

[64] Roldan BM, Shivers RR. The uptake and storage of iron and lead in cells of the crayfish (*Orconectes propinquus*) hepatopancreas and antennal gland. Comparative Biochemistry and Physiology. C. 1987;**86**:201-214

[65] Meyer W, Kretschmer M, Hoffmann A, Harisch G. Biochemical and histochemical observations on effects of low-level heavy metal load (lead, cadmium) in different organ systems of the freshwater crayfish, *Astacus astacus* L. (Crustacea: Decapoda). Ecotoxicology and Environmental Safety. 1991;**21**:137-156

[66] Anderson MB, Preslan JE, Jolibois L, Bollinger JE, George WJ. Bioaccumulation of lead nitrate in red swamp crayfish (*Procambarus clarkii*). Journal of Hazardous Materials. 1997;**54**:15-29

[67] Mackevičienė G. Bioaccumulation of heavy metals in noble crayfish (*Astacus astacus* L.) tissues under aquaculture conditions. Ekologia. 2002;**2**:79-82

[68] Reinecke AJ, Snyman RG, Nel JAJ. Uptake and distribution of lead (Pb) and cadmium (Cd) in the freshwater crab, *Potamonautes perlatus* (Crustacea) in the Eerste River South Africa. Water, Air, and Soil Pollution. 2003;**145**:395-408

[69] WHO/SDE/WSH. Lead in Drinking-Water Background Document for Development of WHO Guidelines for Drinking-water Quality. WHO/SDE/WSH/03.04/09/Rev/1. Geneva: World Health Organization; 2011

[70] Greenberg AE, Clesceri LS, Eaton AT. Standard Methods for the Examination of Water and Wastewater. 18th ed. Washington: American Public Health Association; 1992. pp. 490-596

[71] Eisler R. Chromium hazards to fish, wildlife, and invertebrates: A synoptic review. In: U.S. Fish and Wildlife Service. Biological Report 85(1.2). 1986. p. 85

[72] Jorhem L, Engman J, Sundström B, Thim AM. Trace elements in crayfish: Regional differences and changes induced by cooking. Archives of Environmental Contamination and Toxicology. 1994;**26**:137-142

[73] Eisler R. Cadmium hazards to fish, wildlife, and invertebrates: A synoptic review. In: U.S. Fish and Wildlife Service. Biological Report 85(1.2). 1985

[74] Anderson RV, Vinikour WS, Brower JE. The distribution of Cd, Cu, Pb and Zn in the biota of two freshwater sites with different trace metal inputs. Holarctic Ecology. 1978;**1**:377-384

[75] Giesy JP, Bowling JW, Kania HJ. Cadmium and zinc accumulation and elimination by freshwater crayfish. Archives of Environmental Contamination and Toxicology. 1980;**9**:683-697

[76] Bagatto G, Alikhan MA. Copper, cadmium and nickel accumulation in crayfish populations near copper-nickel smelters at Sudbury, Ontario, Canada. Bulletin of Environmental Contamination and Toxicology. 1987a;**38**:540-545

[77] Devi M, Thomas DA, Barber JT, Fingerman M. Accumulation and physiological and biochemical effects of cadmium in a simple aquatic food chain. Ecotoxicology and Environmental Safety. 1996;**33**:38-43

[78] Schmitt CJ, Brumbaugh WG, Linder GL, Hinck JE. A screening-level assessment of lead, cadmium, and zinc in fish and crayfish from North-Eastern Oklahoma, USA. Environmental Geochemistry and Health. 2006;**28**:445-471