Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 28(4): 1915 – 1936 (2024)
www.ejabf.journals.ekb.eg

Water Physicochemical Properties and Metal Deposition in the Crayfish, *Procambarus clarkii*, and Sediments of Sharkia Province, Egypt, Under Water Pollution

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ARTICLE INFO

Article History:
Received: July 3, 2024
Accepted: Aug. 20, 2024
Online: Aug. 21, 2024

Keywords:
Crayfish,
Environmental biomarker,
Heavy metals,
Potential ecological risk,
Sediment contamination,
Water quality

ABSTRACT

The uncontrolled release of domestic sewage, industrial effluents, agricultural fertilizers, pesticides, and heavy metals into the freshwater causes extensivedramatic problems to most of the aquatic creatures. Heavy metals cause a major problem since they are toxic and accumulate in the body organs. The crayfish, particularly *Procambarus clarkii*, can serve as effective bio-monitors for water pollution caused by heavy metals. This species acts as a bioindicator of water quality, contributing to the assessment of environmental health and sustainability. The experiment was performed at two sites in Sharkia Governorate (30.7° N, 31.63° E), Egypt. The physico-chemical parameters indicated that water transparency had the highest differences at site I compared to site II. However, no significant differences were detected in temperature, pH value, salinity, alkalinity, TDS, oxygen content, and carbon dioxide content. The analysis of atomic absorption showed the highest concentration estimated for arsenic (As) and the lowest for lead (Pb) in the water, sediment, and the crayfish's muscle and hepatopancreas. Meanwhile, the differences between heavy metal concentrations in the sediment and the liver of *P. clarkii* from the current sites indicated that the highest differences were in arsenic (As) and cadmium (Cd), while mercury (Hg) and lead (Pb) were the lowest. Furthermore, the correlation between heavy metal concentrations in the water and crayfish muscle and hepatopancreas was the highest in Pb, while the lowest correlation was noticed in Hg. This investigation contributes significantly to heavy metal potential risk indexes of Muweis Canal at the two sampling sites, which are limited in the literature on the perceived value relevance of water and sediment quality. Potential counteractive health impact in such applications could be prevented if the water and sediment were sufficiently treated.

INTRODUCTION

In aquatic habitats, trace elements formed from different anthropogenic and natural origins, viz. atmospheric deposition, geologic weathering, agricultural activities, and residential and industrial manufactures **(Demirak, *et al*., 2006; Jabeen & Chaudhry, 2010)** attempts to reduce waste, and environmental effects, are widely prevented as the fluvial system naturally drains all areas around it by washing many poisonous materials into the river **(Shinn *et al*., 2009)**.

Trace elements, comprising both non-essential and essential metals, have an ecotoxicological importance **(Ebrahimpour & Mushrifah, 2010)** due to their long occurrence, toxicity, and food chain biomagnifications **(Yousafzai *et al*., 2010)**. The concentration of pollution depends on the contaminant kind, trophic level, study area, fish species, and their feeding mode **(Asuquo *et al*., 2004)**.

Sediments act as potential sources and sinks of different pollutants in aquatic habitats. Distribution and accumulation of elements inside the aquatic ecosystem are controlled by complicated processes of substance exchange impacted by different human activities or/and natural methods, comprising riverine or air inputs, seafloor and coastal erosion, biological activities, urban discharge, industrial wastewater, and water drainage **(Christophoridis *et al*., 2009)**. The suspended sediments imbibe contaminants from water, followed by descending their accumulation in the water column, or they can be discharged into water column due to special disorders **(Agarwal *et al*., 2005)**, causing a possible danger to environment **(Chow & Gaines, 2005; Hope, 2006)**. Moreover, bottom sediments stand as a food source and habitats for the benthic creatures. Hence, contaminants can indirectly or directly harm the aquatic fauna.

Shrimps and fish may be sampled simply when compared with other aquatic fauna (**Moiseenko & Kudryavtseva, 2001)** and are used as bio-monitors in aquatic habitats for water pollution determination **(Canli & Atli, 2003; Brumbaugh *et al*., 2005; Fernandes *et al*., 2007)**. Heavy metals enter fish body via five essential ways (non-food or food materials, water, skin, and gills); they find their way to the blood and are stored or transformed in the liver **(Jabeen & Chaudhry, 2010)**. The liver of fish is the essential organ of accumulation, biotransformation, and excretion of contaminants **(Shinn *et al*., 2009)**. Species with low feeding limits are subjected to relatively less pollution; fish in the top of food web are inclined to accumulate elements **(Terra *et al*., 2008)** Furthermore, fish are the highest creatures in freshwater habitats; they are used for the determination of heavy metal pollution and the prospective risk of man utilization **(Rashed, 2001)**. Consequently, the analysis of trace element distribution in sediments surrounding the populated locations may be utilized to observe anthropogenic effects on environment and might aid in the estimation of dangers presented by man waste effluents **(Hu *et al*., 2002; de Mora *et al*., 2004; Zheng *et al*., 2008)**. In specific cases, these elements can accumulate to a harmful concentration limit which can damage the ecosystem **(Jefferies & Freestone, 1984)**. Procedures used to assess the environmental hazards posed by trace elements in sediments include the prospective ecological hazard index **(Hakanson, 1980)**, the enrichment factor (EF) **(Hilton *et al*., 1985)**, and the geo-accumulation index **(Förstner, 1989)**, with the first two indicators being the most widely used. The analysis of sediment, water, and aquatic creatures such as shrimps and fish might show the limit and the direction of contamination. Thus, this analysis is essential for the environmental defense and fish quality in the water **(Giri & Singh, 2015)**.

The purpose of this observation motivated to estimate heavy metals concentrations in sediment, water, in addition to the muscle and hepatopancreas of the crayfish at two sampling sites (El-Shabakat and Tal-Haween sites) along the Muweis Canal in Sharkia Governorate since Tal-Haween area is suffering from the death of some species of fishes. Therefore, the study aimed to test the hypothesis that fish at the top of the food web tend to concentrate various elements, and that proximity to contaminated areas increases the likelihood of finding polluted fish. Additionally, the study assessed whether this species could serve as an ecological indicator of the overall health of public aquatic ecosystems.

MATERIALS AND METHODS

1. The investigated areas and sampling method

The current study was carried out on the crayfish, *Procambarus clarkii*, which are the most dominant arthropods at the investigated sites. The crayfish were hunted alive bimonthly from autumn 2019 to summer 2020 at two sites (El-Shabakat and Tal-Haween villages; site I and site II, respectively) along Muweis Canal in Sharkia Governorate (30.7° N, 31.63° E), Egypt (Fig. 1). Forty-eight crayfish were gathered from each site. The water and sediment samples were forty-eight collected from each site (six samples/ month). One liter of water was sampled from the surface water of the canal and stored in a refrigerator till analysis. Sediment samples from the depth below the surface (0–30cm) were taken from two study areas, dried in the air and then sieved using a mesh sieve of 0.2mm to remove gravel and debris.

2. Physico-chemical characteristics of water

After filtration, water samples were collected, and then put in a pure collecting glass bottle, as mentioned by **Boyd (1990)**. The physico-chemical properties of the water samples wee examined. The water temperature of the samples was determined using the mercury thermometer (0 to 50˚C scale). Moreover, water salinity was measured by a digital salinometer (model Atago Hand Refractometer). The pH value was recorded by utilizing a digital Mini-pH meter model 55. Additionally, transparency, TDS, O_2, CO_2, and alkalinity were determined **(Ibraheim & Khater, 2013)**.

3. Heavy metal accumulations in the sediment

A solution of sediment sample to measure metals was carried out by adding 10mL of concentrated nitric acid (HNO_3) and 5mL of 60% perchloric acid ($HCLO_4$) to 1g of sediment sample in 100mL conical flask. The mixture was heated on a hot plate for 15min at 95°C till white fumes appeared. A digest was refrigerated, filtered by Whatman paper number 42 into a volumetric conical flask (50mL) and washed by deionized water till a mark **(Nasr *et al*., 2020)**. Heavy metal residues were estimated in sediment samples (n = 48) of two contaminated areas and estimated by an atomic absorption spectrophotometer (AAS).

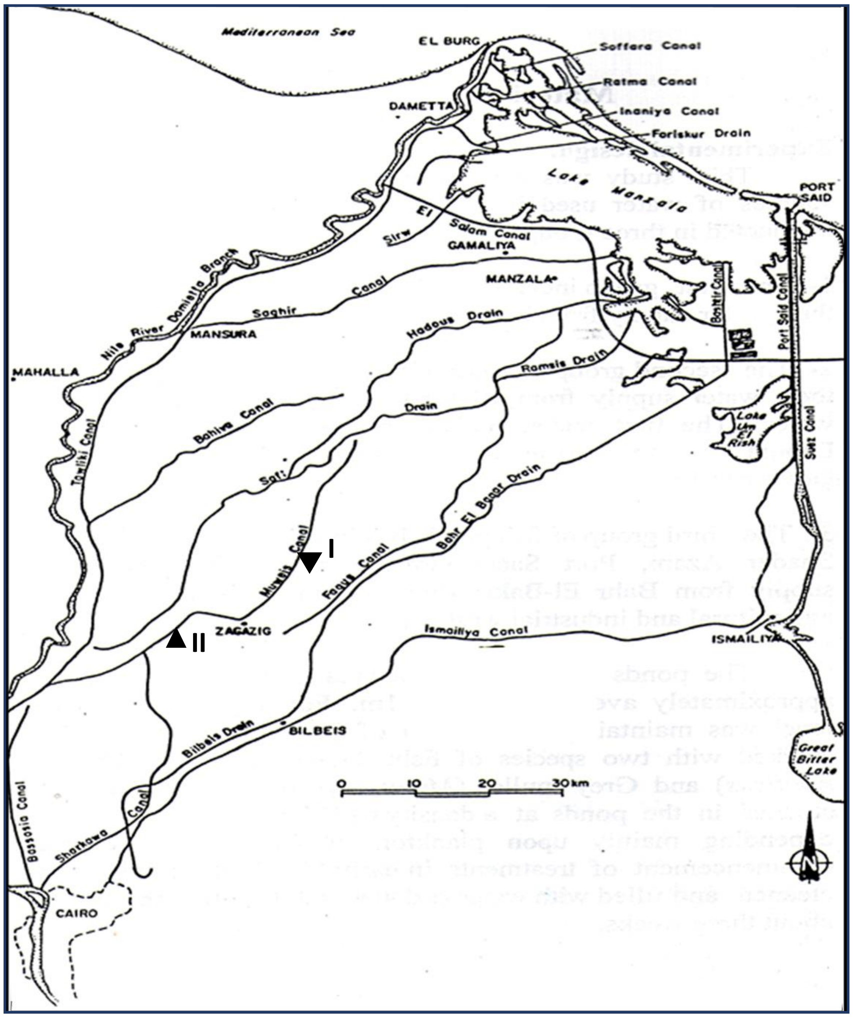


Fig. 1. Map of water resources in Sharkia Governorate

4. Heavy metal accumulations in muscle and hepatopancreas of *P. clarkii*

One gram of the tissue (muscle or hepatopancreas sample) was digested by putting 5mL of concentrated nitric acid in a beaker stoppered with glass watch and heated at 95°C on a hot plate till dryness. After cooling, concentrated sulphuric acid of about 5mL was put, and mixture was heated again for sixty minutes then cooled down to ordinary temperature. Two millimeters of hydrogen peroxide (30 % H_2O_2) was put and reheated. Finally, the reatment was repeated till the solution became clear. The solution was diluted by deionized water in a conical flask up to 50mL and stored until measurement **(Abd El-Shafee, 2003)**, then heavy metal residues in hepatopancreas and muscle of *P. clarkii* (n = 48) from the two polluted sites were evaluated by using AAS.

5. Statistical analysis

The results were statistically estimated to determine the independent t-test and ANOVA following the methods of **Sokal & Rohlf (1981)** to determine the significance different between heavy metal limits in water, sediment, and crayfish muscle and hepatopancreas from the investigated sites by SPSS software **(Norusis, 2005)**. The data were examined for correlation to estimate the possibility of combinations between heavy metal levels in water, sediment, and crayfish muscle and hepatopancreas.

6. Measurement of potential ecological risk (RI)

It was assessed using the methods of **Hakanson (1980)**, which suggest that the susceptibility of an aquatic ecosystem depends on its productivity. A potential ecological risk index evaluates the pollution limit of the trace elements in sediments, according to environment responsibility and toxicity of heavy metals:

$RI = \Sigma E^i_r$ (I)

$E^i_r = T^i_r C^i_f$ (II)

$C^i_f = C^i_o / C^i_n$ (III)

Where, RI means the summation of all risk variables for heavy metals presence in a sediment; T^i_r stands for the toxic-response factor of the given material that represents the poisonous requirement and the susceptibility requirement, and E^i_r represents the monomial potential ecological risk factor. While, C^i_o is the metals concentration in sediment; C^i_f= the contamination factor, and C^i_n means the reference value of metals, as mentioned in Table (6).

Hakanson's (1980) risk factor, RI, is based on eight elements (As, Hg, Cd, Pb, Cr, Zn, PCB, and Cu), but this investigation excluded PCB, Zn, Cu, and Cr. Using Equations (I) to (III) and the data presented in Table (1), the potential ecological risk indices, RIR_IRI and EirE_{ir}Eir, were calculated for each study site. Potential ecological risk of a single regulator (E^i_r) with the ranking of $E^i_r<40$ stands for the low risk; $40 \leq E^i_r < 80$ indicates moderate risk; $80 \leq E^i_r < 160$ is considerable; $160 \leq E^i_r < 320$ is high, and finally $E^i_r \geq 320$ is very high.

RI means potential ecological risk index of total heavy metal representing a susceptibility of different ecosystems to poisonous materials **(Rashed, 2001)**, which also belongs to terminology: $RI<95$ is low ecological risk to all variables, $95 \leq RI < 190$ is moderate, $190 \leq RI < 380$ is considerable, and finally $RI \geq 380$ is very high **(Weber *et al.*, 2013)**.

Table 1. The toxicity coefficients (T^i_r) and the reference levels (C^i_n) of heavy metals in sediment samples.

Heavy metal	Cd	As	Pb	Hg
C^i_n (μg/g)	0.6	6	31	0.2
T^i_r	30	10	5	40

RESULTS AND DISCUSSION

1. Physico-chemical characteristics of water

The current results indicated the physicochemical properties of water samples of two study areas (Table 2). Data revealed that the transparency of water at the Tal-Haween site (0.252m) was higher than that recorded at the El-Shabakat site (0.238m) and was significantly different. It is worthy to mention that, water transparency is an essential indicator of water goodness; this is an indicator of water direction and its ecological media for remaining.

Table 2. Comparison of differences between physico-chemical properties (mean ± SE) of water samples from El-Shabakat (site I) and Tal-Haween (site II) sites of Muweis Canal.

Parameter	Water samples		T-Test	
	Site I	Site II	T-statistic	*P*-value
Temperature (° C)	23.5 ± 1.722	23.25 ± 1.820	-0.100	> 0.05
Transparency (m)	0.252 ± 0.014	0.238 ± 0.007	-0.873*	≤ 0.05
pH value	7.871 ± 0.132	7.7112 ±0.190	-0.691	> 0.05
O2 content (ppm)	2.625 ± 0.57562	1.775 ±0.79006	-0.870	> 0.05
CO2 content (ppm)	6.9375 ± 0.570	7.4375 ±0.49495	0.662	> 0.05
Salinity (ppt)	0.304 ± 0.006	0.301 ±0.009	1.079	> 0.05
Alkalinity (ppm)	151.250 ± 16.252	148.500 ± 22.865	-0.226	> 0.05

* Statistically there was significant difference ($P \leq 0.05$), using Independent T-Test (n = 48).

Water temperature is a highly effective environmental factor influencing the growth and metabolism of fish and their body component **(Khater, 2011)**. This study indicated that the fluctuation in the water temperature at different examined sites during various seasons was attributed to changes in air temperature, and this level of water temperature is suitable for fish as mentioned in previous studies **(Ayoola & Kuton, 2009; Khater, 2011; Dirican, 2015; Ma *et al.*, 2020)**.

In the current investigation, pH values at the study sites were always in the alkaline range. The distribution of pH values in both sites showed a general trend of increasing values in summer and winter seasons. The rise in the summer may be attributed to rise in primary production that prompts the photosynthesis increase, which represents the free carbon dioxide uptake from water and calcium carbonate precipitation **(Pandey & Tiwari, 2009)**. However, the rise in winter can be related to agricultural or industrial activities that depend on the production and usage of different chemical and physical agents that continuously drain into the study areas. These agents may generate reactive oxygen like hydroxyl radical (OH^-), hydrogen peroxide (H_2O_2), and superoxide anion (O_2) which certainly raise the pH-value of the areas, as reported by **Misiira & Biiatt (2008)** and **Ma *et al*. (2020)**.

The present data revealed that the range of pH at both investigated sites lies within the suitable limits (6.2-8.3) required for fish survival and growth, and this finding is in accordance with those of **Adeyemo *et al*. (2008)**, **Pandey & Tiwari (2009)** and **Khater (2011)**.

The less in transparency was accompanied with a gradual accumulation in algal density, while the remarkable high transparency was mostly related to low total suspended matter and to low phytoplankton standing crop. This finding agrees with those of **Ohimain *et al*. (2008)**, **Owei & Ologhadien (2009)** and **Dirican (2015)**.

The highest values of DO during summer at the observation sites may be related to the increase of photosynthesis activity causing the production of a large amount of DO during the warm season. The decrease of DO content in the cold seasons (winter, spring, and autumn) might be attributed to the consumption of DO in the decomposition of the high load of organic matter (by bacteria). This decomposition can be raised in the study areas due to the die-off of phytoplankton in the cold season (with low light). This study indicates a correlation between DO production and primary productivity (phytoplankton) at the study sites. From the obtained data, the DO value at the observed sites is below the limits (>5 mg/L), which disagrees with necessity of beneficial fish production as recorded by **Dirican (2015)** and **Ma *et al*. (2020)**. On the other hand, this finding is consistent with the results of **Khater (2011)**.

The decrease of CO_2 content in the present study is in accordance with that of **Shatalov (2009)** and **Alkhazan & Sadddiq (2010)**. The observed data cleared that CO_2 content lied under the safe limit (< 10mg/ l) needed for successful fish production as reported by **Sithik (2009)** and **Ibraheim & Khater (2013)**.

From the current data, salinity content was low at both study sites. The higher values of salinity observed in the autumn and summer seasons can be ascribed to the increase rate of evaporation during these seasons. However, this range of salinity (<3g/ L) is favorable for fish growth and survival, as mentioned by **Khater (2011)** and **Dirican (2015)**.

Furthermore, the alkalinity contents in the current observations are high, and this limit of alkalinity (20mg/ L) was not advised by **Ibraheim & Khater (2013)** and **Ma *et al*. (2020)**.

2. Heavy metals accumulation in the water

Comparing the mean of heavy metals concentration at both investigated sites, the results reported in Table (3) and Fig. (2a I, II) showed seasonal and annual differences in heavy metal limits of the water samples.

Table 3. Comparison of differences between heavy metal concentrations (mean ± SE) of the water samples collected from El-Shabakat (site I) and Tal-Haween (site II) sites at Muweis Canal.

Heavy metal	**Water samples (ppm)**		**T-Test**	
	Site I	**Site II**	**T-statistic**	***P*-value**
Arsenic (As)	0.120 ± 0.003	0.109±0.023	- 0.704**	≤ 0.001
Mercury (Hg)	0.038 ± 0.005	0.114±0.084	1.363**	≤ 0.001
Lead (Pb)	3.575E-4± 2.217E-4	0.006±0.004	2.398**	≤ 0.001
Cadmium (Cd)	0.012 ± 0.003	0.023±0.003	2.581	> 0.05

*Statistically, there was significant difference ($P \leq 0.05$). **Statistically, very highly significant difference was present ($P \leq 0.001$), using Independent T-Test (n = 48).

The mean limits of As observed here were higher than the permissible limits (0.025mg/ L) recommended by **ANZECC (2000a)** in different water samples. Similar As limits were reported by **Frisbie *et al*. (2002)**, **Shankar *et al*. (2014)**, **Bakhshinezhad & Bakhtavar (2019)** and **Nassar & Khater (2023)**.

The average Hg concentrations were higher than the legal limits (0.001mg/ L) advised by **ANZECC (2000a)** in the study areas. Similar Hg limits were reported by **Yin & Balogh (2002)**, **Julia *et al*. (2013)**, **Sim *et al*. (2016)** and **Nassar & Khater (2023)**.

The mean limits of Pb found here were under the permissible levels (0.01mg/ L) stated by **WHO (2008)** in the collected water samples. The Pb concentrations in the current investigation were lower than that reported by **El Weber *et al*. (2013)**, **Assal *et al*. (2017)** and **Abdel Gawad (2018)**.

The average limits of Cd found here were upper than the legal levels (0.003mg/ L) advised by **Frankowski *et al*. (2009)** in the water samples collected from the study locations. Similar Cd limits were reported by **Assal *et al*. (2017)**, **Abdel Gawad (2018)** and **Kamzati *et al*. (2020)**.

The maximum concentrations of all heavy metals were recorded in spring and winter, while the low levels were observed in autumn and summer. Current results are in accordance with that reported by **Khater (2011)**, who found that heavy metals concentration indicated seasonal differences, being great in winter and low in summer. The reason may be related to high phytoplankton growth in autumn and summer seasons that can accumulate huge amounts of trace elements from water.

Although some heavy metals concentration exceeded the legal limits at the investigated sites, the high pH value may be the reason for decreasing the poisonous effect of these metals. This coincides with the explanation of **Malcolm (1995)** and **Saeed (2000)**, who found that heavy metals toxicity is decreased when pH raises since at high ranges of these variables, the metals combined to give carbonate and hydroxide compounds, which are less toxic to fish rather than the element ion. Thus, there are reductions in limits of the metallic ion (which is more poisonous) at high pH value.

3. Heavy metals accumulation in the sediment

Under natural states, heavy metals are found in specific quantities in various ecological systems. Heavy metal concentrations in an ecosystem are raised due to human actions such as consumption of fossil fuels, agricultural fertilizers, active explosions, insecticides and pesticides **(Steevens, 2001)**. In the current observation, heavy metal concentrations in the sediment samples from the two contaminated sites are depicted in Table (4) and Fig. (2b I, II). It indicated remarkable differences in the concentrations of heavy metal in the sediment samples. The levels had the order: As > Hg> Cd> Pb.

Table 4. Comparison of differences between heavy metal concentrations (mean ± SE) in the sediment samples collected from El-Shabakat (site I) and Tal-Haween (site II) sites at Muweis Canal.

Heavy metal	Sediment samples (µg/g)		T-Test	
	Site I	Site II	T-statistic	*P*-value
Arsenic (As)	11.719 ±0.568	11.529 ±1.120	-206	> 0.05
Mercury (Hg)	5.156 ± 0.514	5.801 ± 0.726	0.844	> 0.05
Lead (Pb)	0.863 ± 0.127	0.870 ± 0.081	0.054	> 0.05
Cadmium (Cd)	1.936 ± 0.609	1.4987 ±0.292	-0.957	> 0.05

* Statistically, there was significant difference ($P \leq 0.05$) using Independent T-Test (n =48).

The average concentrations of As in present study were higher than the permissible limits (6µg/ g) advised by **ANZECC (2000b)**. These present values are higher than those reported by **Hounkpè *et al.* (2017)**, **Duncan *et al*. (2018)** and **da Silva *et al*. (2019)**. However, the average concentrations are consistent with the findings recorded by **Yi *et al*. (2011)**.

The present results showed that the average Hg concentrations are higher than the legal limits (0.2µg/ g) recorded by **ANZECC (2000b)**. Morever, comparative Hg limits were recorded by **Guan *et al.* (2018)** and **da Silva *et al*. (2019)**.

Concerning the average Pb concentrations, the limits are less than the permissible levels (<31) estimated by **ANZECC (2000b)** at the present sites, while cooinciding with the findings of **Weber *et al.* (2013)** and **Abdel Gawad (2018)**, and less than those recorded by **Mao *et al*. (2020)**.

The mean Cd levels are higher than the permissible limits (< 0.6µg/ g) mentioned by **ANZECC (2000b)** in all sediment samples. The Cd concentrations in the current study are similar to those reported by **Weber *et al.* (2013)** and higher than those recorded by **Abdel Gawad (2018)**, **Kamzati *et al*. (2020)** and **Mao *et al*. (2020)**.

The thesis is that sediment is the main sink for element contamination and has an essential role in the uptake of trace element by fish **(Yi *et al*., 2011)**. Thus, controlling the contaminated origins of sediment and water in the aquatic ecosystem has the potential to fish protection. The high metal concentration present in detritivore species can be utilized as an indicator for metal pollution biomonitoring **(Weber *et al*., 2013)**.

4. Heavy metals accumulation in tissues of *P. clarkia*

The data in Tables (5, 6) and Fig. (2c, d) show that there were significant differences between heavy metal levels in the muscle tissues and hepatopancreas of the polluted *P. clarkii* of the two investigated sites, in the descending direction: As, Hg, Cd, and Pb.

Table 5. Comparison of differences between heavy metal concentrations (mean ±SE) in the muscle samples of *Procambarus clarkia* from El-Shabakat (site I) and Tal-Haween (site II) sites of Muweis Canal.

Heavy Metal	Muscle samples (µg/g)		T-Test	
	Site I	Site II	T-statistic	*P*-value
Arsenic (As)	7.451 ± 0.974	7.303 ± 0.352	-0.194	> 0.05
Mercury (Hg)	1.441 ± 0.535	1.976± 0.604	0.738	> 0.05
Lead (Pb)	0.427 ± 0.125	0.223 ± 0.049	-1.853 *	≤ 0.05
Cadmium (Cd)	0.343 ± 0.107	0.813 ± 0.319	1.952 *	≤ 0.05

* Statistically, there was a significant difference ($P \leq 0.05$) using Independent T-Test (n = 48).

Table 6. Comparison of differences between heavy metal concentrations (mean ± SE) in the hepatopancreas samples of *Procambarus clarkia* from El-Shabakat (site I) and Tal-Haween (site II) sites of Muweis canal.

Heavy metal	Hepatopancreas samples (µg/g)		T-Test	
	Site I	Site II	T-Statistic	*P*-Value
Arsenic (As)	9.328 ± 0.356	9.684 ± 0.511	0.558	> 0.05
Mercury (Hg)	2.001 ± 0.178	2.608 ± 0.083	2.921	> 0.05
Lead (Pb)	0.693 ± 0.182	0.097 ± 0.072	-1.462 *	≤ 0.05
Cadmium (Cd)	0.674 ± 0.184	0.163 ± 0.036	3.895 *	≤ 0.05

* Statistically, there was a significant difference ($P \leq 0.05$) using Independent T-Test (n = 48).

The arsenic (As) levels exceeded the safe limits (<0.05µg/ g) which are recommended by **ANZECC (2000a)**. Similar As levels were reported in the studies of **Mandal (2017)**, **Oymak *et al.* (2017)**, **Pei *et al.* (2019)** and **Nassar & Khater (2023)**.

Mercury limits in the current investigation were above the legal limits (< 0.02µg/ g), recorded by **WHO (1993)** for the tissues of *P. clarki* in the two study areas. Moreover, comparative Hg limits were recorded by **Yi *et al.* (2011)**, **Mandal (2017)**, **da Silva *et al.* (2019)** and **Nassar & Khater (2023)**.

The lead levels in this investigation were above the permissible levels (< 0.02µg/ g) advised by **ANZECC (2000a)** and are like those recorded by **Kuklina *et al.* (2014)** and **Mistri *et al.* (2020)**.

On the other hand, cadmium limits in the current study were above the legal limits (< 0.0011µg/ g) mentioned by **ANZECC (2000a)** for the examined species. Similar Cd limits were studied by **Khater (2011)**. Similar data were reported in the study of **Velcheva (2006)**, who elucidated that trace elements were significantly high in the animal viscera. These results agree with data postulated by **Weber *et al.* (2013)**, **Kuklina *et al.* (2014)** and **Mistri *et al.* (2020)**.

Heavy metal concentration in the muscle has been widely addressed since it is the major fish organ consumed by man **(Meche *et al.*, 2010; Yi *et al.*, 2011)**. Yet, compared to the liver, the fish muscle is not the perfect indicator of the fish whole-body pollution. The former is an organ of continuous storage, detoxification, and biotransformation, giving further rapid estimation of the present environmental limit of contaminants **(Jaric *et al.*, 2011)**. Totally, fish from Muweis Canal are not secure for man exhaustion deeming trace element accumulation. The thesis that fish in the top web food tend to accumulate further elements was found in the present investigation; the maximum metal concentration limits were observed in the waste species **(Weber *et al.*, 2013)**, indicating that omnivore fish stored 65.2% extra metal load than carnivore fish. Various accumulations of heavy metals in several fish species may be a reason of diverse environmental requirements, metabolism, and trophic patterns **(Allen-Gil & Martynov, 1995)**.

5. Relationships between heavy metal limits in the environment and fish

The highest correlation between heavy metal accumulations was observed in arsenic (As) levels between sediment and crayfish hepatopancreas tissues at Site I. In contrast, Site I showed a significantly different high correlation between lead (Pb) levels in crayfish tissues and water. Additionally, Site II exhibited significant correlations for Pb concentrations across water, sediment, and crayfish tissues, as well as cadmium (Cd) concentrations in sediment, water, and muscle tissues.

Table 7. Correlation coefficient between heavy metals content (ppm or µg/g) for *P. clarkii* from El-Shabakat village along Muweis Canal (Site I) from autumn 2019 to summer 2020.

Heavy metal	Tissues	Liver	Muscle	Sediment	Water
Arsenic (As)	Liver	1	-0.495	0.777*	-0.240
	Muscle	-0.495	1	-0.471	0.405
	Sediment	0.777*	-0.471	1	-0.126
	Water	-0.240	0.405	-0.126	1
Mercury (Hg)	Liver	1	-0.076	-0.480	0.382
	Muscle	-0.076	1	0.280	-0.567
	Sediment	-0.480	0.280	1	-0.195
	Water	0.382	-0.567	-0.195	1
Lead (Pb)	Liver	1	0.790**	-0.297	0.849**
	Muscle	0.790**	1	-0.006	0.747*
	Sediment	-0.297	-0.006	1	-0.546
	Water	0.849**	0.747*	-0.546	1
Cadmium (Cd)	Liver	1	-0.020.	0.597	0.431
	Muscle	-0.020	1	-0.358	0.412
	Sediment	0.597	-0.358	1	-0.288
	Water	0.431	0.412	-0.288	1

* Correlation is significantly different at the 0.05 level, 2-tailed. ** Correlation is highly significantly different at the 0.01 level, 2-tailed.

Table 8. Correlation coefficient between heavy metals content (ppm or µg/g) for *P. clarkii* from Tal-Haween village along Muweis Canal(Site II) from autumn 2019 to summer 2020.

Heavy metal	Tissues	Liver	Muscle	Sediment	Water
Arsenic (As)	**Liver**	1	-0.356	0.638	-0.646
	Muscle	-0.356	1	-0.262	0.520
	Sediment	0.638	-0.262	1	-0.684
	Water	-0.646	0.520	-0.684	1
Mercury (Hg)	**Liver**	1	-0.133	0.315	-0.290
	Muscle	-0.133	1	-0.534	0.092
	Sediment	0.315	-0.534	1	0.190
	Water	-0.290	.092	0.190	1
Lead (Pb)	**Liver**	1	0.541	0.187**	0.918
	Muscle	0.541	1	0.674*	0.759
	Sediment	0.187**	0.674*	1	0.365
	Water	0.918	0.759*	0.365	1
Cadmium (Cd)	**Liver**	1	0.609	0.688	-0.432
	Muscle	0.609	1	0.684	-0.870**
	Sediment	0.688	0.684	1	-0.819**
	Water	-0.432	-0.870**	-0.819*	1

*Correlation is significantly different at the 0.05 level, 2-tailed. ** Correlation is highly significantly different at the 0.01 level, 2-tailed.

The correlations of the metals were determined between various matrices, i.e., water, fish, and sediment, to estimate the association between them, as recorded in Tables (7, 8). Data suggested a potent combination of Pb between water and fish samples and As between fish samples and sediment. Correlation of elements between sediment, water, and fish tissues has been recorded in other investigations **(Fatma, 2008; Giri & Singh, 2015)**. Pb levels in the fish samples are observed to be combined with sediments at site II, while As in hepatopancreas tissues are found to be associated with the sediments at site I. This finding concurs with those of previous studies **(Vicente-Martorell *et al*., 2009; Giri & Singh, 2015)**. The Cd levels were served in water samples, and correlation coefficient was not significant between fish and sediment samples. This is due to high mobility and bioavailability of Cd and it was firstly searched by organic matter, iron–manganese oxide elements, and non-detrital carbonate elements **(Prusty *et al*., 1994)**.

6. Potential ecological risk

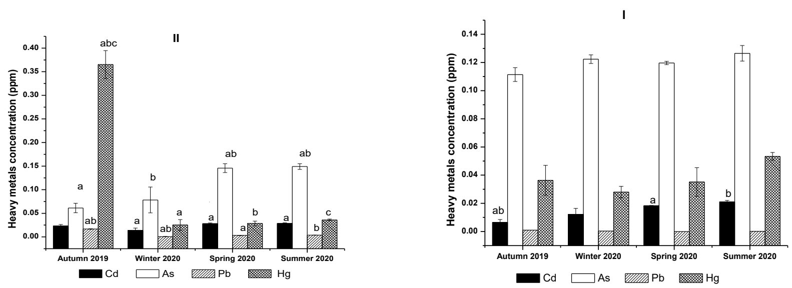
Both As and Pb have less potential ecological risk at all collecting sites along Muweis Canal, excluding Cd that had potential ecological risk of moderate to considerable ranges at sites II & I, respectively. Moreover, Hg recorded a highly raised potential ecological risk in both sampling regions. Overall, trace element potential ecological risk index concluded that all sampling areas have very high ecological risk due to Hg (Table 9).

Table 9. Heavy metal potential risk indexes at Muweis Canal sampling sites.

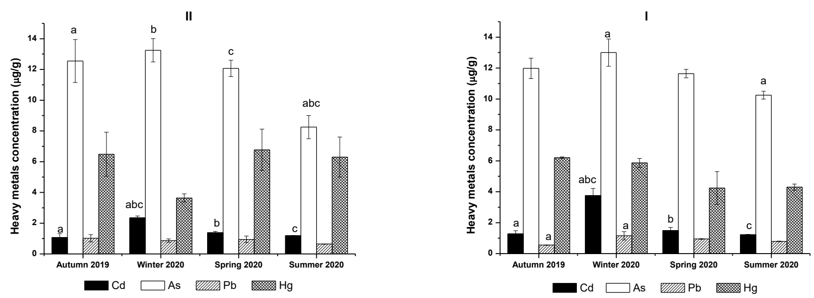
Sites	**E^i_r**				**RI**
	Cd	**As**	**Pb**	**Hg**	
Site I	96	19.5	0.15	1040	1155.65
Site II	75	19	0.15	1160	1254.15

Risk index gives simple and fast quantities on the potential ecological risk of a provided contaminated situation in river system or a special lake **(Hankanson, 1980)**. The potential ecological risk of single regulator indexes to Muweis Canal in all sampling areas indicated low to considerable potential ecological risk for different examined metals, excluding Hg which had an extremely high potential ecological risk at both sites (disastrous risk: $E^i_r \geq 150$ and RI ≥ 300). On the other hand, in rivers and lakes, Hg showed lesser ecological risk **(da Silva *et al*., 2019)**, while in this observation, the reason is related to the high Hg toxicity coefficient and its higher accumulation due to pollution. Ecological risk of cadmium in the Muweis Canal might also be attributed to fertilizers and particularly phosphate, as the normal presence of different trace elements in a phosphate rock unremoved in the industrial process **(Camargo *et al*., 2000)**. Moreover, the maintenance and construction of crops removes the soil which is formed from basalt rocks that can liberate a considerable amount of elements in the sediment **(Hatje *et al*., 1998)**. The less overall trace element potential risk along Muweis Canal indicated the high hazard of heavy metals to inhabitant aquatic creatures of this freshwater canal, and this finding disagrees with those of **Weber *et al*. (2013)**, **Giri & Singh (2015)** and **da Silva *et al*. (2019)**.

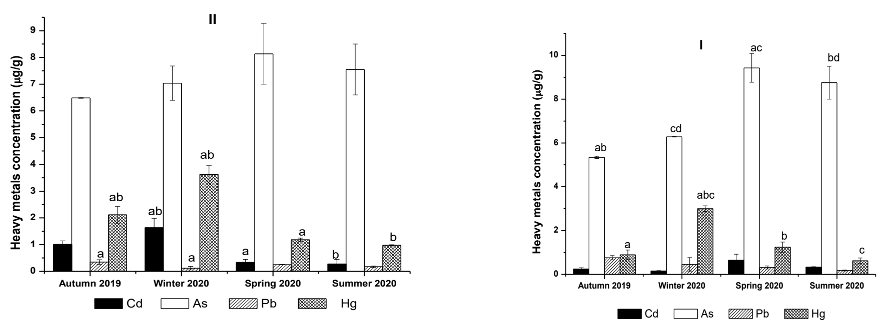
Water (a)



Sediment (b)



Procambarus clarkii muscle (c)



Procambarus clarkii hepatopancreas (d)

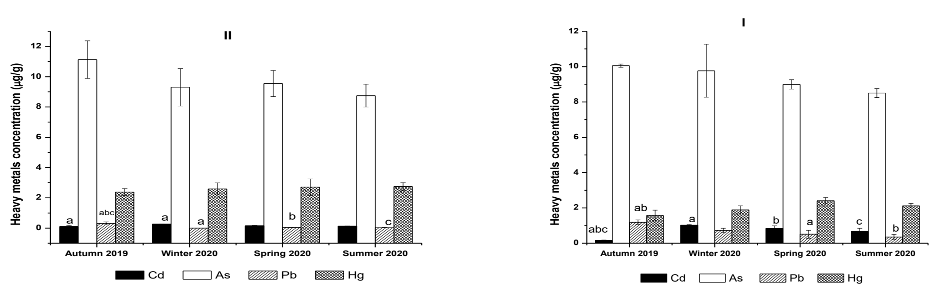


Fig. 2. (a) Comparison of differences between heavy metal concentrations in water samples, **(b)** sediment samples, **(c)** muscle, and **(d)** hepatopancreas of *P. clarkii* from El-Shabakat (I) and Tal-Haween (II) sites in Muweis Canal

CONCLUSION

Upon addressing the two sites under study, it was noticed that metal concentrations were at their highest in fish hepatopancreas and muscles, sediment, and water, except for lead, which had higher concentrations in sediment and water. Sediment was identified as the primary source of metal contamination in Muweis Canal. Both sites demonstrated high metal accumulation across all examined properties, indicating that these areas are among the most contaminated regions with waterborne elements. The total potential ecological risk index for heavy metals concluded that all observed areas are facing an exteremly high ecological risk, particularly due to mercury (Hg). The invasive species *Procambarus clarkii* exhibited the highest concentrations of all examined elements, and thus can serve as a bio-monitor of its aquatic habitat. Muweis Canal in El-Shabakat and Tal-Haween villages is not documented in the ecological literature concerning metal toxicity and does not meet the standard limits recommended by the WHO and ANZECC. This contamination has had a significant impact on the crayfish and other fish in Sharkia Province, Egypt, leading to the death of species such as *Bagrus bayad*. It is crucial to address water contamination risks and implement effective treatment measures to prevent potential adverse health impacts.

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