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RESEARCH ARTICLE

Bioaccumulation Influences of Some Heavy Metals on Growth Performance of *Solea solea* Fish in Lake Qaroun, Egypt

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Abstract

The present research examined the levels of lead (Pb), cadmium (Cd), copper (Cu), and zinc (Zn) in water, sediments, and some vital organs of *Solea solea* fish from Lake Qaroun, Egypt, such as liver, gills, kidney, muscle and end of the alimentary. The contamination factor values of Pb, Cd, Cu, and Zn are low contamination which contamination factor less than 1. According to the results, fish hunted from the eastern and southeast areas of the lake had the highest concentrations of the various heavy metals in the following order: The current findings make it evident that Zn accumulated in the studied organs in the following order: Kidneys greater than liver greater than gills greater than end of alimentary canal greater than muscles. Furthermore, Cd bioaccumulation occurs in *Solea solea* in the following order: gills greater than end of alimentary canal greater than kidney greater than liver greater than muscles. However, the liver, gills, and kidneys of fish that were received from the lake's southeast and eastern regions clearly showed damage and underwent histopathological changes. Fish collected from the lake's southeast and eastern regions revealed a much higher white blood cell count and a highly significant decrease in red blood cell counts, hemoglobin, and hematocrit values compared with fish taken from the western sector, which showed roughly normal values. The results demonstrated that there were remarkably large differences in the uric acid levels, creatinine, total protein, activities of serum aspartate amino transferase, and alanine amino transferase for the *Solea solea* that were gathered from the various study sites. Around Lake Qaroun. Pb and Cd concentrations in our study are higher than the allowed limits, however, Cu and ZN concentrations in the water are lower than the allowed limits for heavy metals.

Keywords: Biochemical, Egypt, Growth performance, Heavy metals, Hematological and histopathological features, Lake Qaroun, *Solea solea*

1. Introduction

Heavy metals can bioaccumulate in aquatic habitats and aquatic creatures, they are particularly dangerous. They have lengthy biological half-lives and are typically not biodegradable. The (WHO) states that limiting the amount of heavy metals in food sources is required to protect the general public (Heidarieh et al., 2013). Aquatic creatures absorb and collect heavy metals in two ways: the food supplies and the surrounding medium. Carnivorous fish, especially deep-sea species, are particularly good at storing metals in their muscles across the chain of food (Gokoglu et al., 2008).

The following external factors can affect the amount of heavy metal accumulation: such as interactions between metals, dissolved oxygen, physico-chemistry, and dissolved metals. Geographical variations, seasonal effects, diet, and sediment. Furthermore, internal variables like individual variation, body size, stage of development,

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sex, brooding, breeding environment, molting, and growth (Çoğun et al., 2006). Since many marine fish species can concentrate significant amounts of specific metals in different tissues, like muscle and gills, they are frequently used to evaluate the quality of aquatic environments. Sustaining and maintaining natural resources is a valuable target in Egypt for increasing and maintaining their ability to produce proteins and helping society's welfare. Qaroun and Wadi El-Rayan lakes are among these resources in El-Fayoum Governorate (Fishar and Ali, 2005). El-Bats and El-Wadi are the two main drains that supply Lake Qaroun with sewage and agricultural water. Which degrades its water quality as well as the fauna that lives there (Fathi and Flower, 2005). It is believed that the most significant element influencing the health and disease conditions of both farmed and wild fish is the water quality of the aquatic ecosystem. Fish health is greatly affected by the deterioration of the aquatic environment brought on by industrial, municipal, and agricultural waste (Authman and El-Sehamy, 2007). Biological signs of pollution and environmental degradation may be found in fish in particular. Fish growth rate, physiological and biochemical state, and meat quality can all be strongly impacted by the bioaccumulation of heavy metals and pesticides in fish (Gaafar et al., 2010). Because some metals that are dissolved in water can concentrate in significant levels in fish. Consuming contaminated fish can allow the contaminants to enter human metabolism via the food chain, and thus, putting people at risk for major biomagnifications and a decline in their state of health (El-Batrawy et al., 2018).

Moreover, the direct toxic effects of pollutants on edible organs may be responsible for the alterations in the histological features of the target organs (Rajeshkumar et al., 2015). Histological studies are therefore a useful tool for determining the long-term effects of water pollution and should be used to assess the level of pollution. Elwasify et al. (2021a, 2021b) investigated the effects of certain heavy metals' bioaccumulation and biosedimentation on the histological characteristics of *Tilapia zillii,* an Egyptian cichlid fish that lives in Lake Qaroun. This study demonstrated the need for preventative actions to be done in order to avoid contamination with heavy metals in the future. According to various research, including (Mohamed and Sabae, 2015; Ibemenuga et al., 2019), mentions that the histological investigations should ascertain the extent of pollution since they are a useful tool for marking the long-term impacts of water pollution.

Heavy metal pollution of water and sediments by humans has been shown in numerous studies; however, there is little information on the bioaccumulation and biosedimentation of heavy metals in the various tissues of the fish under investigation (Sanou et al., 2021).

Thus, measuring the concentrations of four metals as cadmium (Cd), lead (Pb), copper (Cu), and zinc (Zn) in the impacted tissue of a commercially valuable species of benthic marine fish was the main goal of this study.) *Solea solea* (, surface water and sediment to provide comparable data about the quality of water and sediment along various sites of Lake Qaroun, which is considered a reservoir of drainage water in El-Fayoum Governorate. Additionally, a few physiological and biochemical parameters of *Solea solea* fish raised in the different study locations were investigated. It was also concerned with the study's examination of the quality of *Solea solea* collected from three study locations and the impact of effluent discharged directly into the lake's examined sites on growth indices.

2. Methodology

2.1. Samples collection

2.1.1. Water and sediments sampling

The samples of Fish were collected from the same locations as water samples as follows: The first area (Site I) is the lake's eastern sector, where El-Bats drain discharged its effluents directly without prior treatment, the second one is the southeastern area (Site II) of the lake, where the effluent of an agricultural canal called El-Wadi drain, and the third at the western area of the lake (Site III), where no sources of pollution were identified.

Within polyethylene bottles Heavy metal samples were collected for analysis. During the sediment sampling, a Van Veen type grab was used. The sediment samples were collected in plastic bags and transported to the laboratory (Cabrera et al., 1992; American Public Health Association, 2005).

2.1.2. Fish sampling

Solea solea (Fig. 1) was collected from the previously selected sites along Lake of Qaroun in El-Fayoum governorate. The samples were collected using fishermen's nets and then transported to a laboratory for analysis. The fish were identified, and fish total length of each one was measured and documented to the nearest 0.1 cm. Each sample was dissected to examine the muscle, gills, liver, kidney, and alimentary canal tissues. Using FAO procedures, each sample was put into a decomposition

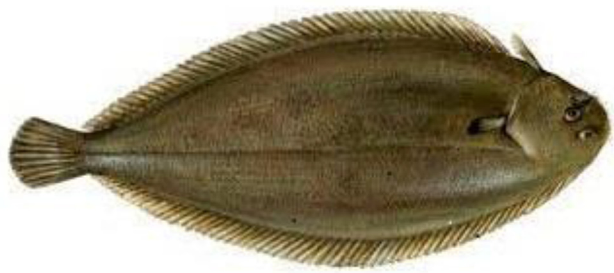

Fig. 1. The type of the studied fish species (Solea solea) collected from Lake Qaroun.

beaker and then filled with pure sulphoric acid and nitric acid-hydrogen peroxide (1 : 1) v/v. FAO/SIDA (1983). On a hot plate, they were evaporated to dry. Subsequently, the leftover materials were dissolved and added to 50 mL of 2.5% nitric acid. Chemicals of analytical quality were employed to dissolve the sample. Atomic absorption spectroscopy was used to measure Cu, Zn, Pb, and Cd. Spectrometry (Varian Model- Liberty Series II). Metal concentrations were measured in micrograms/gram of dry weight (μg g^{-1} wt). Ten randomly selected *Solea solea* muscle samples were taken from various collection locations in order to measure the levels of Pb, Cd, Cu, and Zn. For lipid analyses, fish were individually frozen and kept at −20 °C (Schreck and Moyle, 1990).

2.2. Ecological risk assessment methods (pollution assessment)

2.2.1. A geoaccumulation index (Igeo)

Chakravarty and Patgiri (2009) introduced the Igeo index, which uses a comparison of present concentrations with pre-industrial levels to identify and characterize metal contamination in sediments.

$$Igeo = \mathrm{Log}\, 2 \frac{Cn}{1.5Bn} \tag{1}$$

Where Bn is the geochemical background value of element n in average shale, Cn is the observed concentration of heavy metals in sediments, and 1.5 is the background matrix correction for terrigenous effects. Table 1 illustrates the seven different ranges of the geo-accumulation index (Igeo), which includes Igeo 0, unclassified; groups 0: not contaminated, group 1: slightly contaminated, group 2: moderately contaminated, group 3: heavily contaminated, group 4: highly contaminated, group 5: highly contaminated, and group 6: extremely contaminated (Buccolieri et al., 2006).

Table 1. Müller's classification for the Geo-accumulation Index, I_{geo}.

I_{geo} value	Class	Sediment quality
≤0	0	Uncontaminated
0–1	1	Uncontaminated to moderately contaminated
1–2	2	Moderately contaminated
2–3	3	Moderately to strongly contaminated
3–4	4	Strongly contaminated
4–5	5	Strongly to extremely contaminated
>5	6	Extremely contaminated

2.2.2. Contamination factor

The degree of contamination can be determined using the contamination factor (CF). Using the following formula, one can determine the CF by dividing the concentration of each element in the sediment by the reference or background value. Turekian and Wedepohl found that concentrations are used as the foundation for the background value, which is derived from element abundances in sedimentary strata. 'CF1' for very low contamination, 'CF3' for moderate contamination, 'CF6' for substantial contamination, and 'CF6' for very high contamination are some common terms for describing the level of contamination (Turekian and Wedepohl, 1961).

2.3. Growth parameters

2.3.1. The condition factors

For every fish taken from the three study sites, body weight was calculated to the closest gram and total body length was measured to the nearest 0.1 cm. Using the Schreck and Moyle formula, the condition factor (K) was determined for every single fish (Schreck and Moyle, 1990).

$$\text{Condition Factor (K)} = \frac{\text{Wet weight (g)}}{\text{Total length (cm)}} \text{X100} \tag{2}$$

2.3.2. Hepatosomatic index (H.S.I.)

It was calculated as the liver percentage to the whole body weight according to Schreck and Moyle (1990) as follow:

$$\text{H.S.I.} = \frac{\text{Liver weight (g)}}{\text{Body weight (g)}} \text{X 100} \tag{3}$$

2.4. Blood and biochemical analysis

The *arteria caudalies* were used to remove blood samples. In order to measure the hematological parameters, the first portion was collected using the anticoagulant 10% ethylene diamine tetraacetate.

The indirect method was used to count the total number of red blood cells (RBCs) and white blood cells (WBCs), measure hematocrit (Ht), and determine hemoglobin (Hb) using hemoglobin kits (Reitman and Frankel, 1957; Martins et al., 2004). The serum for the biochemical analysis and measurements was obtained by centrifuging the second portion, which was collected without the use of an anticoagulant (Kawthalkar, 2019). The formula for calculating oxygen carrying capacity was given by (Olson et al., 1987). Alkaline phosphatase, alanine aminotransferase (ALT), and aspartate aminotransferase (AST) were measured in accordance with (Reitman and Frankel, 1957).

2.5. Histopathological study

After the fish was dissected, samples of the kidney, liver, and gills were taken and immediately fixed in alcoholic Bouin's solution for a minimum of 24 h. This allowed the tissue to be examined under a light microscope to detect pathological tissue changes using hematoxylin and eosin (Pearse, 1968).

3. Results and discussion

3.1. Assessment of physicochemical characteristics and heavy metal concentration

3.1.1. Physicochemical parameters of water samples

Analysis of water quality samples taken directly from various locations along Lake of Qaroun is part of the ongoing field investigations. The mean of the heavy metals and physicochemical parameters under study in water samples is displayed in (Table 2). The pH of Lake of Qaroun is clearly alkaline, ranging from 7.85 in the western sector to 8.45 in the eastern sector. While the western sector of the lake (site III) had the highest value of dissolved oxygen, while the southeastern sector (site II) and the eastern sector (site I) had the lowest value. Hypoxia and fish mortality may result from agricultural discharges of high concentrations of organic materials, inorganic salts, and heavy metals (Mohamed, 2009). The most recent data also showed that the lake's water ammonia and nitrite levels were highest in the eastern and southeast sectors and lowest in the western sector.

3.1.2. Heavy metals concentration in water

Heavy metal contamination of water is frequently linked to discharges from cities, farms, and industries. Metals in the water column have three possible fates: they can be assimilated by living organisms, deposited in sediments, or stay in the water for a long time. In aquatic systems, heavy

Table 2. Physicochemical parameters and some heavy metals concentration of water samples collected from the different studied sites along lake Qaroun

Studied sites of collection	pH	DO (mg/l)	Total Hardness as $CaCO_3$ mg/l	Total alkalinity ($CaCO_3$) Mg/l	Salinity g/l	NH_3 mg/l	NO_2 mg/l	Cu^{+2} P.l. = 1.0 mg/l	Zn^{+2} P.l. = 5.0 mg/l	Cd^{+2} P.l. = 0.01 mg/l	Pb^{+2} P.l. = 0.05 mg/l
Eastern sector	8.45 ± 0.09	6.05 ± 0.09	815 ± 9.4	383 ± 5.1	37 ± 0.76	0.49 ± 0.04	0.60 ± 0.04	0.465 ± 0.013	0.02 ± 0.004	0.30 ± 0.04	0.140 ± 0.02
Southeastern sector	8.20 ± 0.08	6.65 ± 0.13	803 ± 8.5	368 ± 6.6	38.5 ± 0.57	0.36 ± 0.02	0.35 ± 0.19	0.40 ± 0.02	0.035 ± 0.006	0.24 ± 0.05	0.045 ± 0.009
Western sector	7.85 ± 0.06	7.65 ± 0.09	785 ± 5.67	354 ± 6.05	40.5 ± 0.94	0.15 ± 0.02	0.09 ± 0.004	0.10 ± 0.003	0.36 ± 0.02	0.04 ± 0.004	0.015 ± 0.002
F-values	15.3**	55**	3.5*	6.2**	5.2**	34**	108**	191**	319**	13**	21**

Data are represented as means of eight samples±S.E.
N.D., Not detectable; **P.l.**, Permissible level in water according to WHO (1995).
Means with the same letter for each parameter are not significantly different, otherwise they do.
**Highly Significant difference ($P < 0.01$).

metals are widely dispersed due to industrial development and the extensive use of chemicals in agriculture. They are essential for food efficiency and growth rate, but they can also cause a decrease in the growth rate of different fish species (Coulibaly et al., 2020). Higher concentrations of heavy metals than fish can tolerate, however, have an adverse effect on fish populations by lowering fish growth, reproduction, and/or survival rates, and may even cause fish deaths (Elwasify et al., 2021a, 2021b). Comparing the average concentrations of heavy metals in the studied sites, we find that the presence of the studied metals Cu, Zn, Cd, and Pb in the following order: According to (Table 2), the eastern sector greater than the southeastern sector greater than the western sector of the lake.

The findings demonstrated that, in comparison to samples taken from the western sector (Site III), the concentrations of Cu, Pb, Zn, and Cd in the water were higher in the presence of industrial and agricultural effluents discharged directly to the lake's eastern site (Site I) and agricultural effluents discharged directly to the lake's southeastern sector (Site II). The quality of the industrial and agricultural drainage water, rich in chemicals and fertilizers, that feeds the lake may be the cause of the high concentrations of Cu, Zn, Pb, and Cd found in water taken from the lake's eastern and southeast sectors (El-Agri, 2021).

Numerous researchers' findings (Abdel-Satar et al., 2010; Abdel Wahed et al., 2015; Goher et al., 2018; Mohamed, 2019) coincide with these findings. Elghobashy et al. (2001) linked the usage of fertilizers and other chemicals in agriculture, as well as the breakdown of organic matter, to the rise in heavy metals found in drainage water. Therefore, human influences rather than naturally occurring metal enrichment in water could be the primary causes (El-Sayed et al., 2015).

3.1.3. Heavy metals concentration in sediment

Metals can be found in aquatic systems as suspended, colloidal ions, dissolved ions and complexes, and solids in sediments. Sediments in freshwater and marine environments absorb metals. In research on aquatic ecosystems, the importance of sediments in the cycling of chemical elements has frequently been overlooked, and the exchange of elements especially nutrients between sediments and water is still a crucial subject (Arain et al., 2008). Fig. 2 depicts the mean concentrations of Cu, Zn, Cd, and Pb in sediment samples collected from the three different studied sectors along Lake Qaroun. All heavy metal concentrations among the various research collection sites showed blatantly significant differences (F-test) (F-values = 69.7, 4.1, 52, and 33, respectively).

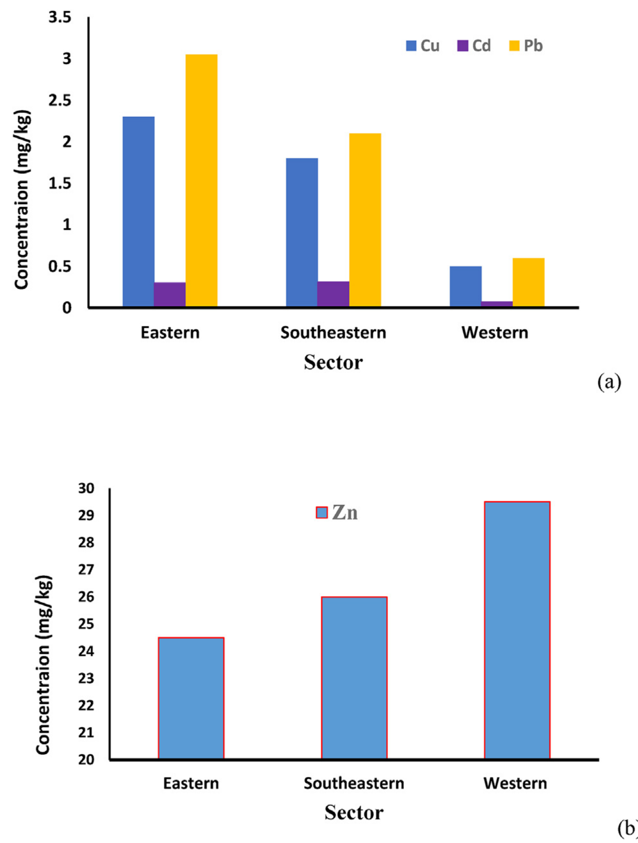

Fig. 2. Concentration of Heavy metals in sediment samples (mg/kg dry weight) collected from the different studied sites along Lake Qaroun. Cu, copper; Cd, cadmium; Pb, lead; Zn, Zinc.

The current study found that the concentrations of Cu, Zn, Pb, and Cd in sediment samples collected from the lake's eastern sector were higher than those collected from the lake's southeastern sector. Furthermore, the results revealed that the lowest concentrations of Cu, Cd, Pb, and Zn were found in sediment samples collected from the lake's western sector. When the average concentrations of heavy metals (Cu, Zn, Cd, and Pb) in sediment samples collected from various sites along Lake Qaroun were compared, the following metals were found in the following order: Cu: eastern sector greater than southeastern sector greater than western sector. Zn: western sector greater than southeastern sector greater than eastern sector. Cd: eastern sector greater than southeastern sector greater than western sector.

Lead: eastern sector greater than southeastern sector greater than western sector.

According to the results of the current study, fish and sediments have higher concentrations of metals than water does. This suggests that, in contrast to

Table 3. Contamination factor (CF) and Geo-accumulation index (Igeo) of heavy metals in the surface sediments.

Contamination factor (CF)			
Pb	Cd	Cu	Zn
0.1525	1	0.05	0.25
0.105	1.03	0.04	0.27
0.03	0.23	0.01	0.31
Geochemical index (Igeo)			
Pb	**Cd**	**Cu**	**Zn**
−3.29		−4.87	−2.54
−3.83	−0.53	−5.22	−2.45
−5.64	−2.68	−7.07	0

water, metals are adsorbed on sediment and bioaccumulated in fish. Metal concentrations in surface sediments and water have an impact on the rate of sediment deposition (Arain et al., 2008).

Contamination Factor (CF): An approach to comparing the degree of heavy metal pollution is the empirical index. Table 3 displays the CF values for all samples pertaining to heavy metals. It indicates that Pb, Cd, Cu, and Zn have low contamination levels, with CF values of less than 1.

Geo-accumulation index (Igeo) of heavy metals in sediments: The average values of the geo-accumulation indices for the investigated metals are all below the 0 value. That rules out the possibility of pollution in the region studied (Table 2). The outcomes of Igeo are presented in (Table 3). According to Muller (1969) categorization, the geo-accumulation index found that Cd, Cu, Pb, and Zn metals in the negative results indicate that the sampling areas are not contaminated with these elements (Muller, 1969).

3.1.4. Residual heavy metals

Human health may be at risk from heavy metals that enter the food chain and bioaccumulate in fish tissue in aquatic environments. These metals include Cu, Zn, Pb, and Cd, among others (Alprol et al., 2022). The amounts of the investigated heavy metals (Pb, Cu, Zn, and Cd) in a few key organs (kidney, gills, liver, the end of the alimentary canal, and muscle) of *Solea solea* that were taken from the different Lake Qaroun study sites are displayed in (Fig. 3). The fish taken from the eastern and southeast sectors of the lake had the highest concentrations of the different heavy metals, in the following order: liver tissues greater than kidneys greater than gills greater than end of alimentary canal greater than muscles in the case of Cu bioaccumulation; kidney greater than end of alimentary canal greater than liver greater than gills and muscles in case of lead bioaccumulation. It is clear from the present findings that Zn accumulated in the studied organs in the following order: Kidneys greater than liver greater than gills greater than end of alimentary canal greater than muscles. Furthermore, Cd bioaccumulation occurs in *Solea solea* in the following order: gills greater than end of alimentary canal greater than kidney greater than liver greater than muscles.

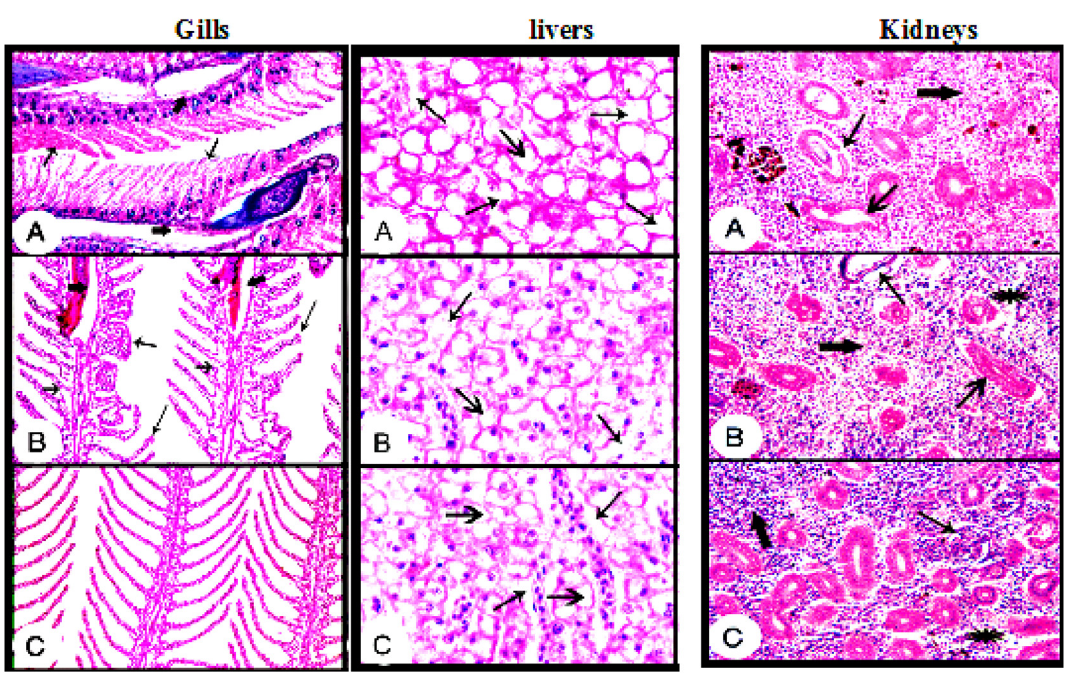

Fig. 3. Histological sections in gills, liver and kidney of Solea solea collected from different sites along Lake Qaroun. H and E (X200). (A) Eastern sector of the Lake (El-Bats drain), (B) South-Eastern sector of the Lake (El-Wadi drain), (C) Western sector of the Lake (unpolluted area).

The results also showed that fish tissues taken from the western sector, which is far from any sources of pollution, had the lowest concentrations of the heavy metals under study.

The liver is one of the primary metabolic organs where heavy metal accumulation occurs. The liver stores metals for detoxication by generating metallothioneins (Bhardwaj et al., 2021). Fish gills typically had higher concentrations of heavy metals than muscle tissue. The metal concentration in the gill could be explained by the element complexion with the mucus that is difficult to remove entirely from the lamellae before tissue is prepared for analysis. As the primary site of contamination in water, the gill surface's adsorption of metals may have a substantial effect on the overall metal levels in the gills (Heath, 1995). However, as previously noted by Mohamed and Gad (2008), the low levels of metals in the muscles may be caused by the muscles' lower blood supply.

Furthermore, variations in feeding habitats, ecological requirements, metabolism, and physiology may account for variations in the metal distribution pattern in the examined fish species, *Solea solea* (Authman and El-Sehamy, 2007).

3.1.5. Histopathological studies

Histopathological changes and obvious harm to *Solea solea's* gills, liver, and kidneys supported earlier biochemical studies.

3.1.6. Gills

The first physiological processes to be affected by salts, heavy metals, pesticides, and fertilizers transported to aquatic habitats by drainage water are the functions of gills in respiration, ion regulation, and acid-base balance (Gaber, 2007). The histopathological changes and evident damage found in fish gills from the eastern and southeast sectors of the lake included epithelial cell necrosis, epithelial hyperplasia with ballooning degeneration, and epithelial desquamation. These alterations may result in damage to the gill epithelium, hypertrophy, and hyperplasia, which would ultimately eliminate the cell's permeable ability (Dhaneesh et al., 2012). These alterations are comparable to those found in fish taken from the Nile River that were subjected to varying levels of heavy metal exposure (Wagh et al., 1985; Abbas, 1994; Ahmed, 1996).

The investigated fish's gill morphology is similar to that of tilapia, whose gill lamellar epithelium is primarily made up of pavement cells and mitochondria-rich chloride cells. The pavement cell, which makes up more than 90% of the entire epithelial surface area, is the more prevalent of the two cell types under normal circumstances (Kamel and Fathalla, 1995). However, exposure of fish to heavy metals caused a proliferation of interlamellar chloride cells (Gaber, 2007), the authors postulated that the increase in the number of chloride cells is associated with trials of fish to compensate for stress. Furthermore, because these chloride cells are the locations of Ca^{++} and Cl-uptake from water, they are essential to ionic regulation.

The authors hypothesized that fish trials to compensate for stress are linked to an increase in chloride cell counts. Furthermore, because these chloride cells are the locations of Ca and Cl-uptake from water, they are essential to ionic regulation. The results of the other study demonstrated distinct histopathological alterations in the *Solea aegyptiaca* gills that were taken from Lake Qaroun. These changes included severe epithelial cell hyperplasia, secondary lamellae fusion, some secondary gill lamellae bending or curling, and vasodilation with blood congestion (El-Agri, 2021).

3.1.7. Liver

The liver is one of the first and main targets of metal toxicity in vertebrates and is recognized as the primary organ for metals in fish. Some authors claim that when studying the toxicological effects of both organic and inorganic chemicals in various fish species, the liver has received special attention (Tapia et al., 2012). Fish liver sections taken from the lake's eastern and southeast regions displayed distinct histopathological alterations, including the breakdown and necrosis of hepatic cells and unique parenchymal cells. In addition, parenchymal hepatocyte shrinkage, karyomegaly, necrosis, fatty vacuolation, pyknosis, and the formation of more lipofuscin granules. Rough endoplasmic reticulum was also disorganized, while smooth endoplasmic reticulum was proliferating. The pathological changes seen in *Channa punctatus* exposed to 37 mg Zn/l for 12 h (Khangarot and Durve, 1982) and *Oreochromis niloticus* collected from polluted locations along El-Burullus Lake (Zaghloul, et al., 2007) are comparable to the histopathological changes seen in the liver of *Solea solea* in the current study.

3.1.8. Kidneys

Fish kidney sections taken from the east and southeast of the lake showed signs of hemopoietic tissue depletion, damage to the wall of the renal blood vessels, and progressive damage to the kidney tubules associated with tubular necrosis. In the current study, *Solea solea* kidney tissues from the eastern and western sectors of the lake showed histopathological changes. Damage to kidney tubules linked to tubular necrosis, damage to the renal blood vessel wall, and a decrease in hemopoietic tissues were among the changes that were seen. These symptoms match those that have been noted by Zaghloul et al. (2000).

3.2. Growth indices

3.2.1. Condition factor

To evaluate the effect of environmental changes on fish performance, the condition factor 'k' values are estimated for comparison (Mona et al., 2015). Thus, the variation in 'k' might be an indication of the fish's overall health as well as the amounts of protein and fat in them (Jamil Emon et al., 2023). According to the current study, fish collected from Lake Qaroun's western sector had the highest *Solea solea* condition factor, while fish collected from the lake's eastern and southeast sectors had the lowest. This variation was noted at all of the lake's study locations.

The lower values of the condition factor 'k' of *Solea solea* collected from the lake's eastern and western sectors could be attributed to the toxic effects of various heavy metals accumulated at high concentrations in the fish's tissues (Salah El-Deen, 1999).

On the other hand, the high values of 'k' of fish collected from unpolluted area in the west is in agreement with the results recorded by Saeed (Shaaban et al., 1999; Saeed, 2000) who attributed that to the high total phosphorus and nitrogen concentrations and the increase in the water productivity accompanied by increase in fish growth.

3.2.2. Hepatosomatic index (HIS)

According to the current investigation, there was no discernible difference in the hepatosomatic index (Table 4), another biological metric that is useful for examining fish growth, between fish that were taken from the eastern and southeastern locations. Additionally, compared with fish hunted from the lake's western sector, the hepatosomatic index of fish taken from the eastern and southeast locations significantly decreased. This result is in line with the findings of Jamil Emon et al. (2023) who suggested that the fish's need for energy to withstand the stress was caused by a loss of liver glycogen followed by hyperglycemia. Hyperglycemia in fish taken from the lake's eastern and western sectors attests to this.

Table 4. Condition factor and hepatosomatic index of Solea solea collected from the different studied sites along Lake Qaroun

Studied sites of collection	Condition factor 'k'	Hepatosomatic index
Eastern sector	0.65 ± 0.02	0.95 ± 0.06
Southeastern sector	0.72 ± 0.01	1.2 ± 0.04
Western sector	0.82 ± 0.01	1.39 ± 0.03

3.3. Blood parameters

The blood parameters consisted of two parts the first is the complete blood count and the second is the serum analysis.

3.3.1. The complete blood picture (CBC)

Haematological investigations are therefore useful methods for examining physiological alterations brought on by environmental contaminants. In actuality, the easiest way to determine the overall health of an animal's body is through its blood (Adakole, 2012). Table 5 illustrates the investigations conducted in this study regarding the counts of RBCs, Hb, and Ht, mean corpuscular volume, mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), and WBC counts. High concentrations of heavy metals found in water samples may have reduced the production of red blood cells in the hematopoietic organs, which could explain the highly significant decrease in RBCs, Hb, and Ht values of fish collected from the eastern and southeast sectors of the lake compared with those collected from the western sector (Zaghloul et al., 2007). The intrahepatic and intrasplenic hemorrhage brought on by the action of accumulated heavy metals may also be the cause of this decrease. Additionally, the hemoglobin content of fish taken from the lake's eastern site significantly decreased, with fish taken from its southeast site exhibiting the greatest declines. A comparison of *Solea solea* white blood cell counts revealed a highly significant variation in WBCs between fish taken from the various Lake Qaroun study sites (Table 5).

In order to increase O_2-carrying capacity and maintain the level of oxygen transference from water to tissues, changes in red blood cell parameters suggest a compensatory response to the disruption of the structural integrity of gills with consequent reduction of respiratory surface (tissue damage and cell proliferation) (Turko et al., 2014).

The rise in Ht and RBCs could be a sign of a compensatory reaction to boost the blood's ability to carry oxygen. As mentioned, the alterations in fish gill epithelia brought on by copper, such as cell hypertrophy, cell proliferation, and epithelial lifting, may be a protective reaction. The fact that these modifications lengthen the distance that copper must diffuse in order to enter the bloodstream. While lamellar fusion decreases the respiratory area, they also lengthen the water-blood distance for O_2 diffusion. The gill tissue alterations likely

Table 5. The complete blood picture (CBC) of Solea solea collected from the different studied sites along Lake Qaroun

Studied sites	RBCs ($X\ 10^6/mm^3$)	Hb (g/dl)	Ht (%)	MCV (fentolitre)	MCH (pg/cell)	MCHC (g/dl)	WBCs ($X10^3/mm^3$)
Eastern sector	1.0 ± 0.08	3.05 ± 0.17	14 ± 0.76	142 ± 3.2	27.5 ± 2.07	22.5 ± 0.19	82 ± 1.13
Southeastern sector	1.50 ± 0.04	3.65 ± 0.21	15 ± 0.76	123 ± 6.42	24 ± 0.76	24.5 ± 0.18	69.5 ± 1.7
Western sector	2.35 ± 0.09	6.25 ± 0.10	20.5 ± 0.57	129 ± 9.1	31.5 ± 0.19	31.0 ± 0.38	52.5 ± 1.32
F-values	87**	107**	25**	2	8.6**	277**	111**

Data are represented as means of eight samples±S.E.
Means with the same letter for each parameter in the same column are not significantly different, otherwise they do.
*Significant difference ($P < 0.05$).
**Highly Significant difference ($P < 0.01$).

hinder branchial gas transfer, creating an internal hypoxia that could trigger the release of erythrocytes from organ storage into the bloodstream through an adrenergic stimulus (Mazon et al., 2002). Moreover, a slight excess of copper may promote the formation of erythrocytes or their release from hemopoietic tissue, since copper is necessary for the synthesis of hemoglobin. The rise in Ht on its own is typically linked to either hem concentration as a result of decreased plasmatic volume or a stress response that causes RBC swelling (Wilson and Taylor, 1993).

Mean corpuscular volume and MCH both rise in tandem with a drop in blood Hb. This might be the result of the hemolytic action, which caused the tissues to lose fluid and the plasma volume to drop as a result (Swift, 1981). The observation of leukocytosis in the current study could be attributed to an increase in leukocyte mobilization as a result of Cu-damaged tissue, which serves to protect the body against infections. According to one theory, the rise in fish WBCs suggests a shift in the defense mechanisms that fish tissues are using to fend off the highly toxic copper and Zn buildup (Tavares-Dias, 2021).

3.3.2. Serum constituents

Serum component analyses have shown a promise tool in the identification and diagnosis of metabolic disorders and illnesses. The serum components under investigation in the current study varied greatly; fish serum total lipids had the lowest values, while serum glucose, AST, ALT, creatinine, and uric acid had the highest values (Table 6).

The current study suggests that the increased breakdown of glycogen in the liver of the fish species collected and examined from the eastern and southeast regions of Lake Qaroun may be the cause of the observed hyperglycemia. This breakdown may also be influenced by the bioaccumulation of the heavy metals under investigation, an increase in catecholamine and corticosteroid plasma concentrations as a stress response in fish exposed to various stress conditions, or fish glycogen depletion (Paris-Palacios et al., 2000).

The metabolism and control of water balance are major functions of serum total proteins. Metals have an impact on the blood protein and enzyme levels in *Solea solea*. The fish under investigation experienced a decrease in serum total protein levels compared with those of the fish collected from the western sector upon exposure to the effluents in the lake's eastern and southeast sectors. It is possible to explain the observed hypoproteinamia by considering energy production during pollutant toxicity, as well as various pathological processes such as renal damage, elimination in hepatic blood flow, and/or plasma dissolution (Mourad et al., 2017). Moreover, copper may circulate within the body attached to low-molecular-mass proteins such as albumin (Harris, 2000).

Furthermore, a variety of stimuli, including stress and heavy metals, can trigger the synthesis of the metalothionin, a protein that binds to metals (Shamsi and Fatima, 2014).

Enzymatic activity measurements could be used to monitor water pollution. Serum AST and ALT

Table 6. Serum constituents of Solea solea collected from the different studied sites along lake Qaroun

Studied sites	Glucose (mg/dl)	Total protein (g/dl)	AST (U/l)	ALT (U/l)	Creatinine (mg/dl)	Uric acid (mg/dl)
Eastern sector	133 ± 4.7A	2.30 ± 0.11C	75.0 ± 4.91A	31.0 ± 0.76A	3.90 ± 0.07A	37.0 ± 2.27A
Southeastern sector	118 ± 4.72B	2.95 ± 0.17B	55.0 ± 2.64B	25.0 ± 1.51B	2.95 ± 0.02B	33.0 ± 1.51B
Western sector	85.5 ± 2.07C	4.75 ± 0.25A	33.0 ± 1.51C	16.5 ± 0.94C	2.40 ± 0.04C	25.5 ± 1.32C
F-values	35**	47**	40**	42.5**	230**	11**

Data are represented as means of eight samples±S.E.
Means with the same letter for each parameter in the same column are not significantly different, otherwise they do.
*Significant difference ($P < 0.05$).
**Highly Significant difference ($P < 0.01$).

activities were higher in fish from the eastern and southeast sites than in fish from the western sector. The damage caused to the liver and kidney cells by the accumulated heavy metals may account for this discrepancy.

After a cell is damaged, the membranes become permeable, and the serum and extracellular fluid contain the enzymes. Therefore, measuring liver enzymes (AST, ALT) has been beneficial in identifying fish liver disease (Shahsavani et al., 2010).

Increased transaminases may be seen in fish exposed to heavy metals. (AST and ALT) activity, which could indicate increased liver synthesis of enzymes or potential enzyme leakage through damaged plasma membranes (Yousafzai and Shakoori, 2011).

Kidney functions such as uric acid and creatinine can be used as a crude indicator of renal glomerular filtration rate. Low levels of urea, uric acid, and creatinine do not significantly indicate kidney problems, but high levels do (Alkaladi et al., 2015).

Fish taken from the lake's eastern and southeast locations had higher creatinine and uric acid levels during the current study. This could be explained by the way that heavy metals affected the glomerular filtration rate, leading to pathological alterations in the kidney (Hadi and Alwan, 2012) stated that glomerular insufficiency, a decrease in the metabolism of carbohydrates, or an increase in the breakdown of muscle tissue could all be the cause of an elevated creatinine level.

Additionally, Renal dysfunction can be indicated by elevated serum levels of creatinine and uric acid. Renal cell damage and malfunction caused by heavy metal accumulation resulted in elevated serum creatinine and uric acid levels (ALzhrani, 2020).

Though their exact mechanism is still unknown, heavy metals have a noticeable impact on the levels of ammonia in the blood that circulates in freshwater fish. Despite an elevated plasma-to-water gradient, this appears to be the result of increased stress-induced ammonia production coupled with unchanged excretion (Grosell and Wood, 2002). Serum urea responded to acute and prolonged copper exposure in a far more sensitive and noticeable way, leading to a three-fold increase in circulating urea levels, serum ammonia clearly responded to copper exposure. This teleost's unusual capacity to change ammonia into urea most likely accounts for this reaction. Freshwater fish exposed to copper typically respond by producing more ammonia due to metal-induced stress and having a reduced capacity to expel ammonia through the gills, which raises serum ammonia levels. The reason for the greater rise in serum urea than ammonia could potentially be attributed to the toadfish's capacity to utilize their fully operational ornithine–urea cycle to convert ammonia to urea. Well, it is intriguing to hypothesize that toadfish exposed to copper may shift from excreting primarily ammonia to urea in order to prevent ammonia toxicity (Grosell et al., 2004).

Table 7. Health risk valuation for fish consumption.

Water				
	Pb	Cd	Zn	Cu
Eastern sector	0.14	0.3	0.02	0.4
Southeastern sector	0.04	0.24	0.03	0.4
Western sector	0.015	0.04	0.36	0.1
WHO (1995) mg/l	0.05	0.01	5.0	1.0
Muscles				
Sector	**Pb**	**Cd**	**Zn**	**Cu**
Eastern	0.7	0.48	8	1.7
Southeastern	0.5	0.29	7	1.25
Western	0.3	0.095	12	0.65
WHO World Health Organization (1995)	2	0.5	40	30
FAO (mg/kg, ww) (Nauen, 1983)	0.5	0.05	30	30
FAO/WHO (Bawuro et al., 2018)	0.5	1	40	30

3.4. Health risk assessment for fish consumption

To assess the public health risk associated with *Solea solea* fish consumption in Lake Qaroun, the maximum permissible Limits for human consumption, as set by various organizations, were compared with the metal concentrations in the fish muscle in this study (Table 7). With very few exceptions, the levels of metals in the fish species from Lake Qaroun that were studied had concentrations below the maximum permissible Limits that FAO/WHO, WHO, and FAO recommend for human consumption. It was clear that the acceptable limit (PML) for human consumption for the essential metals Zn and copper was not being met. Similarly, the levels of the superfluous metal Cd were below the PML recommended by the WHO, FAO, and FAO/WHO only for fish species that belong to the *Solea solea* family. The amount of Pb nonessential metal exceeded the FAO's maximum allowable limits. They posed a risk to public health due to their Pb contamination. Given that the lake is open to industrial areas; human sources are most likely to blame for this.

3.5. Conclusion

Generally, it was possible to conclude that fish harvested from the western part of the lake had high growth indices and flesh that was suitable for ingestion. However, the effluents from the drainage water that are directly discharged into the southeast and eastern parts of Lake Qaroun without first undergoing treatment pose a health risk to humans by stunting fish growth and reducing the quality of their meat. According to the geo-accumulation index, the absence of Pb, Cd, Cu, and Zn metals in the negative results suggests that these elements are not present in the sample areas. Accordingly, fish from Lake Qaroun's western sector had the highest *Solea solea* condition factor in the current study, while fish from the lake's eastern and southeast sectors had the lowest condition factor.

Also, Fish immune systems and fish tissues may be negatively impacted by contaminated environments, which could result in significant financial losses for the natural resources. The present study's results also highlight the necessity of prompt action from the relevant authorities to address the issue and the need for ongoing monitoring of changes in lake conditions to support the development of prudent management strategies for Lake Qaroun. Furthermore, a greater rate of bioaccumulation and pathological changes in the target organs indicated that ingesting the material would pose a serious risk to the health of humans and fish. Thus, the current study's findings showed that preventative measures must be taken to ensure that heavy metal pollution does not occur again.

Conflicts of interest

The authors declare that they have no conflict of interest.

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