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Oreochromis niloticus as Bio-Indicator of Aquatic Contamination: Assessing Bioaccumulation, Health Risks, and Ecological Impacts Through Risk Assessment at the Damietta Branch, Egypt

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ABSTRACT

The current research was conducted to assess potential health risks for human consumers and the effects of various anthropogenic actions on the heavy metal load in *O. niloticus* gathered at various sites in the Damietta branch (Egypt). In fish muscles, metals accumulated in the following sequence: Fe > Zn > Cu > Mn > Pb. Among all sample locations, station 6 recorded the greatest values for metal pollution index (MPI) and hazard quotient, aligned with a higher metal pollution index. The current study may serve as a warning to regular consumers, especially given the high consumption rates of the *Oreochromis* type. In *Oreochromis niloticus*, metal buildup exhibited tissue-specific patterns. The liver and gill tissues were high bio accumulators compared to muscle tissues, as evidenced by the computed bioaccumulation factor and metal pollution index. The hazard index (H.I.) calculation showed that individual metals had a modest H.I. However, the combined effects of total metals posed a severe risk to eaters.

INTRODUCTION

The Damietta branch, referred to as the Eastern Nile, is a crucial water source for irrigation and agriculture in the area. This branch features various canals and channels transporting water to adjacent agricultural lands. Additionally, it contains multiple dams and locks employed to regulate water flow and mitigate the risk of flooding. Historically, Damietta was a significant maritime city, and the Damietta branch was utilized for commercial purposes and transportation. The city of Damietta, located at the delta of the Damietta Branch, is a vital industrial center. Its port is a significant hub for exporting and importing goods, particularly agricultural products. The River Nile played a crucial role in fueling the economic growth of Egypt **(El-Sayed & Moharram, 2007)**. The Damietta branch's role, known as the Eastern Nile, extends beyond providing potable water. It supports various other functions, including fishing, irrigation, industry, navigation and hydropower generation **(El-Bokhty & El-Far, 2014; Hamouda *et al*., 2014; Elhaddad & AL Zyoud, 2017)**. This branch of the Nile River spans five governorates and has an

average width of 200 meters and a length of 242 kilometers **(Abdelsalam, 2014)**. However, Damietta is exposed to substantial quantities of pollutants that negatively impact the ecological balance of the River Nile, particularly in terms of its water quality **(Ragheb, 2016)**. The sources of pollution include agricultural, industrial and domestic effluents **(Bastami *et al*., 2015)**. Heavy metals are the most prevalent type of ecological contaminant, and their presence in the ecosystem can be attributed to natural or anthropogenic sources **(Guo *et al*., 2015)**. The primary causes of metal pollution in the ecosystem are soil leaching and the weathering of minerals **(El Bouraie *et al*., 2010)**.

The sediment plays a crucial role in the composition of fluvial ecosystems. It is a primary source of persistent and bioaccumulative toxic chemicals that threaten human and ecological health **(Giannoulis *et al*., 2005)**. The recent contamination of river sediment with hazardous chemicals directly impacts water quality and serves as a reservoir for these toxic substances **(Khali & Faragallah, 2008)**.

In the aquatic food chain, fish such as tilapia, often occupy the top predator position and may contain high concentrations of metals. These metals can accumulate in different ways in fish organs, posing significant health risks to humans who consume them **(Authman *et al*., 2013; Aiman *et al*., 2016)**. Due to its profitability, tilapia production has recently dramatically increased, particularly in Africa **(Durr & Gonzalez, 2002)**. In Egypt, fish play a vital role in the economy, and *O. niloticus* is one of the ten most important species, contributing to the protein supply-demand balance **(Hatem *et al*., 2013; Mahrou *et al*., 2022)**. Given the increasing importance of tilapia species, this paper aimed to assess the impact of domestic and agricultural waste discharge into the Damietta branch on the bioaccumulation of heavy metals in the tilapia fish. Additionally, this study seeked to evaluate the health risks posed to consumers, as well as assessing the contamination risk to fish, sediment and water.

MATERIALS AND METHODS

Six sediment sampling places were considered on the Damietta branch, beginning from the north of Cairo to the north of the Damietta branch. Water samples were collected in the winter of 2019 from the Damietta branch. The water was collected from six stations (North of delta barrage (S_1), near Banha City (S_2), Kafr shoukr (S_3), near Mit Gahamr (S_4), Talkha City (S_5), and near Sherbeen City (S_6), The first one was selected as control. Water samples were collected from Damietta and kept in clean polyethylene bottles from six stations, and the fish were also collected. The fish were delivered immediately to the lab in an ice box. At room temperature, the specimens were defrosted, and their weight and total length were noted.

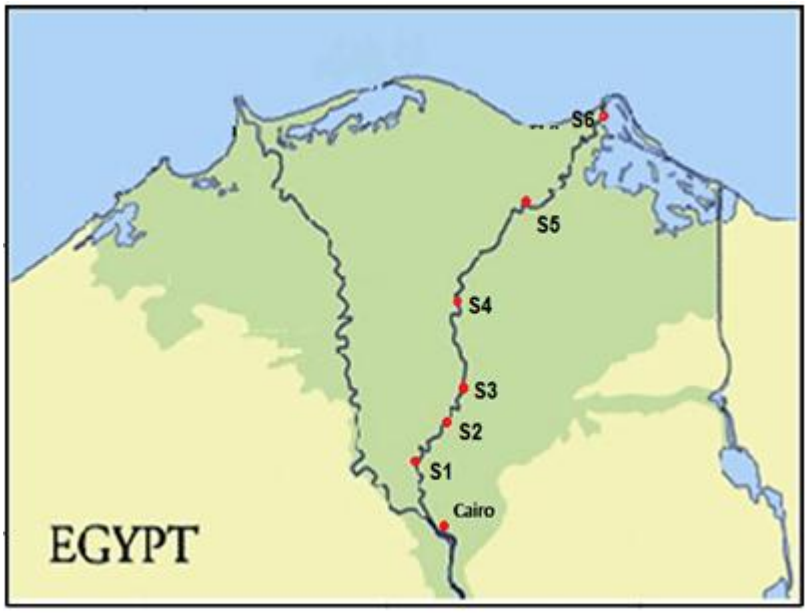

Fig. 1. The Nile Delta map showing several sample locations along the Damietta branch of the Nile River

Water samples

Surface water was taken from locations distributed around the branch from the main channel and two banks using a water sampler.

Water analysis

Electrical conductivity and dissolved oxygen for water samples collected at the stations were determined in the Hydro-Lab, while ammonia was colorimetrically determined **(Sauter & Stoup, 1990)**. However, nitrite and nitrate were measured by ion chromatography (I.C.) (model DX-600, USA) as described in **APHA (2005)**.

Sediment sample

Sediment samples were taken by Ekman grab sampler. The sediment has a sandy clay texture. The examined region presented varying height and width topography. The depth of water varies from 12 to 20m. Samples were oven dried for 48hrs and then grinded and kept in dry, hygienic plastic bags. The sediment was taken from the middle of the branch. The method of **Kouadia and Trefry (1987)** was used for sediment digestion. The mixture of HNO_3: H.F.: $HClO_4$ was used for digestion. For each 0.5 gm of nitric (4 ml), $HClO_4$ (4ml) and H.F. (15ml) were added. The mixture was heated at 80◦C until dryness, and then 2ml of $HClO_4$ was added with evaporation till dryness. Further, 2ml of HCl and 10ml of distilled water were added to the rest. Conc. HNO_3 (0.5ml) was then added and completed with distilled water

Fish samples

Oreochromis niloticus specimens were collected from the same sediment sampling sites, and fishermen collected water samples. The weight (g) and length (cm) were determined, and a block of muscle, liver and gills was divided to separate organs. Heavy metals were extracted from tissue and digested by acid **(Hseu, 2004)**.

Heavy metals measurement

According to **APHA (2005)**, flame atomic absorption spectrophotometry was used to evaluate the concentrations of six metals in fish, water, sediment and tissues.

Metal pollution index (MPI)

It was implemented using the following equation:

$$MPI = (M_1 \times M_2 \times \ldots \times M_n)^{1/n} \quad \text{eq (1)}$$

Where, M_n is the quantity of metal in fish ((mg/kg dry wt.) **(Useroeal, 1997)**

.**Bioaccumulation factor (BAF) in tissues**

It is the amount of the contaminant in the tissue to the quantity in the surrounding ecology (U.S. EPA, 2010). The bioaccumulation factors (BAFs) were obtained by the following equation **(Barron, 2006):**

$$BAF = (M_t/M_w) \quad \text{eq (2)}$$

Where, M_w is the quantity in water (mg/l), and M_t is the quantity in tissue (mg/kg).

Average daily dose (ADD)

The amount of exposure generated by consuming a particular chemical in a fish edible organ can be calculated using this equation and an estimate of a daily consumption:

$$\text{Average Daily Dose (mg/kg/day)} = (C \times IR \times EF)/(B_w \times AT) \quad \text{eq (3)}$$

Where, C is the metal in the organ (mg/kg); I.R. is the ingestion rate; E.F. (Exposure frequency) is equal to 365 days/year; E.D. is the exposure period in the year; B.W. is the Body weight, and AT is the average time **(Jayaprakash *et al.*, 2015)**.

Hazard index (H.I.)

The following equation evaluates the hazard index:

$$\text{Hazard Index} = \text{ADD/Oral RfD} \quad \text{eq (4)}$$

Where, Oral RfD = Oral Reference dose of chemical (mg/kg/day) considering the oral reference doses (RfD) **(USEPA, 2011)**.

RESULTS

The physicochemical parameters of the water sampled from the analyzed locations are displayed in Table (1), with all measures. The current findings revealed that the values of E.C., BOD, NH_3, NO_2 and NO_3 were directly related to the pollution activities; however, D.O. levels were negatively related to them (Table 1).

Table 1. Physicochemical properties of water taken from the study sites, mean S.E. **n=6**

	S1	**S 2**	**S 3**	**S 4**	**S 5**	**S 6**
Electric conductivity	370±14.5^{d}	377±18.34^{c}	473±23.45^{d}	489±2.34^{b}	546±23.45^{a}	623±23.56^{d}
Dissolved oxygen (mg/l)	7.16 ± 0.23^{b}	7.29 ± 0.55^{d}	4.83 ± 0.25^{a}	4.31 ± 0.31^{b}	3.92 ± 0.98^{a}	1.67 ± 0.34^{b}
Biological oxygen demand (mg/l)	3.3 ± 0.71^{a}	3.9 ± 0.56^{d}	11.23 ± 0.96^{b}	12.34 ± 0.6^{d}	14.12 ± 0.51^{b}	23.12 ± 0.97^{a}
Ammonia (mg/l)	0.67 ± 0.45^{b}	0.98 ± 0.45^{a}	7.12 ± 0.67^{c}	8.02 ± 0.56^{c}	9.35 ±5 0.34^{c}	9.97 ± 0.89^{a}
Nitrite (µg/l)	14.56 ±2.45^{b}	15.45 ± 2.67^{c}	25.34 ± 2.34^{c}	27.26 ± 3.45^{b}	36.45 ± 2.26^{d}	44.23 ± 3.1^{b}
Nitrate (µg/l)	33.34 ±4.71^{a}	37.67 ± 4.71^{c}	53.3 ± 3.23^{a}	55.2 ± 3.45^{a}	75.34 ± 3.18^{a}	62.15 ± 3.45^{b}

The results indicated that no significant differences (P<0.05) were observed among the means with the same letter in the row.

Whereas, Table (2) shows the concentrations of metals in sediment and water samples obtained from locations under study. The examined metal levels revealed varying degrees of pollution, with a very significant rise in station 6, compared to the reference site.

The seasonal variations of the amount of the metals in water, with respect to Fe, Zn, Mn, Pd and Cd were measured in water samples. The outcomes display that higher concentration in S6 is related to control station S1. This was owing to the contamination from agricultural and industrial drains. The measured metal concentrations in water were determined, with Fe at its maximum level and Cd at the lowest. The accumulation of metals in the water was in the following sequential order: Cd<Zn<Cu<Pb<Mn<Fe.

Table (1) displays the amount of metals (Fe, Zn, Mn, Pb, and Cd) in chosen organs (liver, Gills and muscles) of *O. niloticus* from the study region.

Table 2. Heavy metals content in water samples (mg/l) and sediment samples (mg/kg dry wt.)

		S1	S 2	S3	S4	S5	S6
Fe							
	water	0.24 ± 0.03[a]	0.31 ± 0.02[c]	0.47±0.06[b]	0.51±0.02[a]	0.56±0.03[a]	0.75±0.06a
	sediment	246.5±31.51[a]	251.5±34.55[c]	376.34±21.45[c]	393.56±35.67[a]	454.34±56.45[d]	554.78±43.23[d]
Cu							
	Water	0.014±0.002[a]	0.016±0.004[b]	0.023±0.005[b]	0.026±0.006[c]	0.039±0.004[a]	0.046±0.005[a]
	sediment	0.81±0.12[a]	0.94±0.20[b]	4.12±0.78[b]	5.78±1.2[b]	7.89±2.56[a]	12.34±3.4c
Zn							
	Water	0.016±0.004[c]	0.018±0.003[d]	0.039±0.004[b]	0.045±0.005[a]	0.058±0.003[a]	0.08±0.004[b]
	sediment	3.89±0.67[c]	4.34±1.1[d]	8.4±2.4[b]	9.2±2.3[b]	14.56±2.6[b]	18.45±3.61[b]
Mn							
	Water	0.028±0.006[b]	0.031±0.005[b]	0.126±0.023[b]	0.134±0.004[c]	0.254±0.005[a]	0.323±0.006[a]
	sediment	40.45±2.45[b]	45.34±4.56[b]	57±5.89[d]	61.78±11.4[c]	78.88±9.78[b]	99.14±12.78[b]
Pb							
	Water	0.018±0.004[b]	0.025±0.003[a]	0.036±0.001[a]	0.039±0.003[c]	0.049±0.006[b]	0.063±0.004[d]
	sediment	0.23±0.01[a]	0.27±0.3[a]	0.64±0.06[a]	0.74±0.07[c]	0.93±0.006[b]	1.2±0.01[d]
Cd							
	Water	0.001±0.0004[c]	0.0015±0. 0001[a]	0.002±0.001[b]	0.002±0.001[a]	0.0024±0.002[a]	0.0027±0.001[d]
	sediment	0.01±0.002[c]	0.014±0.003[a]	0.019±0.005[b]	0.02±0.003[a]	0. 023±0.004[a]	0.028±0.004[d]

The results indicated that no significant differences (P<0.05) were observed among the means with the same letter in the row.

On the other hand, Table (3) shows that the iron values were 82.56- 545.89, 65.78–439.89 and 8.78–98.78mg/ kg dry wt. for liver, gills and muscles, respectively. The average levels were noticed in the following order: liver < gills < and muscles. Copper values were 2.29–14.67, 1.87–11.23 and 1.76–7.89mg/ kg dry wt. for liver, gills and muscles, respectively. The average levels were identified in the following order: liver < gills < and muscles. Zinc values were 14.89-59.45, 9.56-41.56 and 3.34- 23.89mg/ kg dry wt. for the liver, gills and muscles, respectively. The average levels were identified in the following order: liver < gills < and muscles. While, manganese values ranged from 8.89–57.56, 6.82– 36.34, and 1.78–4.67mg/ kg dry wt. for the liver, gills, and muscles, respectively. For lead values, they were 0.47-7.56, 0.32-4.93 and 0.21-2.82mg/ kg dry wt. The average levels were identified in the following order: liver< gills< muscles. Whereas, cadmium values were in the ranges of 0.12-1.98, 0.09- 1.12 and 0.04- 0.56mg/ kg dry wt. for liver, gills and muscles, respectively.

Table 3. *O. niloticus* bioaccumulated metals in various organs (mg/kg dry wt), mean S.E., **n =6**

	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**P. L.**
Fe							
Liver	82.56±11.89^{b}	256.78±21.67^{b}	278.67±25.98^{c}	355.84±31.89^{c}	402.76±35.78^{a}	545.89±35.9^{b}	100^{A}
Gills	65.78±8.91^{b}	214.78±24.89^{b}	247.89±31.78^{c}	286.78±28.67^{c}	325.78± 29.56^{a}	439.89±29.09^{b}	
Muscles	8.78±1.02^{b}	56.93±6.89^{c}	67.81±11.56^{c}	71.78±7.89^{c}	87.34±12.78^{b}	98.78±17.98^{b}	
Cu							
Liver	2.29±0.34^{a}	7.38±0.89^{c}	7.98±1.1^{b}	9.78±2.67^{d}	11.78±2.67^{c}	14.67±3.98^{c}	30^{A}
Gills	1.87±0.29^{a}	6.98±0.78^{c}	7.41±1.23^{b}	8.45±1.98^{d}	9.87±2.78^{c}	11.23±2.98^{c}	
Muscles	1.76±0.23^{a}	3.12±0.98^{c}	4.56±0.89^{b}	5.56±0.78^{d}	6.89±2.87^{c}	7.89±1.89^{c}	
Zn							
Liver	14.89±2.89^{b}	29.67±4.89^{a}	33.34±4.89^{d}	38.89±4.78^{b}	44.78±5.81^{c}	59.45±5.89^{a}	100^{A}
Gill	9.56±1.67^{b}	17.78±3.89^{b}	23.56±2.78^{d}	28.89±3.78^{b}	35.89±2.89^{c}	41.56±4.78^{a}	
Muscles	3.34±0.78^{b}	7.86±1.78^{b}	11.78±1.78^{c}	15.89±3.89^{b}	18.78±1.39^{c}	23.89±2.9^{a}	
Mn							
Liver	8.89±0.78^{a}	14.89±2.89^{c}	19.78±2.89^{a}	27.76±3.89^{a}	38.56±4.08^{b}	57.56±4.19^{c}	1^{A}
Gills	6.82±0.78^{b}	10.78±1.89^{c}	15.78±2.76^{a}	20.78±3.89^{a}	26.78±3.18^{c}	36.34±3.28^{b}	
Muscles	1.78±0.05^{b}	2.78±0.12^{b}	3.17±0.89^{a}	3.78±0.90c^{a}	4.27±0.98^{c}	4.67±0.78^{b}	
Pb							
Liver	0.47±0.03^{c}	2.91±0.09^{b}	3.74±0.11^{b}	4.83±0.81^{c}	5.89±1.11^{d}	7.56±1.23^{b}	0.5^{A}
Gills	0.32±0.02^{c}	1.47±0.08^{b}	2.11±0.21^{b}	2.83±0.76^{c}	3.67±0.92^{d}	4.93±0.87^{b}	
Muscles	0.21±0.01^{c}	0.8±0.05^{b}	1.42±0.09^{b}	1.82±0.67^{b}	2.31±0.87^{c}	2.82±0.78^{b}	
Cd							
Liver	0.12±0.004^{d}	0.39±0.03^{a}	0.44±0.04^{c}	0.89±0.01^{b}	1.12±0.3^{b}	1.98±0.31^{c}	
Gills	0.09±0.004^{d}	0.28±0.02^{a}	0.34±0.05^{c}	0.45±0.02^{b}	0.92±0.2^{b}	1.12±0.21^{c}	
Muscles	0.04±0.001^{d}	0.19±0.02^{a}	0.24±0. 04^{c}	0.29±0.01^{b}	0.32±0.01^{b}	0.56±0.13^{c}	

The results indicated that no significant differences (P<0.05) were observed among the means with the same letter in the same row.

P. L. permissible limits according to ^{A}**FAO/WHO (1989)**

Obviously, based on the outcoms, the metal ions bioaccumulated in the liver are higher than others, while the lowest level was detected in the meat (Table 4). The heavy metals accumulate in fish by absorption consuming polluted sediment, or through food or gills **(Pallaya-Baleta *et al*., 2022)**. Heavy metal accumulation is related to numerous reasons, such as the pollutants in sediment, water, size, diet and sex in addition to feeding ways.

Table 4. BAF of the tested metals (l/kg) in various organs of *O. niloticus* at locations under study

	S1	S2	S3	S4	S5	S6
Fe	344	828.32	592.91	697.72	719.21	727.85
	274.08	690.3226	527.42	562.31	581.75	586.52
	36.583	183.6452	144.27	140.74	155.96	131.70
Cu						
	163.57	461.25	346.95	376.15	302.05	318.91
	133.57	436.25	322.17	325	253.07	244.13
	125.71	195	198.26	213.84	176.66	171.52
Zn						
	930.62	1648.33	854.87	864.22	772.06	743.12
	597.5	987.77	604.10	642	618.79	519.5
	208.75	436.66	302.05	353.11	323.79	298.62
Mn						
	317.5	480.32	156.98	207.16	151.81	178.20
	243.57	347.74	125.23	155.07	105.43	112.50
	63.57	89.67	25.15	28.20	16.81	14.45
Pb						
	16.78	93.87	29.6	36.04	23.18	23.40
	11.42	47.41	16.74	21.11	14.44	15.26
	7.5	25.80	11.26	13.58	9.09	8.73
Cd						
	6.66	15.6	12.22	22.82	22.85	31.42
	5	11.2	9.44	11.53	18.77	17.77
	2.22	7.6	6.66	7.43	6.53	8.88

Bioaccumulation happens both through water and the transformation of food to organs. Previous research has shown that metal levels are negatively related to trophic status, and that fish diet is the main factor contributing to organ metal buildup. Usually, metal levels were concentrated lower in muscles, gills and liver. Hence, it is predictable that, the head includes other metals; this is why the gills are not appropriate for human food, and they should be removed in addition to the metal accumulating in the head.

Pb and Mn levels are above the acceptable limits set by FAO for the muscles, while all the elements are higher in the liver and gills than the acceptable limits of FAO. High Pb concentrations significantly concern human intake and the natural environment. As a result, the source of the Pb contamination must first be identified. The major sources of lead contamination in the Nile River are the industrial discharges. Besides, the use of lead-containing pesticides and fertilizers in agriculture can result in soil and water

contamination with lead **(Redwan & Elhaddad 2020)**, and thus, pollution prevention measures must be implemented. On the other hand, the high Cd concentrations seen in muscle should be considered.

Table (4) presents the outcomes of BAF of chosen tissue of *O. niloticus*. Fe, Zn and Cd had the highest accumulated concentration, while Pb and Cd showed the lowest. It was found that the maximum BAF was in the liver. The muscle considered had the lowest bioaccumulation factor.

In addition, Table (5) shows the MPI of H.M. in the muscles of *O. niloticus*. MPI of H.M. was arranged as follows: S6 > S5 > S5 > S3>S2>S1.

Table 5. Metal pollution index (MPI) of the analyzed metals in *O. niloticus*

	Liver	**Gills**	**Muscles**
Station1	4.96	2.13	0.73
Station 2	4.11	3.45	0.84
Station 3	10.47	7.93	1.98
Station 4	10.67	8.32	2.34
Station 5	16.61	11.67	4.22
Stattion 6	25.12	18.03	7.45

Table 6. Average daily dose (ADD) of heavy metals for fish samples

	S1	S2	S3	S4	S5	S6
Fe	0.0039	0.0253	0.0302	0.0319	0.0389	0.0440
Cu	0.0007	0.0013	0.0020	0.0024	0.0030	0.0035
Zn	0.0014	0.0035	0.0052	0.0070	0.0083	0.0106
Mn	0.0007	0.0012	0.0014	0.0016	0.0019	0.0020
Pb	0.00009	0.0003	0.0006	0.0008	0.001	0.0012
Cd	1.783E-05	8.47E-05	0.0001	0.0001	0.0001	0.0002

The muscle Fe, Cu, Zn, Mn, Pb, and Cd values did not exceed one, suggesting that ingesting the tested fish poses no health risk.

All elements investigated in the current study had H.M. values lower than 1. Although Pb had the maximum THQ, followed by Cd > Zn > Fe > Cu>Mn, while S6 had the maximum THQ, proceeded by S6 > S5 > S4>S3>S2>S1(Table 7).

Table 7. The target hazard quotient (THQ) and hazard index (H.I.) of the predicted metals induced by muscle consumption

THQ	S1	S2	S3	S4	S5	S6
Fe	0.006	0.039	0.057	0.049	0.061	0.068
Cu	0.006	0.01	0.015	0.018	0.022	0.025
Zn	0.007	0.016	0.024	0.033	0.039	0.049
Mn	0.005	0.008	0.009	0.011	0.012	0.013
Pb	0.026	0.1	0.177	0.227	0.288	0.352
Cd	0.018	0.08	0.107	0.129	0.143	0.25
HI	0.067	0.26	0.38	0.47	0.56	0.77

DISCUSSION

The high values of various physicochemical parameters and the significant decrease in dissolved oxygen (D.O.) levels indicate a deterioration in water quality. Elevated levels of biochemical oxygen demand (BOD) indicate increased biological activity, excessive microorganism growth and significant biological contamination of the water **(Avigliano *et al.*, 2019)**.

Additionally, high concentrations of nitrite and nitrate in water indicate the active biological processes occurring, which can lead to decreased oxygen levels and excessive algae growth **(Avigliano *et al.*, 2019)**. In this respect, **Bramha *et al.* (2014)** found that, the decomposition of floating organic matter can result in a decline in D.O. levels, forcing fish to increase their breathing rate to compensate low oxygen concentrations. This high breathing rate increases the accumulation of pollutants through the gill membranes, and prolonged exposure to low oxygen levels can make fish more vulnerable to other environmental stressors.

The presence of highly active contaminants, such as effluent and sewage discharge, agricultural runoff and organic matter degradation can be indicated by elevated ammonia (NH_3) levels in the water. Heavy metal analysis in sediments is a more practical and effective method for measuring the level of water contamination and identifying the

sources of pollution. For instance, industrial pollution and sewage discharge can result in high levels of heavy metals in sediments **(Ishak *et al*., 2020)**.

This is mainly due to significant amounts of inorganic and organic contaminants in water and the accumulation of animals and other metal-rich debris. The levels of heavy metals in the sediments were several times higher than those recorded in the water column **(Khalil *et al*., 2017)**.

Furthermore, some metals can bind with biological molecules in water, accumulating metals in the sediments. When polluted particulate matter or sedimentary material enters the ecosystem, it mixes with detritus, water and living food items, leading to continuous contamination of all environmental matrices. Metals accumulate primarily in aquatic organisms' livers, gills and muscle organs at lower levels **(Abdel Rahman *et al*., 2017)**.

The elevated levels of heavy metals in contaminated fish samples compared to the reference concentrations can be attributed to the continuous discharge of metals into the site, leading to the absorption and bioaccumulation of these metals in various fish organs **(Elabd *et al*., 2019)**. Studies have demonstrated that the liver is a compelling target organ for metal bioaccumulation, as it plays a crucial role in pollutant storage, transformation and redistribution **(Pyle *et al*., 2005; Ylmaz *et al*., 2010)**. Copper absorption in the liver may be related to this organ's metabolic functions and Cu-catalyzed reactions **(Amin & Almahasheer, 2021)**. The low levels of heavy metals found in the muscular tissue could be attributed to the accumulation in the liver **(Dural *et al*., 2007)**. Moreover, low metal content in fish flesh might indicate low metallothioneins (M.T.s) **(Ylmaz *et al*., 2007)**. The mucosal surface on the surface of the fish skin acts as a barrier against metal ions, thus maintaining the quality of the fish flesh. The gill tissue of contaminated fish showed the highest concentrations of heavy metals compared to the muscle tissue, which could be attributed to the trapping of metals by M.T.s **(Ali & El-Magd, 2016)**. The gill epithelia are covered in a protective mucus layer, which functions as an ion exchange mechanism and helps in trapping heavy metals **(Ali & El-Magd, 2016)**.

The elevated levels of heavy metals found in fish gills can be attributed to their absorption through the protective mucus that serves as an ion exchange mechanism. In contrast, the lower levels reported in the muscle tissue compared to the gills suggest that gills are the primary route of heavy metal absorption from the water **(Salah *et al*., 2021)**. Due to their high concentrations of metallothioneins (M.T.s), the liver and gill tissues can act as sinks for toxic elements in contaminated fish. The presence of heavy metals in the liver might also be due to the stimulation of M.T.s that bind to them. **Masoud *et al*. (2007)** reported that the gill tissue exhibits significant heavy metal accumulation. This could be due to the competition between heavy metals and calcium for uptake locations in the gills. Moreover, **Rogers and Wood (2004)** found that heavy metals could be ingested by fish through Ca^{2+} uptake pathways in branches, leading to interaction at gill uptake sites. The acceptable daily intake (ADD) levels in fish muscle were lower than the

oral reference dose (RfD) recommendations for all the metals investigated, indicating that consuming infected muscle tissue poses no health risks. The target hazard quotient (THQ) levels in the muscle for Fe, Cu, Mn, Pb, and Cd were below one, suggesting that eating the tested fish is safe. Therefore, consuming muscle tissue at the current rate does not pose any health risk to consumers. The main objective of studying the fish in this area is to determine the presence of harmful metals in the commercially available fish that face contamination in the Damietta branch. The bioaccumulation levels of metals in edible flesh can provide valuable insights into the impact of certain metals on biology at elevated concentrations beyond just evaluating health hazards **(Anli & Atlı, 2003)**. The health index (H.I.) results did not pose any health threats to humans, but caution should be taken if fish is considered a primary source of protein. The bioaccumulation effect is linked to the aqueous metal level in the examined fish's environment. The accumulation of metals in aquatic biota is a complex interaction between internal and external factors, including the bioavailability of metals, the physicochemical characteristics of the surrounding water, and the type, gender and physiological state of the organism **(Malins, 2018)**. In general, less efficient bioaccumulation occurs with non-essential metals than with essential metals, which have high bioaccumulation efficiency in various tissues. The increased bioaccumulation factor (BAF) of essential elements can be attributed to their role as activators of various enzymes present in fish **(Jayaprakash *et al*., 2015)**. These findings are consistent with those of **Elgaml *et al*. (2019)**, who reported the highest BAF levels of Pb, Mn, Fe and Zn in liver and gill tissues **(Baki *et al*., 2018)**. The study's main objective was to identify and quantify potentially hazardous metals in the edible tissue of fish exposed to varying levels of pollution along the Nile River.

CONCLUSION

The study results indicate that tilapia can bioaccumulate a range of metals in its organs, making it a valuable bioindicator for monitoring metal contamination in aquatic environments. Results showed that all sampling locations exhibited varying metal accumulation in water, sediment and fish. The presence of certain bioaccumulated metals in edible fish tissue near or exceeding safety threshold values raised concerns about potential health risks to consumer.

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