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Assessment of some heavy metals contamination and thier pollution indices in water and fish organs of (*Oreochromis niloticus* and *Clarias gariepinus*) in Burullus and Edku lakes, (A comparative study)

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ABSTRACT
The present study aims to investigate some heavy metal concentrations in water and fish organs (liver, gills and muscle) of Oreochromis niloticus and Clarias gariepinus in Edku and Burullus lakes. In addition, estimate pollution indices such as Pollution index (PI), heavy metal evaluation index (HEI), contamination index (Cd), and its potential health risk assessment (HQdermal). Also, the health risks from fish muscle consumption (THQS) and Bioconcentration factor (BCF). Heavy metals concentrations in water were found in the following order Fe > Zn > Mn > Pb > Cd in Burullus lake, whereas they follow the order of Fe > Mn > Pb > Zn > Cd in Edku lake. Where, Edku lake ranked as second after Burullus lake in accumulation of metals (Mn, Zn, Pb) with slightly increasing in concentrations of Fe and Cd. For, the same heavy metals in fish organs of the two examined species in Burullus and Edku lakes had the order: Fe> Zn> Mn> Pb> Cd and the residues of all investigated heavy metals in liver and gills of the both examined fish species were much higher than that in their muscles. The pollution indices showed that both lake's water is highly contaminated based on PI, HEI and Cd. where PI average values of Fe and Cd were higher in Edku lake than Burullus lake. While, PI average values for Mn, Zn and Pb were higher in Burullus lake than Edku lake. Values of HQdermal, THQS and their HI were lower than 1 for all heavy metals from all sites in both lakes during the study seasons. From the above results, it's concluded that the two lakes suffer from different types of pollution and the control of this pollution depends on the treatment of sewage, agricultural and industrial wastes before dumping into these lakes.

INTRODUCTION

Pollution of the aquatic environment by inorganic and organic chemicals is a major factor posing serious threat to the survival of aquatic organisms including fish **(Aly *et al.*, 2020)**. And human may be affected by these pollutants through consumption of contaminated fish and other aquatic foods from this environment **(Aderinola *et al.*, 2009)**.

Heavy metals considered a critical concern to aquatic ecosystem contamination due to their potential toxicity and accumulation in aquatic habitats (**Tscheikner-Gratl *et al*., 2019)**. In Egypt, environmental pollution with heavy metals is one of the biggest problems that face human being. Metals are natural trace components of the aquatic ecosystem, but their levels have been increased due to industrial wastes, geochemical structure, agricultural and mining activities **(Al Naggar *et al*., 2018)**.

Egyptian coastal lakes considered an important source of aquaculture sectors. These lakes occupy about 13% of worldwide coastal areas and 25% of total wetlands of the Mediterranean **(Saad, 2003)**. The Egypt's northern Delta Lakes represented by the main five lakes (Manzala, Edku, Burullus, Mariout and Bardawil Lakes). These Lakes are situated on the Mediterranean Coast of the Delta and cover about 6% of the non-desert surface area of Egypt. And have an important natural resource for fish production in Egypt. These Lakes have always contributed more than 40% of the country's total fish production, but at present this percentage has been decreased to less than 12.22% **(GARFD, 2013)**. The northern coastal-deltaic lakes (Edku, Burullus and Manzala) suffer from serious environmental pollution as they receive agricultural drainage, industrial wastewater as well as domestic wastewaters directly without any treatments **(Shalaby *et al*., 2017)**.Tilapia species including *Oreochromis niloticus*, *Oreochromis aureus*, *Sarotherodon galilaeus* and *Tilapia zillii* ranked first followed by *Clarias gariepinus* in the fish production of the Egyptian Lakes **(Saeed and Shaker, 2008; Zahran *et al*., 2015)**.

Burullus Lake is the second largest coastal lake in Egypt. It has received a great attention because of its environmental and economic importance for being a significant source of fish production in Egypt. It is suffering from changes in water quality that resulted from the high load of effluents discharged directly into it **(Darwish, 2011; Aly *et al*., 2020)**. It receives about 4.1 billion m^3 drainage water annually through a system of eight drains, namely, West El-Burullus, Gharbia Drain, El-Khashaah Drain, Tirrah Drain, Drain No. 7, Drain No. 8, Drain No. 9, and El-Hoks Drain, as well as Brinbal Freshwater Canal **(EMI, 2012)**. Agricultural lands encompass the southern and eastern fringes of the lake.

Edku Lake is the third largest wetland area in the Nile Delta. It lies just west of Rosetta branch of River Nile and currently covers an area of about 62.5 km^2, which represents less than the half of its original size (120 to 130 km^2) **(Zaghloul and Hussein, 2000)**. Edku lagoon represent about 15% of the total commercial fishing areas in Egypt **(Abdel-Hamid, 2017)**. The Lake receives huge amounts of drainage water from two main drains; El-Khairy and Barsik drains. The water sources of El-Khairy Drain are from three drains denominated: El-Bousely, Edku and Damanhour sub-drains, transporting domestic, agricultural and industrial wastes as well as the drainage water of more than 300 fish farms. Barseek Drain transports mainly agricultural drainage water to the lake **(Okbah and El-Gohary, 2002; Badr and Hussein 2010)**. These drains responsible for increasing the contamination in the Lake and Increasing contamination associated with increasing levels of heavy metals which adversely affected the fishery **(Shetaia *et al*., 2020)**.

Therefore, the present study aims to investigate some heavy metal concentrations in water and fish organs of *Oreochromis niloticus* and *Clarias gariepinus* in Edku and

Burullus Lakes. Moreover, evaluate some pollution indices such as Pollution index (PI), heavy metal evaluation index (HEI), contamination index (C_d), and its potential health risk assessment (HQ_{dermal}). Besides, health risk from fish muscle consumption (THQ_S) and Bioconcentration factor (BCF).

MATERIALS AND METHODS

Study region

Burullus Lake is situated in a middle locus between the two branches of the Nile that forms the Delta. It extends between 30° 22′31° 35′ N and 30° 33′31° 08′ E. It connects to the sea through a narrow strait called Al-burg inlet or Boughaz El-Burullus at its northeast side **(EMI, 2012)**. The average area of the lake is 370 km^2 with an average tall and width about 70 km and 17 km, respectively **(GAFRD, 2013)**.

Edku Lake is situated west of Rosetta Nile branch (about 30 km E of Alexandria) between longitudes 30º 30` and 30º 23` E and Latitudes 31º 10` and 31º 18` N (Fig. 1). It has an average depth of about 1 meter, a surface area of about 85 km^2 and water volume of about 85.0×10^6 m^3 **(Saeed, 2013)**.

Sampling protocol

Burullus Lake was divided to nine sites and Edku Lake divided to seven sites (Fig. 1). Selected sites location was determined using Geographic Positioning System (GPS) (Table 1). Surface water samples were collected by a PVC vertical water sampler at a depth of 50 cm from different places at each selected sampling site of the two Lakes during four seasons for the year 2019. One liter of water samples at each site was placed in polyethylene bottles previously washed with acid (0.01 N HNO_3) and rinsed by distilled water, then placed in a cooler at 4 °C in an ice box and transferred to the lab for further analysis according to **APHA (2000)**.

Fish samples (5-10 specimens of *Oreochromis niloticus* and *Clarias gariepinus*) were collected fresh from the local fishermen during the same period of water sampling. Fish samples were stored by ice inside an icebox until they were transferred to the laboratory. The samples were dissected to obtain organs (liver, gills and muscles), placed in polyethylene bags and then frozen until they were analyzed.

Analyses methods

Water samples were digested by Nitric Acid Digestion method for heavy metals concentration according to **APHA (2000)**. One gram of each of the selected organs (liver, gills and muscle) of the examined fish species was oven dried, ignited and digested with concentrated acids (HNO_3 and HCl) according to procedures recommended by **AOAC (2005)**. Finally, all samples were analyzed using Flame Atomic Absorption Spectrophotometer (Thermo Electron Corporation S Series AA Spectrometer) for iron (Fe), Manganese (Mn), zinc (Zn), Lead (Pb) and cadmium (Cd) as mg/l for water and μg/g as dry weight (d.w.) for fish organs tissues. Where, Wet weight conc. = dry wt. x (100 - % moisture) / 100, to compare with safe standard permissible limits for human consumers .

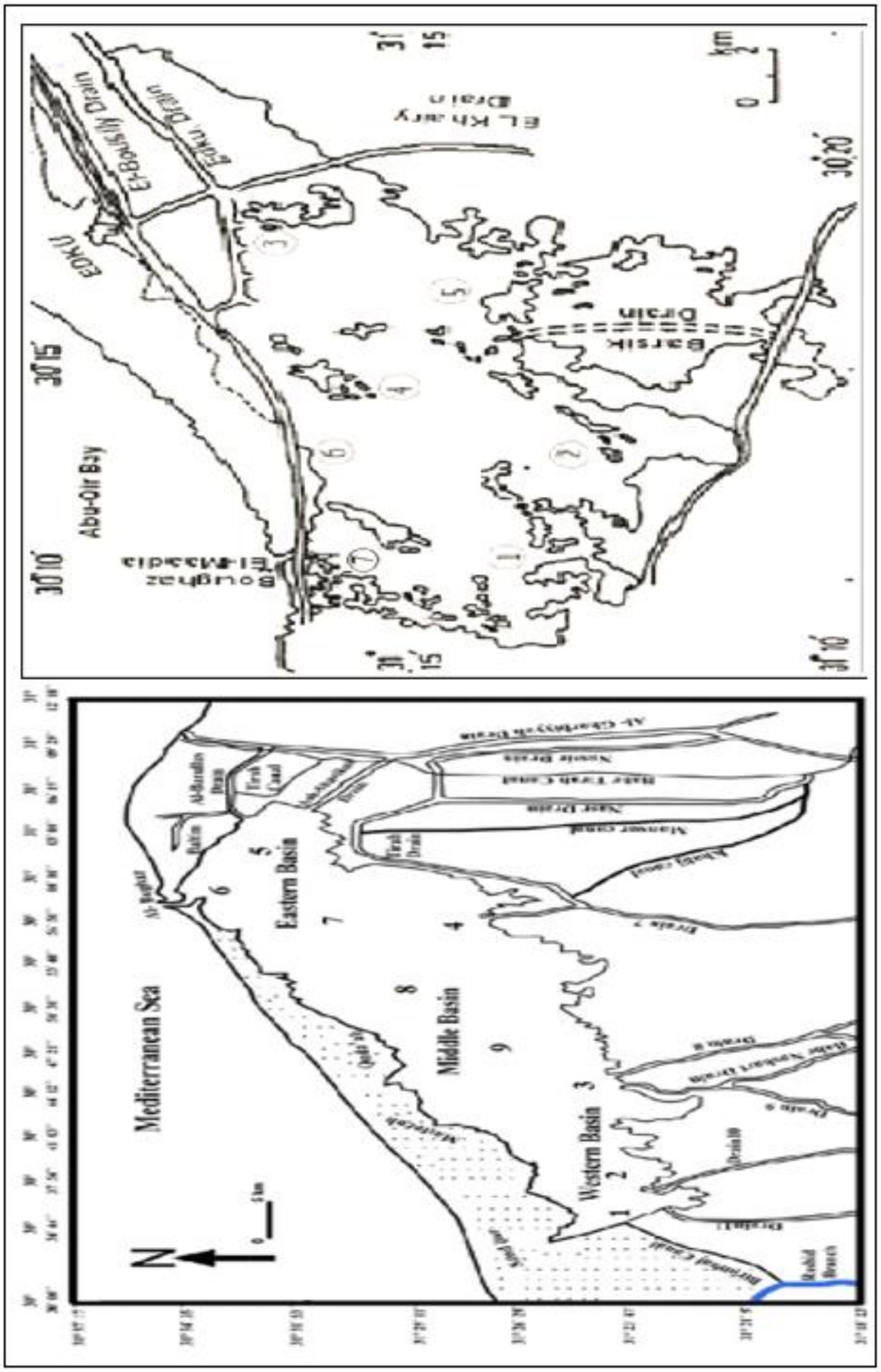


Fig. 1. Sampling sites in the two studied lakes (Burullus and Edku)

Sites	Burullus lake		Edku lake	
	latitude	longitude	latitude	Longitude
1	31° 24.082'N	30° 35.731'E	31° 14.878'N	30° 10.505'E
2	31° 23.978'N	30° 37.543'E	31° 13.997'N	30° 11.394'E
3	31° 24.972'N	30° 45.328'E	31° 15.788'N	30° 17.834'E
4	31° 28.051'N	30° 56.075'E	31° 15.025'N	30° 13.123'E
5	31° 32.739'N	31° 3.531'E	31° 14.842'N	30° 14.004'E
6	31° 33.719'N	30° 58.822'E	31° 15.627'N	30° 12.353'E
7	31° 31.606'N	30° 56.702'E	31° 15.672'N	30° 10.733'E
8	31° 29.307'N	30° 53.731'E	-	-
9	31° 27.069'N	30° 48.658'E	-	-

Table 1. Sampling sites in in the investigated Lakes (Burullus and Edku).

Pollution Assessment Indices

Several pollution indices were employed to determine the pollution status of heavy metals in Burullus and Edku lakes.

Pollution Index (PI): Pollution index is based on individual metal calculations and categorized to five classes (Table 2) according to the following equation **(Caeiro *et al.*, 2005)**:

$$PI = \frac{\sqrt{\left[\left(\frac{Ci}{Si}\right)^2_{max} + \left(\frac{Ci}{Si}\right)^2_{min}\right]}}{2}$$

Where Ci is the concentration of each element, and Si is the standard values according to **CCME (2007)**.

Table 2. Categories of water pollution index.

Class	PI value	Class
1	<1	No effect
2	1–2	Slightly affected
3	2–3	Moderately affected
4	3–5	Strongly affected
5	>5	Seriously affected

Heavy Metal Evaluation Index (HEI)

HEI represents the overall surface water quality with respect to heavy metals content, and is calculated by the following equation **(Al-Ani *et al*., 1987; Ameh, 2013)**:

$$HEI = \sum_{i=1}^{n} \frac{M_i}{MAC_i}$$

Where, M_i and MAC_i are the monitored value and maximum admissible concentration of the ith parameter, respectively. The calculated HEI values could be classified as <10 for low, 10 - 20 for moderate and >20 for high pollution.

Contamination Index (C_d)

The C_d is computed separately for each sample of water analyzed, as a sum of the contamination factors of individual components exceeding the upper permissible value **(Edet and Offiong, 2002)** and determined as:

$$C_d = \sum_{i=1}^{n} C_{fi}$$

$$C_{fi} = \frac{C_{Ai}}{C_{Ni}} - 1$$

Where, C_{fi} = contamination factor for the i-th component, C_{Ai} = analytical value for the i-th component, C_{Ni} = upper permissible concentration of the i-th component (N denotes the ‘normative value’) and C_{Ni} is taken as MAC. The computed C_d values could be classified as: low (C_d<1), medium (C_d = 1-3) and high (C_d >3).

Human health Risk Assessments

Risk assessment is defined as the method of assessing the possibility of occurrence of any given possible magnitude of adverse health effects over a specified time period and is a function of the hazard and exposure. Meanwhile, the potential exposure of humans to trace metals could be through three main pathways such as direct ingestion, inhalation and dermal absorption through exposed skin **(USEPA, 2004; Wu *et al*., 2009; Meng *et al*., 2016)**. Fishermen population spends more time with contact with lake water during fishing. Therefore, the exposure dose for dermal absorption through exposed skin was calculated as the following:

$$CD_d = \frac{Cw \times SA \times Kp \times ET \times EF \times ED \times CF}{BW \times AT}$$

Where CD_d is the dermal absorption, µg/kg/day; *Cw* is the concentration of heavy metal in water, µg/l; *SA* is the exposed skin area, in this study, 17,000 cm^2; *Kp* is the skin permeability coefficient in water, cm/h; *ET* is the exposure time during bathing and shower, in this study 0.6 h/day; *EF* is the exposure frequency, in this study 350 day/year assuming that the local inhabitants spend 15 days of the year outside the site; *ED* is the exposure duration, in this study 68 years; *CF* is the unit conversion factor, 1 l/1000 cm^3; *BW* is the average body weight, in this study 65 kg; *AT* is the averaging time (in days), *ED* × 365 days, in this study 23,800. These values were obtained from **Tripathee *et al*. (2016)**.

Human health risk through dermal route assessment was computed using Hazard Quotients (HQs) for metals as the following:

$$HQs = \frac{CD_d}{RfD}$$

Where, *RfD* is the reference dose for different metals, for Fe: 45, Mn: 0.8, Zn: 60, Cu: 12, Pb: 0.42 Hg: 0.0003 and Cd: 0.005 μg/kg/day, according to U.S. risk-based assessments **(USEPA, 2006)**.

Health risk from fish consumption

The target hazard quotient (THQ) is used to determine the non-carcinogenic risk level due to pollutant exposure. To assess the health risk from metal contaminated muscle of fish during this study as the following:

$$\text{THQ} = \frac{\text{MC} \times \text{IR} \times \text{EF} \times \text{ED} \times \text{CF}}{\text{RfD} \times \text{BW} \times \text{ATn}} \times 10^{-3}$$

Where, MC is the heavy metal concentration in muscle of *Oreochromis niloticus* and *Clarias gariepinus* (µg/g d.w.),IR is the fish ingestion rate (49.5 g/kg d.w.) **(BBS, 2011)** EF is the exposure frequency (365 days/year), ED is the exposure duration (30 years) for non-cancer risk as used by USEPA, CF is the conversion factor 0.208 (to convert dry weight to wet weight by considering 79% of moisture content), RfD is the reference dose of individual metal (0.7µg/g for Fe, 0.14µg/g for Mn, 0.3 µg/g for Zn, 0.0036 µg/g for Pb and 0.001 µg/g for Cd) **(USEPA, 2011)**, BW is an average adult body weight(70 kg) and ATn is the average exposure time for non-carcinogens (10,950 days) **(USEPA, 2011)**.

Hazard index (HI)

The hazard index from THQs is denoted as the total of the hazard quotients **(USEPA, 2011)**.

HI = THQ(Fe) + THQ(Mn) + THQ(Zn) + THQ(Pb) + THQ(Cd)

Bioconcentration factor (BCF) estimation

Bioconcentration is a situation in which the levels of a pollutant in an organism exceed the levels of that in the surrounding environment. Bioconcentration factor (BCF) are defined as the ratio of the steady-state metal ion concentrations in the fish tissue vs the concentration in water **(Orata and Birgen, 2016)**. The higher the ratio, the more severe the bioconcentration of pollutants, in this study, the heavy metal level in fish muscle. The BCF were calculated using the following equation **(Gobas *et al*., 2009):**

$$\text{BCF} = \frac{\text{Concentration in fish at steady state (mg/kg wet fish)}}{\text{Concentration in water at steady state (mg/L)}}$$

Where, Tissues with BCF greater than 1,000 are considered high, and less than 250 low, with those between classified as moderate **(Landis *et al.* 2011)**.

Statistical Analysis

The obtained data were subjected to two-way ANOVA to test effect of sites and seasons and interactions between them on heavy metal concentrations in water of Burullus and Edku lakes. While, three-way ANOVA was applied to test the effect of seasons, fish organs, fish species and interactions between them on heavy metal concentrations in fish organs of the two examined fish species studied in the two Lakes. Tukey's Multiple Range's Test was used as a post-hoc test to compare means at $P < 0.05$. The software SPSS, version 17.0 (SPSS, Richmond, Virginia, USA) was used as described by **Dytham (1999)**.

RESULTS AND DISCUSSION

Assessment of heavy metals in water of Burullus and Edku lakes

Water is the most important and precious natural resources that is essential for the survival of living organisms, and which man has exploited more than any other resources for the sustenance of life **(Pyrbot and Laloo, 2015)**. Water pollution occurs when unwanted materials with potentials to threaten human and other natural systems find their ways into rivers, lakes, wells, streams, boreholes or even reserved fresh water in homes and industries **(Aboyeji, 2013)**.

Seasonality variations of heavy metals (Fe, Mn, Zn, Pb and Cd) in the two lakes water were tabulated in Tables (3 and 4). All studied metals affected significantly by sites, seasons and their interaction ($P<0.05$) in the two lakes, except Cd which did not affect significantly by sites, seasons, or their interaction ($P>0.05$) in Burullus lake. Furthermore, Fe have not affected significantly by interaction of sites and season ($P>0.05$) in the same lake.

In Burullus lake, Fe conc. ranged between 0.092- 0.305 mg/l, 0.122- 0.327 mg/l, 0.144- 0.421 mg/l and 0.127- 0.376 mg/l during winter, spring, summer and autumn, respectively. Where, the highest Fe concentrations were recorded at eastern sites (4, 5 and 7) followed by middle sites (8 and 9) and this agree with **El-Batrawy *et al*. (2018**) who indicated that the highest values of Fe in Burullus water at East sites can be attributed to the decrease in the pH of the water at the eastern area due to the growth of aquatic plants where CO_2 is liberated with high rates as a result of the respiration of such plants and there is a matter of fact that Fe may be assimilated from both water and sediments by plants grow intensively at the lakes.

Mn concentration ranged between 0.012- 0.106 mg/l, 0.029- 0.121 mg/l, 0.058- 0.144 mg/l and 0.032- 0.125 mg/l during winter, spring, summer and autumn, respectively. While, Zn conc. ranged between 0.086- 0.125 mg/l, 0.092- 0.148 mg/l, 0.107- 0.176 mg/l and 0.095- 0.161 mg/l during the same seasons, respectively. The highest Mn concentrations were registered at site 4 front of Drain No. 7 followed by sites 1, 2 and 3 of western Basin which may be related to the Drain No. 7 located at the southern part of the lake discharge its drainage water with higher concentrations of Mn and this agree with that indicated by **Darwish (2016)** and **El-Batrawy *et al*. (2018)** in Burullus lake. The highest Zn concentrations were at site 5 followed by sites nearest to drains where the high concentration of Zn in drainage water than fresh water may be due to considerable amount of zinc leached from agriculture soils with drain of these soils as mentioned by **(Hamed, 1998; El Morshedy, 2017)**.

Pb concentration ranged between 0.019- 0.083 mg/l, 0.028- 0.089 mg/l, 0.035- 0.111 mg/l and 0.026- 0.094 mg/l. Cd concentration ranged between 0.0017- 0.0045 mg/l, 0.0025- 0.0049 mg/l, 0.0039- 0.0058 mg/l and 0.0031- 0.0055 mg/l during the same seasons, respectively.

Table 3. The investigated heavy metals concentrations in water of Burullus lake (mg/l).

Sites	Seasons	Fe	Mn	Zn	Pb	Cd
1	winter	0.092±0.0010 ^{fg}	0.07±0.0015 ^{n}	0.101±0.0015 ^{kl}	0.019±0.0006 ^{n}	0.0017±0.0001 ^{b}
	spring	0.122±0.0015 ^{f}	0.092±0.0015 ^{ijk}	0.108±0.0010 ^{jk}	0.028±0.0010 ^{l}	0.0025±0.0001 ^{b}
	summer	0.144±0.0015 ^{cdef}	0.107±0.0015 ^{de}	0.1233±0.0024 ^{ghi}	0.035±0.0012 ^{k}	0.0039±0.0003 ^{b}
	autumn	0.128±0.0010 ^{ef}	0.094±0.0015 ^{ij}	0.116±0.0006 ^{hij}	0.026±0.0012 ^{lm}	0.0031±0.0002 ^{b}
2	winter	0.131±0.0010 ^{ef}	0.088±0.0012 ^{kl}	0.109±0.0015 ^{jk}	0.021±0.0021 ^{mn}	0.0019±0.0001 ^{b}
	spring	0.147±0.0021 ^{cdef}	0.095±0.0015 ^{hi}	0.118±0.0015 ^{ghij}	0.029±0.0010 ^{l}	0.0029±0.0001 ^{b}
	summer	0.218±0.0012 ^{bcdef}	0.123±0.0012 ^{b}	0.129±0.0017 ^{fg}	0.042±0.0025 ^{j}	0.0044±0.0003 ^{b}
	autumn	0.191±0.0006 ^{cdef}	0.106±0.0021 ^{ef}	0.1227±0.0033^{ghi}	0.035±0.0010 ^{k}	0.0035±0.0001 ^{b}
3	winter	0.242±0.0025^{bcdef}	0.102±0.0010 ^{fg}	0.1227±0.0037 ^{ghi}	0.048±0.0021 ^{ij}	0.0036±0.0002 ^{b}
	spring	0.271±0.0010^{abcdef}	0.111±0.0015 ^{d}	0.128±0.0010 ^{fgh}	0.051±0.0026 ^{hi}	0.0042±0.0002 ^{b}
	summer	0.421±0.0064 ^{a}	0.122±0.0015 ^{b}	0.144±0.0070 ^{de}	0.078±0.0021 ^{c}	0.0054±0.0001 ^{ab}
	autumn	0.288±0.0049 ^{abcde}	0.116±0.0015 ^{c}	0.1437±0.0038 ^{de}	0.062±0.0020 ^{ef}	0.0042±0.0001 ^{b}
4	winter	0.305±0.0025 ^{abcd}	0.106±0.0021 ^{ef}	0.114±0.0131 ^{ij}	0.048±0.0012 ^{ij}	0.003±0.0001 ^{b}
	spring	0.327±0.0021 ^{abc}	0.121±0.0026 ^{b}	0.1163±0.0078 ^{ghij}	0.051±0.0010 ^{hi}	0.004±0.0002 ^{b}
	summer	0.421±0.0049 ^{a}	0.144±0.0012 ^{a}	0.1287±0.0068 ^{fgh}	0.078±0.0026 ^{c}	0.0054±0.0001 ^{ab}
	autumn	0.376±0.0006 ^{ab}	0.125±0.0012 ^{b}	0.1237±0.0026 ^{ghi}	0.062±0.0021 ^{ef}	0.0042±0.0001 ^{b}
5	winter	0.246±0.0006 ^{bcdef}	0.056±0.0015 ^{q}	0.1253±0.0012 ^{ghi}	0.056±0.0021 ^{gh}	0.0039±0.0002 ^{b}
	spring	0.279±0.0015 ^{abcdef}	0.072±0.0015 ^{n}	0.139±0.0087 ^{ef}	0.068±0.0010 ^{d}	0.0042±0.0001 ^{b}
	summer	0.342±0.0012 ^{abc}	0.099±0.0030 ^{gh}	0.176±0.0017 ^{a}	0.079±0.0015 ^{c}	0.0054±0.0001 ^{ab}
	autumn	0.304±0.0006 ^{abcd}	0.086±0.0010 ^{l}	0.161±0.0020 ^{b}	0.059±0.0021 ^{efg}	0.0048±0.0002 ^{b}
6	winter	0.146±0.0021 ^{cdef}	0.012±0.0010 ^{t}	0.086±0.0010 ^{m}	0.083±0.0036 ^{c}	0.0045±0.0002 ^{b}
	spring	0.179±0.0010 ^{cdef}	0.029±0.0012 ^{s}	0.092±0.0015 ^{lm}	0.089±0.0020 ^{b}	0.0049±0.0001 ^{b}
	summer	0.228±0.0015 ^{bcdef}	0.058±0.0015 ^{pq}	0.107±0.0012 ^{jk}	0.111±0.0020 ^{a}	0.0058±0.0003 ^{a}
	autumn	0.217±0.0006 ^{bcdef}	0.032±0.0015 ^{s}	0.095±0.0015 ^{lm}	0.094±0.0021 ^{b}	0.0055±0.0002 ^{ab}
7	winter	0.257±0.0010 ^{bcdef}	0.058±0.0015 ^{pq}	0.122±0.0010 ^{ghi}	0.031±0.0021 ^{kl}	0.002±0.0001 ^{b}
	spring	0.207±0.0010 ^{cdef}	0.072±0.0021 ^{n}	0.141±0.0015 ^{de}	0.044±0.0021 ^{j}	0.0026±0.0003^{b}
	summer	0.321±0.0021 ^{abc}	0.094±0.0010 ^{ij}	0.157±0.0006 ^{bc}	0.059±0.0021 ^{efg}	0.0045±0.0001 ^{b}
	autumn	0.271±0.0010 ^{abcdef}	0.081±0.0015 ^{m}	0.148±0.0023 ^{cde}	0.046±0.0010 ^{ij}	0.0035±0.0001 ^{b}
8	winter	0.231±0.0012 ^{bcdef}	0.058±0.0012 ^{pq}	0.119±0.0012 ^{ghij}	0.0453±0.0013 ^{ij}	0.0029±0.0094^{b}
	spring	0.266±0.0015 ^{abcdef}	0.072±0.0012 ^{n}	0.138±0.0012 ^{ef}	0.055±0.0046 ^{gh}	0.0031±0.0002 ^{b}
	summer	0.317±0.0010 ^{abc}	0.099±0.0012 ^{gh}	0.152±0.0010 ^{bcd}	0.078±0.0015 ^{c}	0.0051±0.0002 ^{b}
	autumn	0.278±0.0010 ^{abcdef}	0.081±0.0012 ^{m}	0.141±0.0006 ^{de}	0.061±0.0010 ^{efg}	0.0043±0.0002 ^{b}
9	winter	0.222±0.0015 ^{bcdef}	0.04±0.0015 ^{r}	0.119±0.0010 ^{ghij}	0.046±0.0010 ^{ij}	0.0036±0.0002 ^{b}
	spring	0.259±0.0012 ^{bcdef}	0.061±0.0020 ^{op}	0.141±0.0012 ^{de}	0.059±0.0012 ^{efg}	0.004±0.0001 ^{b}
	summer	0.322±0.0025 ^{abc}	0.09±0.0012 ^{jkl}	0.161±0.0010 ^{b}	0.08±0.0006 ^{c}	0.0058±0.0001 ^{a}
	autumn	0.269±0.0010 ^{abcdef}	0.065±0.0012 ^{o}	0.148±0.0021 ^{cde}	0.065±0.0026 ^{de}	0.0051±0.0003 ^{ab}
Minimum		0.092	0.012	0.086	0.019	0.0017
Maximum		0.421	0.144	0.176	0.111	0.0058
Average		0.249583	0.083667	0.128233	0.056147	0.003983
ESC (1994)		1	0.5	5	0.05	0.01
USEPA (2006)		1	-	0.12	0.0025	0.0025
WHO (2011)		-	0.4	≤ 3	0.01	0.003
Two Way ANOVA			***P* value**			
Sites		0.0001	0.0001	0.0001	0.0001	0.078
Seasons		0.005	0.0001	0.0001	0.0001	0.251
Sites × Seasons		0.173	0.0001	0.003	0.0001	0.477

Means having the same letter in the same column are not significantly different at $P<0.05$

Table 4. The investigated heavy metals concentrations in water of Edku lake (mg/l).

Sites	Seasons	Fe	Mn	Zn	Pb	Cd
1	winter	0.355±0.0042^{n}	0.064±0.0036 ^{jk}	0.031±0.0020 ^{lm}	0.022±0.0006 ^{f}	0.004±0.0001 ^{k}
	spring	0.396±0.0026 ^{j}	0.079±0.0030 ^{ef}	0.038±0.0012 ^{jk}	0.027±0.0015 ^{ef}	0.0058±0.0001 ^{fgh}
	summer	0.472±0.0015 ^{d}	0.092±0.0021 ^{cd}	0.049±0.0010 ^{fg}	0.039±0.0021 ^{def}	0.0068±0.0001 ^{c}
	autumn	0.398±0.0021 ^{j}	0.071±0.0021 ^{hi}	0.041±0.0031 ^{ij}	0.032±0.0010 ^{def}	0.0051±0.0001 ^{i}
2	winter	0.346±0.0015 ^{o}	0.0723±0.0018 ^{gh}	0.035±0.0015 ^{kl}	0.075±0.0525 ^{abc}	0.005±0.0002 ^{i}
	spring	0.405±0.0010 ^{i}	0.083±0.0015 ^{e}	0.043±0.0006 ^{i}	0.025±0.0010 ^{f}	0.0063±0.0002 ^{de}
	summer	0.479±0.0012 ^{c}	0.111±0.0015 ^{b}	0.051±0.0015 ^{efg}	0.033±0.0010 ^{def}	0.0079±0.0002 ^{a}
	autumn	0.401±0.0012 ^{i}	0.092±0.0015 ^{cd}	0.044±0.0006 ^{hi}	0.028±0.0012 ^{ef}	0.0058±0.0002 ^{fgh}
3	winter	0.372±0.0015 ^{m}	0.067±0.0015 ^{ij}	0.047±0.0006 ^{gh}	0.034±0.0025 ^{def}	0.0048±0.0000 ^{ij}
	spring	0.424±0.0012 ^{g}	0.089±0.0015^{ef}	0.051±0.0021 ^{efg}	0.051±0.0015 ^{cdef}	0.0064±0.0001 ^{d}
	summer	0.535±0.0010 ^{a}	0.135±0.0015 ^{a}	0.072±0.0015 ^{b}	0.082±0.0010 ^{ab}	0.0073±0.0001 ^{b}
	autumn	0.434±0.0012 ^{f}	0.096±0.0010 ^{c}	0.054±0.0010 ^{de}	0.066±0.0010 ^{abcd}	0.006±0.0001 ^{defg}
4	winter	0.351±0.0010 ^{n}	0.037±0.0010 ^{o}	0.034±0.0000 ^{kl}	0.021±0.0012 ^{f}	0.0031±0.0001 ^{o}
	spring	0.390±0.0010 ^{k}	0.0513±0.0015 ^{m}	0.042±0.0010^{ij}	0.024±0.0010 ^{f}	0.0036±0.0002 ^{lm}
	summer	0.467±0.0015 ^{e}	0.074±0.0010 ^{gh}	0.051±0.0009 ^{efg}	0.029±0.0010 ^{ef}	0.0045±0.0002 ^{j}
	autumn	0.411±0.0021 ^{h}	0.062±0.0010 ^{kl}	0.042±0.0010 ^{ij}	0.026±0.0015 ^{ef}	0.0038±0.0002 ^{kl}
5	winter	0.378±0.0006 ^{l}	0.059±0.0012 ^{l}	0.048±0.0010 ^{fg}	0.039±0.0012 ^{def}	0.0055±0.0002 ^{h}
	spring	0.411±0.0010 ^{h}	0.077±0.0015 ^{fg}	0.057±0.0006 ^{d}	0.048±0.0015 ^{bcdef}	0.0062±0.0001 ^{def}
	summer	0.512±0.0010 ^{b}	0.112±0.0010 ^{b}	0.077±0.0010 ^{a}	0.077±0.0012 ^{ab}	0.0074±0.0002 ^{b}
	autumn	0.436±0.0010 ^{f}	0.081±0.0000 ^{ef}	0.063±0.0010 ^{c}	0.062±0.0012 ^{abcde}	0.0063±0.0002 ^{de}
6	winter	0.279±0.0010 ^{s}	0.017±0.0010 ^{r}	0.022±0.0015 ^{p}	0.036±0.0010 ^{def}	0.0034±0.0001 ^{mn}
	spring	0.311±0.0006 ^{q}	0.023±0.0021 ^{q}	0.027±0.0010 ^{no}	0.048±0.0015 ^{bcdef}	0.0045±0.0001 ^{j}
	summer	0.396±0.0010 ^{j}	0.044±0.0021 ^{n}	0.035±0.0006 ^{kl}	0.0753±0.0142 ^{abc}	0.0057±0.0001 ^{gh}
	autumn	0.352±0.0012 ^{n}	0.037±0.0017 ^{o}	0.030±0.0025 ^{mn}	0.0763±0.0044 ^{abc}	0.0048±0.0001 ^{ij}
7	winter	0.206±0.0015 ^{t}	0.018±0.0010 ^{r}	0.011±0.0012 ^{r}	0.0٣٦±0.0٠1٠ ^{def}	0.0051±0.0001 ^{i}
	spring	0.277±0.0012 ^{s}	0.027±0.0010 ^{pq}	0.017±0.0010 ^{q}	0.041±0.0006 ^{cdef}	0.0059±0.0001 ^{efg}
	summer	0.321±0.0010 ^{p}	0.047±0.0015 ^{mn}	0.024±0.0012 ^{op}	0.096±0.0012 ^{a}	0.0074±0.0002 ^{b}
	autumn	0.285±0.0010 ^{r}	0.029±0.0010 ^{p}	0.021±0.0012 ^{p}	0.082±0.0015 ^{ab}	0.0062±0.0001 ^{def}
Minimum		0.206	0.017	0.011	0.021	0.0031
Maximum		0.535	0.135	0.077	0.096	0.0079
Average		0.3859	0.06595	0.041321	0.047521	0.0055496
ESC (1994)		1	0.5	5	0.05	0.01
USEPA (2006)		1	-	0.12	0.0025	0.0025
WHO (2011)		-	0.4	≤ 3	0.01	0.003
Two Way ANOVA		***P* value**				
Sites		0.0001	0.0001	0.0001	0.0001	0.0001
Seasons		0.0001	0.0001	0.0001	0.0001	0.0001
Sites × Seasons		0.0001	0.0001	0.0001	0.011	0.0001

Means having the same letter in the same column are not significantly different at $P<0.05$

In Edku lake, Fe concentration ranged between 0.206- 0.378 mg/l, 0.277- 0.424 mg/l, 0.321- 0.535 mg/l and 0.285- 0.436 mg/l during winter, spring, summer and autumn, respectively. While, Mn concentration ranged between 0.017- 0.072 mg/l, 0.023- 0.089 mg/l, 0.041- 0.135 mg/l and 0.029- 0.096 mg/l during the same seasons, respectively. Zn concentration ranged between 0.011- 0.048 mg/l, 0.017- 0.057 mg/l, 0.024- 0.077 mg/l and 0.021- 0.063 mg/l during the same seasons, respectively.

These results reversed that the highest concentrations of these metals were recorded at sites (3, 5 and 2) front of Drains (Barsik, El Khairy, El-Bousely and Edku) and this compatible with the results of **Shetaia *et al*. (2020)** in the same lake. The explanation for this is due to the richness of drainage water with the organic compounds that chelate these metals **(Moussa, 2004; Farouk, 2009; El Morshedy, 2017)**.

Pb concentrations in Edku lake ranged between 0.021- 0.039 mg/l, 0.024- 0.051 mg/l, 0.029- 0.096 mg/l and 0.026- 0.082 mg/l during winter, spring, summer and autumn, respectively. Cd conc. ranged between 0.0031- 0.005 mg/l, 0.0036- 0.0064 mg/l, 0.0045- 0.0079 mg/l and 0.0038- 0.0063 mg/l during the same seasons, respectively.

Generally, the highest concentrations of Pb and Cd were recorded at the Boughaz site, followed by the closest ones in both Lakes which may be resulted from boat activities that include disposal of liquid wastes as fishing boats exhaust as well as the materials used in coating boats and use of paints, also the agriculture wastewater **(Farouk, 2009; Darwish, 2016; El Morshedy, 2017; El-Batrawy *et al*., 2018)**. The high levels of Cd and Pb in water can be attributed to industrial and agricultural discharges **(Mason, 2002)**. While, **Saeed and Shaker (2008)** indicated that the high level of Pb in water of northern delta Lakes can be attributed to heavily traveled roads that run along the Lakes.

Metals concentrations in water were found in the following order: Fe > Zn > Mn > Pb > Cd in Burullus lake, whereas they follow the order of Fe > Mn > Pb > Zn > Cd in Edku lake. Where, Edku lake ranked as second after Burullus lake in accumulation of metals (Mn, Zn, Pb) with slightly increasing in concentrations of Fe and Cd which may be attributed to the increased prevalence of aquatic plants, which cover the water surface in abundance in Edku lake which absorb metals from water **(Saeed and Shaker, 2008)**. While, Burullus lake suffers from increasing of drains numbers and amount of drainage water discharged into it.

Iron values had significantly the highest concentrations than other metals in the two Lakes and perhaps this is due to the high rate of iron in the drainage water of the two Lakes from the multiple drains **(Farouk, 2009; Darwish, 2016; El Morshedy, 2017)**.

The above results revealed that concentrations of the investigated heavy metals in the two Lakes significantly increase at sites nearest to the drains due to the highly content of these metals in these drains. Similar finding obtained by many researchers **(Koussa, 2000**; **Moussa, 2004**; **Saeed and Shaker, 2008; Farouk, 2009; Darwish, 2016; El Morshedy, 2017; El-Batrawy *et al.*, 2018; Shetaia *et al*., 2020)**.

The study seasons showed a marked variation in the heavy metal concentrations in both Lakes, which may be due to the fluctuation of the amount of agricultural drainage water, untreated domestic sewage and industrial wastes discharged into the canals and drains which feed ponds **(Authman, 2008; Authman *et al.*, 2008)**. Where, summer season recorded significantly increasing in concentrations of heavy elements than other seasons, and this may be due to increase of evaporation rate during it, leading to increased concentration of pollutants in the water to the side of increasing the activity of fishermen during the summer increases with waste and exhaust fishing boat and These results are good in agreement with those obtained by **(Farouk, 2009; Bahnasawy *et al.*, 2011; Farouk, 2014; Shaker and Elnazer, 2015**, **Shaker, *et al.*, 2015; Darwish, 2016; El Morshedy, 2017)**. Also, **El-Batrawy *et al.* (2018)** who reported that this may be attributed to agricultural runoff, which may carry higher values of these metals and arise from anthropogenic activities such as the use of chemical fertilizers and pesticides in agriculture land.

By comparing the heavy metals values in water of the two Lakes with different standard of permissible limits in Tables (3 and 4), it's represented that Fe, Mn and Zn concentrations in the both Lakes are under chronic Criterion Continuous Concentration for protection of freshwater aquatic life for fish procuction according to **(ECS, 1994**; **USEPA, 2006; WHO, 2011)**. Except, Zn values in some sites of Burullus lake which recorded slightly higher than the maximum permissible limits of **USEPA (2006)**. While, Pb values in both lakes were violate the maximum permissible limits of **(ECS, 1994; USEPA, 2006; WHO, 2011)**. Cd values in both lakes were suitable in range of **ECS, 1994**. And, it were violate the maximum permissible limits of **USEPA (2006)**; **WHO (2011)**.

Lead and cadmium are of the most dangerous metals that can be harmful to human health even in very low concentrations, as well as being highly toxic and non-degradable **(Tao *et al.*, 2012)**.

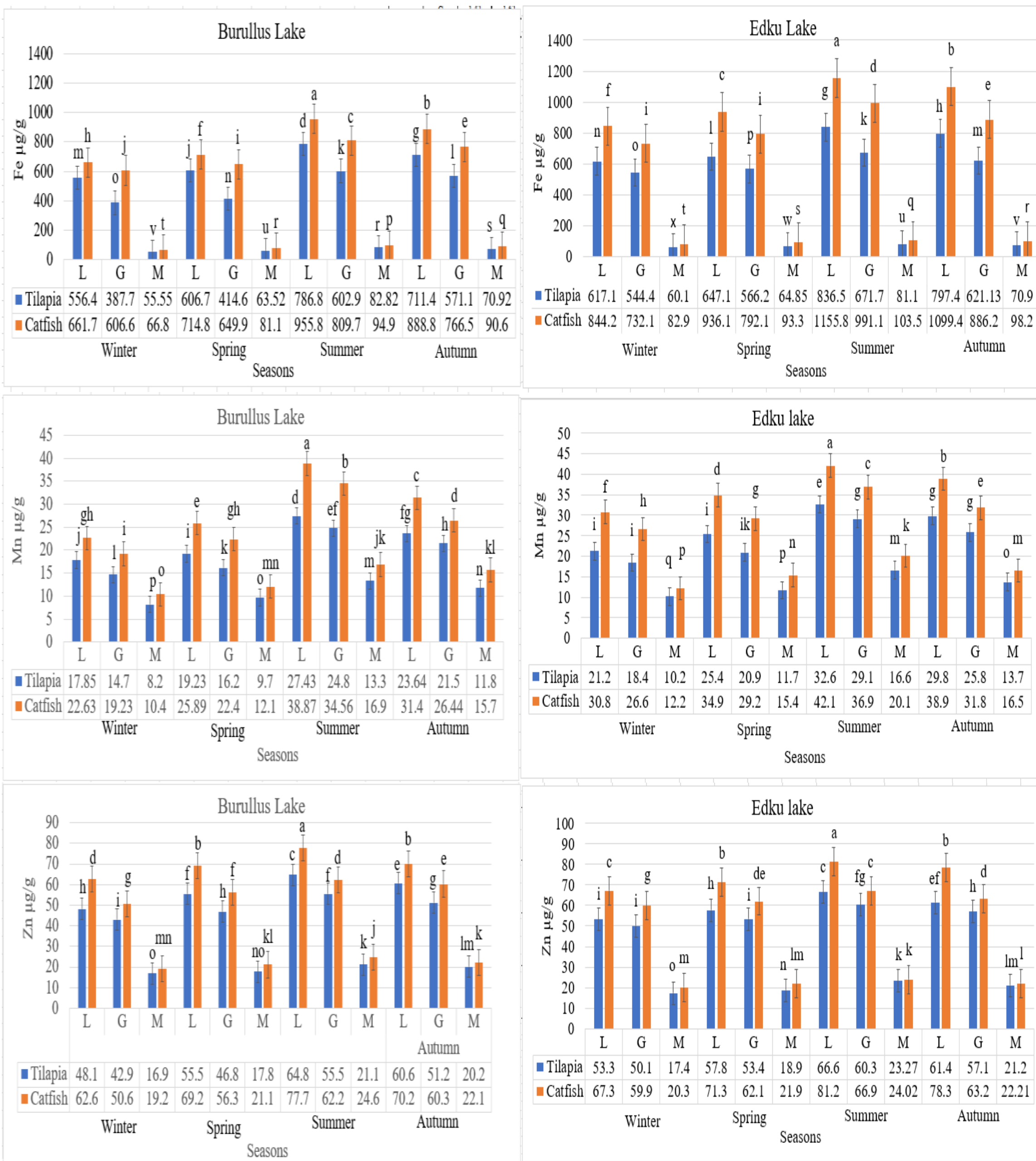
Assessment of the investigated heavy metals in fish organs (*O. niloticus* and *C. gariepinus*) of Burullus and Edku lakes

Fish widely used to biologically monitor the degree of metal pollution in aquatic ecosystems **(Al-Sayegh Petkovšek *et al*., 2012)**, as fish may concentrate large amounts of some metals from the water **(Daviglus *et al*., 2002)**. Toxic elemental contaminants are transferred into human metabolism through consumption of contaminated fish that leads to serious deterioration of human health status **(Alinnor and Obiji, 2010)**. Therefore, they are highly toxic for consumers when exceeding the recommended safety concentrations **(Basiony, 2014)**.

Fig. 2 represents the values of the investigated heavy metals concentrations (Fe, Mn, Zn, Pb and Cd as μg/g in dray weight) in the (livers, gills and muscle) organs of *O. niloticus* and *C. gariepinus* fish collected from the two Lakes during different seasons for the year 2019., Table 5 represents descriptive statistics to assess the impact of seasons, fish organs and fish species studied, as well as the effect of interaction between these factors on heavy metals values of fish organs during the study year. Where, all investigated heavy metals were significantly affected by the seasons, fish organs, fish species and the interaction between them ($P<0.05$). Except, Pb which did not affect by seasons and fish species interaction ($P>0.05$) in the two Lakes. Besides, it has not affected significantly by seasons, fish organs and fish species interaction ($P<0.05$) in Edku lake., Cd did not affected by seasons and fish species interaction ($P<0.05$) and interaction between seasons, fish organs and fish species ($P<0.05$) in Burullus lake.

Heavy metals are taken up through different organs of the fish according to the affinity between these organs. So, many of these heavy metals are concentrated at different levels in different organs of the fish body **(Gad, 2005)**. In the present study, residues of the investigated metals (Fe, Mn, Zn, Pb and Cd) were fluctuated in liver, gills and muscle of

O. niloticus and *C. gariepinus* in both lakes as follows, Fe residues in liver ranged between 556.4- 786.8 µg/g and 661.7- 955.8 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 617.1- 836.5 µg/g and 844.2- 1155.8 µg/g in liver of *O. niloticus* and *C. gariepinus*, respectively. Gills, iron residues ranged between 387.7- 602.9 µg/g and 606.6 809.7 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 544.4- 671.7 µg/g and 732.1- 991.1 µg/g in both of *O. niloticus* and *C. gariepinus*, respectively. Muscle, iron ranged between 55.55- 82.82 µg/g and 66.8- 94.9 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 60.1- 82.9 µg/g and 81.1- 103.5 µg/g respectively.



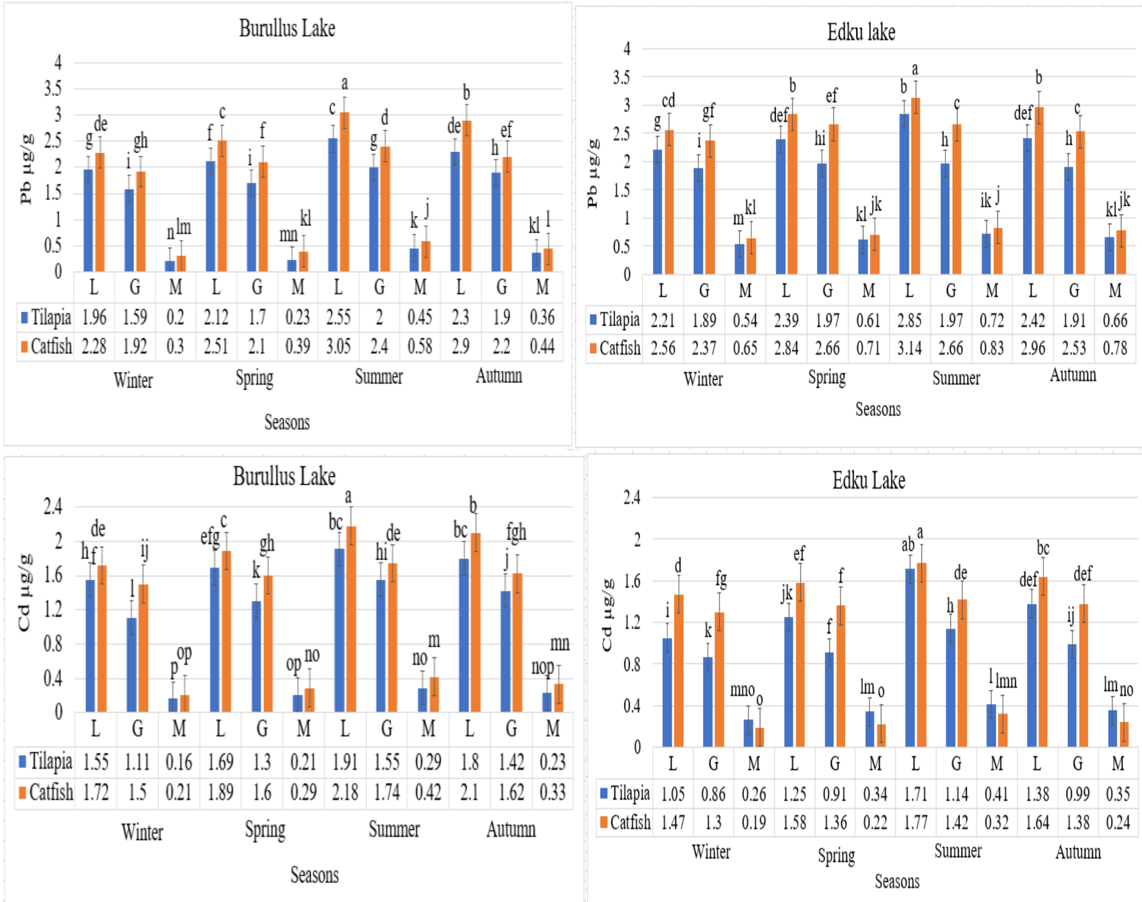


Fig. 2. Heavy metals residues (µg/g as dray weight) in the (livers, gills and muscles) of *O. niloticus* and *C. gariepinus* fish collected from the two Lakes (Burullus and Edku) during seasons of the study year 2019.

Mn residues in liver ranged between 17.85- 27.43 µg/g and 22.63- 38.87 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 21.2- 32.6 µg/g and 30.8- 42.1 µg/g respectively. In gills, Mn residues ranged between 14.7- 24.8 µg/g and 19.23- 25.89 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 18.4- 29.1 µg/g and 26.6- 36.9 µg/g respectively. Muscle, Mn residues. ranged between 8.2- 13.3 µg/g and 10.4- 16.9 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 10.2- 16.6 µg/g and 12.2- 20.1 µg/g respectively.

Zn residues in liver ranged between 48.1- 64.8 µg/g and 62.6- 77.7 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 53.3- 66.6 µg/g and 67.3- 81.2 µg/g respectively. In gills, Zn residues. ranged between 42.9- 55.5 µg/g and 50.6- 62.2 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 50.1- 60.3 µg/g and 59.9- 66.9 µg/g in gills of *O. niloticus* and *C. gariepinus*, respectively. In muscle, Zn residues. ranged between 16.9- 21.1 µg/g and 19.2- 21.1 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 17.4- 23.27 µg/g and 20.3- 24.02 µg/g respectively.

Table 5. Descriptive statistics to evaluate the effect of the seasons, fish organs and two fish species studied along with the effect of the interaction between them on the evaluation of the heavy metal values in Burullus and Edku lakes during seasons of the study year 2019.

	Heavy metals / Three Way ANOVA	*P* value				
		Fe	**Mn**	**Zn**	**Pb**	**Cd**
Burullus lake	**Seasons**	0.0001	0.0001	0.0001	0.0001	0.0001
	Organs	0.0001	0.0001	0.0001	0.0001	0.0001
	Fish species	0.0001	0.0001	0.0001	0.0001	0.0001
	Seasons × Organs	0.0001	0.0001	0.0001	0.0001	0.001
	Seasons × Fish species	0.0001	0.0001	0. 034	0.052	0.815
	Organs × Fish species	0.0001	0.0001	0.0001	0.0001	0.0001
	Seasons × Organs × Fish species	0.0001	0.002	0.003	0.044	0.140
Edku lake	**Seasons**	0.0001	0.0001	0.0001	0.0001	0.0001
	Organ	0.0001	0.0001	0.0001	0.0001	0.0001
	Fish species	0.0001	0.0001	0.0001	0.0001	0.0001
	Seasons × Organ	0.0001	0.0001	0.0001	0.0001	0.0001
	Seasons× Fish species	0.0001	0.0001	0.0001	0.317	0.0001
	Organs × Fish species	0.0001	0.0001	0.0001	0.0001	0.0001
	Seasons × Organs × Fish species	0.0001	0.0001	0.0001	0.242	0.013

Means in the same column are not significantly different at $P<0.05$

Pb residues in liver ranged between 1.96- 2.55 µg/g and 2.28- 3.05 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 2.21- 2.85 µg/g and 2.56- 3.14 µg/g respectively. In gills, Pb residues. ranged between 1.59- 2.0 µg/g and 1.92- 2.4 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 1.89- 1.97 µg/g and 2.37- 2.66 µg/g, respectively. In muscle, Pb residues. ranged between 0.2- 0.45 µg/g and 0.3- 0.58 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 0.54- 0.72 µg/g and 0.65- 0.83 µg/g respectively.

Cd residues in liver ranged between 1.55- 1.91 µg/g and 1.72- 2.18 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 1.05- 1.71 µg/g and 1.47- 1.77 µg/g, respectively. Gills, Cd residues ranged between 1.11- 1.55 µg/g and 1.5- 1.74 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 0.86- 1.14 µg/g and 1.3- 1.42 µg/g respectively. In muscle, Cd residues ranged between 0.16- 0.29 µg/g and 0.21- 0.42 µg/g for *O. niloticus* and *C. gariepinus*, respectively in Burullus lake. While, in Edku lake it ranged between 1.05- 1.71 µg/g and 1.47- 1.77 µg/g, respectively.

The above results of heavy metals in fish organs revealed that the residues of the investigated heavy metals in fish liver and gills of *O. niloticus* and *C. gariepinus* are much higher than that in the muscles and this confirmed with that recorded by many authors **(Saeed and Shaker, 2008; Farouk, 2009; Yosef and Goma, 2011; Abd-El -Khalek *et al*., 2012; EL-Shaer and Alabssawy, 2019; Aly *et al*., 2020)**.

This can attribute to metallothionein proteins, which are synthesized in liver and gills tissues when fishes are exposed to heavy metals to detoxify them. These proteins are thought to play an important role in protecting tissues from damage by heavy metal toxicants **(Jobling, 1995; Yacoub, 2007)**. Moreover, fish liver plays a primary role in the metabolism and excretion of xenobiotic compounds **(Rocha and Monteiro, 1999)**, besides one of the most important functions of liver is to clean pollutants from the blood coming from the intestine, so it is considered as indicator of aquatic environmental pollution **(Soufy *et al*, 2007)**. Gills are the site directly exposed to the ambient conditions and also are known for their excretory function even for some metals **(Matthiessen and Brafield, 1977)**. Alongside, gills were the initial site for the accumulation of waterborne metals, where they bind to the external gill cytosolic compounds via covalent bonds **(Wepener *et al*., 2001)**. **Heath (1995)** indicated that increasing heavy metals in gills than muscle may be due to mucus, which is impossible to completely remove from the platelets. The adsorption of metals onto the gill surface, as the first target for pollutants in water, could also be an important influence in the total metal levels of the gills. **Karadede and Ünlü, (2000)** mentioned that muscle is not an active tissue in accumulating heavy metals. Similar observations were reported by many studies carried out with various fish species **(Guerrin *et al*., 1990; Alam *et al.*, 2002)**, which, may be due to lack of their binding affinity with the muscle proteins **(El-Shaer and Alabssawy, 2019)**.

C. gariepinus organs have shown a marked increase in the values of heavy elements than that in *O. niloticus* during the different seasons of the current study year. Further confirmed by another study as **(Farouk, 2009; El-Shaer and Alabssawy, 2019)**, this may be due to the food habits of *C. gariepinus* because they are benthic and predatory fish. **Romeoa *et al*. (1999)** indicated that the observed variability of heavy metals levels in different fish species depends on feeding habits, ecological needs, and metabolism **(Canli and Furness, 1993)**, age, size and length of the fish and their habitats **(Canli and Atli, 2003)**, water sources, water change rate, plankton abundant, soil and aquaculture systems **(Shaker, 2006)**. Obtained results also, confirmed with **Eneji *et al*. (2011)** who stated that the difference in ability of some fish to accumulate more metals than other fish species have been attributed to differences in physiological role of fish organs, including their regulatory ability, behavior and feeding habits of the fish.

Obtained results also showed that the residues of the investigated heavy elements in the fish of both examined lakes are higher than their concentration in the waters of both lakes. This is confirmed by **(Gümgüm *et al.*, 1994**; **Olaifa *et al.*, 2004)** and **Abd-El -Khalek *et al*. (2012)** who stated that aquatic organisms such as fish accumulate metals to concentrations many times higher than present in water or sediment and they can concentrate metals at different levels in their different body organs.

Summer season recorded the highest residues of the investigated heavy metals in fish organs in both lakes during the study year. This can be attribute to the increase in the biological and physiological processes of fish, besides increasing the rates of food conversion of fish during the summer **(Hossain *et al*., 2014)**. In addition to the increased amounts of drainage water that discharged into the both lakes **(El-Batrawy *et al*., 2018)**. This is confirmed with **Authman *et al.* (2013)**, where they found that metals residues in fish organs exhibited seasonal variations and they attribute these variations to the fluctuations in drainage water that discharged into the drainage canal. **Tekin-Özan and Kir (2008)** described that bioavailability of metals may influenced by physiological activities of fish during different seasons.

The accumulation levels of the investigated heavy metals in fish organs of *O. niloticus* and *C. gariepinus* in Burullus lake and Edku lake have been detected in the order: Fe > Zn> Mn > Pb > Cd, which agree with those obtained by **Darwish (2016)** and **El-Batrawy *et al*. (2018)** in *O. niloticus of* Burullus lake and **El Morshedy (2017)** in *O. niloticus* of Edku lake. This also complies with **Watanabe *et al.* (2003)** and **Masoud *et al.* (2007)** who mentioned that, bioaccumulation of metals in tissues varies from metal to metal. Moreover, **Koca *et al.* (2005)** postulated that the accumulation patterns of contaminants in fish and other aquatic organisms depend on both uptake and elimination rates of contaminants.

Obtained results indicated that iron, zinc and manganese were the most concentrated metals in fish organs, this had been interpreted by **Kumar *et al*. (2011)** who stated that iron, zinc, copper, and manganese are from the essential metals which exist in increased values, presumably due to their function as co-factors for the activation of a number of enzymes and regulated to maintain a certain homeostatic status in fish. On the other hand, the nonessential metals have no biological function or requirement, and its values in fishes are generally low. Where, cadmium and lead are toxic at low concentrations, non-biodegradable, non-essential heavy metals and have no role in biological processes in living organisms. Thus, even in low concentration, it could be harmful to fish **(Badr *et al.*, 2014)**.

The recommended daily intake for an adult of Fe, Pb and Cd is 50.0, 0.214 and 0.05 mg/day wet weight, respectively according to **WHO (2011)**. While, the permissible daily intake of Mn and Zn is 10 and 30 mg/day wet weight, respectively according to **(SCF, 1993)**. The concentration of metals in the edible part (muscles) of *O. niloticus* and *C. gariepinus* in Burullus and Edku lakes are safe for consumers.

Pollution Assessment Indices

Pollution Index (PI)

The calculated PI of the studied heavy metals in water of Burullus lake were ordered as Pb> Cd> Zn> Mn> Fe (Table 6). While, in Edku lake were ordered as Pb> Cd> Mn > Zn> Fe where, Fe shows No effect on aquatic life in both lakes (PI< 1) during the study seasons except during autumn season in Edku lake, where it shows Slightly effect on aquatic life (PI= 1.039). While, Mn shows Slight effect on aquatic life in both lakes except during winter (PI= 0.739) and spring (PI= 0.919) in Edku lake. Zn showed moderate effect on aquatic life in Burullus lake during summer (PI= 2.05) and as Slight effect (PI= 1-2) during the other seasons. While, in Edku lake, it had no effect (PI< 1) on aquatic environment during all study seasons. Moreover, Pb had Serious effect on aquatic life in Burullus lake during the four study seasons and during summer and autumn in Edku lake (PI> 5). However, Cd had Strong effect (PI= 3-5) during all seasons in Edku lake and in Burullus lake during summer and autumn while, during winter and spring it's (PI) described as Moderate effect (PI= 2-3). Generally, PI average value of Fe and Cd were higher in Edku lake than Burullus lake. While, PI average value for Mn, Zn and Pb were higher in Burullus lake than Edku lake.

Table 6. Pollution index of the measured metals in water of Burullus and Edku lakes.

etals	Seasons	Burullus lake		Edku lake	
		PI value	Effect	PI value	Effect
Fe	**winter**	0.530956	NO effected	0.717480	NO effected
	spring	0.581695	NO effected	0.844105	NO effected
	summer	0.741577	NO affected	1.039853	Slightly affected
	autumn	0.661448	NO effected	0.868141	NO effected
Mn	**winter**	1.066771	Slightly effected	0.739797	NO effected
	spring	1.244267	Slightly effected	0.919239	NO effected
	summer	1.552417	Slightly affected	1.410886	Slightly affected
	autumn	1.29031	Slightly effected	1.002846	Slightly effected
Zn	**winter**	1.517267	Slightly effected	0.492443	NO effected
	spring	1.742642	Slightly effected	0.594811	NO effected
	summer	2.059733	Moderately effected	0.806536	NO affected
	autumn	1.869385	Slightly effected	0.664078	NO effected
Pb	**winter**	6.081924	Seriously affected	3.263891	Strongly effected
	spring	6.664328	Seriously effected	4.026063	Strongly effected
	summer	8.313377	Seriously affected	7.163185	Seriously affected
	autumn	6.966392	Seriously effected	6.144518	Seriously effected
Cd	**winter**	2.405203	Moderately effected	3.156739	Strongly effected
	spring	2.750455	Moderately effected	3.671512	Strongly effected
	summer	3.494639	Strongly effected	4.545877	Strongly effected
	autumn	3.156739	Strongly effected	3.678655	Strongly effected

Heavy Metal Evaluation Index (HEI)

Heavy metal evaluation index was applied to assess the quality of surface water of the both lakes with respect to heavy metal contents. The values of HEI in Burullus lake varied from 15.11 at site 1 to 93.36 at site 4 (Table 7) with an average of 43.58. While, in Edku lake HEI values varied from 17.54 at site 4 to 68.59 at site 7 (Table 8) with an average of 36.19. In general, all values of the both lakes during different study seasons were found to be higher than 20, except during winter season at sites (1 and 2) in Burullus lake and at sites (1, 2 and 3) in Edku lake shows as moderate pollution. This indicating high pollution status of heavy metals in the both examined lakes water.

Contamination Index (C_d)

The contamination index (C_d) value varied from 10.11 at site 1 to 88.35 at site 4 (Table 7) with an average of 38.59 in Burullus lake. While, it is varied from 15.11 at site 4 to 93.36 at site 7 (Table 8) with an average of 43.58 in Edku lake. Generally, all examined water samples indicating very high contamination of both lakes water by the heavy metals studied.

Human Health Risk Assessment

The results obtained for human health risk assessment estimated from the hazard quotient (HQ_{dermal}) using the USEPA risk assessment models for all monitoring data of heavy metals in the both lakes, for non-cancer effect, are presented in Tables (7 and 8).

Table 7. Heavy Metal Evaluation Index (HEI), Contamination Index (C_d), Hazard Quotient (HQ_{dermal}l) and their Hazard index (HI) for water samples of Burullus lake.

Sites	Seasons	HEI		C_d		HQ_{dermal}					HI
		Value	Pollution Rank	Value	Pollution Rank	Fe	Mn	Zn	Pb	Cd	
1	winter	15.11	moderate	10.11	high	0.00032082	0.01373083	0.000158492	0.007098901	0.053353846	0.07466283
	spring	21.97	high	16.97	high	0.00042543	0.01804615	0.000169477	0.010461538	0.078461538	0.10756414
	summer	27.52	high	22.52	high	0.00050215	0.02098846	0.000194585	0.013076923	0.122400521	0.15716212
	autumn	20.90	high	15.90	high	0.00044287	0.0184385	0.000182031	0.009714320	0.097292311	0.12606995
2	winter	17.07	moderate	12.07	high	0.00045682	0.01726151	0.000171046	0.007846154	0.059630769	0.08536633
	spring	22.95	high	17.95	high	0.00051261	0.01863461	0.000185169	0.010835165	0.091015385	0.12118294
	summer	33.04	high	28.04	high	0.00076020	0.02412692	0.000205569	0.015692308	0.138092308	0.17887731
	autumn	27.60	high	22.60	high	0.00066605	0.0207923	0.000197723	0.0130769	0.109846201	0.14457915
3	winter	36.47	high	31.47	high	0.00084390	0.0200077	0.000185169	0.017934066	0.112984615	0.15195544
	spring	44.33	high	39.33	high	0.00094502	0.02177307	0.000202431	0.022043956	0.131815385	0.17677987
	summer	56.37	high	51.38	high	0.00109846	0.02393076	0.000236954	0.028395604	0.156923077	0.21058486
	autumn	50.59	high	45.59	high	0.00100430	0.0227538	0.0000220	0.0254066	0.1380923	0.18727902
4	winter	36.66	high	31.66	high	0.00106359	0.02079232	0.000158492	0.017934066	0.094153846	0.13410230
	spring	39.41	high	34.41	high	0.00114031	0.02373461	0.000189877	0.019054945	0.125538462	0.16965820
	summer	58.37	high	53.81	high	0.00146810	0.02824615	0.000193015	0.029142857	0.169476923	0.22852705
	autumn	47.14	high	42.13	high	0.00131117	0.0245192	0.000191446	0.0231648	0.1318154	0.18100207
5	winter	41.01	high	36.01	high	0.00085785	0.01098460	0.000196154	0.020923077	0.122432001	0.15536169
	spring	49.59	high	44.59	high	0.00097292	0.01412307	0.000230677	0.025406593	0.131815385	0.17254865
	summer	93.36	high	88.35	high	0.00119261	0.01941923	0.000276185	0.029516484	0.169476923	0.21988143
	autumn	44.21	high	39.21	high	0.00106010	0.0168692	0.000252646	0.022044	0.1506462	0.19087208
6	winter	57.82	high	52.82	high	0.00050913	0.00235380	0.000134954	0.031010989	0.141230769	0.17523969
	spring	62.46	high	57.46	high	0.00072185	0.00568846	0.000144369	0.033252747	0.153784615	0.19349439
	summer	78.25	high	73.25	high	0.00079507	0.01137692	0.000167908	0.041472527	0.182030769	0.23584320
	autumn	66.24	high	61.24	high	0.00075671	0.0062769	0.000149077	0.035120921	0.1726154	0.21491898
7	winter	23.80	high	18.80	high	0.00089621	0.01137690	0.000191446	0.011582418	0.062769231	0.08681622
	spring	32.70	high	27.70	high	0.00089272	0.01412307	0.000221262	0.016439561	0.081621310	0.11310574
	summer	44.35	high	39.34	high	0.00111938	0.01843846	0.000246369	0.022043956	0.141230769	0.18307894
	autumn	34.17	high	29.17	high	0.00094502	0.0158885	0.000232246	0.016813201	0.109846220	0.14372507
8	winter	33.93	high	28.93	high	0.00080554	0.01098462	0.000186738	0.017186813	0.091015385	0.12017909
	spring	43.18	high	38.18	high	0.00062421	0.01431923	0.000216554	0.022043956	0.097292308	0.13479963
	summer	57.29	high	52.29	high	0.00110543	0.01941923	0.000238523	0.029142857	0.160061538	0.20996758
	autumn	45.12	high	40.12	high	0.00096943	0.0156923	0.000221262	0.022791212	0.1349538	0.17462806
9	winter	33.80	high	28.80	high	0.00077415	0.00784621	0.000189877	0.01718681	0.112984615	0.13898161
	spring	43.24	high	38.24	high	0.00092759	0.01196538	0.000232246	0.02204395	0.128676923	0.13681122
	summer	58.71	high	53.71	high	0.00112287	0.01765384	0.000252646	0.02989011	0.182030769	0.23095024
	autumn	49.04	high	44.04	high	0.00093805	0.0127500	0.000233815	0.02503312	0.1600615	0.19931639

Table 8. Heavy Metal Evaluation Index (HEI), Contamination Index (C_d) and Hazard Quotient (HQ_{dermal}) and their Hazard index (HI) for water samples of Edku lake.

Sites	Seasons	HEI		C_d		HQ_{dermal}					HI
		Value	Pollution Rank	Value	Pollution Rank	Fe	Mn	Zn	Pb	Cd	
1	winter	19.06	moderate	14.06	high	0.001237949	0.012554	0.0000486	0.00822	0.125538	0.147598683
	spring	23.50	high	18.50	high	0.001380923	0.015496	0.0000596	0.010088	0.182031	0.209055389
	summer	32.48	high	27.48	high	0.001645949	0.018046	0.0000769	0.014571	0.213415	0.247755808
	autumn	26.45	high	21.45	high	0.001387897	0.0139269	0.0000643	0.011956	0.1600615	0.187396741
2	winter	18.84	moderate	13.84	high	0.001206564	0.014123	0.0000549	0.007846	0.156923	0.180153795
	spring	22.46	high	17.46	high	0.001412308	0.016281	0.0000675	0.009341	0.197723	0.22482429
	summer	29.26	high	24.26	high	0.001670359	0.021773	0.0000800	0.01233	0.247938	0.283791599
	autumn	24.45	high	19.45	high	0.001398359	0.0180462	0.0000690	0.0104615	0.1820308	0.212005867
3	winter	27.48	high	22.48	high	0.001297231	0.013142	0.0000738	0.012703	0.150646	0.177862743
	spring	40.04	high	35.04	high	0.001478564	0.017458	0.0000863	0.019055	0.200862	0.238939048
	summer	62.49	high	57.49	high	0.001865641	0.026481	0.0001130	0.030637	0.229108	0.28820445
	autumn	50.13	high	45.13	high	0.001513436	0.0188308	0.0000847	0.0246593	0.1914462	0.236534438
4	winter	17.54	moderate	12.54	high	0.00122400	0.007258	0.0000534	0.007846	0.097292	0.113673508
	spring	20.21	high	15.21	high	0.001380923	0.010004	0.0000659	0.008967	0.112985	0.133402325
	summer	24.66	high	19.66	high	0.001628513	0.014515	0.0000800	0.010835	0.141231	0.168289862
	autumn	21.90	high	16.90	high	0.001433231	0.0121615	0.0000659	0.0097143	0.1192615	0.142636501
5	winter	30.91	high	25.91	high	0.001318154	0.011573	0.0000753	0.014571	0.172615	0.200153367
	spring	37.67	high	32.67	high	0.001433231	0.015104	0.0000894	0.017934	0.194585	0.229145204
	summer	58.62	high	53.62	high	0.001785436	0.021969	0.0001208	0.028769	0.232246	0.284890882
	autumn	48.59	high	43.59	high	0.00152041	0.0160846	0.0000989	0.0239121	0.1977231	0.239339052
6	winter	26.87	high	21.87	high	0.000972923	0.003335	0.0000345	0.013451	0.106708	0.124500303
	spring	35.52	high	30.52	high	0.001084513	0.004512	0.0000424	0.017934	0.141231	0.164803256
	summer	63.43	high	58.43	high	0.001380923	0.008631	0.0000565	0.032879	0.178892	0.221839613
	autumn	51.43	high	46.43	high	0.001227487	0.0072577	0.0000471	0.0265275	0.1506462	0.185705883
7	winter	27.09	high	22.09	high	0.000718359	0.003531	0.0000173	0.013451	0.160062	0.177778478
	spring	31.23	high	26.23	high	0.000965949	0.005296	0.0000267	0.015319	0.185169	0.206776692
	summer	68.59	high	63.89	high	0.001119385	0.008042	0.0000377	0.035868	0.232246	0.27731364
	autumn	58.74	high	53.74	high	0.000993846	0.0056885	0.0000330	0.0306374	0.1945846	0.23193724

The HQ_{dermal} of all heavy metals (Fe, Mn, Zn, Pb and Cd) in sites of the both lakes during study seasons were lower than one and their hazard index values also. The $HQ_s < 1$ and $HI < 1$ meaning that these non-carcinogenic pollutants may have not negative health effects. Where, **Tripathee *et al*. (2016)** noted that pollutants may pose potential adverse health effects if the HQ value of the metal is greater than unity.

Health risk from fish muscle consumption

The target hazard quotients for Fe, Mn, Zn, Pb and Cd estimated through the muscle consumption of two fish species (*O. niloticus* and *C. gariepinus*) in the both lakes (Burullus and Edku) are showed in Table 9. The assessment of health risk is done based on assumptions. According to USEPA, the acceptable value is 1 for THQ_S **(USEPA, 2011)**. In the present study the THQ_S and their HI were less than 1 for all heavy metals from all sites in the both lakes during the study seasons. Therefore, there is no non-carcinogenic health risk from ingestion of these metals individually and collectively through *O. niloticus* and *C. gariepinus* consumption in the both lakes. This indicating that the fish species (*O. niloticus* and *C. gariepinus*) from all sites of Burullus lakes and Edku lake through the current study were found safe for consumption. Where, the possibility of health risk associated with non-carcinogenic effect is very low for continuous consumption for 30 years.

Bioconcentration factor (BCF) estimation

BCF values were calculated in the muscle tissues of *O. niloticus* and *C. gariepinus* consumption in the both lakes (Table 10), vs exposure to heavy metals (Fe, Mn, Zn, Pb and Cd) in the lake water during the study seasons in the both lakes. According to BCF classification scale of **Landis *et al.* (2011)**, Fe values showed as a moderate pollution (BCF= 250-1000) in the both fih species (*O. niloticus* and *C. gariepinus*) during study seasons of Burullus lake. And, in Edku lake, *O. niloticus* species were showed low pollution (BCF< 250) during the study seasons, while *C. gariepinus* species were showed low pollution (BCF< 250) during spring and summer and moderate pollution (BCF< 250) during winter and autumn. However, BCF values of pb and Cd were showed as low polluted (BCF< 250) in the both species (*O. niloticus* and *C. gariepinus*) of the both lakes during study seasons.

Moreover, BFC values of Mn were showed as low pollution (BCF< 250) in *O. niloticus* in the both lakes during the study seasons. Also, in *C. gariepinus*, Mn were showed as low pollution (BCF< 250) in the both lakes during the study seasons except winter and spring were showed as moderate pollution values (BFC= 255.55-251.28, respectively). For, Zn values were showed as low pollution (BCF <250) in in *O. niloticus* in Burullus lake during the study seasons. While, *C. gariepinus* species were showed as moderate pollution (BCF= 250-1000) during the study seasons in Edku lake. Generally, the accumulation order of metals in muscle tissues (*O. niloticus* and *C. gariepinus*) of Burullus lake were as follow (Fe> Zn> Mn> Cd> Pb). While, in Edku lake were as follow (Zn> Mn> Fe> Cd> Pb).

Table 9. Target hazard quotient (THQs) for different heavy metals and their hazard index (HI) from consumption of fish muscles species collected from two lakes (Burullus and Edku) during the study seasons.

Metals / Seasons in two lakes		THQs Fe		Mn		Zn		Pb		Cd		HI	
		O. niloticus	*C. garpinus*	*O. niloticus*	*C. garpinus*	*O. niloticus*	*C. garpinus*	*O. niloticus*	*C. garpinus*	*O. niloticus*	*C. garpinus*	*O. niloticus*	*C. garpinus*
Burullus lake	Winter	0.011683	0.014036	0.008615	0.010926	0.008286	0.009413	0.007354	0.012666	0.023534	0.030888	0.059472	0.077929
	Spring	0.013343	0.017041	0.010191	0.012712	0.008727	0.010345	0.009397	0.015934	0.030888	0.042655	0.072546	0.098687
	Summer	0.017398	0.019941	0.013973	0.017755	0.010345	0.012061	0.018386	0.023697	0.042655	0.061776	0.102757	0.13523
	Autumn	0.014898	0.019037	0.012397	0.016495	0.009904	0.010835	0.014709	0.017977	0.03383	0.048538	0.085738	0.112882
Edku lake	Winter	0.012628	0.017419	0.010716	0.012817	0.008531	0.009953	0.022063	0.026557	0.038242	0.027946	0.09218	0.094692
	Spring	0.013626	0.019604	0.012292	0.016179	0.009266	0.010737	0.024923	0.029009	0.050009	0.032359	0.110116	0.107888
	Summer	0.017041	0.021748	0.01744	0.021117	0.011409	0.011777	0.029417	0.034729	0.030888	0.047067	0.106195	0.136438
	Autumn	0.014898	0.020634	0.014393	0.017335	0.010394	0.010889	0.026966	0.031869	0.05148	0.035301	0.118131	0.116028

Table 10. Bioconcentration factors (BCFs) of heavy metals in fish muscles species collected from two lakes (Burullus and Edku) during the study seasons.

Metals / Seasons in two lakes		BCFs Fe		Mn		Zn		Pb		Cd	
		O. niloticus	*C. gariepinus*	*O. niloticus*	*C. gariepinus*	*O. niloticus*	*C. gariepinus*	*O. niloticus*	*C. gariepinus*	*O. niloticus*	*C. gariepinus*
Burullus lake	Winter	267.31**	321.53**	125.52*	159.18*	151.79*	172.46*	4.07*	7.01*	53.14*	69.74*
	Spring	277.83**	354.84**	120.25*	149.99*	140.28*	166.29*	4.25*	7.22*	58.16*	80.31*
	Summer	283.56**	325.00**	127.88*	162.5*	148.13*	172.69*	6.34*	8.18*	57.62*	83.44*
	Autumn	274.92**	351.31**	135.29*	180.00*	151.75*	166.03*	6.27*	7.66*	53.90*	77.34*
Edku lake	Winter	183.95*	253.74**	213.77*	255.69**	534.22**	623.25**	18.09*	21.77*	58.90*	43.04*
	Spring	173.26*	249.27*	190.91*	251.28**	474.20**	549.46**	16.17*	18.83*	61.49*	39.79*
	Summer	178.41*	227.69*	190.80*	231.03*	452.47**	467.05**	11.35*	13.40*	31.28*	47.66*
	Autumn	182.66*	252.99**	204.47*	246.27*	503.05**	527.02**	12.52*	14.79*	64.30*	44.09*

Where, BCF value greater than 1,000 are considered high (***), and less than 250 low (*), with those between classified as moderate (**) (**Landis *et al.* 2011**).

CONCLUSION

1- In general, the average concentrations of different investigated heavy metals in the water of the two examined lakes were under chronic Criterion Continuous Concentration such as (Fe and Mn) and some metals were higher than the permissible limits such as (Cd and Pb) mentioned by **USEPA (2006)**.
2- Concerning the degree of Pollution Indices, both lakes water is highly contaminated based on HPI, HEI and Cd, and this indicated that the Edku and Burullus lakes suffer from serious environmental pollution as they receive agricultural drainage, industrial wastewater as well as domestic wastewaters directly without any treatments.
3- Because of the different pollution problems in lakes, the following procedures are strongly recommended for better protection and conservation of these lakes: treating sewage, agricultural and industrial wastes before discharged into lakes, dredging El Boughazes to increase their depths in order to permit a suitable rate of water exchange between the lakes and the Sea.

REFRENCES

Abdel-Hamid, E. A. A. (2017). Assessment of water quality and Bacterial Contamination in Water, Sediments and Fish of Lake Manzala. Egy. J. Aquac., 7(1):55-75.

Abd-El -Khalek, D. E.; El -Gohary, S. El. and El -Zokm, G. M. (2012). Assessment of heavy metals pollution in *Oreochromis niloticus* in El-Max fish farm, Egypt. Egypt. J. Exp. Biol., 8(2): 215-222.

Al-Ani, M.Y.; Al-Nakib, S.M.; Ritha, N.M. and Nouri, A. H. (1987). Water quality index applied to the classification and zoning of Al Jaysh canal, Baghdad–Iraq. Journal of Environmental Science & Health Part A, 22(4):305-319

Aboyeji, O. O. (2013). Fresh water pollution in some Nigerian local communities, causes, consequences and probable solutions, Academic Journal of Interdisciplinary Studies, 2(13), 111-117.

Aderinola, O. J.; Clarke, E. O.; Olarinmoye, O. M.; Kusemiju, V. and Amatekhai, M. A. (2009). Heavy metals in surface water, sediments, fish and Perwinkles of lagos lagoon. *American-Eurasian J. Agric. & Environ. Sci*., 5(5): 609-617.

Alam, M. G. M.; Tanaka, A.; Allinson, G.; Laurenson, L. J. B.; Stagnitti, F. and Snow, E. T. (2002). A comparison of trace element concentrations in cultured and wild carp (*Cyprinus carpio*) of Lake Kasumigaura, Japan. Ecotox. Environ. Safe, 53: 348–354.

Alinnor, I. J. and Obiji, I. A. (2010). Assessment of trace metal composition in fishsamples from Nworie River. Pakistan Journal of Nutrition, 9(1): 81–85.

Al Naggar, Y.; Khalil, M. S. and Ghorab, M. A. (2018). Environmental Pollution by Heavy Metals in the Aquatic Ecosystems of Egypt, Open Access J. Toxico., 3(1): 1-9.

Ameh, E. G. (2013). Geo-statistics and heavy metal indexing of surface water around Okaba coalmines, Kogi State, Nigeria. Asian Journal of Environmental Science, 8(1): 1-8.

American Public Health Association (APHA) (2000). Standard Methods for the Examination of Water and wastewater (20th edition). Washington, D.C.

Al-Sayegh Petkovšek, S.; MazejGrudnik, Z. and Pokorny, B. (2012). Heavy metals and arsenic concentrations in ten fish species from the šalek lakes (Slovenia): assessment of potential human health risk due to fish consumption. Environmental Monitoring and Assessment, 184: 2647–2662.

Aly, M. Y. M.; El-Gaar, D. M. K.; Salaah, S. M. and Abdo, M. H. (2020). Evaluation of Heavy Metals and Oxidative Stress with Biochemical Parameters as Bioindicators of Water Pollution and Fish in Lake Burullus, Egypt. Mari. Scie. Res. Ocean. J., 1(3): 30-34.

Association of Official Analytical Chemists (AOAC) (2005). Official Method 999.11 of Analysis of lead,cadmium, copper, iron and zinc in foods. Atomic Absorption spectrophotometry. Washington, D.C.

Authman, M. M. N. (2008). *Oreochromis niloticus* as a bio monitor of heavy metal pollution with emphasis nonpotential risk and relation to some biological aspects. Global Veterinaria, 2 (3): 104-109.

Authman, M. M. N.; Bayoumy, E. M. and Kenawy, A. M. (2008). Heavy metal concentrations and liver histopathology of *Oreochromis niloticus* in relation to aquatic pollution. Global Veterenaria, 2(3): 110-116.

Authman, M. M. N.; Abbas, H. H. and Abbas, W. T. (2013). Assessment of metal status in drainage canal water and their bioaccumulation in *Oreochromis niloticus* fish in relation to human health. Environ. Monit. Assess., 185:891–907.

Badr, A. M.; Mahana, N. A. and Eissa, A. (2014). Assessment of Heavy Metal Levels in Water and Their Toxicity in Some Tissues of Nile Tilapia (*Oreochromis niloticus*) in River Nile Basin at Greater Cairo, Egypt. Global Veterinaria, 13(4): 432-443.

Badr, N. B. E. and Hussein, M. M. A. (2010). An input/ output flux model of total phosphorous in Lake Edku, a northern eutrophic Nile Delta Lake, Global J. of Environ. Res. 4(2): 64-75.

Bahnasawy, M.; Khidr, A. A. and Dheina, N. (2011). Assessment of heavy metal concentrations in water,plankton, and fish of Lake Manzala, Egypt. Turkish Journal of Zoology, 35(2): 271-280.

Basiony, A. I. (2014). Environmental studies on heavy metals pollution and management of lake Burullus, Egypt. M. Sc. Thesis, Faculty of Science, PortSaid University, Egypt.

BBS (2011). Household Income and Expenditure Survey, Bangladesh Bureau of Statistics, Bangladesh.

Caeiro, S.; Costa, M. H.; Ramos, T. B.; Fernandes, F.; Silveira, N.; Coimbra, A. and Painho, M. (2005). Assessing heavy metal contamination in Sado Estuary sediment: an index analysis approach. Ecological indicators,5(2): 151-169.

CCME (Canadian Council of Ministers of the Environment), (2007). For the rotection of aquatic life 2007. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, 1999, Winnipeg.

Canli, M. and Atli, G. (2003). The relationships between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. Environmental Pollution, 121: 129–136.

Canli, M. and Furness, R. W. (1993). Toxicity of heavy metals dissolved in sea water and influences of sex and size on metal accumulation and tissue distribution in the Norway lobster Nephrops norvegicus. Marine Environment and Toxicological Chemistry, 14: 819–828.

Darwish, D. H. (2011). Studying of some pollutants by using chemical analysis and remote sensing for Burullus Lake, Egypt. M. Sc. Thesis, Damietta Faculty of Science, Mansoura University, Egypt.

Darwish, S. I. (2016). Water quality and heavy metals pollution in soil, water and fish in Lake Burullus, Ph.D. Thesis. Fac. of Agriculture. Univ. of Saba Basha (Alex.). Dep. of fish production.

Daviglus, M.; Sheeshka, J. and Murkin, E. (2002). Health benefits from eating fish. Comments on Toxicology, 8: 345–374.

Dytham, C. (1999). Choosing and Using Statistics: A Biologist s Guide. Blackwell Science Ltd., London, UK.

Edet, A. E. and Offiong, O. E. (2002). Evaluation of water quality pollution indices for heavy metal contamination monitoring. A study case from Akpabuyo-Odukpani area, Lower Cross River Bas in (southeastern Nigeria). Geo Journal, 57(4): 295-304.

Egyptian Chemical Standards (ECS), (1994). Protection of the Nile River and Water Stream from pollution, Ministry of Irrigation, Cairo, Egypt, Law No 4.

El-Batrawy, O. A.; El-Gammal, M. I.; Mohamadein, L. I.; Darwish, D. H. and El-Moselhy, Kh. M. (2018). Impact assessment of some heavy metalson tilapia fish, Oreochromis niloticus, in Burullus Lake, Egypt. Basic and Applied Zoology J., 79(13): 1-12.

El Morshedy, E. M. (2017). Effect of pollution on water quality, soil and fish performance in lakes and fish farm ponds. Ph.D. Thesis. Fac. of Agriculture. Univ. of Saba Basha (Alex.). Dep. of fish production.

EL-Shaer, F. M. and ALabassawy, A. N. (2019). Assessment of heavy metals concentration in water and edible tissues of Nile tilapia (*Oreochromis niloticus*) and (*Clarias garpinus*) from Burullus lake, Egypt with liver histopathological as pollution indicator. J. Egypt. Soc. Parasitol. (JESP), 49(1): 183-194.

EMI (2012). Egyptian Ministry of Irrigation, the amount of agricultural drainage water which entered the Lake Burullus during 2010. Organization of Mechanic and Electricity, Central Administration of the Central Delta stations, Kafr El- Sheikh, Egypt.

Eneji, I. S.; Sha'Ato, R. and Annune, P. A. (2011). Bioaccumulation of heavy metals in fish (Tilapia zilli and Clarias gariepinus) organs from River Benue, North Central Nigeria. Pak. J. Anal Environ. Chem., 12(1 and 2): 25 - 31.

Farouk, A. A. (2009). Some studies on water pollution of Manzala Lake by heavy metals and others and effect of these on stock assessment of fish. M.SC. Thesis. Fac. of sci. Al Azhar Univ. Chemistry Dep.

Farouk, A. A. (2014). Studies on Water Quality, Pollution by Heavy Metals in Water, Soil & Fish and Stock Assessment in Bardawil Lake. Ph.D. Thesis. Fac. of sci. Al Azhar Univ. Chemistry Dep.

Gad, N. S. (2005). Impact of environmental pollution in the southern region of lake Manzalah Egypt on some biochemical parameters of Tilapia zillii. J. Egypt Ger. Soc. Zool., 48: 279-298.

GARFD, (2013). General Authority for Fishery Resources Development. Year-Book of Fishery: Statistics, Cairo, Egypt.

Gobas, F. A. P. C.; Wolf, D.; Burkhard, W.; Verbruggen, L. P.; Plotzke, K., *et al*. (2009). Revisiting bioaccumulation criteria for POPs and PBT assessments. Integrated Environmental Assessment and Management, 5: 624–637.

Guerrin, F.; Burgat-Sacaze, V. and Saqui-Sames, P. (1990). Levels of heavy metals and Environmental Monitoring and Assessment, 184, 2647–2662. exposure to carbofuran pesticides. Glob. Vet., 1: 45-52.

Hamed, M. A. (1998). Distribution of trace metals in the River Nile ecosystem, Damietta branch between Mansoura city and Damietta Province. J/ Egypt., Ger. Soc. Zool., Vol. 27(A) Comparative Physiology, 399–415.

Heath, A. G. (1995). Water Pollution and Fish Physiology. CRC Press Inc Boca Raton Florida 359pp.

Hossain, Md. I.; Khatun, M.; Kamal, B. M. M.; Habib, K. A.; Tumpa, A. S.; Subba, B. R.; Hossain, Md. Y. (2014). Effects of seasonal variation on growth performance of mirror carp (*Cyprinus carpio Ver. Specularis*) in earthen nursery ponds. Our Nature, 12(1): 8-18.

Jobling, M. (1995). Environmental Biology of Fishes. 1sted. Printed in Great Britian. Chapman and Hall, London.

Karadede, H. and Ünlü, E. (2000). Concentrations of some heavy metals in water, sediment and fish species from the Atatürk Dam Lake (Euphrates), Turkey. Chemosphere, 41(9): 1371–1376.

Koca, Y. B. M.; Koca, S.; Yildiz, S.; Gurcu, B.; Osanc, E. and Tuncbas, O. (2005). Investigation of histopathological and cytogenetic effects on *Lepomisgibbosus* (Pisces: Perciformes) in the Cine stream (Aydin/Turkey) with determination of water pollution. Environ Toxicol., 20:560–571.

Koussa, A. A. (2000). Effect of industrial and organic pollution on potential productivity and fish stock of Lake Mariut, Northern Egypt with a predictive study of that effect on the Lake. Ph.D. Thesis. Fac. Sci. Ain Shams Univ. Egypt.

Kumar, B.; Mukherjee, D. P. N.; Sanjay Kumar; Meenu Mishra; Dev Prakash; Singh, S. K. and Sharma, C. S. (2011). Bioaccumulation of heavy metals in muscle tissue of fishes from selected aquaculture ponds in east Kolkata wetlands. Annals of Biological Research, 2(5):125-134.

Landis, W.; Sofield, R.; Yu, M. H.; Landis, W. G.; Sofield, R. M. (2011). Introduction to environmental toxicology: molecular substructures to ecological landscapes. 4th ed. Boca Raton, Florida: CRC Press. ISBN 9781439804100.

Mason, C. F. (2002). Biology of freshwater pollution. 4rd ed. Essex Univ. England. 387 pp.

Masoud, M. S.; El-Samra, M. I. and El-Sadawy, M. M. (2007). Heavy-metal distribution and risk assessment of sediment and fish from El-Mex Bay, Alexandria, Egypt. Chem Ecol., 23: 201–216.

Matthiessen, P. and Brafield, A. E. (1977). Uptake and loss of dissolved zinc by stickle back Gasterosteus aculeatus (L). J. Fish. Biol., 10:399-410.

Meng, Q.; Zhang, J.; Zhang, Z. and Wu, T. (2016). Geochemistry of dissolved trace elements and heavy metals in the Dan River Drainage (China): distribution, sources, and water quality assessment. Environmental Science and Pollution Research , 23(8): 8091-8103.

Moussa, S. M. (2004). Impact of Inorganic Pollutants on Aquatic Environment and Fish Performance in Lake Borollus. Ph. D. Thesis, Inst. of Environment Stud. and Res., Biol. and Phys. Dep., Ain-shams. Univ., Egypt.

Okbah, M. A. and El-Gohary, S. El. (2002). Physical and chemical characteristics of Lake Edku Water, Egypt. Medit. Mar. Sci., 3(2): 27–39.

Olaifa, F. E.; Olaifa, A. K.; Adelaja, A. A. and Owolabi, A. G. (2004). Heavy metal contamination of *Clarias garpinus*from a lake and fish farm in Ibadan, Nigeria. Afr. J. Biomed. Res., 7: 145-148.

Orata, F. and Birgen, F. (2016). Fish tissue bio-concentration and interspecies uptake of heavy metals from waste water lagoons. Journal of Pollution Effects & Control, 4(2), 157.

Pyrbot, W. and Laloo, R. C. (2015). Toxic elements of river Myntdu in Jaintia hills district Meghalaya, India. Intern. J. Curr. Res., 7(05): 15531-15537.

Rocha, E. and Monteiro, R. A. F. (1999). Histology and Cytology of Fish Liver: A Review. In: Ichthyology: Recent Research Advances, Saksena D.N. (Ed.). Science Publishers, Enfield, New Hampshire. ISBN: 1-57808-053-3, pp: 321-344.

Romeoa, M.; Siaub, Y.; Sidoumou, Z. and Gnassia-Barelli, M. (1999). Heavy metal distribution in different fish species from the Mauritania coast. Sci Total Environ., 232: 169–75.

Saad, M. A. H. (2003). Impact of diffuse pollution on the socio-economic development opportunities in the coastal Nile delta lakes. Diffuse Pollution Conference Dublin 2003 ECSA, 5: 6-81.

Saeed, S. M. and Shaker, I. M. (2008). Assessment of heavy metals pollution in water and sediment and their effect on *Oreochromis Niloticus* in the northern delta Lakes, Egypt. 8th International Symposium on Tilapia in Aquaculture, 475-490.

Saeed, S. M. (2013). Impact of environmental parameters on fish condition and quality in Lake Edku, Egypt. Egypt. J. Aquat. Biol. & Fish, 17(1): 101-112.

SCF (1993). Reports of the Scientific Committee for Food. Thirty-first series. Nutrient and energy intakes for the European Community.

Shaker, I. M. (2006). Water hyacinth as a biological treatment for sewage wastewater in aquaculture earthen ponds. Egyptian Journal of Aquatic Biology and Fisheries, 10: 1–20.

Shaker, 1. M.; Rabie, G. H.; Ismaiel, A. A. and T. Mekawy, M. (2015). Impacts of Some Environmental Conditions on Water Quality and Some Heavy Metals in Water of Different Aquaculture Sites. Middle East Journal of Applied Sciences ISSN 2077- 4613, 5(3): 742-750.

Shaker, M and Elnazer, A. A. (2015). Interpolation Distribution Mapping for Studying Behavior of Some Heavy Metals in Lake Borollus Northeast of Rosetta Branch of the river Nile, Egypt. Poll Res., 34(2): 1-5.

Shalaby, B. N.; Samy, Y. M.; Mashaly, A. O. and El Hefnawi, M. A. (2017). Comparative geochemical assessment of heavy metal pollutants among the Mediterranean Deltaic Lakes sediments (Edku, Burullusand Manzala), Egypt. Egy. J. Chem., 60(3): 361- 377.

Shetaia, S. A.; Abu Khatita, A. M.; Abdelhafez, N. A.; Shaker, I. M.; El Kafrawy, S. B. (2020). Evaluation of potential health risk, heavy metal pollution indices and water quality of Edku Lagoon- Egypt. Egy. J. Aqua. Biol.& Fish, 24(2): 265–290.

Soufy, H.; Soliman, M.; El-Manakhly, E. and Gaafa, A. (2007). Some biochemical and pathological investigations on mono sex Tilapia following chronic exposure to carbofuran pesticides. Glob. Vet., 1: 45-52.

Tao, Y.; Yuan, Z.; Xiaona, H. and Wei, M. (2012). Distribution and bioaccumulation of heavy metals in aquatic organisms of different trophic levels and potential health risk assessment from Taihu lake, China. Ecoto. and Enviro. Saf., 81: 55-64.

Tekin-Özan, S. and Kir, I. (2008). Seasonal variations of heavy metals in some organs of carp (*Cyprinus carpio*L., 1758) from Beyşehir Lake (Turkey). Environmental Monitoring and Assessment, 138(1-3): 201-206.

Tripathee, L.; Kang, S.; Sharma, C. M.; Rupakheti, D.; Paudyal, R.; Huang, J. and Sillanpää, M. (2016). Preliminary health risk assessment of potentially toxic metals in surface water of the Himalayan Rivers, Nepal. Bulletin of environmental contamination and toxicology, 97(6): 855-862

Tscheikner-Gratl, F.; Bellos, V.; Schellart, A.; Moreno-Rodenas, A.; Muthusamy, M.; Langeveld, J.; ... and Breuer, L. (2019). Recent insights on uncertainties present in integrated catchment water quality modelling. Water research, 150: 368-379.

USEPA (2004). Risk assessment guidance for superfund volume I: human health evaluation manual (part E, supplemental guidance for dermal risk assessment) final. EPA /540/R/99/005 OSWER 9285.7-02EP PB99-963312 July 2004, Office of Superfund Remediation and Technology Innovation.

USEPA (2006)**.** National Recommended Water Quality Criteria. United States Environmental Protection Agency. Office of Water, Office of Science and Technology.

USEPA (2011). USEPA Regional Screening Level (RSL) Summary Table: November.

Watanabe, K. H.; Desimone, F. W.; Thiyagarajah, A.; Hartley, W. R. and Hindrichs, A. E. (2003). Fish tissuequality in the lower Mississippi River and health risks from fish consumption. Sci. Total Environ., 302: 109-126.

Wepener, V.; Van Vuren, J. H. J. and Du Preez, H. H. (2001). Uptake and distribution of a copper, iron and zinc mixture in gill, liver and plasma of a freshwater teleost, *Tilapia sparmanii*. Water SA., 27(1): 99-108.

World Health Organization (WHO) (2011). Iron, Zinc, Copper, Manganese, Cadmium and Lead in drinking-water. Guidelines for drinking-water quality, Geneva, World Health Organization, 4^{th} ed.

Wu, B.; Zhao, D. Y.; Jia, H. Y.; Zhang, Y.; Zhang, X. X. and Cheng, S. P. (2009). Preliminary risk assessment of trace metal pollution in surface water from Yangtze

River in Nanjing Section, China. Bulletin of environmental contamination and toxicology, 82(4): 405-409.

Yacoub, A. M. (2007). Study on Some Heavy Metals Accumulated in Some Organs of Three River Nile Fishes from Cairo and Kalubia Governorates. Afr. J. Biol. Sci., 3: 9-21.

Yosef, T. A. and Gomaa, G. M. (2011). Assessment of Some Heavy Metal Contents in Fresh and Salted (Feseakh) Mullet Fish Collected from El-Burullus Lake, Egypt. J. American Science, 7(10): 137-144.

Zaghloul, F. A. and Hussein, N. R. (2000). Impact of pollution on phytoplankton community structure in Lake Edku, Egypt. Bull. NIOF, 26: 297-318.

Zahran, M. A.; El Amier, Y. A.; Elnaggar, A. A.; Abd El Azim, H. and El Alfy, M. A. (2015). Assessment and Distribution of Heavy Metals Pollutants in Manzala Lake, Egypt. J. Geoscience and Environment Protection, 3: 107-122.