



# Risk assessment of pollution with heavy metals in water and fish from River Nile, Egypt

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## Abstract

The aim of this study is to investigate the level of contamination with metals (Fe, Mn, Zn, Cu, and Pb) in the Nile River at the great Cairo region. Samples of water and fish were collected seasonally from different sites along the investigated area. Physical and chemical parameters of the studied water samples such as temperature, transparency, electrical conductivity, pH, BOD, and COD were measured. In aquatic ecosystems, heavy metal concentrations are monitored by detecting some indices like water pollution indices (WPI) and bioaccumulation factor (BAF). The results clarified that Fe, Pb, and Mn concentrations in water exceed the allowed limits set by WHO, 2011 in all sites while Cu and Zn are in allowed limits. While in fish muscle Fe and Cu are within the permissible limits set by FAO, 1992, but Mn, Zn and Pb exceed the limits. Some of the metals like Cu, Fe, Mn, Ni and Zn are essential for animals and plants while many other like Pb, Cd, Cr and Co are classed as nonessential metals. All values of HI were below 1 except for Pb in case of habitual fish eaters that give alarm to fish consumer.

**Keywords** Heavy metals · Water · Fish · Pollution · River Nile

## Introduction

The River Nile is the main source of drinking water in Egypt; however, in recent years, huge quantities of industrial and agricultural wastes are discharged into the water body (Nada et al. 2016 and Al-Halani 2017). Pollution has a harmful effect on the water quality by decreasing dissolved oxygen and transparency of water; however, water temperature, electric conductivity, levels of nutrient salts, total dissolved solids and water alkalinity were increased (Ibrahim et al. 2013). In aquatic ecosystems, heavy metal concentrations are monitored by detecting their concentration in water (Ebrahimpour and Mushrifah 2008). Some of the metals like Cu, Fe, Mn, Ni and Zn are essential for animals and plants while many other like Pb, Cd, Cr and Co have no known physiological activities (Aktar et al. 2010). Essential and nonessential metals have a great importance in ecotoxicology (Vinodhini and Narayanan 2008). According to (FAO 2013), Egypt is the eighth global aquaculture producer with about 986,820

tons in 2011. Fish consumption in Egypt rose from 8.5 kg/person/year in 1996 to 15.4 kg in 2008 and 20.8 kg in 2013 according to the General Authority for Fisheries Resource Development (GAFRD) (Eltholth et al. 2015 and Talab et al. 2016). Nile tilapia (*Oreochromis niloticus*) fish is one of the most common species in Egypt and preferred as food depending on its excellent rate of growth which is independent on low protein diets (Balirwa 1992). Fishes are good biomonitors for describing the quality of aquatic systems and for testing levels of metal pollution (Rashed 2001 and Lamas et al. 2007). Moreover, fish may accumulate metals in their flesh and throw them to human by eating these infected fish and causing different diseases (Al-Yousuf et al. 2000). Has-Schön et al. (2008) reported that accumulation in fish tissue is mainly result from concentrations of metals in water and also to environmental factors like exposure time, water temperature, pH, oxygen concentration and dissolved organic carbon (Has-Schön et al. 2008). On the basis of the health effect of heavy metals on the human, this study aims to study the environmental and ecological pollution of heavy metals in River Nile using water and fish samples. For this purpose, the pollution indices including water pollution index (WPI), metal pollution index (MPI), bioaccumulation factor (BAF) and hazard index (HI) for fish are investigated.

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## Materials and methods

### Study area

Water and fish samples from the different sites along the area under investigation were collected seasonally (from autumn 2018 to summer 2019) at the mid-stream of each station as shown in Table 1.

### Collection and analysis of water sample

Physical parameter of water sample (transparency, electrical conductivity and temperature) were measured in the field using a multi-probe portable meter (Model CRISON, Spain). While chemical parameter (BOD, COD and DO) and heavy metals were measured according to American public health association (APHA 1992) methods. Heavy metals ( $\text{Fe}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Cu}^{2+}$  and  $\text{Pb}^{2+}$ ) concentration were determined using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), Varian Liberty Series II, Italy. The detection wavelengths were as follows; 324.752, 259.993, 259.610, 283.305 and 206.200 nm for  $\text{Cu}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Pb}^{2+}$  and  $\text{Zn}^{2+}$ , respectively.

### Collection and analysis of fish samples

Nile tilapia fish samples (mean weights  $200 \pm 57.7$  g, length  $25.5 \pm 1.3$  cm) were collected seasonally from the same sites of water samples. They were washed with tap water to remove any adhering contaminants then preserved in a cooler at 4 °C to be transported to pollution laboratory, National Institute of Oceanography and Fisheries, El-Kanater El-Kairia Research Station, for carrying out the analysis. Fish muscle and liver were prepared for the analysis according to the method reported by (Mechea et al. 2010). ICP-OES (Varian liberty series II Italy) instrument was used to determine  $\text{Cu}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Pb}^{2+}$  and  $\text{Zn}^{2+}$  as mentioned above.

### Water pollution index (WPI)

It can be calculated for water samples as reported by (Caerio et al. 2005). So when  $\text{PI} < 1$  (there is no pollution), 1–2 (slightly affected), 2–3 (moderately affected), 3–5 (strongly affected) and  $> 5$  (seriously affected).

### Pollution load index (PLI)

The pollution load index (PLI) in water of great Cairo region was proposed by (Tomlinson et al. 1980).

### Bioaccumulation factor

Bioaccumulation factor (BAF) is the ratio of metal concentration in the organism to its concentration in the surrounding water and can be calculated for muscles and liver using equation illustrated by (Kalfakakour and Akrida-Demertzi 2000).

### Health risk assessment

According to (USEPA 2000), hazard index (HI) is the ratio between the (ADD) average daily intake of specific chemical over lifetime to the (oral RFD) oral reference dose of metal as shown in the equation below.  $\text{HI} < 1$  means that daily exposure has no adverse effects during person lifetime.  $\text{HI} > 1$  it means daily exposure may have adverse effects during person lifetime (Pawelczyk 2013 and USEPA 2002).

### Statistical analysis

All analyses were performed in triplicate. Statistical data analyses of the results were performed using WINDOWS 2010. The means of the replicates and evaluation of significant differences between different samples were determined using descriptive statistics and analysis of variance (ANOVA), respectively.

## Results and discussion

### Physical and chemical parameters of water

The results of physicochemical parameter of water at different sites of the investigated area are represented in (Fig. 1). Temperature shows maximum value at site I in summer, while minimum value recorded at site III during winter. (Ghannam and Talab 2009) reported that water temperature related to the sampling times, number of

**Table 1** Different sites of the investigated area along River Nile

Site	Name of sites	Latitude	Longitude	Type of pollution
I	El-Tbeen district	29°48'0"N	31°17'45"E	Industrial activities
II	Manyal district	30°0'54.56" N	31°13'17.62"E	Domestic activities
III	El-Kanater El-Kairia City	30°11'1"N	31°8'20"E	Agricultural activities

sunshine and agree with the obtained results that highest values in summer and the lowest value was in winter season. Transparency shows minimum value during spring in site II, while maximum value recorded during autumn in site II. In spring, the increase in amount of phytoplankton lead to decrease in transparency, science transparency depends on the suspended solid and organic matter found in water body (Ghannam and Talab 2009). The same results obtained by (Olsen and Sommerfeld 1977) who stated that higher value of transparency is related

to settling out of suspended particles to the bottom sediments that present during autumn season. For (EC), the lowest value was during spring at site III and the highest value was at site III during summer. The high values of EC may be attributed to the presence of large amount of organic and inorganic constituents that discharged into the Nile (Ghannam and Talab 2009). (Elewa and Mahdi 1988) recorded that decrease of EC during spring may be related to the increase of water level and the uptake of dissolved salt by phytoplankton (Siliem 1995). DO values showed

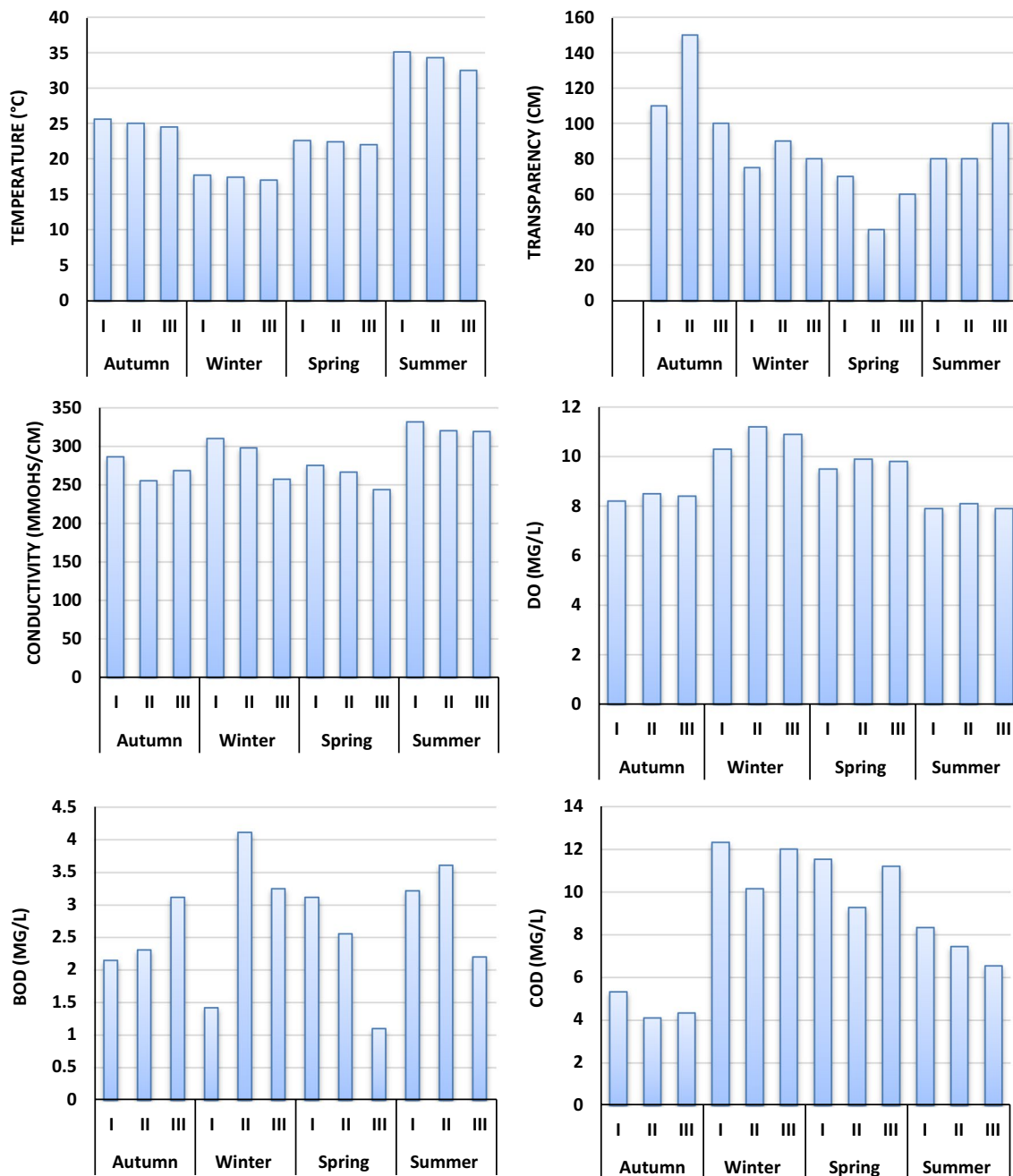
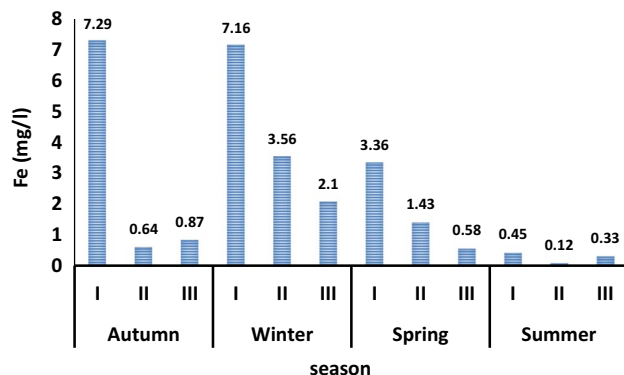


Fig. 1 Physicochemical parameter of water collected from different sites of the investigated area from autumn 2018 to summer 2019

the order: winter > spring > autumn > summer were highest value was in winter and the lowest was in summer. The same results obtained by (Ghannam and Talab 2009) who found that temperature, pH and photosynthesis activity have a strong effect on dissolved oxygen. Biochemical oxygen demand (BOD) showed maximum value at site II during winter and minimum was observed at site III during spring. The values obtained during summer and autumn may be depend on the presence of dead microorganism at the bottom layer of water that not able to make aerobic biochemical oxidation of wastes especially at low oxygen content (Siliem 1995). While the increase in winter value may be depend on the wind prevailing mixing water layers in Nile due to decline in depth that increasing the biological activity in aquatic system (Ghannam and Talab 2009). In chemical oxygen demand, the maximum value was at site I during winter while minimum value was at site II during autumn and the order was winter > spring > summer > autumn. Egyptian ministry of health gives maximum limits for COD ranged from 10 to 15 mg/L in Nile water, also (Beger 1974) reported that, good water contains organic matter not more than 12 mg/L and that expressed as oxygen consumed by permanganate. El-Sherbini (1996) determined the COD values in River Nile from Aswan to El-Kanater El-Kairia and found that the values were in range 5–25 mg/L and 65% of measured samples were less 10 mg/L.

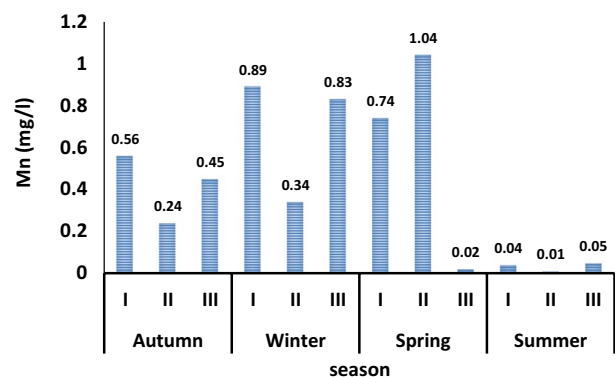
### Heavy metals in water

The maximum value for iron was observed at site I during autumn, and the lowest value was at site II during summer. For Cu, the maximum value was observed at site III during spring, and the minimum value was recorded at site II during summer. The maximum value for Zn was at site I during winter, and the minimum value was recorded at site II during summer. For Pb, the maximum value was recorded

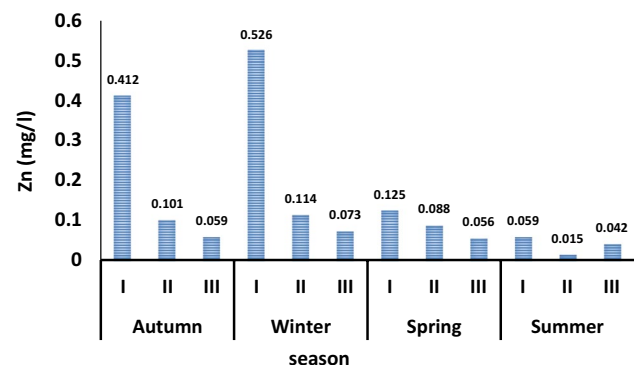


**Fig. 2** Fe concentration (mg/L) in water samples from autumn 2018 to summer 2019 along the investigated area

at site I during winter, while the minimum value was at site III during summer. Finally, Mn maximum value was at site II during spring, also minimum value was at site II during summer (Figs. 2, 3, 4, 5, 6). According to Egyptian drinking water quality standards (2007) limit and (WHO 2011), the allowed concentration of Fe, Pb, Mn, and Cu are 0.3, 0.01, 0.1 and 2.0 mg/L, respectively. From (Figs. 2, 3, 4, 5, 6) it is shown that Fe, Pb, and Mn concentrations exceed the allowed limits in all sites which may cause a negative health effect (Kempster et al. 1997), while Cu and Zn are in allowed limits. The higher concentrations of Mn during winter and spring season may be related to the drought period and the extraction of manganese from dead aquatic plants that become easy as a result of decreasing in water level with settling in water current beside the dissolution of sediment manganese and its presence water during spring (Ghannam et al. 2014). High values of Cu during spring may be depend on the high evaporation rate and increase of air and water temperatures or the release of copper from sediment to surrounding water (Warren and Zimmerman 1994). (Adelaide et al. 2000) recorded



**Fig. 3** Mn concentration (mg/L) in water samples from autumn 2018 to summer 2019 along the investigated area



**Fig. 4** Zn concentration (mg/L) in water samples from autumn 2018 to summer 2019 along the investigated area

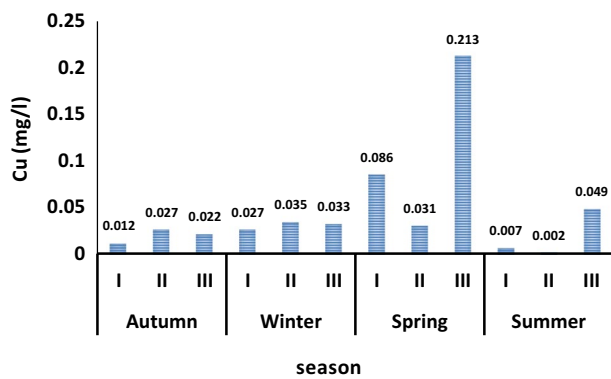


Fig. 5 Cu concentration (mg/L) in water samples from autumn 2018 to summer 2019 along the investigated area

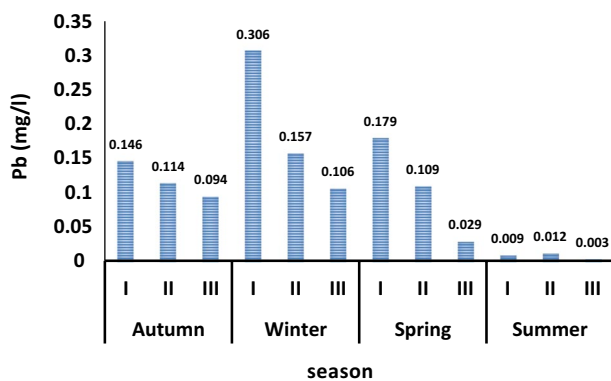


Fig. 6 Pb concentration (mg/L) in water samples from autumn 2018 to summer 2019 along the investigated area

that the factors that causing highest Zn values in winter were drought period and decrease in zinc sorption at low temperature. Also, Pb higher concentrations during winter and spring seasons may be related to drought period while low Pb concentrations during summer is come from the formation of Fe(OH)<sub>3</sub> which act as adsorbent (Foster and Charlesworth 1996). Also, Pb is easily dissolved in water because it is weakly associated with air particles (Badr et al. 2006).

### Heavy metals in fish organs

Concentration of heavy metals in muscles and liver of (*Oreochromis niloticus*) is recorded in Table 2. In fish muscle, the maximum value of Fe (21.8) was recorded at site I during spring while for Mn was (43.0 µg/g dry wt) at site III during summer. For Zn the value was (51.11 µg/g dry wt) at site II during spring where, in cu was (4.9 µg/g dry wt) at site I in summer, finally for Pb was (2.12 µg/g dry wt) at site I during winter. While in liver, the maximum values were (94, 59, 65, 6.34 and

6.39 µg/g dry wt) for (Fe, Mn, Zn, Cu and Pb), respectively. Accumulation of heavy metals in muscles is lower than liver because muscles have low level of binding proteins and enzymatic activities (Papagiannis et al. 2004). According to (FAO 1992), the results for fish muscle indicate that Fe and Cu metals are within the permissible limits but Mn, Zn and Pb exceed the limits.

### Water pollution index (WPI)

Water pollution index was calculated for each metal individually (Fe, Mn, Cu, Pb and Zn). According to the results shown in (Fig. 7), the sites are suffering from different kinds of heavy metal contamination. In almost sites, the effects were > 5 which means seriously affected with heavy metal for aquatic life. But site III was in the range 3–5 for Fe and Pb. As reported by (Caerio et al. 2005) in water samples when WPI lower than 1, this indicates that there is no pollution found in this site and by increasing the WPI value from 1 -2 mean, site is slightly affected by pollution. From 2 to 3 moderately affected, from 3 to 5 strongly affected and > 5 seriously affected. In almost site of this study, the values were higher than 5 which give an indication that these sites are seriously affected by different sources of pollution.

Pollution load index for the different sites at different seasons is shown in (Fig. 8). At site (I), the values were ranged between 2.1 and 2.6 and the maximum value was in spring season. At site (II), the values ranged from 2.03 to 2.14 and the highest was in winter. Lastly, at site (III), the values were between 1.26 and 2.07. The calculations indicated that all results are closely and greater than 1 which give an indication to the progressive deterioration of estuarine quality. If the index = 0 this indicate perfection, index = 1 means there is only baseline levels of pollutants are found, index > 1 means progressive deterioration of estuarine quality (Tomlinson et al. 1980). The obtained results of PLI give benefit information about the quality of aquatic system in this area and help the decision-maker to solve this pollution problem (Goher et al. 2014).

### Bioaccumulation factor

Bioaccumulation factor of heavy metals (Fe, Mn, Zn, Cu, and Pb) was determined in flesh and liver of Nile Tilapia (Tables 3, 4). The results showed that the highest value for Fe was (122.60) and for Mn was (1660.00) for Zn (2747.33) and for Cu (1835.00) was recorded at site (II) during summer. The exception was for Pb which recorded (211.11) at site (I) during summer also. The obtained results for liver showed higher values than obtained by muscle but the values showed the same trend obtained by muscle. The maximum values of

**Table 2** Heavy metals concentration in fish muscles and liver ( $\mu\text{g/g}$  dry wt) from autumn 2018 to summer 2019 at sites I, II, III

Season	Site	Fish organ	Fe ( $\mu\text{g/g}$ )	Mn ( $\mu\text{g/g}$ )	Zn ( $\mu\text{g/g}$ )	Cu ( $\mu\text{g/g}$ )	Pb ( $\mu\text{g/g}$ )
Autumn	I	Muscle	11	16.01	33.01	2.32	2.02
		Liver	28	19.62	44.21	3.54	5.70
	II	Muscle	7.1	12	20.22	4.64	0.93
		Liver	15.32	20.21	33.12	6.34	5.05
	III	Muscle	10.56	11.22	12	4.65	0.75
		Liver	12.34	19.34	34.09	6.01	3.22
Winter	I	Muscle	8.1	9.29	23.68	2.12	2.12
		Liver	64.75	16	37	3.55	4.09
	II	Muscle	16.3	17.23	45.32	1.64	1.07
		Liver	21.72	22	46.45	3.59	4.12
	III	Muscle	12.01	7.9	22.21	1.58	0.90
		Liver	21.50	18.89	40.34	5.98	3.19
Spring	I	Muscle	21.80	18	43.22	2.01	1.76
		Liver	94.00	28.12	65	8.31	6.32
	II	Muscle	18.00	41.43	51.11	2.87	1.23
		Liver	19.71	59.00	55.03	3.34	5.29
	III	Muscle	10.00	7.43	21.33	1.58	0.81
		Liver	17.60	31.31	51.31	2.46	4.31
Summer	I	Muscle	15.30	11.01	41	4.90	1.90
		Liver	66.00	14.9	52.2	6.00	6.39
	II	Muscle	14.70	16.6	41.21	3.67	1.02
		Liver	35.10	31.03	47.34	4.02	6.21
	III	Muscle	13.70	43.00	22.00	2.24	0.32
		Liver	18	50.00	51.04	3.56	4.27
MPL			30	30	50	30	2

*MPL* the maximum permissible limit of heavy metals in fish muscles ( $\mu\text{g/g}$  dry wt) according to (FAO 1992)

Fe, Mn, Zn and Cu were recorded at site (II) and for Pb were at site (I) during summer. Variations in ability of organs for accumulation of metal showed that the concentrations of the metals in the organs were in the order of liver > flesh for all metals. The bioaccumulation of metals in liver may be due to its function of metabolism (Zhao et al. 2012), means, chemical processes that happen inside a living organism to keep life. High level of different heavy metals in liver also due to natural protein binding such as Metallothioneins (Gorar et al. 2012). Liver considers as store for metals, redistribution, and detoxification (Amiard et al. 2006). The same results of high level of metals in liver were studied by (Eisler 2010; Dural et al. 2007 and El-Moselhy 2000).

### Human risk assessment

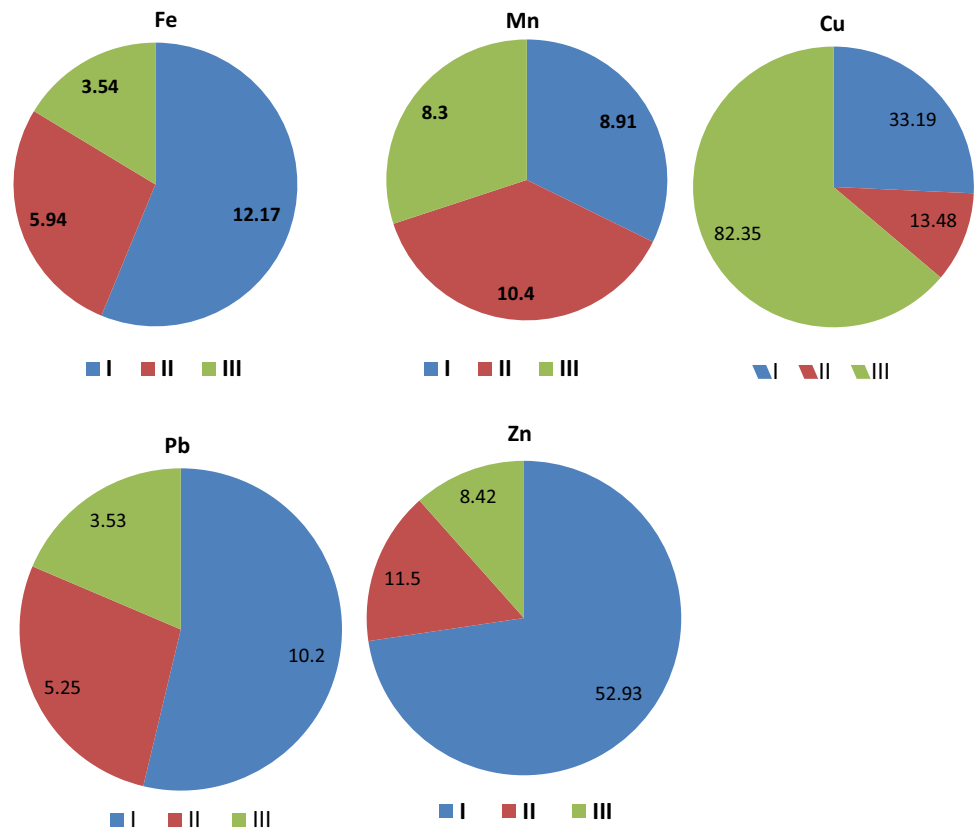
Depending on the values of HI at mean ingestion rate for normal adult no health effect occurred for all metals because all values of HI were below 1. But for habitual, values for Fe, Mn, Zn and Cu were below 1 except Pb, show some exceptions at different seasons in the three sites. But, some HI values

especially lead in case of habitual fish eaters at the three sites were higher than other values along the studied sites showing alarming values Tables 5 and 6. Generally, HI values for each investigated metal do not have unacceptable threats at mean ingestion rate for muscle and liver tissues (Pawelczyk 2013 and USEPA 2002).

### Conclusion

This work concerned with the quality of water and fish in three sites which represent different sources of pollution along the River Nile. Nile tilapia has been used as a bio-indicator to monitor metal pollution by measuring their concentration in flesh and liver and the results indicate lower concentration in flesh than muscle. The results showed different accumulation degrees at the studied sites, where site I in El-Tbeen district that represent the industrial pollution has the highest accumulation extend. The results found that the different site suffering from metal pollution and the order was site I > site II > site III.

**Fig. 7** Water Pollution Index of the measured metals in water collected from investigated area. Pollution load Index



**Table 3** Bioaccumulation factor (L/Kg) of different heavy metals in flesh of Nile Tilapia at different station from autumn 2018 to summer 2019

Season	Site	Fe	Mn	Zn	Cu	Pb
Autumn	I	1.51	28.59	80.12	193.33	13.84
	II	11.09	50.00	200.20	171.85	8.16
	III	12.14	24.91	203.39	211.36	7.98
Winter	I	1.13	10.44	45.02	78.52	6.93
	II	4.58	50.68	397.54	46.86	6.82
	III	5.72	9.52	304.25	47.88	8.49
Spring	I	6.49	24.32	345.76	23.37	9.83
	II	12.59	39.84	580.80	92.58	11.28
	III	17.24	371.50	380.89	7.42	27.93
Summer	I	34.00	275.25	694.92	700.00	211.11
	II	122.50	1660.00	2747.33	1835.00	85.00
	III	41.52	860.00	523.81	45.71	106.67

**Table 4** Bioaccumulation factor (L/Kg) of different heavy metals in liver of Nile Tilapia at different station from autumn 2018 to summer 2019

Season	Site	Fe	Mn	Zn	Cu	Pb
Autumn	I	3.84	35.04	107.31	295.00	39.04
	II	23.94	84.21	327.92	234.81	44.30
	III	14.18	42.98	577.80	273.18	34.26
Winter	I	9.04	17.98	70.34	131.48	13.37
	II	6.10	64.71	407.46	102.57	26.24
	III	10.24	22.76	552.60	181.21	30.09
Spring	I	27.98	38.00	520.00	96.63	35.31
	II	13.78	56.73	625.34	109.68	48.53
	III	30.34	1556.50	916.25	11.55	148.62
Summer	I	146.67	372.50	884.75	857.14	710.00
	II	292.50	3103.00	3156.00	2010.00	517.50
	III	54.55	1000.00	1215.24	72.65	1423.33

**Table 5** Hazard index for muscle of *O. niloticus* at mean ingestion rate (0.0312 kg/day) and subsistence ingestion rate (0.1424 kg/day)

Site	Season	Fe		Mn		Cu		Zn		Pb	
		Normal	Habitual	Normal	Habitual	Normal	Habitual	Normal	Habitual	Normal	Habitual
I	Autumn	0.007	0.032	0.051	0.233	0.026	0.103	0.049	0.224	0.300114	1.369752*
	Winter	0.005	0.021	0.038	0.174	0.052	0.206	0.030	0.137	0.138171	0.630629
	Spring	0.007	0.031	0.036	0.163	0.052	0.206	0.018	0.081	0.111429	0.508571
	Summer	0.005	0.024	0.030	0.135	0.024	0.094	0.035	0.161	0.314971	1.437562*
II	Autumn	0.010	0.047	0.055	0.250	0.018	0.073	0.067	0.307	0.158971	0.725562
	Winter	0.008	0.035	0.025	0.115	0.018	0.070	0.033	0.151	0.133714	0.610286
	Spring	0.014	0.063	0.057	0.262	0.022	0.089	0.064	0.293	0.261486	1.193448*
	Summer	0.011	0.052	0.132	0.602	0.032	0.127	0.076	0.347	0.182743	0.834057
III	Autumn	0.006	0.029	0.024	0.108	0.018	0.070	0.032	0.145	0.120343	0.549257
	Winter	0.010	0.044	0.035	0.160	0.055	0.217	0.061	0.278	0.282286	1.288381*
	Spring	0.009	0.043	0.053	0.241	0.041	0.163	0.061	0.279	0.151543	0.691657
	Summer	0.009	0.040	0.137	0.625	0.025	0.099	0.033	0.149	0.047543	0.21699

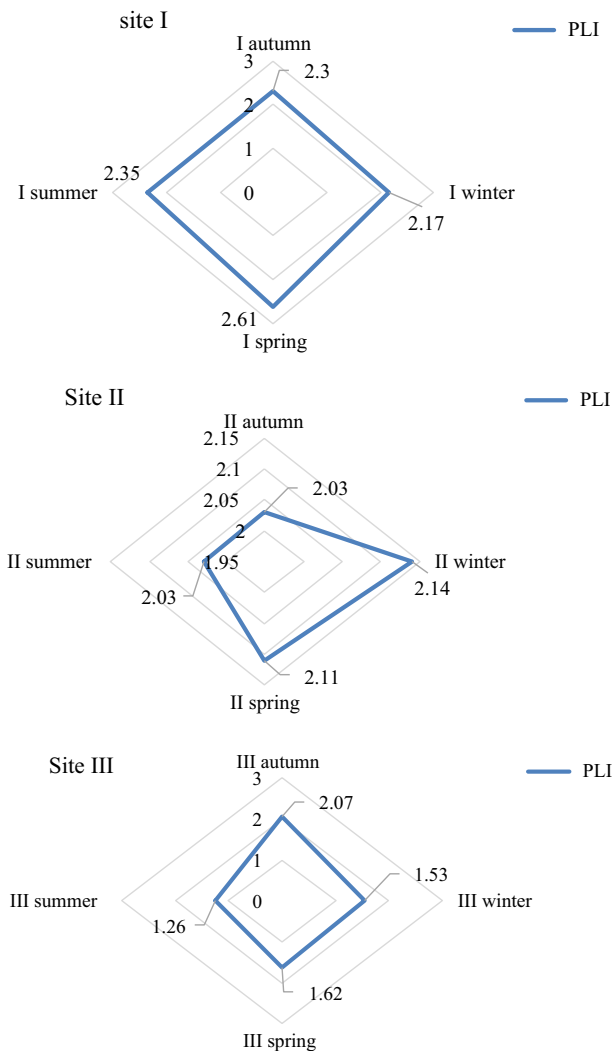
\*means: The values of Hazard index for muscle of *O. niloticus* > 1

**Table 6** Hazard index for liver of *O. niloticus* at mean ingestion rate (0.0312 kg/day) and subsistence ingestion rate (0.1424 kg/day)

Site	Season	Fe		Mn		Cu		Zn		Pb	
		Normal	Habitual	Normal	Habitual	Normal	Habitual	Normal	Habitual	Normal	Habitual
I	Autumn	0.18	0.08	0.06	0.29	0.04	0.18	0.07	0.30	0.85	3.87*
	Winter	0.10	0.04	0.06	0.29	0.07	0.32	0.05	0.22	0.75	3.42*
	Spring	0.08	0.04	0.06	0.28	0.07	0.31	0.05	0.23	0.48	2.18*
	Summer	0.41	0.19	0.05	0.23	0.04	0.18	0.05	0.25	0.61	2.77*
II	Autumn	0.14	0.06	0.07	0.32	0.04	0.18	0.07	0.31	0.61	2.79*
	Winter	0.14	0.06	0.06	0.27	0.07	0.30	0.06	0.27	0.47	2.16*
	Spring	0.60	0.27	0.09	0.41	0.09	0.42	0.10	0.44	0.94	4.29*
	Summer	0.13	0.06	0.19	0.86	0.04	0.17	0.08	0.37	0.79	3.59*
III	Autumn	0.11	0.05	0.10	0.45	0.03	0.13	0.08	0.35	0.64	2.92*
	Winter	0.42	0.19	0.05	0.22	0.07	0.31	0.08	0.35	0.95	4.33*
	Spring	0.22	0.10	0.10	0.45	0.04	0.20	0.07	0.32	0.92	4.21*
	Summer	0.11	0.05	0.16	0.73	0.04	0.18	0.08	0.35	0.63	2.90*

\*means: The values of Hazard index for liver of *O. niloticus* > 1





**Fig. 8** Pollution Load index (PLI) in water at different sites (I, II, III) from autumn 2018 to summer 2019

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**Data availability** Data will be made available upon request.

**Declarations**

**Conflict of interest** The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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