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Influence of Physico-Chemical Characteristics of Water on Metals Accumulation in Water and *Tilapia Zillii* Inhabiting Different Habitats in Egypt

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ABSTRACT

Water and fish (*Tilapia zillii*) samples were collected from six different aquatic habitats, 5 lakes and River Nile, to determine the relationships between physical and chemical characteristics of water and concentration of some metals (Fe, Zn, Cu, Mn, Cd and Pb) accumulated in water and fish tissues. Chemical characteristics (pH, suspended matter, total alkalinity, Ca^{2+} and chlorophyll "a") strongly influenced the bioaccumulation of metals in lakes' water. It appeared to be no strong correlation between fish metals concentration and some water quality parameters. However, metals bioavailability to *Tilapia zillii* is modified significantly by some water chemistry; pH, total alkalinity and dissolved oxygen but the effect is much stronger for some metals than the others. Electric conductivity (EC) had a negative effect on accumulation of Cd and Pb in gills and liver tissue. EC and Ca^{+2} have positive correlation on Zn accumulation in fish muscle tissues. The concentrations of all metals in water (except Cd and Pb in waters of Lake Borollus and Edku) and edible part of fish were found below the notified toxic limits.

Keywords:

INTRODUCTION

Pollution of the aquatic environment by inorganic chemicals has been considered a major threat to the aquatic organisms including fishes. The agricultural drainage water containing pesticides and fertilizers and effluents of industrial activities and runoffs in addition to sewage effluents supply the water bodies and sediment with huge quantities of inorganic anions and heavy metals (ECDG, 2002 and Nwajei *et al.*, 2012). The concentrations of heavy metals in natural water bodies are often elevated due to anthropogenic interferences. The most anthropogenic sources of metals are industrial, petroleum contamination and sewage disposal.

Heavy metals contamination may have a significant impact on aquatic organisms, disturbing the ecological balance and potentially contaminating the aquatic food chain as well as humans. Fish are often at the top of the food chain and have the tendency to concentrate heavy metals from water. Therefore, bioaccumulation of metals in fish can be considered as an index of metal pollution in the aquatic bodies. Nwajei *et al.* (2012) mentioned that, *Tilipia zillii* is a good bioaccumulator of heavy metals and it can be used as indicator for environmental pollution monitoring.

Trace metal analysis of aquatic organisms can provide important information on the degree of environmental contamination, and potential impact of fish consumption. In biological system, a number of metal ions are essential for biological systems as Ca, Mn, Fe, Cu and Zn. These metals become toxic when their concentration levels exceed those required for correct nutrition. Some other metals are non-essential and poison such as Cd and Pb (Mason, 2002). Investigations on heavy metals in natural waters have received considerable attention as they provide a coded history of lake's environment (Singh *et al.*, 2008).

Metal concentrations in water depend in part on water quality and watershed influxes (Mason, 2002). There are many factors, physico-chemical and biological factors, affecting the accumulation and toxicity of metals in aquatic organisms. Physico-chemical factors including temperature, dissolved oxygen, hardness, alkalinity, pH, salinity and suspended particulate matter (Karakoç, 1999). A few studies have correlated aqueous concentrations of metals with other chemical parameters (Stephenson and Mackie, 1988). For instance, aqueous Cd, Pb, and Zn have been related to pH, dissolved oxygen, carbonate, and nutrients (Prahalad and Seenayya, 1989). Metals uptake and their toxicity in aquatic fauna are influenced by many factors such as pH, hardness, alkalinity and temperature of water (Osman and Kloas, 2010).

While there are few data available, an understanding of sources of metals and the impact of water chemistry on metal speciation and bioavailability leads to the conclusion that water chemistry is likely the most important factor influencing fish metal burdens (Mason *et al.*, 2000). Adhikari *et al.* (2006) suggest that pH and alkalinity are important factors controlling metal fate, transport and bioavailability. Other studies showed that fish in two streams of different water chemistry had different levels of metals (Mason *et al.*, 2000 and Lawson and Mason, 2001).

This suggests a need to examine a wide range of water quality variables in different habitats to determine their potential to heavy metals accumulation. The primary objectives of this work were to measure selected physical and chemical water characteristics (that determine metal levels in water and fish) and some metal concentrations in different regions (that varied in size, depth and water chemistry) and to investigate relationships between these parameters and fish tissue metals concentration of *Tilapia zillii* which are common in these different habitats.

MATERIALS AND METHODS

Water and fish samples were collected on spring and summer 2011 from six study areas of different aquatic habitats in Egypt, namely; Borollus, Edku, Wadi El-Raiyan (upper & lower) and Qarun lakes as well as the River Nile. These sites receive a greater input of agricultural, sewage and industrial effluents which may increase loadings of metals.

1- Sampling area

Lake Borollus and Edku are two of the most important northern Delta lakes in Egypt which comprise Manzala, Borollus, Edku and Mariut. These lakes are shallow, brackish water bodies with a depth ranged from 50 to 180 cm with an area reached about 115 and 370 km^2, respectively. Lake Borollus is situated at the northern part of the Nile Delta between the two branches of the Nile (60 km east of Rosetta and 70 km west of Damietta Branch) and extends between longitudes 30º 31′ and 31º 10′ E, and latitudes 31° 21′ and 31º 35′ N. Lake Borollus receives mainly agriculture drainage water (3.2 X 10^9 m^3 y^{-1}) from six drains at its southern region. Lake Edku 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. It is a subject to huge inputs of anthropogenic nutrients discharge, sewage and agricultural runoff (2.06 X 10^9 y^{-1}) via three main drains, Edku, El-Boseily and Barzik situated at its eastern margins drains (Saeed and Shaker, 2008).

Wadi El-Raiyan lakes are two man-made lakes (upper & lower Lakes) of brackish water created at two different levels in Wadi El -Raiyan Depression (703 km^2) situated in the Western Desert, 40 km southwest of Fayoum Province. The first lake has nearly (about 53 km^2) half the area of the second lake (110 km^2), and they are joined by a connecting channel (Mansour and Sidky, 2003). The first lake of Wadi El-Raiyan receives frequent effluent of wastewater from the Wadi Drain. The surplus water from this lake floods to the second one via the shallow connecting channel.

Lake Qarun is a closed saline basin located between longitudes of 30° 24' & 30° 49' E and latitude of 29° 24' & 29° 33' N in the lowest part of El-Fayoum depression, about 80 Km south west of Cairo. The lake has an average area of about 226 km^2, the lake is shallow, with mean depth of 4 m. Nearly, most of the lake’s area has a depth ranging between 5 to 8 meters. The lake receives annually about 470 million cubic metres of drainage water (agricultural and sewage) through 12 drains of which El-Batts and El-Wadi drains carry most of the water brought to the lake (Mansour and Sidky, 2003).

Sampling

Water samples were collected from different regions by a PVC tube column sampler at depth of half meter from the water surface. The samples at each site were mixed in a plastic bucket and a sample of 1 liter was placed in a polyethylene bottle, kept refrigerated and transferred cold to the laboratory for analysis. Thirty specimens of *Tilapia zillii*, from each habitat, were used in this study (total mean lengths of 13.56 cm and total mean weighs of 38.94 g). *Tilapia zillii* was selected as this species is distributed in all these habitats and occupy a similar trophic niche.

2- Laboratory analysis

a) Water

Temperature and pH were measured with pH meter (Model 25, Fisher Scientific). Dissolved oxygen and was measured by using a digital oxygen meter (Model YSI 55). Electric conductivity as mmohs/cm was determined using a salinity-conductivity meter (model, YSI EC 300). Transparency (m) was measured by using a Secchi Disc of 20 cm diameter. The concentration of total alkalinity and total hardness (mg/l as $CaCO_3$), calcium ions (mg/l) and chlorophyll "a" content (µg/l) were measured by methods described in **Boyd and Tucker (1992**). Total metals concentration (solid phase; particles and colloids, an aqueous phase; free ions and dissolved complexes and a biological phase; incorporated into cells or adsorbed on to biological surfaces) of Fe, Zn, Cu, Mn, Cd and Pb were measured after digestion with conc. HNO_3 and HCl according to EPA (1992).

b) Fish

I- Metals residues

The different organs (muscles, gills and liver) were collected separately and the above metals were extracted by the method described in AOAC (2000). Atomic Absorption Spectrophotometer (Model Thermo Electron Corporation) was used to detect metals concentrations in fish organs (µg/g. dry wt) and water samples (mg/l).

3- Statistical analysis

One-way ANOVA and Duncan multiple range test were used to evaluate the significant difference of the concentration of different water quality parameters and fish tissue metals loadings that were studied with respect to different habitats. Significant differences are stated at $P<0.05$ (Bailey, 1981). Correlation coefficients between the different parameters were also computed.

RESULTS AND DISCUSSION

Physico-chemical Properties of Waters

The results as means and SE of the studied physical and chemical parameters for water samples in the selected six sites are given in Table 1. Because of its great impact on aquatic life; controls the behaviour, physiology and distribution of organisms, water temperature is an important component of a water quality assessment. In this study water temperature showed no variation between different sites. Temperature influences the absorption, detoxification and excretion rates of pollutants, so that the overall bioconcentration may vary with temperature (Mason, 2002).

The pH and alkalinity measurement are important and frequently used tests in water chemistry. The pH of the water is important because it affects the solubility and availability of nutrients, and how they can be utilized by aquatic organisms (Osman and Kloas, 2010). According to the present results all the pH values were in alkaline side and showed a noticeable variation between different sites with a lowest value (7.91) recorded at River Nile and a highest one (8.83 and 8.71) at lake Borollus and lake Edku, respectively. High pH of waters in lakes could be ascribed as alkalinity and pH increased as a result of enhanced productivity. Alkalinity (T. alk.) of water is taken as an indication of the concentration of carbonate, bicarbonate and hydroxide content in water. In the Borollus Lake, values of alkalinity were substantially elevated (302.33 mg/l) compared to the

Table 1. ***Physico-chemical properties of waters from studied lakes and River Nile***

Parameter / Site	Temp. (ºC)	pH	T. alk. (mg/l)	DO (mg/l)	SD (cm)	EC (mmohs)	TH (mg/l)	Ca^{+2} (mg/l)	Chl "a" (µg/l)
Lake Borollus	24.62^{a} ± 1.44	8.83a ± 0.09	302.33^{a} ± 14.46	7.60^{ab} ± 0.38	20.17^{d} ± 1.66	4.16^{c} ± 0.72	808.0^{c} ± 68.81	99.33^{c} ± 12.54	69.50^{a} ± 6.41
Lake Edku	23.83^{a} ± 1.36	8.71^{ab} ± 0.35	257.17^{bc} ± 14.40	7.61^{ab} ± 1.01	21.17^{d} ± 2.75	2.13^{d} ± 0.13	460.67^{c} ± 69.16	58.0^{cd} ± 5.07	40.43^{b} ± 7.08
Up. Raiyan	25.67^{a} ± 1.48	8.04^{c} ± 0.42	223.67^{c} ± 11.13	8.75^{a} ± 0.86	123.58^{c} ± 1.48	2.81^{d} ± 0.15	616.67^{c} ± 44.10	54.33^{cd} ± 0.99	7.62^{c} ± 0.66
L. Raiyan	25.56^{a} ± 1.30	8.60^{ab} ± 0.04	242.57^{c} ± 9.44	9.21^{a} ± 4.19	298.70^{a} ± 34.04	12.31^{b} ± 1.14	2392.0^{b} ± 189.75	199.46^{b} ± 4.71	4.49^{c} ± 0.65
Qarun	25.62^{a} ± 2.56	8.48^{b} ± 0.13	290.83^{ab} ± 14.74	10.07^{a} ± 0.87	62.50^{d} ± 3.43	39.42^{a} ± 1.55	14428.67^{a} ±1238.04	426.67^{a} ± 41.00	10.45^{c} ± 1.08
River Nile	21.74^{a} ± 1.85	7.91^{c} ± 0.03	157.50^{d} ± 0.17	5.80^{b} ± 0.52	194.00^{b} ± 5.47	0.22^{d} ± 0.00	148.86^{c} ± 4.95	41.6^{d} ± 1.60	7.76^{c} ± 0.08

Values are shown as mean ± standard error of triplicates.
Within the column values with different letters are significantly different ($P<0.05$).

River Nile values (157.50 mg/l)) as expected if primary productivity is affecting alkalinity (Table 1). In the majority of studies conducted on water bodies, the pH value is generally reported between 6 and 9. The pH range which is not directly lethal to fish is 5 to 9 (Srivastava *et al.*, 2009**)**.

Dissolved oxygen (DO) which is an important parameter in water quality attained higher values in lake Qarun (10.07 mg/l) and this may be attributed to the highly aeration rate in this area and decrease of organic matter. On the other hand, the lower values (5.80 mg/l) of DO recorded in River Nile. This decrease was due to the presence of higher organic matter concentration in theses areas. This may be due to the discharge of industrial effluents into the Nile by some non-compliant factories in these areas, in addition to the discharge of municipal wastewater (untreated and detergent-carrying wastewater) and other wastes into the river (Osman and Kloas, 2010). However, no oxygen depletions were noticed in the studied regions.

The average values of transparency (SD) or water clarity were generally higher in lower Raiyan lake (298.70 cm) and River Nile (194.00 cm), whereas Lake Borollus showed the lower Secchi disc readings (20.17 cm). This may be attributed to depth and the higher primary productivity (phytoplankton growth) as well as high turbidity due to the high content of suspended materials (especially clay particles) in Borollus Lake. Many sources are known to regulate the water clarity in aquatic systems (the amount of plankton, faeces, etc. in the water more plankton, means low water clarity, humic and fulvic substances and resuspended material) (Hakanson, 2006).

Electrical conductivity (EC) is an indirect measure of the ions concentration. Electrical conductivity showed lowest values at River Nile (0.22 mmohs) and the highest value was recorded at Qarun lake (39.42 mmohs) followed by lower Raiyan lake (12.31 mmohs). Such increase may be due to the high evaporation rate in the two closed basin. This trend could be attributed to the evaporation of water from closed basin lakes and subsequent dilution due to precipitation and run-off from the catchment area in Nile Delta lakes and River Nile.

The major salts that contribute to the measurement of water hardness are the positively charged ions calcium and magnesium. Water hardness (TH) was highly increased from River Nile to different lakes recording the highest value at Lake Qarun (14.43 g/l). Table 1 showed that Ca^{+2} nearly have the same distribution as water hardness.

Primary productivity (chlorophyll "a") in natural water is one of the most important steps in the complex analysis of aquatic ecosystems as it constitutes important component of fish food and thus, acts as an index of trophic status of the water body. Chlorophyll "a" concentration which is an indication for the primary productivity (phytoplankton) was high in Borollus and Edku Lake compared to Raiyan and Qarun Lakes as well as River Nile. This can be attributed to the shallowness and increased nutrients in these lakes.

Heavy metals concentration in Water

Spatial variations in different heavy metals concentrations in water from different lakes and River Nile are presented in Table 2. Total trace metals exhibited different behavior, with increasing concentrations from River Nile to northern delta lakes. As regards the effect of site on heavy metals concentration in the water of different

Table 2. Metals concentrations (mg/l) in surface water of different lakes and River Nile.

Metal / Site	Fe	Zn	Cu	Mn	Cd	Pb	T. average
Lake Borollus	**0.704[a] ±0.08**	**0.049[b] ±0.008**	**0.036[a] ±0.008**	**0.284[a] ±0.038**	**0.006[a] ±0.001**	**0.082[a] ±0.016**	**1.16**
Lake Edku	**0.690[a] ±0.05**	**0.026[b] ±0.003**	**0.037[a] ±0.009**	**0.034[b] ±0.007**	**0.004[b] ±0.00**	**0.038[b] ±0.008**	**0.83**
Up. Raiyan	**0.364[b] ±0.09**	**0.024[b] ±0.002**	**0.012[a] ±0.002**	**0.035[b] ±0.007**	**ND[c] ±0.00**	**0.013[bc] ±0.002**	**0.45**
L. Raiyan	**0.32[bc] ±0.030**	**0.030[b] ±0.005**	**0.043[a] ±0.006**	**0.032[b] ±0.09**	**ND[c] ±0.00**	**0.036[b] ±0.004**	**0.46**
Qarun	**0.27[bc] ±0.02**	**0.62[a] ±0.06**	**0.020[ab] ±0.002**	**0.030[b] ±0.004**	**ND[c] ±0.00**	**ND[c] ±0.00**	**0.94**
River Nile	**0.176[c] ±0.04**	**0.039[b] ±0.009**	**0.005[b] ±0.001**	**0.030[b] ±0.001**	**0.002[b] ±0.00**	**0.004[c] ±0.00**	**0.26**
T. average	**2.524**	**0.788**	**0.153**	**0.445[b]**	**0.012**	**0.173**	
***GL (mg/l)**	******	**3.0**	**2.0**	**0.40**	**0.003**	**0.010**	

Values are shown as mean ± standard error of triplicates.
Within the column values with different letters are significantly different ($P<0.05$).
****Guideline values according to WHO, 2011.***
*****No health-based guideline value is proposed for iron because it is not of health concern at levels found in natural water (0.5-50.0 mgl^{-1}).***

lakes, concentrations of metals were at maximum values at Borollus and Edku Lake, while minimum concentrations were observed at the River Nile. This trend could be attributed to the shallowness and increased of suspended matter loaded with metals in these lakes. A remarkably high concentration of Fe compared to other metals indicated that this metal was abundant in soil of the catchment area from where the water reaches to these lakes. The concentrations of heavy metals in water of studied regions remained well below the guideline values proposed by **WHO (2011)** except Cd and Pb (in lake Borollus and Edku) and Pb (L. Raiyan). So, contamination with those two metals was serious in the water of these natural lakes.

Relationship between physico-chemical properties and concentration of heavy metals in water:

Simple correlation coefficients (*r*) computed between physico-chemical properties and concentrations of different heavy metals in water from different lakes are presented in Table 3. The concentrations of Fe, Cu and Pb were significantly and positively correlated with water pH. The concentrations of metals (Fe, Mn and Pb) were significantly and positively correlated with alkalinity of water as well as water productivity estimated by chlorophyll "a" concentration. This means that increase of chlorophyll "a" (which leads to increase water pH and alkalinity) and decrease water clarity (increase of suspended matter) will adsorb high levels of trace metals and led to increase total metals in the water. There was no significant relationship was established between Cd and both pH and alkalinity. However, Cd showed significant positive relationship with chlorophyll "a". The concentrations of Cd were also significantly and negatively correlated with DO. This complies

Table 3 Correlation coefficients between physico-chemical properties and concentration of heavy metals in waters from studied lakes and River Nile.

Metal Parameter	Fe	Zn	Cu	Mn	Cd	Pb
pH	0.6500**	0.7677	0.5693*	0.7677	0.7677	0.5521*
DO	-0.1607	-0.3660	0.2356	-0.2079	-0.6013*	0.0326
Temp.	0.1106	0.0078	0.3728	-0.1624	-0.1948	0.2184
SD	-0.6968**	0.0358	-0.0527	-0.3318	-0.4751*	-0.3872
EC	-0.1152	0.9429***	-0.1152	-0.1152	-0.5152*	-0.1152
T. alk.	0.5733**	0.3764	0.4603	0.5708*	0.3247	0.5420*
TH	-0.1443	0.9860***	0.2509	-0.008	-0.5114*	0.1906
Ca^{+2}	-0.0725	0.6165***	0.1662	0.1095	-0.5428**	0.3173
Chl. "a"	0.8356***	0.3035	0.2229	0.7977***	0.9046***	0.7952***

Significant level at P values: * < 0.05, ** < 0.01, *** < 0.001

with Singh *et al.* (2008) who reported a negative relationship between Cd and DO.

So, the most water quality parameters that affect metals loadings in water are pH, suspended matter (indicated by water clarity or Secchi disc readings), total alkalinity and chlorophyll "a".

Concentration of metals in different tissues and different sites

The concentration of the metals exhibited a wide range of variation between different tissues (M. G and L) and between different sites (Tables 4, 5 and 6). The highest concentration of all

Table 4. The residual analysis of trace metals (µg/g dry weight) in muscle tissue of *Tilapia zillii* inhabiting different lakes and River Nile.

Metal / Site	Fe	Zn	Cu	Mn	Cd	Pb	T. average
Lake Borollus	128.69^{b} ±8.99	71.38^{ab} ±3.06	4.53^{bc} ±0.57	1.03^{b} ±0.03	0.144^{ab} ±0.008	0.24^{b} ±0.01	206.01
Lake Edku	118.54^{b} ±8.95	74.82^{ab} ±9.29	4.59^{bc} ±0.78	2.86^{a} ±0.37	0.224^{a} ±0.033	1.07^{a} ±0.12	202.10
Up. Raiyan	63.47^{d} ±10.08	66.79^{b} ±7.31	7.08^{a} ±0.26	0.80^{b} ±0.03	0.198^{ab} ±0.033	0.23^{b} ±0.02	138.57
L. Raiyan	74.96^{cd} ±3.05	78.78^{ab} ±2.30	6.52^{ab} ±0.75	0.78^{b} ±0.055	0.24^{a} ±0.06	0.14^{bc} ±0.02	161.42
Qarun	101.98^{bc} ±1.91	88.55^{a} ±5.93	5.04^{abc} ±0.89	1.18^{b} ±0.18	0.105^{bc} ±0.010	ND^{c} ±0.00	196.86
River Nile	252.90^{a} ±17.87	41.08^{c} ±2.89	3.39^{c} ±0.20	3.04^{a} ±0.10	0.023^{c} ±0.005	ND^{c} ±0.00	300.43
T. average	740.54	421.4	31.15	9.69	0.934	1.68	
*PL (mg/day) wet wt.	50.0	30.0	5.0	10.0	0.05	0.214	

Values are shown as mean ± standard error of triplicates. Within the column values with different letters are significantly different (P<0.05).

****Permissible limits (average daily intake in wet wt.), Fe, Cd and Pb according to guidelines in WHO, 2011. Cu as in IPCS (1998), Zn and Mn as in (SCF, 1993).***

To compare with PL: Wet weight conc. = dry wt. x (100-% moisture)/100.

Table 5. The residual analysis of trace metals (µg/g dry weight) in gills of Tilapia zillii inhabiting different lakes and River Nile.

Metal / Site	Fe	Zn	Cu	Mn	Cd	Pb	T. average
Lake Borollus	**294.57[d] ±10.74**	**97.88[b] ±12.65**	**3.54[b] ±0.24**	**1.87[b] ±0.15**	**0.083[b] ±0.01**	**0.308[b] ±0.02**	**398.25**
Lake Edku	**815.17[b] ±21.55**	**178.22[b] ±13.62**	**5.82[b] ±0.59**	**23.45[a] ±1.16**	**1.01[a] ±0.04**	**2.02[a] ±0.19**	**1025.69**
Up. Raiyan	**527.34[c] ±33.21**	**104.41[b] ±16.10**	**2.73[b] ±0.31**	**4.79[b] ±0.22**	**0.03[c] ±0.002**	**1.73[a] ±0.13**	**641.03**
L. Raiyan	**490.63[c] ±20.31**	**102.84[b] ±15.41**	**4.48[b] ±0.81**	**2.78[b] ±0.08**	**ND[c] ±0.00**	**ND[c] ±0.01**	**600.73**
Qarun	**463.20[c] ±36.90**	**197.67[b] ±16.96**	**6.51[b] ±0.29**	**6.56[b] ±0.76**	**ND[c] ±0.00**	**0.20[b] ±0.04**	**674.14**
River Nile	**1573.15[a] ±122.05**	**794.85[a] ±21.84**	**93.51[a] ±17.02**	**37.53[a] ±5.11**	**0.21[b] ±0.04**	**0.26[b] ±0.03**	**2499.51**
T. average	**4164.06**	**1475.87**	**116.59**	**76.98**	**1.333**	**4.518**	

Values are shown as mean ± standard error of triplicates.
Within the column values with different letters are significantly different (P<0.05).

studied metals were recorded in the liver (except Mn in gills) comparing to other tissues for all sites. The distribution of the metals were in the order of L > G > M except Mn, G > L > M. Trace metals accumulations in fish muscle (M), gills (G) and liver (L) at sites under investigation were detected in following descending order: Fe > Zn > Cu > Mn > Pb > Cd. The highest concentration of Fe was recorded in the gills of fish collected from River Nile (1573.15 µg/g) and the lowest one was recorded in the muscles of fish collected from upper Raiyan lake (63.47 µg/g). The increase of iron accumulation in fish gills and liver in this study may be related to the increase of dissolved iron (as suspended matter decrease) in Nile water and consequently increase the free metal iron concentration and thereby leads to an increase in metal uptake by different organs (Tayel *et al.*, 2008).

The relatively higher zinc concentration in the liver of the different fish species may be due to the role of zinc as an activator of numerous enzymes present in the liver (Yacoub, 2007). The highest level (470.16 µg/g) was recorded in the liver of fishes collected from Lake Borollus (Table 6)

Table 6. The residual analysis of trace metals (µg/g dry weight) in liver of Tilapia zillii inhabiting different lakes and River Nile.

Metal / Site	**Fe**	**Zn**	**Cu**	**Mn**	**Cd**	**Pb**	**T. average**
Lake Borollus	**641.23[b] ±10.74**	**470.16[a] ±12.65**	**32.02[c] ±0.33**	**0.62[c] ±0.03**	**0.032[c] ±0.021**	**0.98[b] ±0.00**	**1145.04**
Lake Edku	**698.64[b] ±130.16**	**171.17[b] ±25.79**	**120.68[bc] ±12.96**	**9.45[b] ±0.47**	**0.46[a] ±0.08**	**3.24[a] ±0.43**	**1003.64**
Up. Raiyan	**872.13[a] ±32.25**	**76.98[c] ±8.06**	**16.48[c] ±2.11**	**3.39[bc] ±0.12**	**0.51[a] ±0.11**	**0.80[b] ±0.04**	**970.29**
L. Raiyan	**360.83[c] ±22.17**	**91.67[c] ±11.26**	**242.38[b] ±16.47**	**3.83[bc] ±0.63**	**ND ±0.00**	**ND[c] ±0.00**	**698.71**
Qarun	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
River Nile	**669.99[b] ±57.25**	**157.18[b] ±20.11**	**558.07[a] ±31.19**	**26.66[a] ±4.27**	**0.30[b] ±0.06**	**0.209[b] ±0.04**	**1412.41**
T. average	**3242.82**	**967.16**	**969.63**	**43.95**	**1.302**	**5.229**	

Values are shown as mean ± standard error of triplicates.
Within the column values with different letters are significantly different (P<0.05).

and the lowest one (41.08 µg/g) in fish muscle tissue of the River Nile (Table 4).

Copper exhibited highest concentration in the liver comparing to other tissues for all sites. The highest (558.07 µg/g) and lowest (3.39 µg/g) concentration were recorded in the liver and muscles tissue of fish collected from the River Nile. According to Playle *et al.* (1992), enrichment of water with calcium reduced copper accumulation in the gills. Osman and Kloas (2010) recorded high levels of Cu in fish collected from the River Nile. This observation may be due to industrial and sewage wastes. The lower concentration of Cu in the gills than that of livers was possibly due to lower binding affinity of Cu on the gills surface.

Manganese showed a wide range of variation among different tissues and different sites. The highest concentration of Mn was recorded in the gills of fishes from nearly all sites (Tables 4, 5 and 6). The highest concentration (37.53 µg/g) was recorded in the gills of fish collected from the River Nile followed by Lake Edku (23.45 µg/g). The lowest concentration (0.80 µg/g) of Mn was detected in the muscle of fishes collected from upper Raiyan Lake. Also, Osman and Kloas (2010) and Nwajei *et al.* (2012) recorded highest concentration of Mn in fish gills.

According to the present result, Cd accumulated mainly in the liver followed by gills of fishes collected from the selected sites. The highest concentration (1.01 µg/g) was detected in gills of fish collected from Lake Edku followed by fish liver from upper Raiyan Lake (0.51 µg/g). High accumulation of cadmium in liver may be due to its strong binding with cystine residues of metallothionein (Tayel *et al.*, 2008).

Lead is non-essential element and higher concentrations can occur in aquatic organisms close to anthropogenic sources. In all sites the highest lead level was detected in the liver of *Tilapia zillii* followed by gills. The highest concentration was recorded in the tissues of fishes collected from Lake Edku followed by Lake Borollus and upper Raiyan Lake. In agreement with the present results, Saeed (2011) reported the gills and liver as highly Pb-accumulated organ in different fish species. The increase of lead level is due to the discharge of industrial, sewage and agricultural wastes in the investigated sites. The high level of lead may be attributed to high lead concentration in water.

The bioaccumulation of heavy metals varied between the organs (muscle, gills and liver). Fish liver and gills (metabolic active tissues) showed significantly higher abilities for the accumulation of all metals while accumulations were lowest in fish muscle. Muscle, where the metabolic activity is relatively low, accumulates less level of metals. This may be due to elevated metal–binding protein synthesis in gills and liver as recorded by Yacoub (2007). Similar results were also reported by Jabeen *et al.* (2012). The results of *Tilapia zillii* in this study clearly show accumulation of metals in axial muscle that not exceeds the world safe level as shown in Table (4). The recommended daily intake for an adult is 50, 30, 5.0, 10.0, 0.05 and 0.214 mg/day wet weight for Fe, Zn, Cu, Mn, Cd and Pb respectively according to guidelines values in (SCF, 1993, IPCS, 1998 and WHO, 2011). So, a normal daily diet including this fish species from different studied sites poses no health risk to consumer.

Effects of water chemistry on metal bioaccumulation by Tilapia zillii

Table 7 showed that metals accumulation in fish muscle mostly influenced by pH, alkalinity and DO. This complies with previous studies (Prahalad and Seenayya 1989 and Osman and Kloas, 2010) that mentioned that metals uptake and their toxicity in aquatic fauna are influenced

Table 7 ***Correlation coefficients between physico-chemical properties of waters and metals concentration in fish muscle.***

Metal Parameter	Fe	Zn	Cu	Mn	Cd	Pb
Temp.	**-0.3846**	**0.1298**	**0.1715**	**-0.2645**	**0.2686**	**0.2103**
pH	**-0.5648***	**0.4298**	**0.1587**	**-0.3045**	**0.6989****	**0.5767***
T. alkalinity	**-0.5543***	**0.6645****	**0.0686**	**-0.4869***	**0.2936**	**0.1998**
DO	**-0.7285*****	**0.2851**	**0.6196****	**-0.6780****	**0.4972***	**-0.1085**
SD	**0.0598**	**-0.2436**	**0.2974**	**-0.1470**	**0.0591**	**-0.4675**
EC	**-0.3059**	**0.5791***	**0.1012**	**-0.3576**	**-0.0511**	**-0.3653**
TH	**-0.2242**	**0.5227***	**0.064**	**-0.2916**	**-0.1484**	**-0.3688**
Ca^{+2}	**-0.3071**	**0.6104****	**0.0286**	**-0.3991**	**-0.0964**	**-0.3998**
Chl. "a"	**0.0260**	**0.1312**	**-0.3136**	**0.0665**	**0.0516**	**0.4557**

Significant level at P values: * < 0.05, ** < 0.01, *** < 0.001.

by many factors such as pH, suspended particulate matter and alkalinity of water. Fe accumulation from water to fish decreased with increasing pH in water. An opposite accumulation trend was observed for Cd and Pb in which Cd and Pb body concentrations increased with increasing pH. Also, alkalinity has significant effect on Fe, Zn and Mn. Adhikari *et al.* (2006) suggest that pH and alkalinity are important factors controlling metal fate, transport and bioavailability. Other studies showed that fish in two streams of different water chemistry had different levels of metals (Lawson and Mason, 2001). Saleh (1982) stated that fishes live in freshwater accumulate more concentrations of heavy metals than those living in brackish or saline water.

In this study, it is obvious that fish collected from the River Nile accumulated the highest metals concentration. This could be as a result of increasing of dissolved metal ions as calcium decreased in Nile water compared with other sites. With decreasing water hardness (lower Ca^{2+} and higher H^+), there was an associated increase in metals tissue concentrations in River Nile. Low calcium concentrations in water enhance the accumulation of metals because the permeability of the gills membrane to metals is inversely related to the aqueous calcium concentration. Calcium competes with other metal cations for binding sites on the gills surface (Mason, 2002). The fish is thus accumulated lower concentrations in hard waters because the direct uptake of metal ions is reduced. Pyle *et al.* (2005) mentioned that water hardness was an important factor that decreasing Cd accumulation. They also added that branchial Ca^{2+} uptake in hard water probably contribute to a decrease in dietary Cd uptake in fish. Baldisserotto *et al.* (2004) noticed that rainbow trout fed a Ca-supplemented diet took up less waterborne Cd (to gills, liver, and kidney) than fish fed a normal diet. They reasoned that dietary Ca may be transported to the gills where it blocks waterborne Cd uptake. Competition between Ca^{2+} or Mg^{2+} and divalent metal ions for binding sites on the gills surface and Ca^{2+}-mediated changes in the permeability of gills membranes leads to diminish metal accumulation and toxicity in hard waters (Wicklund and Runn 1988).

Also, at low salinity (in River Nile), chloride ion decreases and the complexation of metals with chloride decreases, thus the metal ions increases and the toxicity increases. The toxicity of heavy metals to fish is reported to be a function of the free metal ion concentration, which is controlled by the chloride content of the water (Erickson *et al.*, 1996). As the chloride ion concentration increases, so the concentration of free metal ion decreases relative to the total metal concentration, due to its complication with chloride ions. Karakoç (1999) observed that, the increase of salinity represented by Cl concentration in the medium significantly reduced the accumulation of copper in the liver, gills and muscle tissues of *Tilopia nilotica*. Guhathakurta and Kaviraj (2005) showed that salinity of the medium had a significant effect on the bioaccumulation of metals by fish; Cd and Pb accumulation decreased in saline medium while the accumulation of Zn increased. This explains why Cd and Pb not detected in fish of lower Raiyan and Qarun Lake and increased Zn in Qarun Lake compared to other lakes in muscle and gills tissues (Tables 4 and 5).

Although total metals increase as chlorophyll "a" (the principal food for *T. zillii*) and suspended matter of water increase (Table 3), those two items have no effect on metals accumulation in fish muscle tissues. This may be related to that accumulation of metals in fish tissues depend mainly on the ionic form of the metal which decrease with adsorption and incorporation in biological cells and suspended particles (**Mason, 2002**). In general, complexes of suspended inorganic and organic matter with metals decrease their bioavailability to aquatic biota.

In the literature, heavy metal concentrations in the tissue of freshwater fish vary considerably among different studies, possibly due to differences in metal concentrations and chemical characteristics of water from which fish were sampled, ecological needs, metabolism and feeding patterns of fish (Osman and Kloas, 2010)**.**

Effects of metal concentrations in waters on metal bioaccumulation by Tilapia zillii

As shown in Table 8, the concentrations of metals in the *Tilapia zillii* from the River Nile were higher than other locations. The correlation between fish metals concentration and water metals concentration was weak. Mason (2002) mentioned no consistent correlations between environmental levels of metals and concentrations in fish. The low metals concentration in water, but high fish metals concentration, in the River Nile, reflects the impact of some other factors on metals bioaccumulation in fish.

CONCLUSION

The most water quality parameters that affect metals loadings in water are pH, suspended matter (indicated by water clarity or Secchi disc readings), total alkalinity, Ca^{2+} and

Table 8 ***Correlation coefficients between metals concentrations in waters with different metals in muscle tissues of Tilapia zillii inhabiting studied lakes and River Nile***

Fish / Water	Fe	Zn	Cu	Mn	Cd	Pb
Fe	**-0.2679**	**0.5101**	**-0.1363**	**-0.0827**	**0.3351**	**0.3998**
Zn	**0.3527**	**-0.0043**	**-0.4125**	**-0.0508**	**-0.3471**	**-0.2644**
Cu	**-0.5530***	**0.5235***	**0.0974**	**-0.3344**	**0.3918**	**0.4143**
Mn	**-0.0016**	**0.1990**	**-0.2182**	**-0.2887**	**-0.1378**	**-0.1378**
Cd	**0.2854**	**0.2854**	**0.2854**	**0.2854**	**0.2854**	**0.2854**
Pb	**-0.2234**	**-0.2234**	**-0.2234**	**-0.2234**	**-0.2234**	**-0.2234**

Significant level at p≤0.05

chlorophyll "a" content of waters. Metals bioavailability to *Tilapia zillii* from water is modified by water chemistry; pH, total alkalinity and DO but the effect is much stronger for some metals than the others. EC, hardness and Ca^{+2} has an effect on Zn, Cd and Pb accumulation in fish. Also, it appeared to be no strong correlation between fish metals concentration and the majority of water quality parameters.

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تأثير الخصائص الفيزيائية والكيميائية للمياه على تراكم بعض العناصر فى المياه وسمكة البلطى الزلى التى تقطن بيئات مختلفة في مصر

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تم تجميع أسماك البلطى الأخضر (الزلى) من بيئات مائية مختلفة لدراسة تأثير الخصائص الفيزيائية والكيميائية لمياه هذه البيئات المختلفة على تراكم بعض العناصر الثقيلة فى المياه وأنسجة الأسماك (عضلات ، خياشيم وكبد). وقد تأثر تراكم المعادن بإختلاف البيئات المائية حيث كان تركيز المعادن في المياه كالآتى: البرلس > قارون > إدكو > الريان المنخفضة > الريان المرتفعة > نهر النيل، وفى الأسماك كالآتى: نهر النيل >البرلس> إدكو > قارون > الريان المنخفضة > الريان المرتفعة للعضلات، نهر النيل > إدكو > قارون > الريان المرتفعة > الريان المنخفضة > البرلس للخياشيم، نهر النيل > البرلس > إدكو > الريان المرتفعة > الريان المنخفضة للكبد. لوحظ وجود إرتباط بين درجة الأس الهيدروجينى، المواد العالقة، القلوية الكلية، أيونات الكالسيوم والمادة الخضراء (الكلوروفيل) وتراكم بعض المعادن في المياه. ويرتبط تراكم بعض هذه العناصر فى عضلات الأسماك بدرجة الأس الهيدروجينى، القلوية الكلية والأكسجين الذائب ويكون هذا الإرتباط سلبى وذا دلالة لعنصر الحديد والمنجنيز وإيجابى لعناصر الزنك،النحاس، الكادميوم والرصاص. كان للملوحة تأثير سلبي على تراكم الكادميوم والرصاص في أنسجة الخياشيم والكبد. أظهر تراكم الزنك

فى عضلات الأسماك ترابط إيجابى ذا دلالة مع الملوحة وأيونات الكالسيوم فى المياه. واظهرت الدراسة أن أنسجة الكبد والخياشيم لها قابلية كبيرة لإختزان العناصر بينما أظهرت العضلات ميلا أقل. كان مستوى جميع العناصر فى عضلات الأسماك أقل من الحد المسموح به دوليا وأنها لاتمثل خطورة على جمهور المستهلكين لهذه الأسماك بينما زاد تركيز عنصرى الكادميوم والرصاص فى مياه بحيرتى البرلس وإدكو عن المسموح به عالميا.