



Pollution indices and distribution pattern of heavy metals in Qarun Lake water, Egypt

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ABSTRACT

Qarun Lake is a remnant of the historic Moreis Lake; it is an enclosed lake receives the water through several drains mainly El-Bats and El-Wadi drains carrying agricultural wastewater mixed with domestic and industrial wastes to the lake, which increases the accumulation of pollutants, in particular, the heavy metals in the lake environment. The present study is concerning the levels, distribution pattern as well as the pollution indices of the heavy metals in Qarun Lake water. The sites facing the inlet of the drain showed the highest contents of the metal, recording 587.55, 59.6, 61.92, 26.98, 50.72 and 3.63 $\mu\text{g}/\text{l}$ for Fe, Mn, Zn, Cu, Ni, Cr, Pb and Cd respectively. On the other side the, Metal Index (MI) and Pollution Load Index (PLI) denotes that Qarun Lake is suffering from serious metal pollution for the aquatic life utilization because of the huge amount of wastes discharging into the lake which maybe leads to dangerous adverse impacts on the fish and other aquatic organisms. The study recommended that usage of biological and chemical treatment for wastewater discharging into the lake into to improve the water quality of the lake water.

INTRODUCTION

Salt lakes are widespread and occur on all continents and are found under a range of conditions, including cold and hot temperatures. They are, however, mostly confined to semiarid to arid regions where evaporation exceeds precipitation. They generally form the terminus of a closed (endorheic) drainage system, with the balance between hydrological inputs (surface and groundwater flows, and precipitation over the lake) and outputs (evaporation and seepage) allowing the permanent or temporary persistence of a body of water, conditions that most often occur in arid and semiarid regions (Finlayson, 2016). Williams (2005) reports that almost the whole range of pollutants discharged to fresh waters is also discharged to salt lakes or their inflows. This includes sewerage discharges and agricultural runoff, and domestic and industrial garbage that has resulted in pollution by metals, with examples Qarun Lake in Egypt

Nowadays, Qarun Lake suffers from several environmental problems. Many factors affecting Qarun Lake ecosystem include the climatic conditions, amount of

discharged wastewater, seepage from the surrounding cultivated land and geological aspects (Goher *et al.* 2018). The increase in salinity depends on the input of drainage water and the subtropical climate of the lake leading to high temperature and seasonal fluctuations in water evaporation rate (Anwar *et al.* 2001). The Lake receives the agricultural and sewage drainage waters through a system of drains, mainly, El-Bats and El-Wadi drains (Authman and Abbas, 2007 & El-Shabrawy *et al.* 2015). The Lake received annually about 450 million cubic meters of agricultural drainage water. Due to Qarun Lake is a closed ecosystem, and as a result of, extensive evaporation of water, the accumulation of chemical pollutants (heavy metals, pesticides, and other pollutants) is expected to increase annually in all its components (e.g. water and fish) and to change their quality and affect their aquatic life (Mansour and Sidky, 2003). The quality and quantity of surface water bodies such as lakes depend upon the climate, catchments, geography of the area and the inputs and outputs both natural and manmade (Gray, 1994). The water quality evaluation may be a complicated practice in compound parameters causing numerous anxieties in general quality of water (Bharti *et al.* 2011).

Heavy metals are present in the environment in different phases such as solid phase and in solution, as free ions, or absorbed to solid colloidal particles. The trace metal levels in the environment are due to natural sources as well as an anthropogenic source such as municipal wastewater, agricultural activities and manufacturing industries (Güven and Akýncý, 2008). Heavy metals consist of essential and non-essential elements that have a particular significance in ecotoxicology because they are highly persistent and all have the potential to be toxic to living organisms (Goher *et al.* 2019a). Recent years have witnessed significant attention being paid to the problems of environmental contamination by a wide variety of chemical pollutants, including trace metals (Censi *et al.* 2006). Metals are of particular concern, among environmental pollutants, because of their ability to bioaccumulate in aquatic ecosystems and potential toxic effects (Camusso *et al.* 1995). The main objective of the current study to assess levels of heavy metals in Qarun Lake water, in addition, to evaluate the impact of the drainage water on the metal pollution in the lake in terms of the Metal Index (MI) and Pollution Load Index (PLI).

MATERIALS AND METHODS

Study area:

Qarun Lake is a remnant of "the historic Lake Moeris" (Figure 1) and was originally a fresh water lake. It is a general tank for agricultural wastewater of El Fayoum province. Its surface area is about 243 km² with an irregular shape of about 40 Km length and 6.7 Km maximum width, mean depth 4 m and a volume about 1 Billion m³ and it lies in the arid zone, so it is considered as a tropical lake (Shadrin *et al.* 2016). The lake is located between longitudes of 30 ° 24` & 30 ° 49` E and latitude of 29 ° 24` & 29 ° 33` N (Ibrahim and Ramzy, 2013); latitudes at 43-44 m below the sea level.

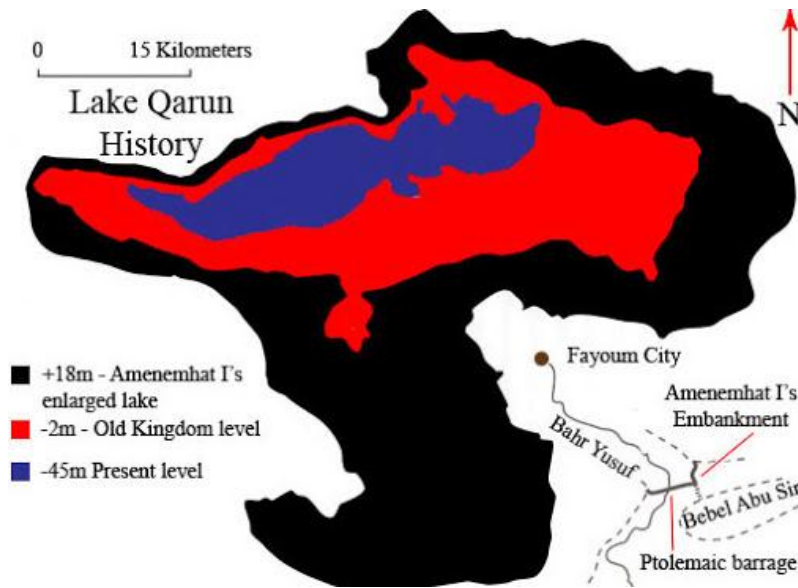


Fig. 1: Long-term changes of Qarun Lake area.

Water sampling:

Twelve sites were selected to cover the area under investigation beside two main drains; El-Bats and El-Wadi drains (Figure 2 and Table 1)

Table 1: The details of the sampling locations.

Qarun Lake				
No.	Name	Latitude	Longitude	
1	In front of the Bats Drain	29°30'48.03"	30°48'11.16"	
2	1 km from the entrance to the Bats Drain	29°30'14.60"	30°48'16.63"	
3	In front of the Oberge	29°29'39.37"	30°47'7.14"	
4	In front of the Armed Forces Hotel	29°29'24.33"	30°45'11.84"	
5	In front of the tongue of Abu Neamah	29°28'55.91"	30°42'19.49"	
6	Khor Mayouf (center of the lake)	29°28'0.88"	30°39'55.83"	
7	In front of El Wadi Drain	29°26'38.91"	30°38'56.47"	
8	1 km from the entrance to El Wadi Drain	29°26'42.71"	30°38'4.34"	
9	North of EL Karn Island (central lake)	29°28'46.05"	30°36'34.29"	
10	In front of Masr Lilitaemir Village	29°26'35.78"	30°33'48.32"	
11	West of the Lake	29°25'30.94"	30°29'42.77"	
12	Mizar navigation (Far West)	29°26'30.06"	30°26'16.44"	

Methods of analysis:

pH, Electrical conductivity (EC), and water temperature were measured *in-situ* using hydro-lab model Orion Research Ion Analyzer 399A, transparency was estimated via the Secchi disk (diameter 30 cm). Water samples were kept in 2-L polyethylene bottles in an icebox to analyze later in the laboratory. The methods of water analyses were done according to APHA (2005), Total heavy metals were determined after digestion using the GBC atomic absorption reader model Savant AA-AAS with GF 5000 graphite furnace.

Statistics:

One-way ANOVA was examined through the Excel-Stat software to analyze the spatial and temporal variations; where $p \leq 0.05$ and $p \leq 0.01$ were taken for

significance and highly significant levels, respectively. The correlations coefficients (r) between the measured parameters were calculated. In addition to the obtained was examined with principal component analysis (PCA) in order to relate the distribution pattern of the heavy metal levels to the physicochemical parameters using XL Stat (2015) program.

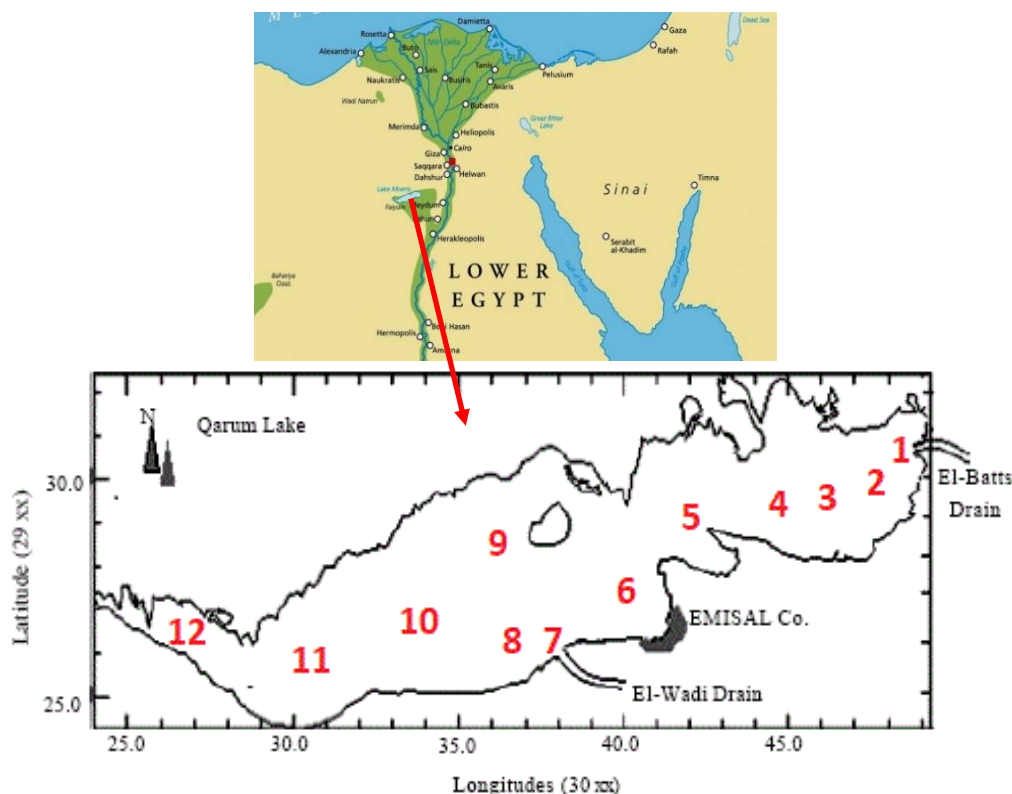


Fig. 2: A map of Qarun Lake showing sampling locations .

Metal Quality indices:

Two different quality indices are used to determine the metal contamination of Qarun Lake water.

Pollution Index (PI):

It is based on individual metal calculations and categorized to 5 classes according to the following equation (Caerio *et al.* 2005).

$$PI = \sqrt{\frac{\left(\frac{C_i}{S_i}\right)_{\max}^2 + \left(\frac{C_i}{S_i}\right)_{\min}^2}{2}}$$

C_i : the concentration of each element.

S_i : metal level according to national water quality criterion.

Metal Index (MI):

It is based on a total trend evaluation of the present status. The higher the concentration of a metal compared to its respective MAC value, the worse the quality of the water. MI value > 1 is a threshold of warning (Bakan *et al.* 2010). According to (Tamasi and Cini, 2004), the MI is calculated by using the following formula:

$$MI = \sum_{i=1}^n \frac{C_i}{(MAC)_i}$$

C_i : the concentration of each element.

MAC: maximum allowable concentration.

RESULTS AND DISCUSSION

Physicochemical characteristics of Qarun water:

Temperature is an important factor in the aquatic environment. It ranged between 12.80 °C at site (4) during winter and 29.10 °C at a site (7) during summer with highly temporal significant difference ($p < 0.01$). In general, the water temperature in Qarun Lake was suitable for fish habitat and was within the permissible limits (8-28°C). Qarun Lake is characterized by water turbidity due to the deteriorating effect of El-Bats and El-Wadi drains. Transparency ranged between the lowest value 15 cm at a site (1) during winter and a site (7) during spring and the highest one 80 cm at a site (6) during autumn with highly temporal significant difference ($p < 0.01$). On the other hand, the water of El-Bats and El -Wadi drains were more turbid, where the transparency ranged between (5-10 cm) and (10-15 cm), respectively. The total dissolved solids (TDS) changed in a wide range 14.24-39.80 g/l with spatial significant difference ($p < 0.01$). The maximum salinity values have observed at site (12), the most western one, during summer due to temperature elevation and evaporation rate (Goher *et al.* 2018). While the sites close to the drains inlet recorded the lowest TDS values due to the dilution effect of the brackish wastewater. TDS in El-Bats and El-Wadi drains water fluctuated between (1.74-3.62) and (1.85-4.82) g/l, respectively (Table 2), which are much, lower than the lake water. The total suspended solids (TSS) changed in a wide range of 13.0-75.12 mg/l with high temporal and spatial significant difference ($p < 0.01$). TSS in El-Bats and El-Wadi drains water fluctuated between (57.0-89.62) and (45.0-79.64) mg/l, respectively, which are higher than the lake water. TSS levels are higher than those of permissible limits (25 mg/l) during all seasons.

Table 2: physicochemical parameters of Qarun Lake water compared to Canadian guidelines for aquatic life protection

parameter	Range	Mean± SD	Aquatic life*	parameter	Range	Mean± SD	Aquatic life**
Temp. (°C)	12.80-29.10	21.20±5.18	8 - 28	pH	7.91-8.75	8.31±0.2	6.5 - 9
Transparency (cm)	15.00-80.00	43.96±11.87		DO (mg/l)	3.60-15.0	7.40±2.99	> 5.5
Salinity (TDS) (g/l)	14.24-40.2	33.49±2.42		BOD (mg/l)	4.05-13.12	6.75±1.62	< 6
TSS (mg/l)	13.0-75.12	37.17±15.46	25	COD (mg/l)	10.40-35.48	25.33±7.96	

* CCME (2017)

pH of Qarun Lake water lies in the alkaline side and is still in the permissible limits (6.5-9) for the aquatic organisms. The maximum pH value (8.75) was recorded at sites (3) and (4) during winter, while the minimum pH (7.91) was recorded at a site (1). ANOVA study shows a spatial significant difference ($p < 0.05$). Dissolved oxygen (DO), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) values varied in the ranges of (3.60-15), (4.05-13.12) and (10.40-35.48) mg/l. with spatial significant difference ($p < 0.01$). The coefficient correlation data showed that BOD and DO are negatively correlated with temperature ($r = -0.58$, $P < 0.01$) and ($r = -0.75$, $p < 0.01$), respectively. However, COD is positively correlated with temperature ($r = 0.62$). DO is negatively correlated with metals as Cr ($r = -0.55$), Fe ($r = -0.48$) and Ni ($r = -0.49$).

Heavy metals:

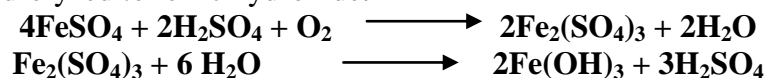
Heavy metals may enter an aquatic ecosystem from different natural and anthropogenic sources, including industrial or domestic sewage, storm runoff, leaching from landfills, shipping and harbor activities and atmospheric deposits (Rajeshkumar and Munuswamy, 2011).

Iron (Fe):

Iron is one of the most abundant metals in the earth's crust. The results showed that Fe fluctuated in the range 158.76-587.55 µg/l with temporal and spatial significant difference ($p < 0.01$) (Table 3). The highest value of iron concentrations (587.55 µg/l) recorded at a site (1) during summer may be attributed to the dissolution of sediments and the release of iron to the overlying water. The lowest value of iron (158.76 µg/l) was recorded at a site (9) during winter may be due to the oxidation of Fe^{+2} to Fe^{+3} and precipitated as hydroxide. These results agreed with (Ibrahim and Ramzy, 2013, Sabae and Mohamed, 2015 and Goher *et al.* 2019b). Also, Massoud *et al.* (2005) showed that the increase of heavy metal uptake by phytoplankton due to blooming phenomena during the cold period decrease their levels in the water column. Also, Goher *et al.* (2019b) reported that the distribution dynamics of iron in the water system depend on the dissolved oxygen and is usually present as insoluble $\text{Fe}(\text{OH})_3$ or ferric oxide. The ferrous form can only exist in the absence of oxygen and the ferric form is almost completely insoluble. In other words, at oxygenated water iron is precipitated as ferric form, while in the absence of oxygen and the water containing CO_2 comes in contact with iron in the ferrous form, in this case, ferrous bicarbonate goes into solution, however at the oxidation occur insoluble ferric hydroxide ions precipitated as follows:



Also, in water contains ferrous sulfate which is unstable in presence of dissolved oxygen, ferrous sulfate and sulphuric acid (formed by the action of microorganisms) react under the presence of oxygen to produce ferric sulfate, which is quickly hydrolyzed to ferric hydroxide.



On the other hand, Fe levels in Qarun Lake water were within the permissible level (300 µg/l) CCME (2017) around the year except for summer. Fe concentration in El-Bats and El-Wadi drains water ranged between (299.46-614.22) and (313.74-501) µg/l, respectively (Table 4). Iron is necessary to photo-synthesizing plants, where it is the metallic part of at least two plant cytochromes; that function in the transfer of electrons during photosynthesis and it is an important trace metal requirement for all biological life. However, at high concentrations, iron (II) is toxic for most organisms that may decrease the species diversity and abundance of periphyton, benthic invertebrates and fishes (Vuori, 1995).

The statistical analysis showed that iron is positively correlated ($P < 0.01$) with temperature ($r = 0.65$), Mn ($r = 0.84$), Zn ($r = 0.84$), Cu ($r = 0.84$), Cr ($r = 0.80$), Ni ($r = 0.76$), Pb ($r = 0.86$), Cd ($r = 0.80$) and COD ($r = 0.36$, $p < 0.05$) which indicates their common source. While it is negatively correlated ($p < 0.05$) with transparency ($r = -0.33$), TDS ($r = -0.33$), pH ($r = 0.30$) and DO ($r = -0.48$, $p < 0.01$), which may be related to the precipitation of iron into the bottom sediment under the effect of the pH and DO, these results are in agreement with many studies (Goher, 1998, 2002 & 2019, Abdel Satar *et al.* 2010 and El Sayed *et al.* 2015).

Manganese (Mn):

Manganese, functions as an essential constituent for bone structure, reproduction and normal operation of the enzymes system. They are toxic only when present in a higher amounts, but at low level is considered as micronutrient (El-Naggar *et al.* 2009). It ranged between (11.31-59.60) µg/l. In similar trend of Iron distribution, the highest values of manganese were recorded during summer that may

be attributed to the elevation in temperature decreases the assimilation rate by aquatic organism especially macrophytes (Berg *et al.* 1995) in addition to the release of metals from the sediments due to the bacterial activity and temperature elevation (Goher *et al.* 2019b). Mn levels are within the permissible level (50 µg/l) along the lake except at site (1) during summer. On the other hand, Mn concentration in El-Bats and El-Wadi drains water in the ranges of (18.88-56.99) and (29.07-43.69) µg/l, respectively. Mn is positively correlated (n=48, p< 0.01) with Temperature (r= 0.55) and COD (r= 0.34, p< 0.05), Cu (r= 0.82), Cr (r= 0.76), Pb (r= 0.79), Cd (r= 0.79) Zn (r=0.73, p< 0.01), and Ni (r= 0.77, p< 0.01). This result agreed with that reported by Goher (2002). While it is negatively correlated (n=48, p< 0.01) with transparency (r= -0.56), TDS (r= -0.44) and DO (r= -0.37).

Table 3: Heavy metals levels (µg/L) in Qarun Lake water during the studied period

parameter	Autumn	Winter	Spring	Summer	Mean± SD	guidelines
Fe	169.65-313.69	158.76-246.17	223.61-373.98	260.99-587.55	270.82±80.84	300
Mn	13.87-38.97	11.31-33.10	20.72-37.65	22.40-59.60	26.44±6.71	50
Zn	13.27-31.74	12.69-23.69	14.60-34.91	34.70-61.92	26.72±13.53	50
Cu	1.39-15.35	1.29-8.24	6.15-18.00	5.69-19.85	8.22±2.94	4
Ni	4.27-8.44	3.97-7.63	6.18-12.18	7.34-12.82	7.47±1.89	25
Cr	6.03-13.62	3.49-9.01	11.03-24.73	13.95-26.98	12.95±6.80	10
Pb	17.29-31.19	16.08-25.11	22.68-47.29	29.94-50.27	27.82±7.21	7
Cd	0.88-1.61	0.18-1.61	1.55-3.17	1.74-3.63	1.59±1.08	1

Table 4: Range and annual mean (± SD) of heavy metals (µg/l) in El-Bats and El-Wadi drains during (2016-2017).

parameter	El -Bats drain		El- Wadi Drain	
	Range	Annual Average ± SD	Range	Annual Average ± SD
Fe	299.46 – 614.22	345.21±143.68	313.74 – 501.00	352.33±80.27
Mn	18.88 – 56.99	42.23 ±18.14	29.07 – 43.69	34.73±6.46
Zn	70.71 – 116.27	77.37±20.03	61.46 – 89.16	65.98±12.02
Cu	19.11 – 34.18	23.16±7.004	15.62 – 26.28	19.82±4.75
Ni	15.29 – 25.24	16.84±4.54	14.61 – 24.30	16.33±4.40
Cr	16.32 – 27.13	21.06±4.89	16.67 – 36.04	19.41±8.97
Pb	32.61 – 65.13	46.97±13.71	29.15 – 66.47	42.36±15.62
Cd	2.084 – 3.200	2.44±0.57	2.22 – 4.042	2.93±0.75

Zinc (Zn):

Zinc is known to be one of the most toxic metals to many organisms above certain concentrations and exposure duration (Maity *et al.* 2008). Zinc may exist in water as the free radicals or as soluble complexes (associated with the soluble chlorides and sulphates), or can be adsorbed on the suspended matter (Authman *et al.* 2015). While insoluble zinc carbonate, zinc oxide and zinc sulfide precipitate out of solution in most natural waters. In Qarun Lake water, Zn ranged between 12.69 and 61.92 µg/l. The lowest value of zinc (12.69 µg/l) was recorded at site a (12) during winter. While the highest value (61.92 µg/l) was recorded during summer at a site (7) that facing El-Wadi Drain that may be attributed to the decomposition of organic matter particulate by bacterial activities (Hassouna *et al.* 2019). On the other hand, Zn concentration in El-Bats and El-Wadi drains water ranged between (70.71-116.27) and (61.64-89.16) µg/l, respectively. Zinc is positively correlated (n=48, p< 0.01) with Temperature (r= 0.71), Cu (r= 0.75), Cr (r= 0.79), Ni (r= 0.78), Pb (r= 0.78) and Cd (r= 0.74). While it is negatively correlated (n=48, p< 0.01) with DO (r= -0.42).

Copper (Cu):

Copper is a fairly common constituent of natural water. It is a micronutrient fundamental to all forms of life; it may be toxic to organisms by inducing a reduction in enzyme activity or a random rearrangement of structural proteins. The toxicity of copper varied with the chemical characteristics of water as pH, hardness, temperature, dissolved oxygen, alkalinity, and the presence of complexing agents (Goher, 2002). The present results showed that the copper was in the range 1.29-19.85 µg/l. The lowest value was recorded at site (11) during winter, while the highest one was recorded during summer at site (1); in front of the discharge point of El Bats Drain; that may be attributable to the heavy metals released from the sediment to the overlying water under the effect of both high temperature and a fermentation process resulting from the decomposition of organic matter (Goher et al. 2014). In addition to the agricultural runoff and domestic sewage effluents, where domestic sources are the major contributors of copper in the environment. On the other hand, Cu concentration in El-Bats and El-Wadi drains water ranged between (19.11-34.18) and (15.62-26.28) µg/l, respectively. Copper is positively correlated ($n=48$, $p < 0.01$) with temperature ($r= 0.58$), Cr ($r= 0.78$), Ni ($r= 0.81$), Pb ($r= 0.83$), Cd ($r= 0.79$) and COD ($r= 0.29$, $p < 0.05$). While it is negatively correlated ($n=48$, $p < 0.01$) with transparency ($r= -0.48$), TDS ($r= -0.42$) and DO ($r= -0.38$).

Nickel (NI):

Nickel is found in natural water in only trace quantities. The toxicity of nickel can be affected by many factors in water such as salinity, dissolved oxygen, hardness, temperature, pH, dissolved solids and alkalinity (Blewett and Leonard EM, 2017). In addition to the adsorbent particles as iron and manganese oxides and organic matter and the sediment texture, (Zhang et al. 2014). Nickel levels in Qarun Lake water ranged between 3.97 and 12.82 µg/l with high temporal significant difference ($p < 0.001$) and were below the permissible level (25 µg/l) for aquatic life protection. The lowest Ni value was recorded at site 11 during winter, while the highest value was recorded at a site (1) during summer. On the other hand, Ni concentration in El-Bats and El-Wadi drains water ranged between (15.29-25.24) and (14.61-24.30) µg/l, respectively. The values of nickel concentration in the drains are higher than in Qarun Lake water recording ranges of (15.29-25.24) and (14.61-24.30) µg/L in El Bats Drain and El Wadi Drain, respectively. Nickel is positively correlated ($n=48$, $p < 0.01$) with Temperature ($r= 0.72$), Cr ($r= 0.86$), Pb ($r= 0.80$), Cd ($r= 0.85$) and COD ($r= 0.36$, $p < 0.05$). While it is negatively correlated ($n=48$, $p < 0.05$) with Transparency ($r= -0.50$) and DO ($r= -0.49$).

Chromium (Cr):

Chromium enters natural water through the discharge of industrial wastes, where its salts are used extensively in industrial processes, in electroplating, as a constituent of corrosion-resistant and hardness of steel, in paints, dyes and fungicides and in leather tanning. So, chromium has a significant constituent of wastewaters, sewage and other refuse, and potentially serious pollutants (Goher, 2002). It ranged between (3.49-26.98) µg/l with high temporal significant difference ($p < 0.001$), which were above the permissible level (10 µg/l) during spring and summer. The highest value was recorded at site (1) during summer, while the lowest value was recorded at site (6) during winter that may be related to the uptake of chromium by phytoplankton and the dead phytoplankton settling to the sediment leaving water poor in trace elements (Goher, 2002 and Ali and Abdel-Satar, 2005). Chromium

concentration in El-Bats and El-Wadi drains are higher than the values of chromium concentration in Qarun Lake water and it ranged between (16.32-27.13) and (16.67-36.04) $\mu\text{g/l}$, respectively. Chromium is positively correlated ($n=48$, $p < 0.01$) with Temperature ($r = 0.81$), COD ($r = 0.45$), Pb ($r = 0.84$) and Cd ($r = 0.90$). While it is negatively correlated ($n=48$, $p < 0.01$) with transparency ($r = -0.47$), DO ($r = -0.55$) and BOD ($r = -0.30$, $p < 0.05$)

Lead (Pb):

Lead is one of these toxic heavy metals largely disseminated in the atmosphere, soils and waters (Eba et al. 2011), It acts by complexing with oxo groups in enzymes and affects virtually all steps in the process of heme synthesis and proline metabolism (Goher, 2002). Lead enters the aquatic environment through lead dust fall out, domestic wastes, leaching of marine paints, erosion and leaching of soil, agricultural discharges and many industrial wastes (Wuana and Okieimen, 2011). It ranged between (16.08-50.27) $\mu\text{g/l}$ with a high temporal significant difference ($p < 0.001$). Where the host seasons (spring and summer) recorded the high lead levels that may be attributed to the high rate of evaporation as a result of temperature elevation and the heavy agricultural run-off which contains fertilizers, agrochemicals and pesticides (Akan et al. 2012). The lowest value (16.08 $\mu\text{g/l}$) was recorded at a site (11), while the highest value (50.27 $\mu\text{g/l}$) was recorded at a site (7). On the other hand, Pb concentration in El-Bats and El-Wadi drains water ranged between (32.61-65.13) and (29.15-66.47) $\mu\text{g/l}$, respectively. The obtained results showed that the levels of Pb in Qarun Lake water were above the permissible level (7 $\mu\text{g/l}$) for aquatic protection that may be due to agricultural runoff and domestic sewage inflow from the drains. Pb is positively correlated ($n=48$, $p < 0.01$) with Temperature ($r = 0.69$), COD ($r = 0.37$), Cd ($r = 0.87$). Pb is negatively correlated ($n=48$, $p < 0.01$) with Transparency ($r = -0.50$), TDS ($r = -0.44$) and DO ($r = -0.47$).

Cadmium (Cd):

Cadmium is one of the heavy metals, which is highly toxic to humans, plants and animals. Cadmium is a nonessential element that has high toxic potential (Pavan and Benarjee, 2015). Cadmium is an extremely dangerous cumulative toxicant causing insidious progressive chronic poisoning in mammals, fishes and other animals (USEPA, 1979). Regarding the present results, Cd ranged between (0.018-3.632) $\mu\text{g/l}$ with a high temporal significant difference ($p < 0.001$). The lowest value was recorded at a site (12) during winter, while the highest value was recorded at site a (7) during summer. On the other hand, Cd concentration in El-Bats and El-Wadi drains water ranged between (2.084-3.200) and (2.220-4.042) $\mu\text{g/l}$, respectively. According to Borg (1984), the heavy metals which have carbonate with low solubility as Cd & Pb are eliminated from the solution as a result of CaCO_3 co-precipitation. Cd levels are above the permissible level (1 $\mu\text{g/l}$) for aquatic life protection recommended by CCME (2017). Cd is positively correlated ($n=48$, $p < 0.01$) with temperature ($r = 0.77$), COD ($r = 0.46$), while it is negatively correlated ($n=48$, $p < 0.05$) with BOD ($r = -0.32$), TDS ($r = -0.33$), transparency1 ($r = -0.53$, $p < 0.01$) and DO ($r = -0.57$, $p < 0.01$).

In General, the high levels of most heavy metals have existed during the hot seasons in particular during summer, that mainly related to the effect of the high temperature leading to increase of the evaporation rate and decrease the water level, as well as, the release of the metals from the bottom sediment and degradable organic matter under the action of the microbial activity. On the other hand, the sites facing

the wastes discharge point recorded the high contents of metals in comparison to the other locations, while, the western side (the most far from the drains inlets) showed the lowest values. Figure (3) show the contour map of the heavy metal levels in the lake water

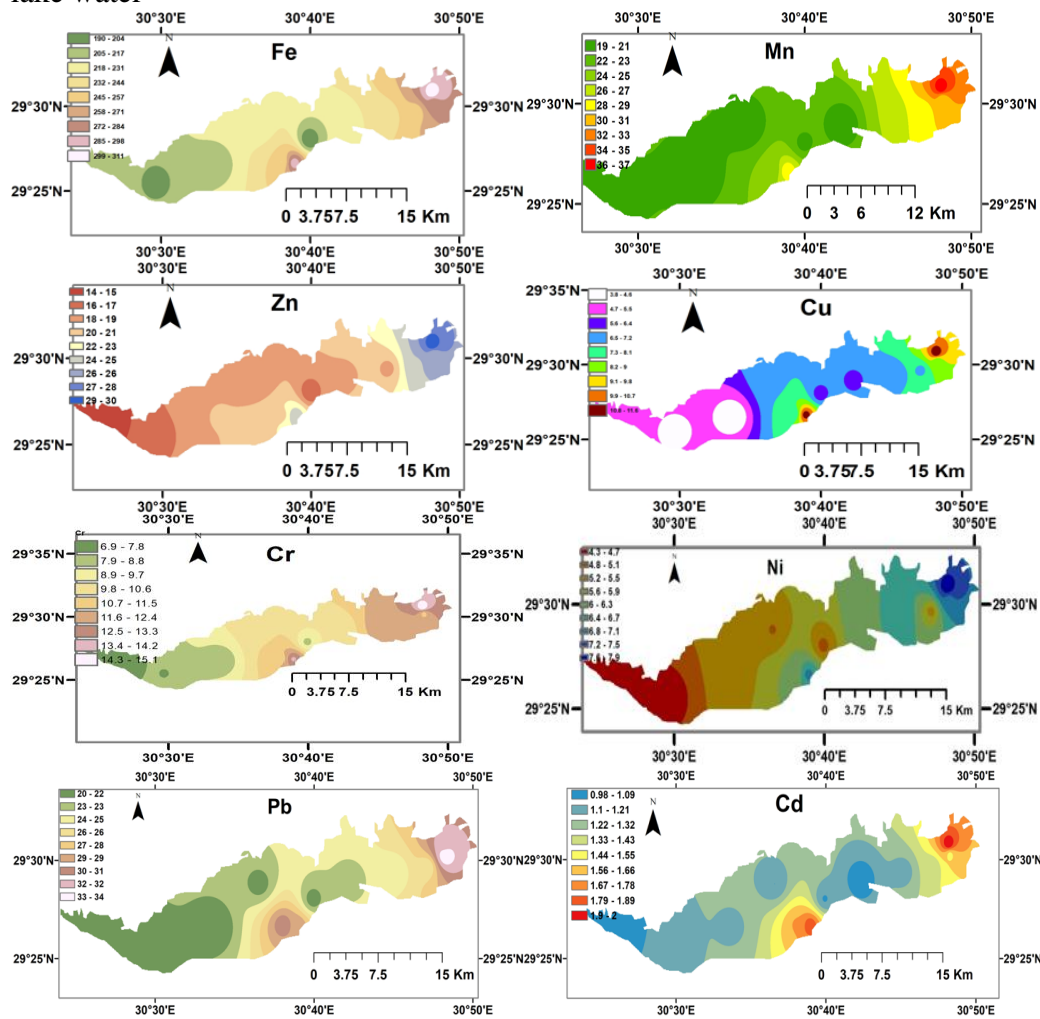


Fig. 3: : Contour map of the annual mean concentration ($\mu\text{g/l}$) of the studied heavy metals in Qarun Lake water during the study period

Metal Pollution indices:

Two different indices are designed to evaluate the metal contamination of Qarun Lake water, the first one is the Pollution Index (PI), that independent of the effect of the individual metal. While the other index, Metal index (MI), based on the effect of the level of the total metal. In the present study, the acceptable limits of the trace metals obtained by CCME (Saffran *et al.* 2001) for aquatic life protection were used as maximum allowable concentration (MAC) value.

Pollution Index (PI):

The pollution index (PI) was used in our study to determine the grade of trace metals toxicity in water samples. It is based on individual metal calculations and categorized to five classes (Table 5) according to (Caeiro *et al.* 2005). The results indicate a various pollution degree of the studied metals for aquatic life in Qarun Lake. Pollution index exhibited that Mn, Ni and Zn have not polluted effect for aquatic life usage. On the other hand, Cd and Cr showed slight pollution to moderate effect at all sites. Fe showed a slight pollution effect at sites 1, 2, 7 and 8. Cu showed

slight pollution to strong effects at all sites. Finally, Pb showed strong pollution to serious effect at all sites (Table 6).

Table 5: Categories of water pollution index.

Class	PI value	Pollution grade
1	≤ 1	no effect
2	$>1-2$	slightly affected
3	$>2-3$	moderately affected
4	$>3-5$	strongly affected
5	>5	seriously affected

Table 6: Pollution index of the measured metals in the Qarun Lake water according to guideline levels of aquatic life utilizations.

Site	Fe		Nn		Zn		Cu	
	PI value	Effect	PI value	Effect	PI value	Effect	PI value	Effect
1	1.50	Slightly	0.96	No	0.89	No	3.80	Strongly
2	1.26	Slightly	0.74	No	0.81	No	2.80	Moderately
3	0.83	No	0.64	No	0.77	No	1.98	Slightly
4	0.88	No	0.51	No	0.74	No	2.13	Moderately
5	0.90	No	0.41	No	0.56	No	1.57	Slightly
6	0.73	No	0.45	No	0.70	No	2.09	Moderately
7	1.37	Slightly	0.72	No	0.91	No	3.57	Strongly
8	1.30	Slightly	0.60	No	0.72	No	2.66	Moderately
9	0.81	No	0.47	No	0.54	No	2.24	Moderately
10	0.77	No	0.48	No	0.60	No	1.76	Slightly
11	0.79	No	0.49	No	0.55	No	1.68	Slightly
12	0.75	No	0.45	No	0.53	No	1.61	Slightly

Site	Ni		Cr		Pb		Cd	
	PI value	Effect	PI value	Effect	PI value	Effect	PI value	Effect
1	0.42	No	2.01	Moderately	5.27	Seriously	2.35	Moderately
2	0.34	No	1.84	Slightly	5.33	Seriously	1.88	Slightly
3	0.31	No	1.52	Slightly	3.95	Strongly	1.56	Slightly
4	0.33	No	1.55	Slightly	3.88	Strongly	1.90	Slightly
5	0.31	No	1.21	Slightly	3.69	Strongly	1.28	Slightly
6	0.28	No	1.39	Slightly	3.82	Strongly	1.61	Slightly
7	0.37	No	1.81	Slightly	5.66	Seriously	2.70	Moderately
8	0.31	No	1.56	Slightly	4.69	Strongly	2.08	Moderately
9	0.30	No	1.36	Slightly	3.59	Strongly	1.56	Slightly
10	0.31	No	1.05	Slightly	3.47	Strongly	1.59	Slightly
11	0.29	No	1.52	Slightly	3.57	Strongly	1.39	Slightly
12	0.28	No	1.42	Slightly	3.60	Strongly	1.31	Slightly

Metal Index (MI):

It is based on a total trend evaluation of the present status. By increasing the concentration of metal compared to its respective maximum allowable value (MAC), the worse impact of the quality of the water appeared. MI value >1 is a threshold of warning limit (Cude, 2001). According to MI values, all selected sites in Qarun Lake are suffering from seriously metal pollution for aquatic life utilization. On the other hand, site 1 and 7 are the most sites exposed to metal pollution due to their close to drainage sources (Fig. 4).

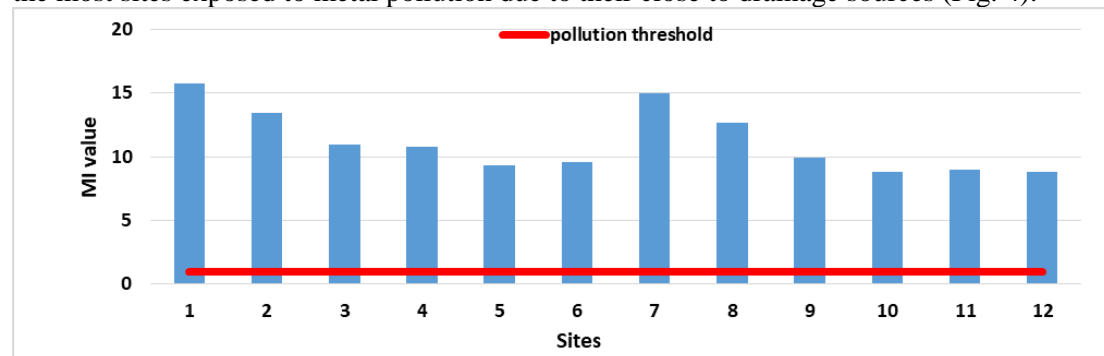


Fig. 4: Metal index of the measured metals in Qarun Lake water for aquatic life utilizations

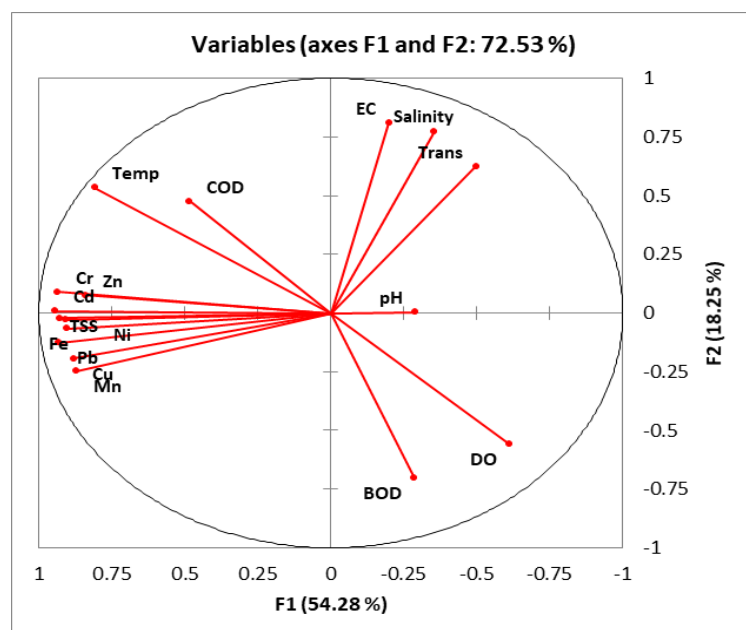


Fig. 5: Principal component analysis (PCA) (Axis I and II) performed on some Heavy metal and some physico-chemical variables

According to Figure (5), the principal component analysis (PCA), heavy metals were positive significantly correlated with each other. That may be attributed to the same allochthonous sources of these metals (the wastes discharged to the lake via the different drains). The first axis explaining 54.28 % of the variables and it was primarily associated with the heavy metals, while axis 2 was explaining 18.25 % of the variance of some physicochemical variables. Also, analysis, showed that all heavy metals closely correlated with COD, TSS and temperature, while negatively with transparency, EC, salinity, pH, DO and BOD. PCA showed that Cr and Cd were more positively affected by the temperature

CONCLUSION

Qarun Lake is one of the most important lakes in Egypt; However, it represents as a tank for the discharging agricultural wastewater of El-Fayoum province. Qarun Lake suffers from several environmental pollution problems. This study was carried out to focus on the contents of Fe, Mn, Zn, Cu, Ni, Cr, Cd and Pb in Qarun Lake water and their contamination levels using the metal pollution indices. The results showed that the high values of heavy metals in Qarun Lake water have existed during the hot seasons that mainly related to the effect of the high temperature leading to the increase of the evaporation rate and decrease the water level, as well as, the release of the metals from the bottom sediment and degradable organic matter under the action of the microbial activity. On the other hand, the sites opposite the waste discharge points recorded the high contents of metals in comparison to the other locations, while the western side showed the lowest values. In addition, the indices of the metal pollution reveal that Qarun Lake water suffers from a different degree of metal contamination that effect on the water quality, especially for aquatic life utilization

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