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Evaluation of heavy metal content in Qaroun Lake, El-Fayoum, Egypt. Part I: Bottom sediments

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ABSTRACT

This paper was undertaken in order to assess the extent of contamination in bottom sediments of Qaroun Lake, El-Fayoum, Egypt. Sediment samples were analyzed for grain size distribution and heavy metals concentration. Ten heavy metals were determined (in ppm) by X-Ray Fluorescence Spectrometry. The average concentration values in sediments are 2.99 (As), 124.89 (Cr), 38.91(Cu), 14.21 (Pb), 54.74 (Ni), 58.76 (Zn), 3.27 (Sn), 6.77 (Mo), 162.77 (V) and 11.70 (Co). Most of these metals are found with high concentrations in the eastern part of the lake, comparing with them in sediments of the central and western parts. The impact of drains effluents on the lake sediment-metals content is revealed. The dependence of concentrations on the sediment grain size is examined and high correlations between silt and clay-sized grains and the concentrations of Cr, Cu, Ni and Mo are deduced (R ranges from 0.61 to 0.73). Potential contamination of the lake is assessed using the contamination indicators, the geo-accumulation index, *Igeo* and contamination factor, *Cf* and the degree of contamination, *Cd*. Based on the obtained results, it is concluded that the lake sediments are found in contamination conditions. They are moderately contaminated with Cr, Mo, V and Co metals.
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1. Introduction

Investigation of heavy metals in sediments of aquatic ecosystems is an essential requirement in order to understand their effects on water and living organisms. In the recent years, heavy metals have been greatly considered in the studies of water environments because of their potential toxic effect, persistence, and bioaccumulation problems (Censi et al., 2006 and Carr & Neary, 2008). Heavy metals exist naturally in the earth's crust rocks and originate from anthropogenic activities. They can reach the water environments via the atmospheric deposition, surface runoff agricultural drainage water, effluents of industrial, petroleum, sewage and household cleaners (Gomez et al., 2007; Mortatti & Probst, 2010; Santos, Silva-Filho, Schaefer, Albuquerque- Filho, & Campos, 2005).

Sediments, as one of the water ecosystem components, act as a reservoir of heavy metals (ECDG, 2002 and Mwamburi, 2003). Sediments reflect the environmental changes occurred in sedimentary basins and provide useful information about

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accumulation of heavy metals, reflecting the natural (geogenic) and anthropogenic impacts. Oftentimes, mixtures of metals pollutants are present in the impacted sediments, which may result in severe contamination leading to destroying the entire aquatic life (Milenkovice, Damjanovice, & Ristic, 2005). The extent of sediment contamination with heavy metals should be investigated extensively to avoid the serious environmental risks. Contamination levels are, usually, determined by comparing the present day metal concentrations with their natural background (regional or local) levels in earth's crust sedimentary rocks or with the preindustrial background values (Dickinson, Dunbar, & McLeod, 1996; Hakanson, 1980; Muller, 1969; Ong, Menier, Shazili, & Kamaruzzaman, 2013; Raulinaitis, Ignatavicius, Sinkevicius, & Ockinis, 2012).

Qaroun Lake is one of the most important inland-aquatic ecosystems in Egypt. It is a distinctive landform lying in El-Fayoum area situated approximately 80 km southwest of Cairo (Fig. 1). Besides its significance as a natural discharge area for El-Fayoum province, the lake is an important place for fishery, salt production, tourism and migratory birds in the Autumn and Winter seasons. Therefore, Qaroun area was declared as a natural protectorate according to the provisions of Law 102/1983, by Prime Ministerial Decree No. 943/1989.

Monitoring the concentration of heavy metals and evaluating their contamination levels in Qaroun lake sediments are imperative and crucial issues to ensure sustainable ecosystem function well in the future. The objective of this paper is to determine the concentration and distribution of some heavy metals (As, Cr, Cu, Pb, Ni, Zn, Sn, Mo, V and Co) in the lake sediments and to assess the degree of contamination. Results of this study may be insights for the decision maker to improve the protection procedures of the lake against the potential serious risks.

2. Materials and methods

2.1. Characterization of the study area

El-Fayoum area (comprising Qaroun Lake, the study area) is a depression excavated naturally in the northeastern part of the Western Desert of Egypt. The surface of the depression is almost flat and slopes downward in a northwesterly direction, from a level of +23 m (MSL) at El-Hawara channel to −35 m (MSL) at the central part of Qaroun Lake (Fig. 1). The major part of the depression is cultivated using a dense net of irrigation canals and drains.

The depression is occupied by the Quaternary sediments, clay, silt, sand, gravels, lacustrine and sabkha (CONOCO Coral, 1987; EEAA/NCS (Egyptian Environmental Affairs Agency/Nature Conservation Sector), 2007; Wendorf & Schild, 1976). It is surrounded from all sides by hills or escarpments composed mainly of Tertiary rocks, hard limestone, calcareous sandstone, shale, basalt sheets, sands and gravels (Abd-Elshafy, Metwally, Abd El Azeam, & Mohamed, 2007; Bown & Kraus, 1988; Koopman, 2007; Said, 1962).

Qaroun Lake is a closed saline basin lying in the lowest-northwest part of El-Fayoum depression, between longitudes 30° 24′ and 30° 50′ E and latitudes 29° 24′ and 29°33′ N. It has an elongated rectangular shape with average dimensions 45 km length, 5.7 km width and 4.2 m depth in average (Gohar, 2002). It is bounded from the south and east by the urban and cultivated areas and from the north and west by the uninhabited desert areas. The drainage in El-Fayoum depression is mainly by gravity. The drainage network consists of three main drains (El-Bats, El Mashroah and El-Wadi drains) and a number of small drains, which terminate into the lake. The lake receives huge mixture of untreated agricultural, industrial, sewage, and household effluents (about 450 million m^3/year) from El-Fayoum province (Gohar, 2002).

2.2. Sample collection and analysis

Contamination of Qaroun Lake sediments with heavy metals was evaluated using some of geochemical tools. In this study, the lake was divided geographically into three parts (east, middle and west) according to the presence of the relevant drains. Fourteen samples were taken from the bottom sediments of the lake for grain size and heavy metal analysis. Their distribution is as follows: 6 samples from the eastern part of the lake, 4 samples from the central part and 4 samples from the western part (Fig. 2). In addition to that, nine samples were collected from the relevant drain bottom sediments and analyzed for heavy metals to reveal their impact on the lake. All samples were taken from 0.0 to 10 cm depth using a suitable grab sampler. The collected samples were put directly in air sealed polyethylene bags and kept at 4 °C until analyses.

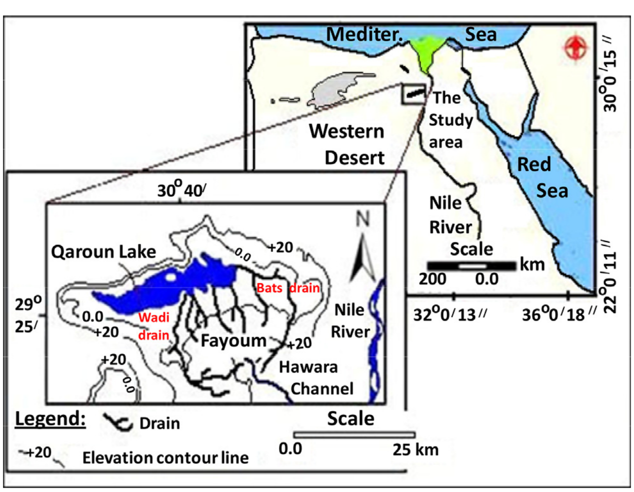

Fig. 1 — . Location map showing the location of Qaroun lake and the relevant drains, El Fayoum, Egypt.

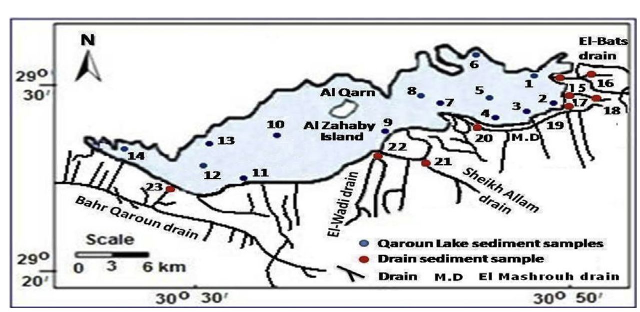

Fig. 2 — . Sediment sampling points, Qaroun lake and relevant drains.

Coordinates of sampling points were identified using GPS instrument, Model XR-4-G, Navistar LTD.

In the laboratory, the lake sediment samples were subjected to mechanical analysis to estimate the percentage distribution of grain sizes (sand, silt and clay fractions). Grain size analysis was intended in order to examine the relationship between grain sizes and heavy metal concentrations. Before starting the mechanical analysis, the samples were air-dried (at room temperature) and the extraneous materials were removed. The samples were homogenized and passed through 2 mm, 1 mm, 0.5 mm, 0.250 mm, 0.125 mm, 0.064 mm and 0.045 mm sieves, using Analytical sieve Shaker (Model, AS 200 Control "g", F, Kurt Retsch Gmbh & Co. KG).

The lake and drain sediment samples were analyzed for arsenic (As), chrome (Cr), copper (Cu), lead (Pb), nickel (Ni), zinc (Zn), tin (Sn), molybdenum (Mo), vanadium (V) and cobalt (Co) metals, using X-Ray Fluorescence (XRF) spectrometry. The XRF analysis was carried out for powder (200 μ) samples using Philips X-Ray Fluorescence equipment, Model PW/1404, with Rh radiation tube and suitable analyzing crystals. Precision and accuracy were estimated using reference and international standards samples. The results were expressed in ppm. The estimated precision ranged between 2 and 7% and the accuracy between 2 and 10% depending on the element analyzed and its concentration. All analyses were done in the Egyptian Mineral Resources Authority (EMRA) laboratories.

2.3. Contamination assessment

To evaluate the degree of sediment contamination with heavy metals, the geo-accumulation index, *Igeo*, contamination factor, *Cf* and degree of contamination, *Cd*) were estimated. As the local background metal values for Qaroun lake basin have not been established, the common regional background metal values in average shale (Turekian & Wedepohl, 1961) were used by the current work as references. The used background values are 13 (As), 90 (Cr), 45 (Cu), 20 (Pb), 68 (Ni), 95 (Zn), 2.6 (Mo), 19 (Co), 6 (Sn) and 130 (V). These values are commonly used in sediment investigations (Nobi, Dilipan, Thangaradjou, Sivakumar, & Kannan, 2010; Ong et al., 2013).

The geo-accumulation index (*Igeo*) was estimated using the following formula: (Muller, 1979)

$$Igeo = log_2(C_n/1.5B_n)$$

where C_n is the measured concentration of heavy metal in sediments and B_n is the geochemical background concentration of the same metal in average shale. The constant 1.5 was introduced to consider the possible variations of the background values due to the lithological variations. The degree of heavy metal contamination in lake sediments was determined based on the *Igeo* classes (Muller, 1979) (Table 1).

The contamination factor (*Cf*) and the degree of contamination (*Cd*) were estimated based on the average concentration values of metals following the method of Hakanson (1980). The applied equations are as follows:

$$Cf = Ms/Mb,$$

and

$$Cd = \sum_{i=0}^{n} Cf$$

where *Ms* is the metal concentration in the sediment, *Mb* is the background value of the same metal in average shale and *n* is number of the investigated heavy metals (in our work $n = 10$). According to Hakanson, the following terms were used to describe contamination factor and the degree of contamination (Table 2).

3. Results and discussion

3.1. Concentration and distribution of heavy metals

Results of heavy metals analysis of sediment samples collected from the bottom sediments of Qaroun Lake and the relevant drains are listed in Table 3. The average concentrations values of As, Cr, Cu, Pb, Ni, Zn, Sn, Mo, V and Co metals in sediments of the eastern part of the lake are 3.09, 121.66, 36.85, 15.85, 46.63, 43.08, 3.62, 7.17, 107.95 and 19.42 ppm, respectively. The relevant drain sediments (the eastern drains, such as El-Bats drain) have sediments with average concentration values of As, Cr, Cu, Pb, Ni, Zn, Sn, Mo, V and Co metals that attain 3.25, 131.76, 53.06, 13.19, 59.42, 86.07, 3.25, 5.80, 225.51, and 5.51 ppm, respectively. Concentrations of most metals in the eastern drain sediments are higher than those in sediments of the eastern part of the lake, and the vice versa is true for the Pb, Sn, Mo and Co metals.

The average concentration values of As, Cr, Cu, Pb, Ni, Zn, Sn, Mo, V and Co metals in sediments of the central part of the lake are 3.34, 115.78, 36.41, 14.33, 62.21, 77.03, 3.17, 3.39, 236.72 and 2.96 ppm, respectively. For the relevant drains sediments (the southern drains, such as El Mashrouh drain), the average concentrations of As, Cr, Cu, Pb, Ni, Zn, Sn, Mo, V and Co metals are 2.88, 155.59, 61.97, 14.09, 75.50, 80.06, 2.93, 6.63, 262.2, and 3.17 ppm, respectively. Concentrations of most metals in the southern drain sediments are found to be higher

Table 1 – Classes of geo-accumulation index and description of sediment quality.

Index Value	Class	Description of sediment quality
$Igeo \leq 0$	0	uncontaminated
$0 < Igeo < 1$	1	uncontaminated to moderately contaminated
$1 < Igeo < 2$	2	Moderately contaminated
$2 < Igeo < 3$	3	Moderately to strongly contaminated
$3 < Igeo < 4$	4	Strongly contaminated
$4 < Igeo < 5$	5	strongly to extremely contaminated
$Igeo < 5$	6	Extremely contaminated

Table 2 – Classes of contamination factor and degree of contamination (Hakanson, 1980).

Contamination factor, *Cf*	Description	Degree of contamination, *Cd*	Description
$Cf < 1$	Low contamination factor	$Cd < 8$	Low degree of contamination
$1 \leq Cf < 3$	Moderate contamination factor	$8 \leq Cd < 16$	Moderate degree of contamination
$3 \leq Cf < 6$	Considerable contamination factor	$16 \leq Cd < 32$	Considerable degree of contamination
$Cf \geq 6$	Very high contamination factor	$Cd \geq 32$	Very high degree of contamination

than those in the sediments of the central part of the lake. On the contrary of that, the As, Pb and Sn metals exceed in the lake sediments.

The average concentrations of metals in sediments of the western part of the lake are 2.54, 137.24, 43.47, 12.44, 55.38,56.13, 2.80, 8.14, 144.24 and 12.72 ppm for As, Cr, Cu, Pb, Ni, Zn, Sn, Mo, V and Co metals, respectively. While in the sediments of the connected drain (Bahr Qaroun drain), the concentrations of metals are 2.84, 89.19, 21.66, 11.99, 34.21,65.5, 3.03, 6.39, 94.01 and 25.80 ppm recorded for As, Cr, Cu, Pb, Ni, Zn, Sn, Mo, V and Co, respectively. Concentrations of As, Zn, Sn and Co in the western drain sediment are higher than those in lake sediments and the converse is found for the remain elements.

For the whole lake sediments, the average concentration values are 2.99 (As), 124.89 (Cr), 38.91(Cu), 14.21 (Pb), 54.74 (Ni), 58.76 (Zn), 3.27 (Sn), 6.77 (Mo), 162.77 (V) and 11.70 (Co). While in the drains sediments, they are 2.99 (As), 125.51 (Cr), 45.56 (Cu), 13.09 (Pb), 56.37 (Ni), 77.21 (Zn), 3.07 (Sn), 6.27 (Mo), 193.90 (V) and 11.49 (Co). It seems from the very high similarity in

Table 3 – Concentrations of specific heavy metals of interest (in ppm) in bottom sediments of Qaroun Lake and the relevant drains.

Location	S.No.	As	Cr	Cu	Pb	Ni	Zn	Sn	Mo	V	Co
Qaroun Lake											
East	1	5.31	226.85	60.43	29.82	63.63	13.06	4.21	15.07	34.05	15.26
	2	1.07	89.38	18.07	12.46	22.2	17.88	4.14	6.60	55.52	35.01
	3	3.05	98.09	28.72	11.72	44.87	56.56	3.86	2.5	150.78	18.03
	4	3.37	79.39	33.49	11.28	52.21	58.66	3.11	2.89	135.81	17.72
	5	4.63	109.35	44.66	15.72	56.11	87.60	2.77	7.45	213.82	6.54
	6	1.12	126.9	35.72	14.14	40.79	24.76	3.64	8.54	57.77	23.95
	M	3.09	121.66	36.85	15.85	46.63	43.08	3.62	7.17	107.95	19.42
	SD	1.75	54.01	14.48	7.03	14.45	29.25	0.57	4.58	70.08	9.5
Central	7	3.57	97.92	45.6	16.30	64.0	91.66	3.31	1.89	257.56	0.62
	8	4.29	87.38	4.11	18.58	55.67	77.12	3.86	3.06	226.69	2.68
	9	2.16	139.58	53.78	12.05	70.46	76.43	2.36	6.71	254.88	0.75
	10	3.37	138.24	42.17	10.42	58.70	62.90	4.06	8.35	207.77	7.81
	M	3.35	115.78	36.41	14.33	62.21	77.03	3.39	5.0	236.72	2.96
	SD	0.88	27.05	22.08	3.76	6.49	11.45	0.76	3.03	23.82	3.36
West	11	3.05	98.09	28.72	11.72	44.87	56.56	3.86	2.50	150.78	18.03
	12	3.0	142.79	47.29	11.73	63.19	72.02	3.44	7.87	220.24	7.18
	13	2.83	145.66	46.85	13.28	64.97	72.30	1.54	10.12	162.56	6.39
	14	1.31	162.43	51.01	13.02	48.51	23.66	2.35	12.07	43.38	19.30
	M	2.54	137.24	43.47	12.44	55.38	56.13	2.80	8.14	144.24	12.72
	SD	0.83	27.50	10.01	0.83	10.17	22.86	1.05	4.13	73.77	6.88
Drains											
East	15	3.10	142.92	59.02	14.13	61.33	99.01	3.12	5.54	243.47	0.59
	16	3.99	143.08	62.14	14.13	63.39	102.5	2.30	6.40	227.65	0.36
	17	2.36	122.04	44.35	12.84	53.42	67.29	3.31	6.33	201.20	16.40
	18	3.99	132.99	55.10	12.03	65.69	80.96	4.05	4.31	260.61	0.88
	19	2.84	117.78	44.69	12.81	53.29	80.57	3.49	6.44	194.65	9.34
	M	3.25	131.76	53.06	13.19	59.42	86.07	3.25	5.80	225.51	5.51
	SD	0.72	11.66	8.18	0.92	5.75	14.55	0.63	0.91	27.85	7.16
Central	20	3.64	129.08	46.40	17.61	62.89	77.38	3.06	5.33	248.72	8.19
	21	2.51	113.25	60.30	12.48	72.57	79.00	2.65	2.97	284.23	0.62
	22	2.50	224.46	79.23	12.18	91.05	83.80	3.09	11.6	253.65	0.71
	M	2.88	155.59	61.97	14.09	75.50	80.06	2.93	6.63	262.2	3.17
	SD	0.65	60.16	16.47	3.05	14.31	3.34	0.24	4.46	19.24	4.34
West	23	2.84	89.19	21.66	11.99	34.21	65.50	3.03	6.39	94.01	25.80

S.No.: Sample number M: mean SD: Standard deviation.

metal contents (As, Cr, Pb, Ni, Sn, Mo and Co) in sediments of the lake and drains that a great part of heavy metals in the lake sediments is coming from the drains.

Distribution patterns of heavy metals concentrations in Qaroun Lake sediments are presented as spatial contour maps (Fig. 3). The maps reveal that the sediments in eastern part of the lake have high concentrations of As, Cr, Cu, Pb, Zn, Mo and Co comparing with those in the central and western parts. The high concentrations of metals could be attributed to the influence of El-Bats drain, pouring its waste water and sediments in this part of the lake. On the other side, the concentrations of V and Ni metals increase in the central part of the lake, which may reflect the effect of the effluents of El Wadi, Sheikh Allam and El Mashrough drains. The Sn metal has an irregular distribution in the lake sediments.

3.2. *Dependence of metals concentrations on grain size*

Grain size distribution plays an important role regarding the content of heavy metals in sediments. Many investigations indicated that sediments composed of smaller grain sizes contain more metals than those formed of coarser ones (Gibbs, 1977; Martincic, Kwokal, & Branica, 1990; Salomons & Forstner, 1984). This was attributed to the fact that the smaller grains have a larger surface area that retains high amounts of heavy metals (Wang, Qin, & Chen, 2006). However, others investigations showed that the coarser size fractions contain high concentration of metals (Singh, Hasnain, & Banerjee, 1999).

The bottom sediment texture of Qaroun Lake is investigated in terms of grain sizes. The results (Table 4) indicate that the sediments are mainly made up of medium and fine sand-

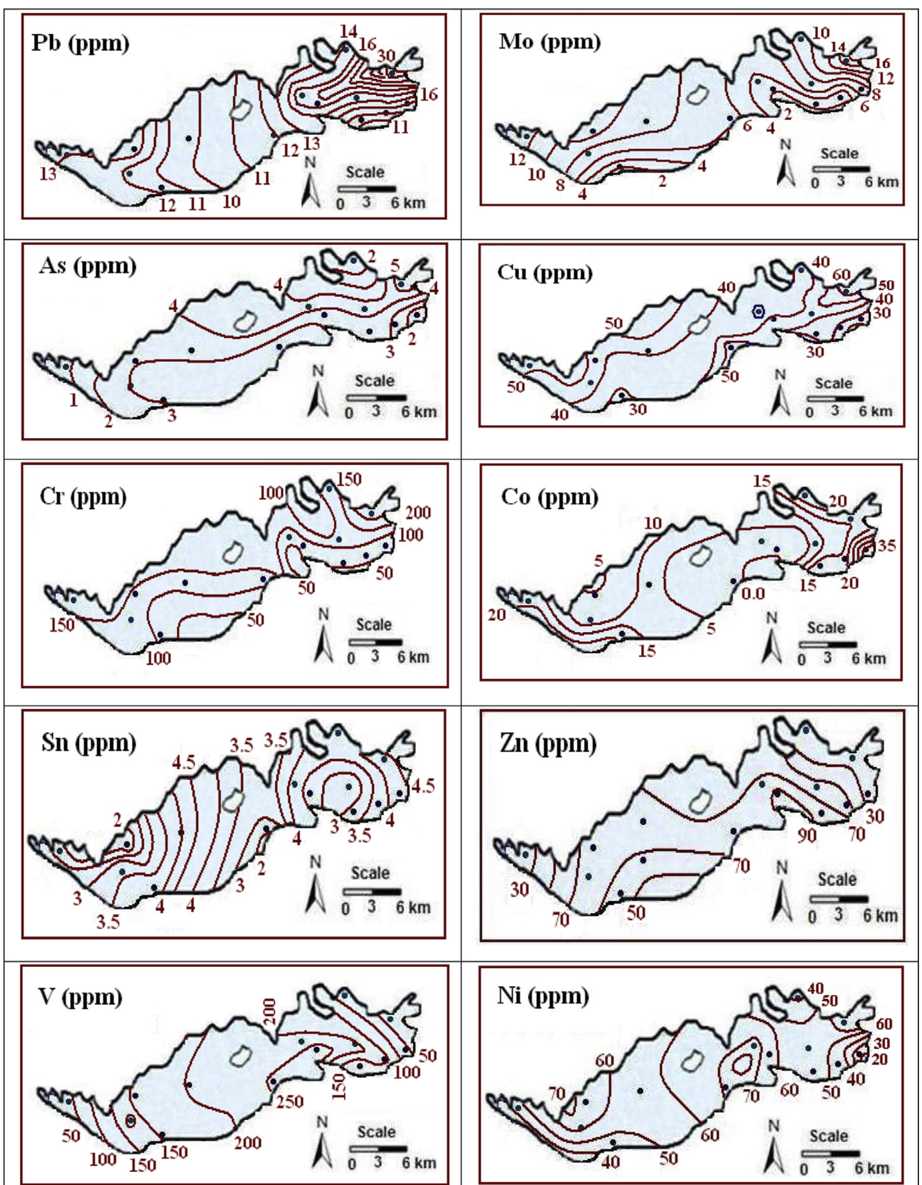

Fig. 3 – . Distribution of Pb, Mo, As, Cu, Sn, Co, Zn, Cr, V and Ni in Qaroun Lake bottom sediments.

Table 4 – Grain size distribution and sediment types of Qaroun Lake bottom sediments (after Folk, 1954, 1980).

Qaroun Lake	S.No.	V.C.Sd.	C.Sd.	M.Sd.	F.Sd	V.F.Sd.	Total sand	Silt	Clay	Silt + Clay	Classification
East	1	–	0.5	2.44	11.68	8.24	22.86	32.45	44.69	77.14	sM
	2	2.11	5.30	31.33	23.97	3.28	65.99	15.81	18.36	34.17	mS
	3	1.89	6.15	29.26	24.06	2.22	63.58	9.54	26.88	36.42	CS
	4	3.26	3.25	36.65	18.81	6.34	68.31	21.56	10.13	31.69	zS
	5	4.29	7.78	16.87	19.26	3.54	51.74	20.04	28.22	48.26	mS
	6	3.87	12.58	11.65	19.29	28.27	75.66	12.65	11.68	24.33	mS
Middle	7	1.13	2.34	24.77	32.76	6.89	67.89	16.12	15.99	32.11	mS
	8	–	5.97	29.94	27.0	5.16	69.07	13.82	17.17	30.99	mS
	9	8.64	6.18	9.02	9.2	3.55	36.59	24.80	38.59	63.39	sM
	10	–	3.73	14.85	16.61	2.63	37.82	24.72	37.46	62.18	sM
West	11	1.78	3.32	17.32	38.10	5.35	65.88	16.02	18.08	34.10	mS
	12	–	4.12	6.93	20.48	3.32	34.85	29.05	36.10	65.15	sM
	13	2.60	3.77	10.08	10.13	5.17	31.75	40.25	28.0	68.25	sM
	14	3.73	4.25	29.33	23.61	4.16	65.08	19.94	14.98	34.92	mS

S. No.: sample number V.C.Sd.: very coarse sand (2–1 mm) C.Sd.: coarse sand (1–0.5 mm).
M.Sd.: medium sand (0.5–0.250 mm) F.Sd.: fine sand (0.250–0.125 mm) V.F.Sd.: very fine sand (0.125–0.064 mm) Silt (0.064–0.045 mm) Clay (<0.045 mm) sM: sandy mud mS: muddy sand zS: silty sand cS: clayey sand.

sized grains, silt and clay-sized particles. Very fine, coarse and very coarse-sized grains present in small percentages. Fig. 4 is a graphical representation showing the distribution of total sands and silt + clay in sediment samples. There is no particular trend as regards the distribution of fine and coarse materials in the lake sediments. However, very close to eastern edge of the lake (sample 1), the sand-sized grains are found in percentage larger than that of silt + clay-sized particles. While adjacent to the western edge (sample 14), the silt and clay-sized grains exceed the sand-sized ones. Textural characteristics are determined according to Folk (1954, 1980) (Table 4). The sediment textural classes in the western and central parts of the lake are sandy mud and muddy sand, While in the eastern part, they are muddy sand, clayey sand, silty sand and sandy mud.

The dependence of the sediment-metals concentrations on the grain size is examined through a number of relationships. The most important relations are found between the smallest grain size (silt + clay) and metals as shown in Fig. 5. This figure shows that the concentration of most heavy metals depend, with different degrees, on the amounts of silt plus clay-sized grains. The silt + caly-sized grains are strongly correlated with the Cr metal (R = 0.73) and highly correlated with the Cu, Ni and Mo metals (R ranges between 0.61 and 0.65). Weak positive relationships are found with Zn, V, Pb, and As metals (R ranges from 0.08 to 0.38). On the other hand, the Sn and Co metals are negatively correlated with the silt + clay fractions, where the correlation coefficients are −0.21 and −0.40, respectively.

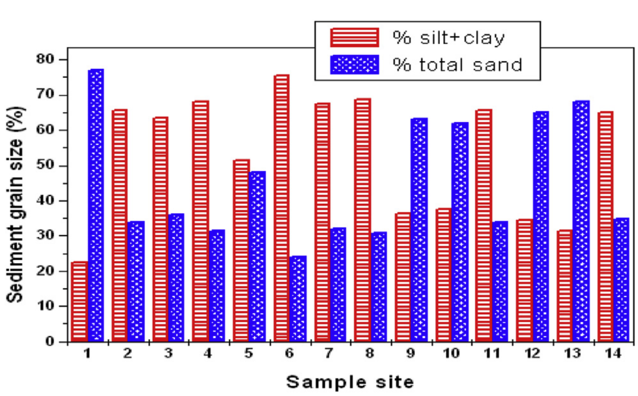

Fig. 4 – . Distribution of total sand and silt + clay in Qaroun Lake bottom sediments.

It is clear from the above discussion that the grain size is an important factor controlling the heavy metal concentrations. The increase in silt + clay-sized grains is generally associated with an increase in heavy metal concentrations. However, this trend is not proved for all elements, which means that the grain size is not the only factor affecting the metal concentrations. Drains effluents, Organic matter content, lithogenic sources and mineralogical composition of sediments as well as the physical, chemical and biological processes are others factors share in controlling the sediment-heavy metal content (Hang et al., 2009; Mortatti, Meneghelg, & Probst, 2011; Presley, Trefry, & Shokes, 1980).

3.3. *Contamination indices*

3.3.1. *Geo-accumulation index (Igeo)*

The geo-accumulation index (*Igeo*) is a common criterion used for quantifying the intensity of heavy metal contamination in terrestrial, aquatic and marine environments (Gaur, Sanjay, Pandey, Gopal, & Misra, 2005; Ozkan & Buyukisik, 2012; Tijani & Onodera, 2009). This index is a single metal approach to evaluate the sediment contamination with heavy metals.

Data of the geo-accumulation index (*Igeo*) of heavy metal accumulation in Qaroun lake bottom sediments are listed in Table 5. Inspection in this table revealed that the *Igeo* values are found to vary from metal to metal and from place to another one inside the lake. Based on Muller (1979) classification, the quality of sediments is described. In the eastern part of the lake, the quality of sediments ranges from uncontaminated to moderately contaminated with metals. The

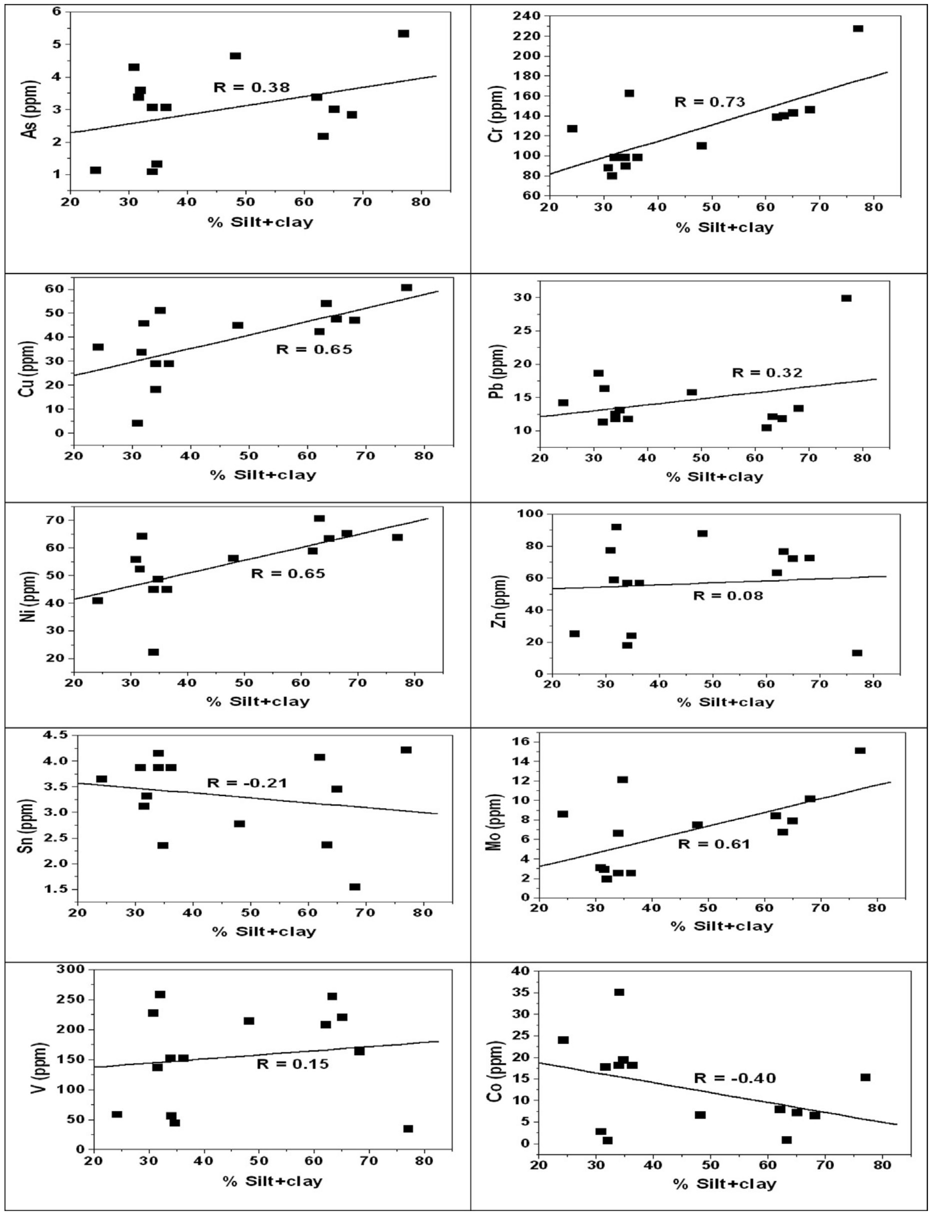

Fig. 5 – . Relationships between heavy metals and silt + clay fractions in Qaroun Lake bottom sediments.

sediments are uncontaminated with As, Cr, Cu, Pb, Ni, Zn, Sn, V and Co metals where the average *Igeo* values are associated with negative signs. Such sediments could be classified as sediments that are uncontaminated to moderately contaminated with respect to Mo metal ($0 < Igeo < 1$, class 1), where the average *Igeo* value equals 0.616.

For sediments in the central part of the lake, there is no contamination with As, Cr, Cu, Pb, Ni, Zn, Sn, and Co metals, where their average *Igeo* values are less than zero. These sediments can be described as uncontaminated to moderately contaminated sediments with Mo and V metals (class 1, $0 < Igeo < 1$) where the average *Igeo* values are 0.122 and 0.274, respectively.

Sediments in the western part of the lake are uncontaminated with As, Cu, Pb, Ni, Zn, Sn, V and Co metals where their *Igeo* values have negative signs. These sediments are practically uncontaminated to moderately contaminated with Cr and Mo metals, where their average *Igeo* values are 0.001 and 0.844, respectively.

3.3.2. *Contamination factor and degree of contamination*

The contamination factor, *Cf*, and the degree of contamination, *Cd*, are indicators that have been used widely to assess the contamination status of sediments in aquatic ecosystems (Abrahim & Parker, 2008; Ntakirutimana, Du, Guo, Gao, & Huang, 2013; Rabajczyk, Jozwiak, Jozwiak, & Kozlowski, 2011). The *Cf* index is used to express the contamination degree with a single metal, while *Cd* index is used to express the contamination degree considering the sum of all contamination factors (*Cf*) (Hakanson, 1980).

The calculated average values of *CF* and *Cd* of metals in Qaroun Lake sediments are shown in Table 6. In accordance

Table 5 – Geo-accumulation index (*Igeo*) values calculated for Qaroun Lake sediments.

Location	S.No.	As	Cr	Cu	Pb	Ni	Zn	Sn	Mo	V	Co
Qaroun Lake											
East	1	−1.876	0.748	−0.159	−8.682	−0.680	−3.447	−1.096	1.95	−2.517	−0.901
	2	−4.188	−0.594	−1.901	−1.267	−2.199	−2.994	−1.120	0.758	−1.812	0.296
	3	−2.676	−0.460	−1.233	−1.356	−1.184	−1.333	−1.221	−0.641	−0.371	−0.660
	4	−2.532	−0.766	−1.011	−1.411	−0.966	−1.280	−1.533	−0.432	−0.521	−0.685
	5	−2.047	−0.304	−0.595	−0.932	−0.862	−0.701	−1.700	0.933	0.133	−2.123
	6	−4.121	−0.089	−0.918	−1.085	−1.322	−2.524	−1.305	1.130	−1.765	−0.260
	Mean	−2.906	−0.244	−0.969	−2.455	−1.202	−2.046	−1.239	0.616	−1.142	−0.722
Central	7	−2.449	−0.463	−0.565	−0.880	−0.672	−0.636	−1.433	−1.045	0.401	−8.297
	8	−2.184	−0.627	−4.037	−0.681	−0.873	−0.886	−1.221	−0.349	0.217	−6.185
	9	−3.174	0.048	−0.322	−1.316	−0.533	−0.899	−1.931	0.783	0.386	−8.022
	10	−2.532	0.034	−0.678	−1.525	−0.794	−1.179	−1.148	1.098	0.091	−1.867
	Mean	−2.585	−0.252	−1.400	−1.100	−0.718	−0.900	−1.433	0.122	0.274	−6.093
West	11	−2.676	−0.460	−1.232	−1.356	−1.185	−1.333	−1.221	−0.641	−0.371	−0.660
	12	−2.700	0.080	−0.513	−1.355	−0.690	−0.984	−1.387	1.013	0.175	−1.989
	13	−2.784	0.109	−0.527	−1.176	−0.651	−0.979	−2.547	1.375	0.262	−2.157
	14	−3.896	0.267	−0.404	−1.204	−1.072	−2.590	−1.629	1.629	−2.168	−0.562
	Mean	−3.014	0.001	−0.669	−1.273	−0.899	−1.471	−1.696	0.844	−0.525	−1.342

Table 6 – Contamination factor (*Cf*) and degree of contamination (*Cd*) for Qaroun Lake sediments.

Qaroun Lake	Contamination factors, [a]*Cf*										[b]*Cd*
	As	Cr	Cu	Pb	Ni	Zn	Sn	Mo	V	Co	
East	0.237	1.351	0.819	0.792	0.687	0.453	0.603	2.757	0.830	1.022	9.551
Central	0.257	1.286	0.809	0.716	0.921	0.811	0.565	1.923	1.817	0.156	9.261
West	0.195	1.525	0.966	0.622	0.814	0.591	0.466	3.131	1.109	0.699	10.12

[a] *Cf*; is calculated as average concentration value for each metal in each part of the lake.
[b] *Cd*; is the degree of contamination.

with the adopted classifications reported by Hakanson (Table 2), the levels of contamination of metals are identified.

For the sediments in the eastern part of the lake, there is a small contamination with As ($Cf = 0.237$), Cu ($Cf = 0.819$), Pb ($Cf = 0.792$), Ni ($Cf = 0.687$), Zn ($Cf = 0.453$), Sn($Cf = 0.603$), and V($Cf = 0.830$), and moderate contamination with Cr ($Cf = 1.351$), Mo ($Cf = 2.757$) and Co ($Cf = 1.022$).

Sediments in the central part of the lake exhibit low contamination levels of As ($Cf = 0.257$), Cu ($Cf = 0.809$), Pb ($Cf = 0.716$), Ni ($Cf = 0.921$), Zn ($Cf = 0.811$), Sn ($Cf = 0.565$), and Co ($Cf = 0.156$), and moderate contamination levels with respect to Cr ($Cf = 1.286$), Mo ($Cf = 1.923$) and V ($Cf = 1.817$).

Sediments in the western part of the lake show different levels of metal contamination. They are slightly contaminated with As ($Cf = 0.195$), Cu ($Cf = 0.966$), Pb ($Cf = 0.622$), Ni ($Cf = 0.814$), Zn ($Cf = 0.591$), Sn($Cf = 0.466$), and Co ($Cf = 0.699$), moderately contaminated with respect to Cr ($Cf = 1.525$) and V ($Cf = 1.109$), and considerably contaminated with Mo ($Cf = 3.131$).

The degrees of sediment contamination (*Cd*) with the studied heavy metals in the eastern, central and western parts of the lake are 9.551, 9.261 and 10.12, respectively, indicating a moderate degree of contamination with these metals.

Generally speaking, the analysis of the contamination indices, *Igeo*, *Cf* and *Cd*, reveal that the lake is in contamination conditions. Its sediments are found to be enriched in Cr, Mo, V and Co metals and depleted in the rest of elements comparing with the shale background values. Reason of that is most probably the contamination delivered by the relevant drains containing industrial wastes (such as paints and ceramic remnants), agricultural wastes (fertilizers and pesticides) and sewage wastes as well as the wastes of the fish farms found in the southern part of the lake. It is worth to mention, herein, that the drains are important source of heavy metals, but not the main one. The Tertiary rocks (such as basalt sheets) of hills and escarpments around the lake area may be others sources of heavy metals. Metals associated to the eroded materials of these rocks could be transported to the lake under the wind and water action.

4. Conclusion

Quality of Qaroun Lake is evalauated in terms of sediment-heavy metal contamination. Fourteen bottom sediment samples were collected from the lake for grain size and metal analysis (As, Cr, Cu, Pb, Ni, Zn, Sn, Mo, V and Co). In addition to that, 9 bottom sediment samples were collected from the relevant drains and analyzed for the same metals to indicate their relations with the lake sediment contamination.

Results of the current work indicate that the average concentrations of heavy metals in lake sediments are found in the following order: V (162.77 ppm) > Cr (124.89) > Zn (58.76 ppm) > Ni (54.74 ppm) > Cu (38.91 ppm) > Pb (14.21 ppm) > Co (11.70 ppm) > Mo (6.77 ppm) > Sn (3.27 ppm) > As (2.99 ppm).

Concentrations of As, Cr, Cu, Pb, Zn, Mo and Co metals increase in the eastern part of the lake. The metals content of the lake sediments is found to be greatly affected by the drains effluents and partly by the textural characteristics (silt and clay-sized grains). The degree of contamination is evaluated using the widely used geo-accumulation *(Igeo)*, contamination factor *(Cf)* and degree of contamination, *Cd* indices. Values of *Igeo* and *Cf* show that the sediments are moderately contaminated with Cr, Mo, V and Co metals, reflecting the effect of agricultural anthropogenic activities. Considering the sum of all contamination factors, the *Cd* index indicated that the sediments are moderately polluted with the investigated heavy metals.

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