Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Ecological Risk Assessment of Heavy Metals Pollution in Recent Sediments of Qaroun Lake, Fayoum, Egypt.

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Abstract

The saline continental Qaroun Lake is situated in the deepest part of the Fayoum mega depression (~2580 km^2 size) within the Western Desert of Egypt. It covers an area of about 245 Km^2 and descends 45 meters below sea level. The lake represents the lowest land in the Nile River floodplain and plays a crucial role as the ultimate stop for both natural (subsurface flow) and artificial (agricultural) drainage in the Fayoum Depression. Hence, it collects most industrial and agricultural wastes including heavy metals as well as fertilizer and pesticides wastes. With continuous evaporation, the concentrations of heavy metals increase, and environmental problems worsen in Lake Qaroun. Twenty-five samples were selected for chemical analysis by XRF.The main objective of the present study is to investigate the ecological risk of heavy metals pollution in the recent sediments of Qaroun Lake. For the environmental assessment of Lake Qaroun sediments, four pollution indicators including three single indices were employed: The Enrichment Factor (EF), Index of Geo-accumulation (I_{Geo}), and Contamination Factor (CF), along with the integrated Pollution Load Index (PLI). The results revealed that the distribution of the measured heavy metals over the lake was found in the range of (0.55 – 7.72%), (227 – 1840 ppm), (43 – 174 ppm), (24 – 76 ppm), (18 – 42 ppm), (48 – 114 ppm), (31 – 94 ppm), (21 – 49 ppm), and (583 – 4944 ppm) for Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Lead (Pb), Cobalt (Co), Nickel (Ni), Rubidium (Rb), and Strontium (Sr); respectively. Another way combines indices like the degree of pollution (Cd), ecological risk factor (RI), and potential ecological risk index (RI). These indices are instrumental in assessing heavy metal contamination in sediment. All parts of Qaroun Lake show high contamination levels (Cd). The ecological risk factor (RI) indicates no contamination in most stations, except for one close to the polluted El-Wadi drain. Importantly, the potential ecological risk index (RI) is consistently low in all stations around Qaroun Lake, providing reassurance about the lake's current state.

Keywords: Heavy Metals; Qaroun Lake; Pollution Indices

1. Introduction

Qaroun Lake is situated in the deepest part of the Fayoum mega depression within the Western Desert of Egypt. It covers an area of about 245 Km^2 and descends 45 meters below sea level **[1]**. It is located about 83 kilometers southwest of Cairo. The represents the lowest land in the Nile River floodplain and plays a crucial role as the ultimate stop for both natural (subsurface flow) and artificial (agricultural) drainage in the Fayoum mega Depression **[2]**, underscoring its vital hydrological function. The Fayoum mega depression is located just west of Beni Suef City, and it is connected to the Nile River by Bahr Youssef, which crosses the desert hills (Eocene Nile-Fayoum divide) through the Hawara channel **[3]**, (Figure. 1). Qaroun Lake, historically known as 'Lake Moreis', was formed by River Nile freshwater, but unfortunately turned into saline water by continuous accumulation of agricultural wastewater and sewage.
Qaroun Lake, a self-contained environment, has been a subject of concern for numerous scientists due to its

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Receive Date: 11 July 2024, Revise Date: 30 July 2024, Accept Date: 11 August 2024
DOI: 10.21608/ejchem.2024.303404.9989

historical and scientific significance. The lake's unique characteristics, such as the significant amount of accumulated fresh and wastewater that naturally evaporates, leading to the accumulation of various harmful substances like heavy metals and pesticides, have raised alarm bells. These substances, found in different parts of the lake, including water and fish, significantly impacted the lake's overall quality and the plants and animals living in it **[4]**. Several authors have indicated that these environmental issues may stem from the effects of elevated pollutants such as iron, cadmium, lead, and ammonia. etc. **[5]**. The toxicity reference value (TRV), a measure of harmful substances in marine sediment with higher salinity, was used to evaluate the water in Qaroun Lake. The lake's surface water has a salinity level of 29.3 and 38.1 grams per Liter **[6]**. Qaroun Lake is one of wet land sediments in Egypt it can used as indications for controlling contaminants in the water environment. They are contaminated with many sources of harmful and toxic substances **[7]**. The pollution in rivers, lakes, and other water bodies shows how the environment is harmed. Impurities from human actions can be collected in certain places because they dissolve, fall out of the water, or stick to surfaces **[8]**. The harmful elements and substances carried by water settle at the bottom and in the sediment along the water's path **[9]**.

Let's reiterate the key points: The Qaroun Lake ecosystem is influenced by the weather, the amount of wastewater entering the lake, the water absorption into the surrounding land, and the composition of the underlying ground **[10]**. The harmful elements and substances carried by water settle at the bottom and in the sediment along the water's path **[9]**. To summarize, the Qaroun Lake ecosystem is influenced by the weather, the amount of wastewater entering the lake, the water absorption into the surrounding land, and the composition of the underlying ground.

All sorts of harmful things that get released into freshwater, like sewage, runoff from farms, and waste from homes and industries, also end up in saltwater lakes or the rivers that flow into them, which cause problems like minerals getting into Qaroun Lake in Egypt **[11]**. Using too many fertilizers and pesticides in farming and not treating sewage and industrial waste properly are the main reasons water in drainage systems becomes polluted; these drains usually get a mix of all these different kinds of wastes **[12]**. Our bodies need tiny amounts of iron, copper, and zinc. But if we're exposed to too much of them, it can be not good for us. There are also metals like lead, cadmium, and mercury that our bodies don't need; even a small amount of these can be harmful **[13]**.

Heavy metals are made up of elements, some of which our bodies need a bit of and others that we don't. These metals are important in studying how they can harm the environment and living things because they don't go away easily and can harm plants and animals **[14]**. When towns and farms release their waste into Qaroun Lake, the water and the stuff at the bottom are dirty. It happens because there's more of the stuff plants and animals need, like nutrients and certain metals (copper, zinc, lead, and cadmium), mixed up in the sediment, which can be risky for the water and the creatures living in it **[15]** .Qaroun Lake currently suffers from several environmental problems, as many factors affect the ecosystem of Qaroun Lake, including climatic conditions, the amount of flowing wastewater, seepage from surrounding cultivated lands, and geological aspects **[5]** . Heavy metals exist in the environment in different phases, such as the solid phase, and in solution as free ions or absorbed in solid colloidal particles. Trace metal levels in the environment are due to natural sources as well as anthropogenic sources, such as municipal wastewater, agricultural activities, and manufacturing industries **[16]**.

In Egypt, environmental pollution with heavy metals is a significant challenge **[17]**. The pollution and increased salinity of the saline lakes threaten the health of Egyptians and the ecological system and reduce fish production. The fish production of northern lakes decreased from 40 % of the total country's production to only 12 % **[18]**. While humans require certain trace elements like iron, copper, and zinc, exposure to higher concentrations can be harmful. The presence of non-essential metals such as Pb, Cd, and Hg, even in low Concentrations, is toxic **[13]**. To address this, we employ various methods such as the contamination factor (Cf), enrichment factor (Ef), geo accumulation index (I_{geo}), and pollution load index (PLI) proposed by **[19;20;21;22]**. These methods are not just tools, but the backbone of our research, enabling us to evaluate trace metals enrichment and identify anthropogenic sources based on the relative concentrations of trace metals in crustal materials **[23]**. The process involves determining background concentrations using the bottom of the deep cores of the research sites **[24;25;26;27].**

The main objective of the current study is to investigate the ecological risk resulting from heavy metal pollution in the recent sediments of Qaroun Lake using single and integrated indices such as the Geo–accumulation Index (I_{Geo}), Enrichment Factor (EF), Contamination Factor (CF), Contamination Degree (CD), and Pollution Load Index (PLI).

1.1. Study Area

Qaroun Lake, a closed saline water, is located in the deepest part of the northern section of the Fayoum mega depression. The lake is located between longitudes 30°34' and 30°49'E and latitudes 29°25' and

29°34'N, at an elevation of about 43 meters below sea level (BSL) **[28]**. The region's agricultural sector is robust, but it's the diverse range of economic and industrial activities that truly impresses. From petrochemicals, potassium and phosphate fertilizers, plastic, leather, mineral, foodstuffs, beverages, fish farms, pottery, ceramic, paper, medicines, mines and quarries, to mechanical and electrical industries, the region is a hub of productivity **[29]**.

Qaroun Lake, a distinctive geographical feature, boasts an irregular shape with two distinct sectors. The western sector, in particular, stands out with its greater depth compared to the eastern sector **[30]**.

Qaroun Lake is a vast saltwater expanse that stretches out like a bowl, spanning approximately 40 kilometers in length and 5.7 kilometers in width. Its water volume is staggering, reaching about 1,100 million cubic meters. The lake's depth varies, gradually increasing from 5 meters in the east to 12 meters in the west **[31;32;33].**

Qaroun Lake (45 X 9 Km) edges look uneven, especially on the northwest side, which makes little lagoons in some places: this unevenness happens because the wind from the north blows sand and creates these shapes **[34].** This lake is in the lowest part of the Fayoum depression, which goes down about 45 meters below sea level **[3]**.

Two big channels pour a lot of sewage water into Qaroun Lake. One is on the east side, called "El-Batts drain," and the other is in the middle of the southern side, named "El-Wadi drain." Besides these big channels, smaller ones also pour water into the lake. This water can cause problems for the lake and the salt that's taken from it. Every year, the lake gets about 450 million cubic meters of mixed-up waste that hasn't been cleaned up – this waste comes from factories, sewage, farms, and people's homes in the El-Fayoum Governorate **[35]**.

The Lake is in arid area, characterized by high temperature, little rainfall (about 10 mm/year), and a high evaporation rate with no outlets. Lake water quality is inferior for aquatic life, which may be the reason for the loss of fish stocks and drastic changes in the ecosystem. These problems were attributed that to the elevated concentrations of iron, cadmium, lead, ammonia, etc., in addition to bacterial and parasitic isopod infection **[36,28].**

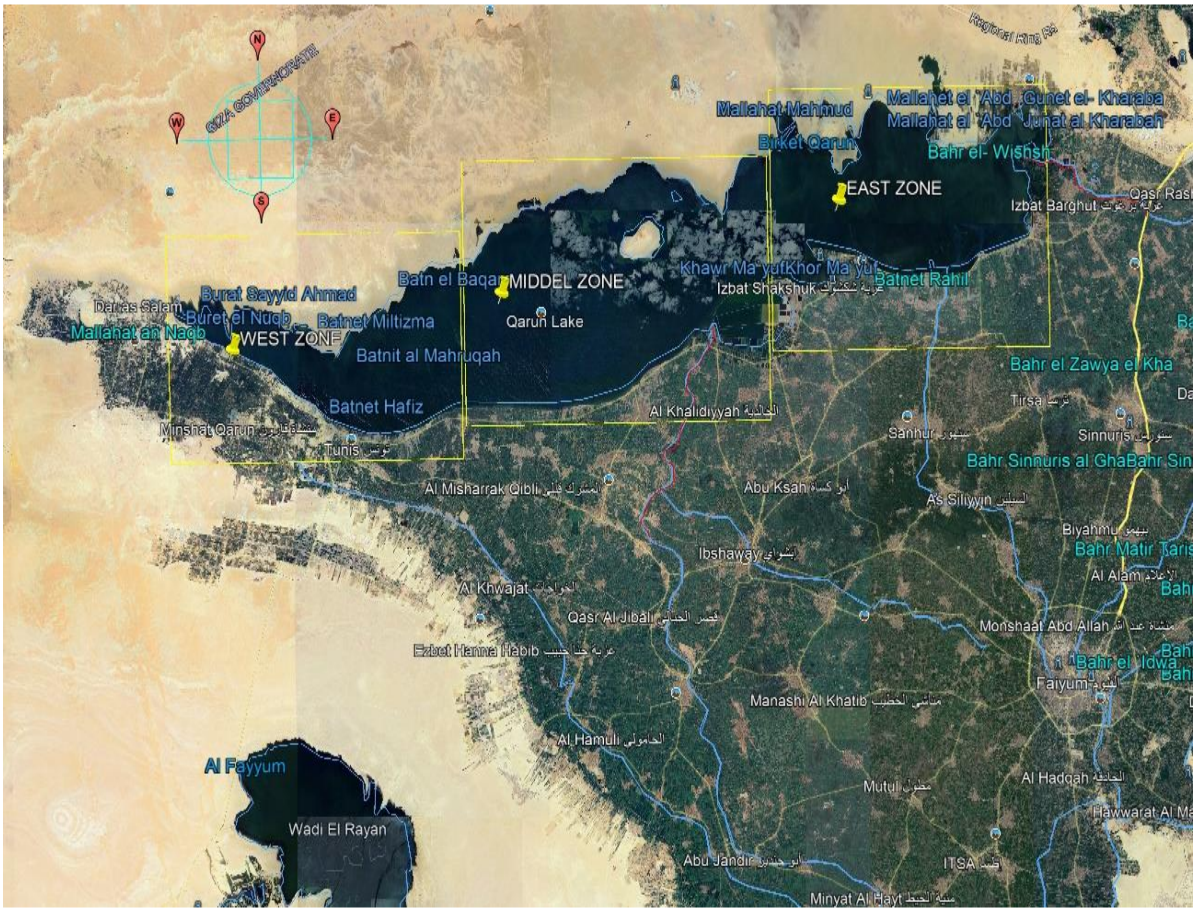

Fig. 1**.** Location map of Qaroun Lake (Source, 2024, Google Earth Pro).

1.2 Field sampling

Twenty-five sediment samples were collected from the lake during February 2017 and divided into three zones, represented in Figure 2: seven (7) samples from the eastern region, eight (8) samples from the middle region, and ten (10) samples from the western region. The samples were collected using a grab sampler Ekhman type.

2. Materials and Methods

The recent bottom sediments samples of Qaroun Lake were analyzed using the XRF analyses at the Unit of Preparation and Chemical analysis by X-Ray Fluorescence, National Research Centre, Dokki, Cairo. The results were obtained using an advanced XRF Wavelength Dispersive Spectrometer (Axios Advanced, PANalytical 2005). Pressed pellets for trace elements determinations were prepared by mixing 6 g of the sample powder with 1.6 g of binding wax through the computerized Mini-Mill II grinding machine for one minute at 380 rpm speed. Then, the mixture was pressed in a standard aluminium cup using an automatic (HTP 40 H, HERZOG) pressing machine under 30KN.

3. Geological Setting, Origin and Tectonic Structure of El-Fayoum Depression

Many esteemed authors, renowned in the field of geology, have described the origin of the El-Fayoum depression and put forth the following theories: the lake-filled depression started to form in the Middle Pliocene and the beginning of the Pleistocene, with aeolian erosion operating until the depression attained its present depth **[37;38]**. Others, with extensive research in tectonic movements and wind erosion, have assumed that the excavation of the depression resulted from a complex action of these forces, which actively weathered the fractured rocks **[39]**. **[40]** a prominent geologist, suggested a tectonic origin for the El-Fayoum depression and considered it to be a crustal sag in the elevated sea floor of the Mediterranean, and **[41]**, a team of geologists, suggested that the El-Fayoum depression formed in a zone of extension between offset strike-slip faults in a pull-apart basin. Tectonic structures that affected the Fayoum Area, such as Flexures, have the shape of bending or curvature of horizontally deposited or inclined layers of rocks and **[42]** has recorded folded structures in the Fayoum Area. **[43]** suggested that the El-Fayoum depression is a closed triangular basin bounded by three faults. These faults are supposedly found on both sides of the depression (east and west) along Qaroun Lake. The land between these faults dropped to form the depression.

Stratigraphically, El-Fayoum depression is occupied by sedimentary rocks belonging to the Tertiary and Quaternary periods (Figure 3). The Tertiary rocks, distributed in a stratigraphic pattern, are better represented in the high topographic lands. Except for the Oligocene, the Tertiary section mainly consists of limestone strata. The Oligocene rocks are exposed in the area north of the depression and include

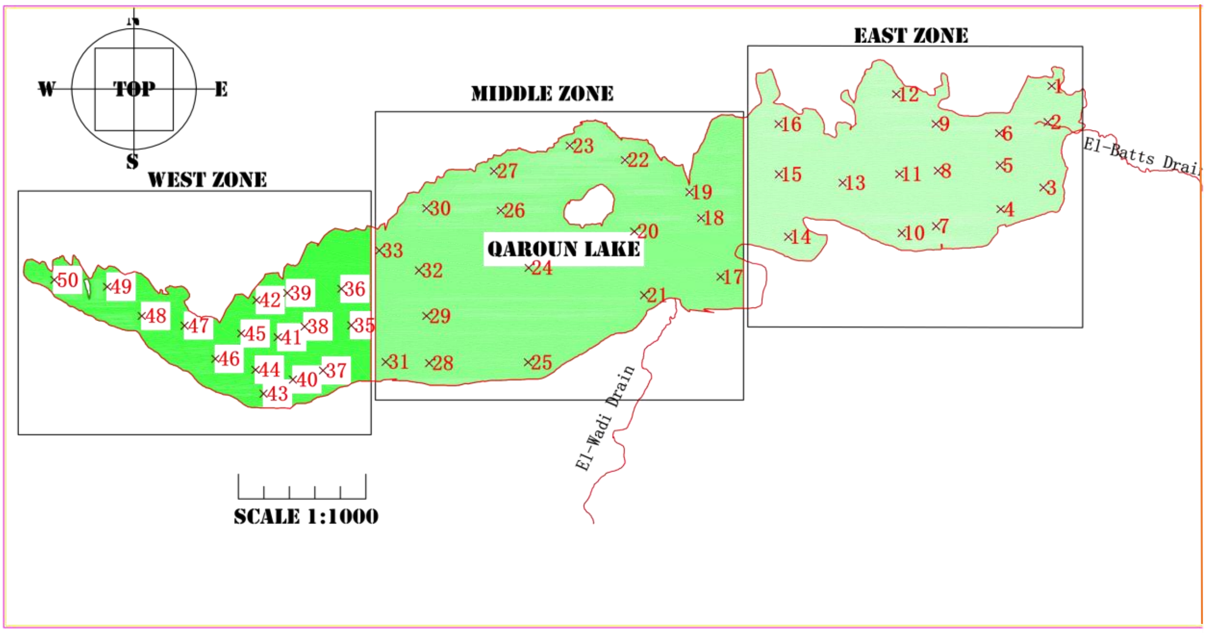

Fig.2. Location map and sampling stations of all collected samples within Qaroun Lake (East, Middle, and West Regions).

the Qatrani Formation formed of sandstone with claystone and marl intercalations, remains of silicified tree trunks, and basalt extrusion (basalt sheets). The basalt sheets are exposed at Gabal Qatrani and have been subdivided from top to base as follows: altered basalts layer rich in cavities filled by secondary calcite and halite pockets; vesicular basalt containing holes filled by calcite and sulfur; and olivine basalt with cracks filled by sulfur **[1]**. Geology of Fayoum area was addressed by many authors **[42;44;45]**. The El Fayoum area is split into four big low parts, like bowls (Nile Valley, El-Fayoum, Hawara, and El-Raiyan).

These bowls are surrounded by pretty old rocks formed between a long time ago and not so long ago. The ground was formed, and different layers of limestone settled over time. There's a lot of thick dirt from more recent times in this area **[46]**. When the Nile River flooded, it brought a mix of dirt and mud to the Fayoum Oasis. This area also has things like diatomite, sediment from tiny plants, and lake mud, clay, and sand that the wind moved around. All these different materials are essential things that have made up the land recently **[47]**.

Grain size distribution

The mechanical analysis of recent bottom sediments in Qaroun Lake revealed a distinct pattern. The average size of deposits in the deeper region, the eastern, and western areas was medium and very fine (i.e., medium silt). However, those in the central area and toward the beach were slightly coarse in size (i.e., fine sand). This pattern suggests a high sediment accumulation east and westwards and towards the deeper zone, which can be attributed to the increase in fine grains of sediments from suspended solids at El-Batts and El-Wadi Drains **[48]**.

The horizontal distribution of different grade sizes among the bottom sediments of Qaroun Lake (Figures 4 and 5) and Table 1 further supports this. Silt and mud are highly accumulated in the eastern region, clay, and gravel is predominant in the central part, while sand

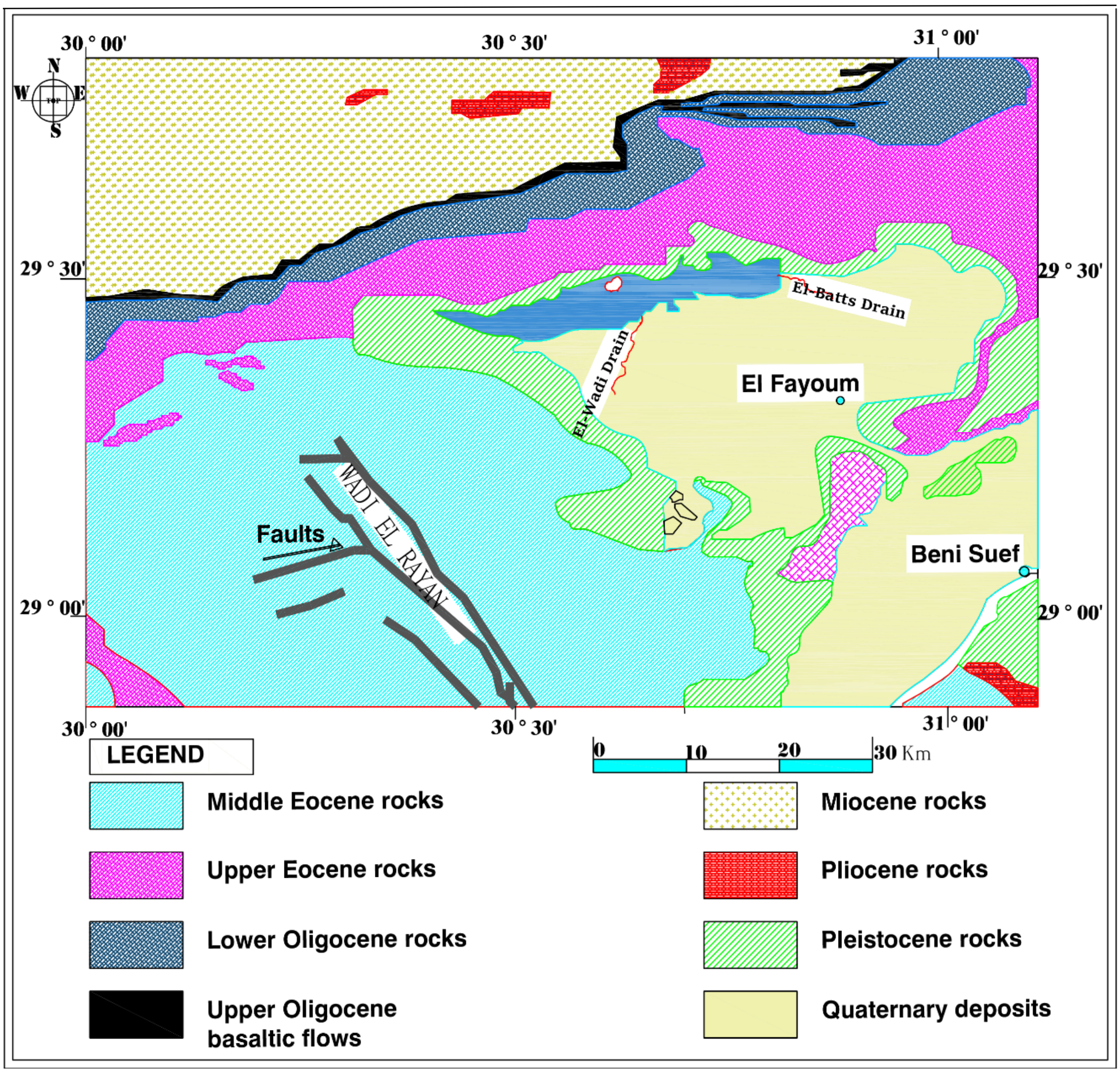

Fig.3. A geologic map of El-Fayoum depression area after **[46]**.

prevails in the western region. Obviously, there is a horizontal variation in the sediment grain-size distribution at the bottom of Qaroun Lake. The sand-size deposits increase in the central region at station 17 due to the high erosion on El-Qarn Island. In contrast, silt size content increases in the eastern part at station 14, and finally, the clay size content increases in the central region at station 18.

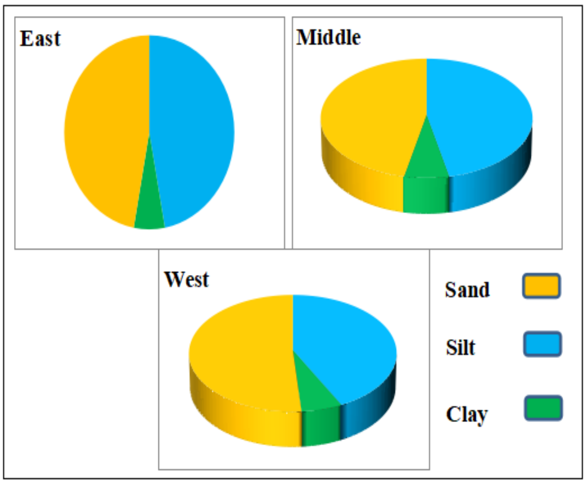

Fig.4. Sand, Silt, and Clay average percentages (%) in the recent bottom sediment of Qaroun Lake (east, middle and west zones).

5.Ecological Indicators for Pollution assessment

For the environmental assessment of Qaroun Lake sediment, we employed four pollution indicators (Table 2). These included three single indices: The Enrichment Factor (EF), Index of Geo-accumulation (I_{geo}), and Contamination Factor (CF), along with the integrated Pollution Load Index (PLI) [49]. These indices are instrumental in assessing heavy metal contamination in sediment. To ensure a comprehensive analysis, we compared the levels of the studied metals in lake sediments with the pre-industrial reference level. In our study, we meticulously used the upper continental crust (UCC) composition as a representative of this pre-industrial reference level of trace/heavy metals.

- Contamination factor (Cf) for each metal was calculated as a ratio of metal content in sediment sample (C_n) [$C_f = c_m/C_n$] as proposed by **[19]**.
- Enrichment Factor (EF) calculation based on the equation provided by **[50]** as follows:

$$EF = (M/Fe)_s/(M/Fe)_b$$

where $(M/Fe)_s$ is the ratio of metal content in the investigated sample and iron content as an immobile element; $(M/Fe)_b$ is the ratio of metal and iron of background uncontaminated sediment.

- Geo-accumulation Index (I_{Geo})

The Geo-accumulation index is calculated based on the following equation proposed by **[21;51]**:

$$I_{geo} = \log_2 (C_n/1.5b_n)$$

Where C_n is the concentration of metal; b_n is the geochemical background of metal, and 1.5 is a factor of background variability.

- Pollution Load Index (PLI)

PLI was calculated for each site and for the lake overall according to the following equation proposed by **[22]**:

$$PLI_{Site} = (CF1 \times CF2 \times \ldots\ldots CF_n)^{1/n}$$

Where n is the metal number under investigation (14); CF is the contamination factor for each metal within each site.

$$PLI_{Lake} = (PLI_1 \times PLI_2 \times \ldots. PLIn)^{1/n}$$

where n is site number (20); PLI is the pollution load index for every site.

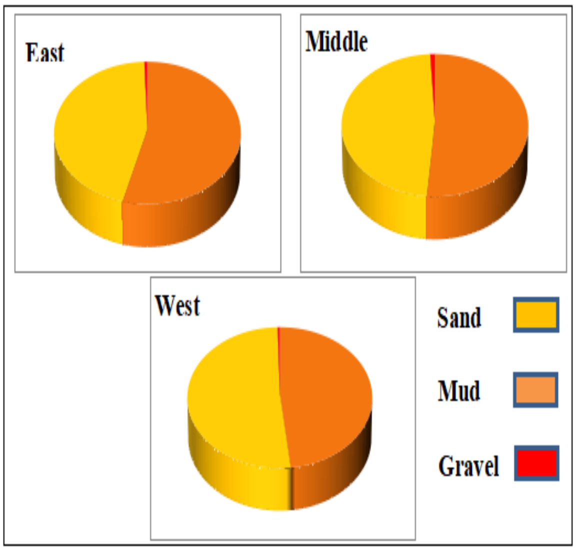

Fig.5. Sand, Mud, and Gravel average percentages (%) in the recent bottom sediment of Qaroun Lake (east, middle and west zones).

Table 1. Average percent of sediment types of Qaroun Lake

Zone	Silt%	Clay%	Mud%	Sand%	Gravel%
East	47.5	5.8	53.3	44.7	0.44
Middle	42.9	6.04	48.97	45.6	0.82
West	41.3	5.9	46.6	49.6	0.4

5.1. Single Indices

There are particular ways to measure how much of one metal is in the sediment, like contamination factor (CF), ecological risk factor (Er), enrichment factor (EF), and index of geo-accumulation (I_{geo}). The contamination levels in the sediment were looked at using these methods, and the results are in Table 3. For example, Fe has low contamination (CF < 1), while other metals such as Mn, Zn, Cu, Pb, Ni, and Co have medium contamination (their CF values are between 1 and 3). Another way to measure the risk to the environment, Er, depends on how sensitive the water system is and how much stuff it can produce **[19]**. Besides looking at how harmful the metal is, another parameters called ecological risk (Er) helps us see how much danger heavy metals can cause in nature. In this case, all the metals had low risks (Er is less than 40), which is good. But when we look at enrichment (EF), we see that manganese (Mn) has a medium to high amount, and zinc (Zn), copper (Cu), and nickel (Ni) have a lot more than usual – some even to high levels. Lead (Pb) went from having little to being added to the environment, and cobalt (Co) went from having less to being added quite a bit. People use EF to see if heavy metals come from nature or human activities **[52;53]**. The I_{geo} is a helpful way to figure out how much pollution is in sediment **[21]**. Using I_{geo}, we see that iron (Fe) and nickel (Ni) don't have much pollution (I_{geo} is very small or zero, in class 0). On the other hand, manganese (Mn), zinc (Zn), copper (Cu), lead (Pb), and cobalt (Co) have a bit of pollution, but not too much (I_{geo} is between 0 and 1, in class 1).

5.2. Integrated Indices

Table 4 reveals that the degree of Pollution (Cd) in all samples at all stations was classified as high contamination (Cd > 3), except three stations at 15, 26, and 45 were classified as medium contamination (Cd = 1-3). The Pollution Load Index (PLI) is a key tool in our assessment, providing a comprehensive view of pollution levels by considering all the metals together **[54]**. The PLI values for Qaroun Lake's recent sediments are less than one, indicating an unpolluted condition for most of the lake, except for one station near the El-Wadi drain with a PLI exceeding 1. The Risk Index (RI) data recorded in all stations are classified as low ecological risk in the eastern, middle, and western regions of Qaroun Lake.

6. Results and Discussion

6.1. Heavy metals distributions

Heavy metals can enter the water where aquatic animals live from various sources, including natural and anthropogenic. For instance, polluted water from factories or homes, water that flows rapidly after a storm, chemicals leaking from waste areas, substances from ships and ports, and even atmospheric deposition can introduce heavy metals into the water **[55]**. The results from investigated samples are presented in Table 5. From it, it is evident that the levels of heavy metals such as iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), lead (Pb), cobalt (Co), nickel (Ni), rubidium (Rb), and strontium (Sr) are varied across these locations. These metals were found in concentrations ranging from 385 to 5400 part per million (ppm) for Fe, 227 to 1840 ppm for Mn, 43 to 174 ppm for Zn, 24 to 76 ppm for Cu, 15 to 42 ppm for Pb, 48 to 114 ppm for Co, 31 to 94 ppm for Ni, 21 to 52 ppm for Rb, and 583 to 4944 ppm for Sr.

In the eastern area of the lake, the average amounts of these metals were about 4127 ppm for Fe, 884 ppm for Mn, 83 ppm for Zn, 57 ppm for Cu, 31 ppm for Pb, 83 ppm for Co, 76 ppm for Ni, 40 ppm for Rb, and 1567 ppm for Sr.

In the middle area of the lake, the average was around 3609 ppm for Fe, 787 ppm for Mn, 115 ppm for Zn, 56 ppm for Cu, 30 ppm for Pb, 85 ppm for Co, 72 ppm for Ni, 40 ppm for Rb, and 2154 ppm for Sr. On the west side of the lake, the amounts were approximately 3469 ppm for Fe, 404 ppm for Mn, 70 ppm for Zn, 51 ppm for Cu, 26 ppm for Pb, 77 ppm for Co, 65 ppm for Ni, 37 ppm for Rb, and 1793 ppm for Sr.

In the eastern part of the lake, it has been noted that the average concentrations of some heavy metals are higher than in the other than in other parts of the lake, such as iron (Fe), manganese (Mn), copper (Cu), lead (Pb), nickel (Ni) and Rubidium (Rb). On the other hand, in the central area of the lake has been noted the average concentrations of some heavy metals higher than in the other than in other parts of the lake, such as zinc (Zn), cobalt (Co), rubidium (Rb), and strontium (Sr), which matches with El-Kady and others found in 2019, where they also saw that metals were more concentrated in the eastern part of the lake, especially near El-Batts drain **[56]**. In all three parts of Qaroun Lake – east, middle, and west zones – there was a high concentration of iron (Fe), more than recorded by **[57]**; it shows that the sediment has more iron than usual, which probably comes from the land around the lake and is causing pollution **[58;59]**. Evaluation of the present data revealed that there is an increase in contents of some heavy metals such as manganese (Mn), copper (Cu), and zinc (Zn), compared to previous data [57] and [56]. Similarly, the result of Pb content was observed to be like the result obtained by **[60]**. At the same time, it was higher than the results obtained by **[61]** The content of the Ni element in the present study is higher than the result obtained in the previous survey **[60]**.

The rise in heavy metals could be attributed to leakage from the mud at bottom to the hot water. Also, with breakdown of plants and other stuff, the resulted gasses might increase the leakage rate of the metals to the water **[62]**. The heavy elements contents of the lake are dependent on the nature of the input drained water , wind speed and the composition of soils and rocks of wastewater streams **[63]**. There's usually only a tiny bit of nickel in regular water. Whether nickel is harmful or not in water depends on many things like how salty the water is, how much air is dissolved in it, how complicated the water is, how warm or cold it is, how acidic or basic it is, and how many dissolved substances are in it **[64]**.

7. Statistical Analys

7. 1. Dendrograms

A two-way cluster statistical analysis was performed using the PCORD5 program to determine the correlation and classification of the studied sample, as shown in Figure 6. According to cluster analysis, the study area was divided into three groups: A, B, and C. Group A contains stations (2, 13, 37, 11, 18, 38 and 25) with a high correlation between stations reaching up to 95%.

Group B contains stations (4, 7, 21, 12, 33, 32, 35, 28, 42, 44, 46, and 48); the correlation between stations in group B reached 85%. Group C contains six stations (15, 24, 41, 50, 45, and 26) and shows a correlation of 75% between stations. The correlation between groups A and B was high, reaching 65%, while the relation between groups (A and B) and group C was very low, reaching 0% (no correlation). Group A has a lot of heavy metals, mud, and sand. In Group B, there's not as much, and in Group C, there's even less.

Table 2. Terminologies for pollution classes on single and integrated indices.

EF Classes[1]	**Pollution**	**Cf Classes[2]**	**Pollution**
EF Value		**CF Value**	
EF<2	Depletion to mineral	CF< 1	Low
2 ≤EF< 5	Moderate	1 ≤ CF≥ 3	Moderate
5 ≤ EF< 20	Significant	3≤CF≥ 6	Considerable
20 ≤ EF< 40	Very High	CF > 6	Very High
EF > 40	Extremely High		

I_{geo} Classes[3]		**Pollution**	**PLI Classes[4]**	**Pollution**
I_{geo}	**I_{geo} Class**		**PLI Value**	
< 0-0	0	Unpolluted	0	Perfection
0-1	1	Unpolluted to moderated	< 1	Baseline Levels
1-2	2	Moderated Polluted	> 1	Polluted
2-3	3	Moderate to high polluted		
3-4	4	Highly Polluted		
4-5	5	Highly to Extremely Polluted		
5-6	> 5	Extremely Polluted		

[1] **According to [65].**
[2] **According to [66].**
[3] **According to [67].**
[4] **According to [22].**

7. 2. Box plots

Figure 7 reveals a significant finding, the highest concentration element is Fe; plays a pivotal role in our study. Its wide range starts from a minimum value of 385 ppm at station 26 and a maximum value of 5400 ppm at station 37; then Mn with range starts from the minimum value of 227 ppm at station 50 to a maximum value of 1840 ppm at station 4. We also observed a few trace elements with concentrations less

than 175 ppm such as Zn, which ranges from 43 ppm at stations 15 and 45 up to 174 ppm at station 32.
Cu, on other hand, ranges from 24 ppm at station 45 to 76 ppm at station 21.
Pb ranges from 15 ppm at station 33 to 42 ppm at station 25. Ni ranges from 31 ppm at station 45 to 94 ppm at station 25. Co with a range from 48 ppm at station 24 to 114 ppm at station 25.

Terminology of the used abbreviations
EF Enrichment Factor
I_{Geo} Index of Geo-accumulation
CF Contamination Factor
PLI Polluted Load Index
UCC Upper Continental Crust
RI Ecological Risk Factor
Cd Degree of Contamination

Table 3. Values and classes of degree of contamination Factor (CF), ecological risk factor (ER), Enrichment Factor (EF) and Index of Geo-accumulation (I_{Geo}) in recent bottom sediments of Qaroun Lake

Index	Heavy Metals	Minimum	Maximum	Classes
CF	Fe	0.008	0.12	Low
	Mn	0.24	1.94	Moderate
	Zn	0.45	1.83	Moderate
	Cu	0.6	1.9	Moderate
	Pb	0	2.1	Moderate
	Ni	0.46	1.38	Moderate
	Co	0	1.68	Moderate
ER	Fe	0.008	0.12	Low Risk
	Mn	0.24	1.94	Low Risk
	Zn	0.45	1.83	Low Risk
	Cu	3	9.5	Low Risk
	Pb	0	10.5	Low Risk
	Ni	2.28	6.91	Low Risk
	Co	0	16.76	Low Risk
EF	Mn	4.598	95.07	Moderate To Extremely High Enrichment
	Zn	7.457	79.23	Significant to Extremely High Enrichment
	Cu	12.09	97.12	Significant to Extremely High Enrichment
	Pb	0	32.71	Depletion to mineral up to V.High Enrichment
	Ni	8.65	74.98	Significant to Extremely High Enrichment
	Co	0	17.31	Depletion to mineral up to Significant Enrichment
I_{Geo}	Fe	-7.51	-3.697	Unpolluted
	Mn	-2.65	0.37	Unpolluted to Moderately Polluted
	Zn	-1.73	0.288	Unpolluted to Moderately Polluted
	Cu	-1.32	0.341	Unpolluted to Moderately Polluted
	Pb	-0.74	0.49	Unpolluted to Moderately Polluted
	Ni	-1.72	-0.197	Unpolluted
	Co	-1.09	0.160	Unpolluted to Moderately Polluted

.

Table 4. Values and classes of Degree of Pollution (Cd), Pollution Load Index (PLI), and risk index (RI) in recent bottom sediments of Qaroun Lake

Station	(C_d)		(PLI)		(RI)	
	Value	Classes	Value	Classes	Value	Classes
2	7.11	High Degree	0.82	Non-Contaminated	34.55	Low Ecological Risk
4	7.91	High Degree	0.85	Non-Contaminated	33.99	Low Ecological Risk
7	6.76	High Degree	0.78	Non-Contaminated	32.53	Low Ecological Risk
11	8.19	High Degree	0.89	Non-Contaminated	39.10	Low Ecological Risk
12	7.32	High Degree	0.83	Non-Contaminated	35.90	Low Ecological Risk
13	6.04	High Degree	0.83	Non-Contaminated	22.69	Low Ecological Risk
15	2.98	Medium Degree	0.57	Non-Contaminated	10.17	Low Ecological Risk
18	6.64	High Degree	0.86	Non-Contaminated	33.86	Low Ecological Risk
21	6.63	High Degree	0.85	Non-Contaminated	24.46	Low Ecological Risk
24	4.39	High Degree	0.63	Non-Contaminated	18.84	Low Ecological Risk
25	9.34	High Degree	1.03	Polluted	43.65	Low Ecological Risk
26	2.86	Medium Degree	0.46	Non-Contaminated	8.53	Low Ecological Risk
28	4.53	High Degree	0.75	Non-Contaminated	12.62	Low Ecological Risk
32	5.66	High Degree	0.84	Non-Contaminated	17.99	Low Ecological Risk
33	5.91	High Degree	0.71	Non-Contaminated	27.31	Low Ecological Risk
35	6.07	High Degree	0.80	Non-Contaminated	30.12	Low Ecological Risk
37	6.96	High Degree	0.81	Non-Contaminated	35.79	Low Ecological Risk
38	5.92	High Degree	0.78	Non-Contaminated	23.94	Low Ecological Risk
41	5.29	High Degree	0.59	Non-Contaminated	26.59	Low Ecological Risk
42	5.66	High Degree	0.65	Non-Contaminated	27.98	Low Ecological Risk
44	5.09	High Degree	0.69	Non-Contaminated	25.97	Low Ecological Risk
45	2.75	Medium Degree	0.43	Non-Contaminated	10.57	Low Ecological Risk
46	5.29	High Degree	0.62	Non-Contaminated	26.38	Low Ecological Risk
48	4.41	High Degree	0.59	Non-Contaminated	18.13	Low Ecological Risk
50	4.46	High Degree	0.56	Non-Contaminated	18.81	Low Ecological Risk

Table 5. The averages of minimum and maximum heavy metals in the eastern, middle and western zones of Qaroun Lake.

Heavy metals	Eastern Zone			Middle zone			Western Zone		
	Min. ppm	Max. ppm	Avg. ppm	Min. ppm	Max. ppm	Avg. Ppm	Min. ppm	Max. ppm	Avg. Ppm
Fe	2224.2	5120	4127	385	4868	3609	1797.5	5400	3469
Mn	623	1840	884	624	1091	787	227	618	404
Zn	43	124	83	62	174	115	43	99	70
Cu	43	70	57	32	76	56	24	72	51
Pb	18	39	31	15	42	30	18	34	26
Co	68	92	83	48	114	85	62	100	77
Ni	49	91	76	42	94	72	31	90	65
Rb	35	47	40	29	52	40	21	49	37
Sr	788	2519	1567	995	4944	2154	583	3056	1793

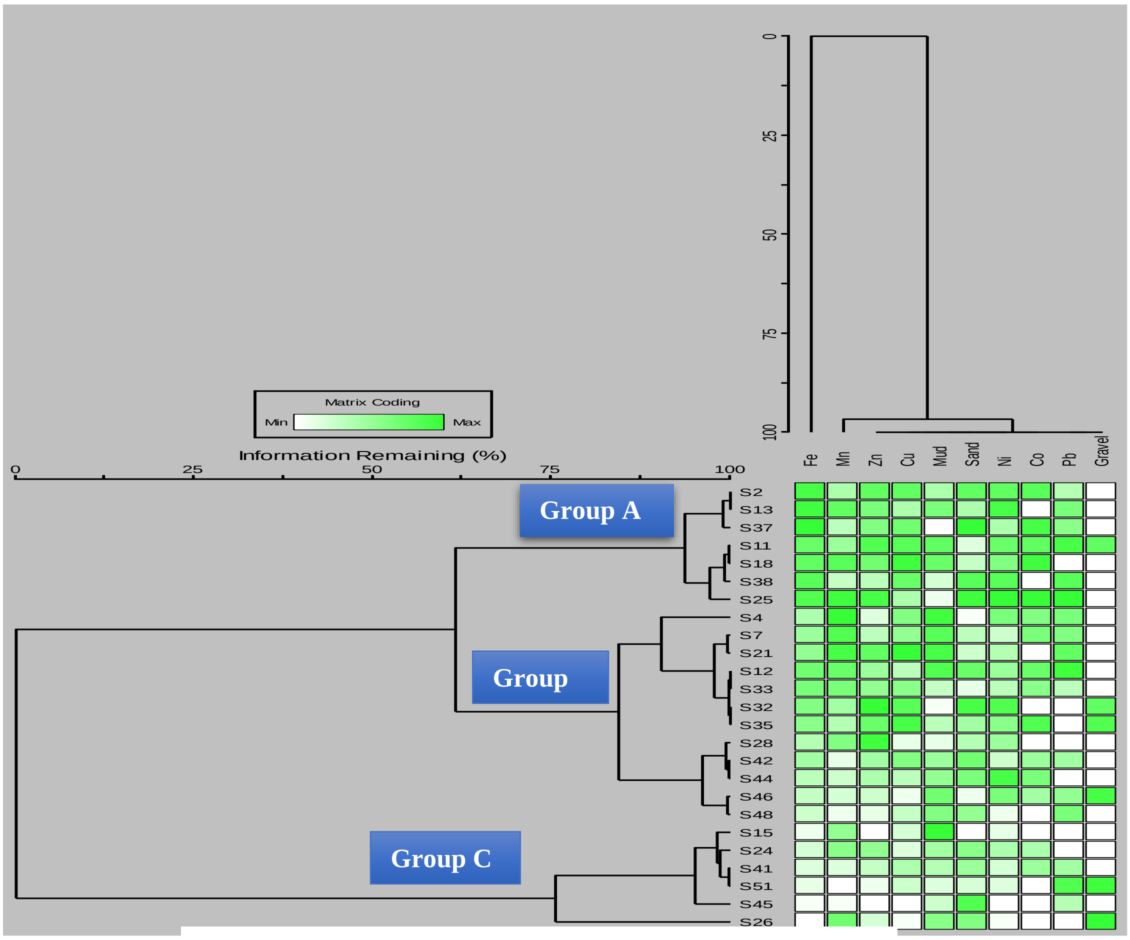

Fig.6. Cluster analysis dendrogram of recent bottom samples of Qaroun Lake.

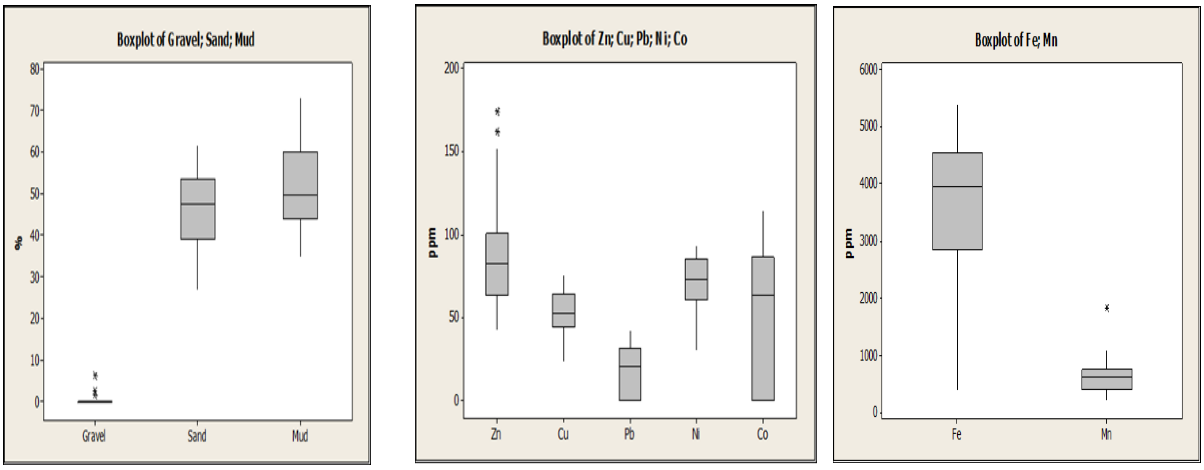

Fig.7. Box plots for heavy metals, Gravel, Sand, and Mud of recent bottom samples of Qaroun Lake.

8. Conclusion and Recommendation

Based on the present investigations and obtained data on the distribution of heavy metals in recent bottom sediments from different sites along Qaroun Lake, the following conclusion and recommendations are outlined:

- The distribution pattern of heavy metals in recent bottom sediments in Qaroun Lake reflected a perspicuous spatial high significant difference for all measured metals where Fe >Sr >Mn >Zn Co> Ni >Cu> Rb.
- Although the potential environmental impact was assessed using a variety of indicators, including Fe ratios, CF is low in Fe and moderate in other metals, EF is low risk in all metals, EF is Depletion to minerals up to V.High Enrichment in Pb and Co, Moderate To Extremely High Enrichment in Mn and Significant to Extremely High Enrichment in Zn, Cu and Ni, I_{geo} is unpolluted in Fe and Ni and is Unpolluted to Moderately Polluted in Mn, Zn, Cu, Pb, and Co and PLI is non contaminated in all samples except sample no 25 is polluted close to El-Wadi drain.

To monitor and reduce pollution in Qaroun Lake, we suggest building two integrated wastewater treatment plants to clean up the dirty water before it goes into El-Batts and El-Wadi drains. Ensure the factories clean their dirty water before it enters the drains. Regularly checking and fixing the places where dirty water is cleaned. Also, we can use the water from El-Batts drain for farming, even if it's mixed with clean water from other channels, as long as we figure out the right amounts based on how clean the water is in each lake **[12]**.

- Proposal for fixing mechanical filters for El-Wadi and El-Batts Drains to reduce pollution and increasing the number of salt extracting factories on the Qaroun Lake to reduce salt concentration **[68].**

Acknowledgements

The authors thank the staff of the National Institute of Oceanography and Fishers, Menoufia University and Al-Osais Co., especially Mr. Ali and Mr. Yousef Board Members for their support and encouragement in this study.

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