



Journal of
**Fisheries and
Aquatic Science**

ISSN 1816-4927



Academic
Journals Inc.

www.academicjournals.com

Recent Environmental Changes in Water and Sediment Quality of Lake Qarun, Egypt

A.M. Abdel-Satar, M.E. Goher and M.F. Sayed
National Institute of Oceanography and Fisheries (NIOF),
Inland Water and Aquaculture Branch, 101 Kasr El Aini St., Cairo, Egypt

Abstract: Lake Qarun, is currently saline, turbid (Secchi disc transparency usually <70 cm) and has no surface outflow. This study was carried out to throw the light on the present status and long term changes of lake water. Surface water and sediment samples were collected and analyzed for nutrient salts, major cations and anions besides some trace metals (Fe, Mn, Zn, Cu, Pb and Cd). Concentrations of nitrite, nitrate and ammonia in the lake sediment (average: 0.89, 9.44 and 156.39 $\mu\text{g g}^{-1}$, respectively) were obviously higher than those reported for water (average: 0.010, 0.039 and 0.378 mg L^{-1}). The majority of water samples contained >50 $\mu\text{g L}^{-1}$ Zn, >20 $\mu\text{g L}^{-1}$ Cu, >50 $\mu\text{g L}^{-1}$ Pb and >10 $\mu\text{g L}^{-1}$ Cd. Present study support prior contamination of the sediments with metals, which were deposited during accidental releases from drainage sewage. Long-term changes in Lake Qarun demonstrate a significant increase of nutrient in water, while salinity and major ions were fluctuated depending on the input drains water and the rate of evaporation.

Key words: Water quality, trace metals, lake sediment, long term change, Lake Qarun

INTRODUCTION

Pollution of the environment is reflected by levels of contamination of rivers, lakes and other reservoirs. There are sites of accumulation of impurities coming from human activity, due to dissolution, precipitation and adsorption (Pertsemli and Voutsas, 2007). Contaminating elements and compounds are transported by water and gather in bottom and alluvial sediments (Ruiz-Fernández *et al.*, 2009). Eutrophication due to nutrient loading is one of the most extensively studied global environmental concerns (Pereira *et al.*, 2008; Norton *et al.*, 2008). Both N and P are highly particle reactive and most N and P, when discharged into a waterway, are deposited in bottom sediments incorporated into organic matter. Here, bacteria decompose organic matter, through oxygen and sulphate reduction, liberating N and P to pore waters and overlying waters (Amirbahman *et al.*, 2003).

Trace metals are of particular concern as pollutants in aquatic systems as they are not readily removed by natural processes as most organic pollutants (Liu *et al.*, 2008). Recently, the problem of some trace metal concentrations in bottom sediments was widely examined. Sediment-associated metals may be released through either physical disturbance or changes in the water's physical and chemical variables. Such remobilization enables entry into the various components of the aquatic ecosystem (Singh *et al.*, 2005; Mendil and Uluozlu, 2007). This availability in the entire system that makes integration into the food chain possible and

Corresponding Author: Amaal M. Abdel-Satar, National Institute of Oceanography and Fisheries (NIOF), Inland Water and Aquaculture Branch, 101 Kasr El Aini St., Cairo, Egypt

the toxicity of the trace metals can have their greatest effect (Cousins *et al.*, 2002). It is therefore, clear that increased environmental levels have the capability of causing significant effects to biota (Abida *et al.*, 2009).

Many factors affecting Lake Qarun ecosystem include the climatic conditions, amount of discharged wastewater, seepage from the surrounding cultivated land and geological aspects (Abdel-Satar *et al.*, 2003). As a result of extensive water evaporation from such closed ecosystems, the gradual increase of salts, trace metals, pesticides and other pollutants is expected to change their quality and affect their food web. For this reason, a number of investigations have dealt with the lake water chemistry (Mansour *et al.*, 2000; Ali, 2002; Saad and Hemeda, 2002; Sabae and Ali, 2004). Mansour *et al.* (2000) found that the salts composing the TDS in lake water were NaCl (61%), MgSO₄ (17.9%), Na₂SO₄ (12.4%), CaSO₄ (3.6%), Ca(HCO₃)₂, CaCO₃ (0.2%) and others (1.8%). Saad and Hemeda (2002) stated that the high nutrient concentrations coincided mainly with spreading of the nutrient enriched drainage water over the dense lake bottom water. The distribution of trace elements showed irregular patterns in the lake as a result of interference between several factors such as surrounding environment, closed basin and climatic effects (Abdel-Satar *et al.*, 2003). Sabae and Ali (2004) showed that the distribution of denitrifying bacteria was controlled by the effect of drainage water via El-Bats and El-Wadi Drains, which are loaded with nutrients. Ali and Fishar (2005) mentioned that the eastern part of the lake was generally highly contaminated (concerning trace metals in water, sediment, benthic invertebrate and fishes) in compared with the western one. Flower *et al.* (2006) concluded that the spheroidal carbonaceous particles were present in the upper 30 cm indicating contamination by low pollution level, probably beginning around 1950.

This study was conducted to infer the present chemical status of the lake water and sediment and long-term changes in lake nutrient, salinity and major ions. The seasonal and regional distribution of heavy metals and the quality of the input water through two main drains (El-Wadi and El-Bats) were also assessed.

MATERIALS AND METHODS

Site Description

Lake Qarun, is a remnant of a much bigger one and was originally a freshwater lake. It is located in the Western desert in the deepest part of Fayoum depression and lies 83 km South West of Cairo (Fig. 1). It is a closed basin that collects the agricultural wastewater

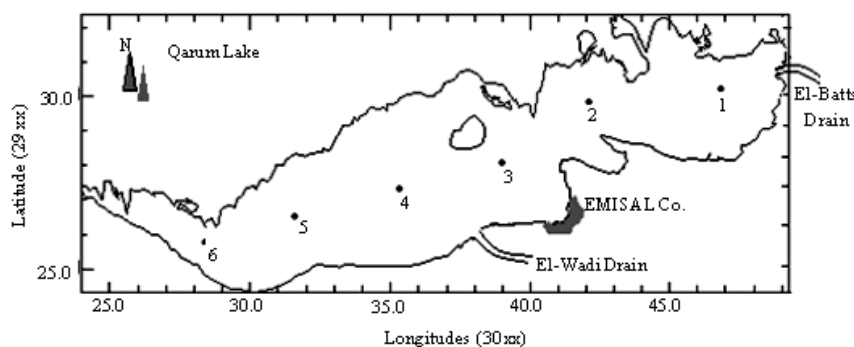


Fig. 1: Map of Lake Qarun showing sampling locations (original)

drainage of Fayoum Province. Most of this discharge is brought to the lake via two large Drains, El-Batts (at the Northeastern corner) and El-Wadi (near mid point of the Southern shore). Lake Qarun is currently saline and turbid (Secchi disc transparency usually <70 cm) and has no surface outflow. The drain water is less saline than that the lake (Fathi and Flower, 2005) but is undoubtedly contaminated by agro-chemicals. The lake supports a moderate fishery and is frequented by water birds, however, the water quality is declining and the bird numbers are diminishing (Meininger and Atta, 1994). The Egyptian Company of Salts and Minerals (EMISAL) was created on its coast to extract salts and minerals. This project was started in 1986 (EMISAL, 1996). The discharge of agricultural drainage water (about 400 million meter³ year⁻¹) in Lake Qarun is considered one of the greatest causes of water quality impairment in the lake (Ali, 2002).

Sampling and Analysis

Surface water and sediment samples were collected from the Lake during four sampling campaigns at six sites in the period from February to November 2006. Sites 1 and 2 represent the Eastern area, while sites 3 and 4 represent the middle area and sites 5 and 6 represent the Western area of the lake (Fig. 1). The water samples were collected by a polyvinyl chloride Van Dorn water sampler and kept cool in ice on the spot. Sediment samples were collected using an Eckman dredge. For water and sediment, triplicate samples were taken and mixed at each site to be representative. The sediments were put in air-sealed plastic bags and kept cool in ice on the spot. Two additional water samples, one in El-Wadi Drain and one in El-Batts Drain were collected.

Field Measurements

The electrical conductivity of the water samples (mS cm⁻¹) was measured by using a conductivity meter (S.C.T.33 YSI), transparency (cm) by Secchi disc, pH by Orion Research Ion Analyzer 399A pH meter and water temperature by an ordinary thermometer. CO₃²⁻ and HCO₃⁻ were measured titrimetrically on the spot, where samples were titrated against standard H₂SO₄ (0.02 N) using phenolphthalein and methyl orange indicators. Also, Dissolved Oxygen (DO) content was determined by azide modification method as specified in APHA (2005).

Water Analysis

Water samples were analyzed for all selected variables, according to procedures specified in American Public Health Association (2005). Total Solids (TS) were measured by evaporating a known volume of well mixed sample, TDS were determined by filtrating a volume of sample with glass micro fiber filter (GF/C) and a known volume of filtrate was evaporated at 105°C. Chemical Oxygen Demand (COD) was performed by potassium dichromate oxidation and Biochemical Oxygen Demand (BOD) by 5 days incubation methods. Chloride was determined by argentometric and sulphate by gravimetric methods. Sodium and potassium were measured directly using the flame photometer model Jenway PFP, UK. Calcium and magnesium were determined by EDTA titrimetric method. Concentrations of nitrite, nitrate, ammonia, orthophosphate (ortho-P) and reactive silicate in water were determined using the calorimetric techniques with formation of reddish purple azo-dye, Cd reduction, phenate, stannous chloride reduction and molybdosilicate methods, respectively. Total phosphorus (total-P) was measured as reactive phosphate after persulphate digestion. Total Fe, Mn, Zn, Cu, Pb and Cd in water were measured after digestion using an atomic absorption reader (Perkin Elmer 3110 USA) with graphite atomizer HGA-600.

Sediment Analysis

For total trace metals, sediment samples were allowed to defrost, then were air-dried in a circulating oven at 60°C. A total digestion for one gram sediment was carried out according to the method of Kouadia and Trefry (1987) to insure complete dissolution of all present elements. The elements determined were Na⁺, K⁺, Ca²⁺, Ba²⁺, Fe, Mn, Zn, Cu, Pb and Cd. The solutions were directly analyzed for total Na⁺, K⁺, Ca²⁺, Ba²⁺, Fe, Mn and Zn by atomic absorption spectrophotometry (Perkin Elmer 3110 USA), while total Cu, Pb and Cd were analyzed by atomic absorption with a graphite atomizer (HGA-600). The sediment samples were also analyzed for some chemical variables: organic matter and carbonate content. The organic matter content was determined by oxidation with K₂Cr₂O₇ in acidic media (Jackson *et al.*, 1984). The carbonate content was determined by the method described in American Society of Agronomy (1982). The dried sample was treated by hydrochloric acid and the carbon dioxide developed was collected in standard sodium hydroxide and then back titrated for the excess hydroxide using phenolphthalein as indicator. The concentrations of exchangeable ammonia, nitrite and nitrate were measured using the KCl extraction and quantified directly by indophenol blue, modified Griess-Hosvay and hydrazine-CuSO₄ reduction methods, respectively according to American Society of Agronomy (1982).

Statistical Analysis

Results of water samples were tested for significant differences for all variables among different seasons, while the sediment variables were tested for different sites by means of one-way ANOVA. In addition, the variables studied in drain's water samples were tested among the two drains. The relationship between the different studied variables in water and sediment were assigned by computing the correlation coefficients (r) to indicate the nature and the sources of the polluting substances.

RESULTS

Water Analysis

The ranges, means and Standard Deviation (SD) of the studied physical and chemical variables in water samples are given in Table 1. In addition, the water level in Lake Qarun during the study period is presented in Fig. 2. The Secchi disk reading showed significant seasonal difference ($p < 0.05$). Sites 4, 5 and 6 exhibited the lowest values (50 cm) during summer. Electrical conductivity showed high significant differences among seasons ($p < 0.01$) and was positively correlated ($n = 6$, $p < 0.05$) with many variables like, TDS

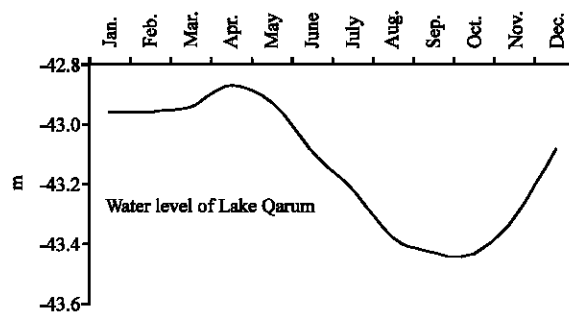


Fig. 2: Water level of Lake Qarun during the study period (Cited from Dr. Radwan Abd-Ellah (NIOF))

Table 1: Ranges, means and SD results of the physical and chemical variables in Lake Qarun water

| Variables | Winter | | Spring | | Summer | | Autumn | |
|--|--------------|--------------------|---------------|--------------------|---------------|--------------------|---------------|--------------------|
| | Range | Mean±SD (n = 6) | Range | Mean±SD (n = 6) | Range | Mean±SD (n = 6) | Range | Mean±SD (n = 6) |
| EC (mS cm ⁻¹) | 43.6-44.5 | 44.08±0.29 | 30.0-40.3 | 37.97±3.95 | 46.2-48.8 | 47.15±0.94 | 36.6-41.4 | 38.8±1.63 |
| Transparency (cm) | 50-65 | 62.5±6.12 | 55-65 | 61.8±4.08 | 50-65 | 55.8±6.65 | 60-70 | 65±3.16 |
| TS (g L ⁻¹) | 37.04-39.25 | 38.51±0.78 | 25.88-39.79 | 34.82±4.93 | 39.53-50.17 | 41.63±4.2 | 35.34-39.51 | 38.46±1.58 |
| TDS (g L ⁻¹) | 35.46-37.76 | 36.45±0.8 | 23.46-35.07 | 32.03±4.31 | 36.73-39.01 | 37.69±0.94 | 33.46-36.23 | 35.08±1.23 |
| pH | 8.12-8.73 | 8.39±0.22 | 8.12-8.33 | 8.21±0.07 | 8.09-8.14 | 8.11±0.02 | 8.18-8.20 | 8.19±0.01 |
| DO (mg L ⁻¹) | 9.30-10.26 | 9.8±0.38 | 8.00-13.20 | 11.47±1.95 | 5.20-8.40 | 6.8±1.1 | 8.80-10.36 | 9.43±0.6 |
| COD (mg L ⁻¹) | 9.0-15.22 | 13.05±2.34 | 7.20-12.0 | 9.13±1.59 | 7.56-14.88 | 12.03±3.08 | 10.76-16.16 | 13.73±2.14 |
| BOD (mg L ⁻¹) | 5.50-6.96 | 6.57±0.55 | 6.40-13.60 | 11.2±2.68 | 3.20-7.60 | 5.79±1.51 | 3.32-6.96 | 5.38±1.18 |
| CO ₃ ²⁻ (mg L ⁻¹) | 20.0-24.2 | 22.17±2.15 | 16.0-40.0 | 28.0±8.76 | 24.0-34.0 | 28.0±4.2 | 16.0-24.0 | 18.67±3.27 |
| HCO ₃ ⁻ (mg L ⁻¹) | 164-184 | 171±6.78 | 96.0-156 | 130.7±25.76 | 152-168 | 160.7±5.89 | 168.0-184.0 | 172.0±6.2 |
| Cl ⁻ (g L ⁻¹) | 12.41-12.94 | 12.62±0.2 | 10.46-14.36 | 12.5±1.25 | 14.18-15.24 | 14.8±0.37 | 9.93-12.64 | 11.99±1.19 |
| SO ₄ ²⁻ (g L ⁻¹) | 7.90-8.6 | 8.15±0.29 | 4.68-5.33 | 5.07±0.29 | 5.70-6.18 | 5.94±0.24 | 4.87-5.33 | 5.16±0.17 |
| Na (g L ⁻¹) | 5.69-6.83 | 6.11±0.55 | 5.97-7.09 | 6.72±0.39 | 7.43-7.89 | 7.68±0.19 | 5.45-5.73 | 5.58±0.1 |
| K (mg L ⁻¹) | 187.3-194.3 | 191.3±2.42 | 160.8-204.5 | 189.6±15.13 | 194.4-200.0 | 196.97±1.89 | 184.6-195.8 | 191.93±3.95 |
| Ca (mg L ⁻¹) | 301.6-801.6 | 554.04±185.8 | 380.76-480.96 | 450.9±37.49 | 440.88-481.0 | 461.57±17.24 | 460.92-565.13 | 500.6±36.42 |
| Mg (mg L ⁻¹) | 948.1-1269.1 | 1136.2±133.8 | 863.01-1312.7 | 1136.4±148.4 | 1329.7-1417.3 | 1371.1±41.14 | 1264.1-1751.3 | 1424.2±188.8 |
| NO ₃ ⁻ (µg L ⁻¹) | 25.37-66.25 | 42.06±17.35 | 16.0-179.99 | 54.57±62.57 | 16.0-52.0 | 32.47±13.66 | 12.0-36.57 | 26.09±9.82 |
| NO ₂ ⁻ (µg L ⁻¹) | 7.93-14.36 | 12.13±2.3 | 10.58-15.87 | 13.35±1.95 | 1.89-20.02 | 6.42±6.88 | 4.16-20.02 | 8.44±6.16 |
| NH ₃ (µg L ⁻¹) | 239.4-498.3 | 321.0±92.39 | 288-435 | 331±54.77 | 336-729 | 472.5±140.45 | 249-642 | 391.5±150.24 |
| Ortho-P (µg L ⁻¹) | 42.4-104.1 | 72.82±20.99 | 89.95-141.35 | 110.94±18.08 | 46.26-539.7 | 148.2±192.66 | 34.7-62.97 | 44.12±9.98 |
| Total-P (mg L ⁻¹) | 0.341-2.314 | 0.98±0.701 | 0.306-0.514 | 0.398±0.075 | 0.416-0.731 | 0.603±0.12 | 0.259-0.58 | 0.364±0.126 |
| SiO ₃ ²⁻ (mg L ⁻¹) | 2.99-9.42 | 5.92±4.16 | 2.15-11.34 | 5.42±4.16 | 0.814-2.501 | 1.614±0.64 | 0.436-2.617 | 1.275±0.74 |
| Fe (µg L ⁻¹) | 288-1067 | 733±269.6 | 272-1810 | 664.5±570.1 | 384-478 | 434.2±33.8 | 476-1239 | 683.8±304.8 |
| Mn (µg L ⁻¹) | 46.0-368 | 131.83±117.4 | 19.0-98.0 | 60.5±31.49 | 44.0-243 | 93.5±74.88 | 21.0-47.0 | 31.0±9.82 |
| Zn (µg L ⁻¹) | 41.0-93.0 | 74.0±20.02 | 46.0-117.0 | 85.33±27.3 | 53.0-75.0 | 64.0±8.88 | 45.0-146 | 74.83±37.65 |
| Cu (µg L ⁻¹) | 29.0-75.0 | 56.17±17.2 | 12.0-193.0 | 56.5±68.8 | 52-59 | 55.0±2.37 | 13-37 | 21.0±8.63 |
| Pb (µg L ⁻¹) | 133-386 | 284.2±96.45 | 38.0-97.0 | 66.5±22.81 | 353-458 | 400.8±50.94 | 48.0-127.0 | 86.17±25.83 |
| Cd (µg L ⁻¹) | 23.0-58.0 | 45.0±13.97 | 6.0-17.0 | 10.5±4.85 | 67.0-85.0 | 77.33±6.38 | 5.0-21.0 | 10.0±5.76 |

Original

($r = 0.9$), Cl^- ($r = 0.84$), SO_4^{2-} ($r = 0.60$), Na^+ ($r = 0.62$) and K^+ ($r = 0.82$), which constitute the major anions and cations in the water. The TS and TDS values showed significant differences among seasons ($p < 0.05$). They increased during summer, while spring sustained the lowest values at most sites. TDS maintained positive relationships ($n = 6$, $p < 0.05$) with HCO_3^- ($r = 0.76$), Cl^- ($r = 0.63$), SO_4^{2-} ($r = 0.53$) and K^+ ($r = 0.81$). The water showed moderately an alkaline character with pH values ranging from 8.1 to 8.73, it showed high significant difference ($p < 0.01$) among different seasons. DO varied from $\sim 5 \text{ mg L}^{-1}$ to more than twofold with high significant differences within seasons. The dominant anions (Cl^- and SO_4^{2-}) and major cations (Na^+ , K^+ , Ca^{2+} and Mg^{2+}) showed higher concentrations in summer. By evaluating the results obtained on a mass basis, it seems that the concentrations of major cations showed proportions of $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+$ and major anions of $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^- > \text{CO}_3^{2-}$. Inorganic nitrogen forms and ortho-Phosphate exhibited local variations with irregular seasonal trends. While the total-P values exhibited regional variations with significant seasonal trends (Table 1, Fig. 3a-f). Silicate showed a gradual decrease from winter up to autumn at different sites. Fe, Mn, Zn and Cu showed irregular distribution patterns, while Pb and Cd values were characterized by remarkable seasonal variations ($p < 0.01$) and highly correlated with each other ($r = 0.99$, $n = 24$, $p < 0.05$).

Long Term Changes in Water Quality of Lake from 1953 till 2006

Long-term studies in lakes have provided direct clues to the effect of increased major nutrients with the increase of water discharge from drains and their effect on abiotic and biotic characters. The mean concentration of the major nutrients (nitrite, ammonia, ortho and total phosphorus) had been gradually increased from 1953 till 2006 (Table 2), corresponding to the enhanced nutrient loading from agriculture and sewage drains.

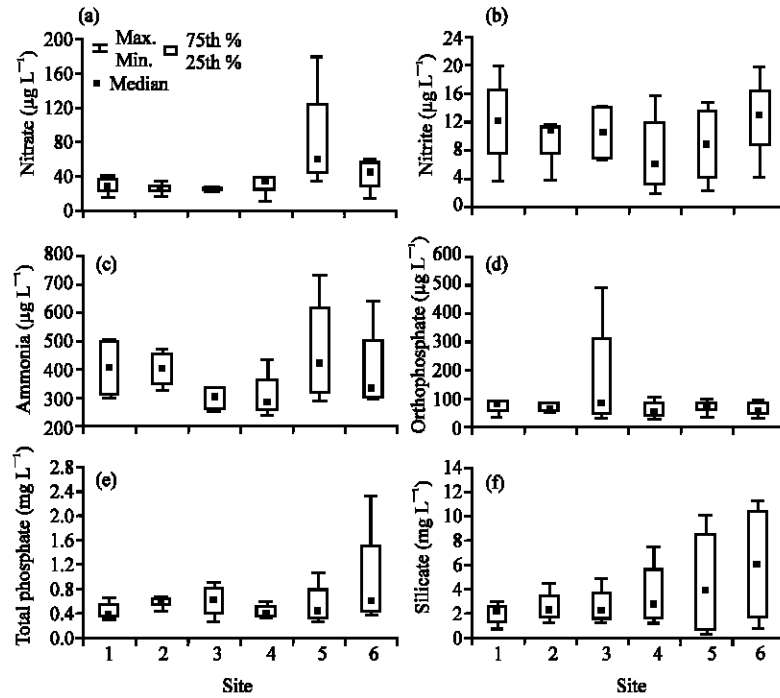


Fig. 3: Multiple box and whisker plots of nutrient salts in lake water. The central box covers the middle 50% of the data values, between the lower and upper quartiles, while the central point represents the median (original). (a) Nitrate ($\mu\text{g L}^{-1}$), (b) Nitrite ($\mu\text{g L}^{-1}$), (c) ammonia ($\mu\text{g L}^{-1}$), (d) orthophosphate ($\mu\text{g L}^{-1}$), (e) total phosphate (mg L^{-1}) and (f) silicate (mg L^{-1})

Table 2: Physical and chemical Features of Lake Qaurn during different time periods

| Variables | 1953-1955 | 1995 | 1999-2000 | 2006 (present results) |
|---|----------------------|-------------------|---------------------|------------------------|
| Water temperature ($^{\circ}\text{C}$) | 25.15 (16.4-32.0) | 24.9 (17.7-31.0) | 23.26 (14.4-32.6) | 24.78 (16.9-32.1) |
| Transparency (cm) | * | 54 (44.3-94) | 59.86 (25-110) | 61.25 (50-70) |
| Salinity (%) | 21.94 (17.9-25.4) | 38.7 (36.5-42.7) | 42.86 (38.38-49.07) | 35.31 (23.46-39.01) |
| Dissolved Oxygen (mg L^{-1}) | * | 6.89 (4.25-11.1) | 7.99 (4.8-12) | 9.37 (5.2-13.2) |
| Chemical oxygen demand (mg L^{-1}) | * | 14.9 (6.2-21.1) | 28.1 (13-43.2) | 11.99 (7.2-16.16) |
| Biological oxygen demand (mg L^{-1}) | * | 4.7 (1.9-10.43) | 6.9 (1.47-11.4) | 7.24 (3.2-13.6) |
| pH | 8.12 (7.98-8.25) | 8.4 (8-8.71) | 8.2 (7.3-8.8) | 8.22 (8.09-8.73) |
| Carbonate (mg L^{-1}) | 34.89 (22.4-60.5) | 89.6 (65.7-118.7) | 65.38 (6.6-125.4) | 24.21 (16.0-40) |
| Bicarbonate (mg L^{-1}) | 164.36 (142.3-186.8) | 191.2 (129.4-284) | 330.2 (198.8-391.6) | 158.58 (96.0-184.0) |
| Sodium (mg L^{-1}) | * | 3880 | 9880 (8130-13700) | 6520 (5450-7890) |
| Potassium (mg L^{-1}) | * | 440 | 460 (381-606) | 192.44 (160.8-204.5) |
| Calcium (mg L^{-1}) | * | 2331 (1619-3669) | 595.9 (432-810) | 491.78 (301.6-801.6) |
| Magnesium (mg L^{-1}) | * | 5505 (4718-5983) | 1589 (1211-1982) | 1270 (860-1750) |
| Nitrite ($\mu\text{g L}^{-1}$) | 0.16 (0.04-0.31) | 4.46 (2.61-13.2) | 8.15 (1.1-43.1) | 10.08 (1.89-20.02) |
| Nitrate ($\mu\text{g L}^{-1}$) | 34.84 (36.83-55.92) | 61.2 (27.4-222.7) | 66.1 (20.2-664.5) | 38.80 (12.0-179.99) |
| Ammonia (mg L^{-1}) | * | 0.05 (0.02-0.25) | 0.36 (0.08-1.1) | 0.378 (0.239-0.729) |
| Ortho-phosphate ($\mu\text{g L}^{-1}$) | 0.38 (0-0.8) | 25.6 (12.3-63.6) | 55.23 (37.8-83.5) | 94.02 (34.1-539.7) |
| Total phosphorus ($\mu\text{g L}^{-1}$) | * | 120 (84.1-250) | 181.9 (122.4-291.5) | 586.5 (258.6-2314.0) |
| Silica (mg L^{-1}) | * | 6.7 (3.35-10.7) | 6.43 (2.15-14.80) | 3.59 (0.44-11.34) |

*Not available, 1953-55 after Naguib (1958), 1995 after Anonymous (1997), 1999-2000 after Ali (2002)

Salinity was reported to be 21.94 % in 1953, showed an increase to 42.86 % in 1999/2000, followed by a re-decreased to 35.31 % in 2006 (Table 2). The concentrations of major cations followed salinity in their feature, where their changes depending on the rate of evaporation and the amount of freshwater discharged from drains.

Table 3: Ranges, means and SD results of the studied variables in Lake Qarun sediment

| Variable | Site 1 | | Site 2 | | Site 3 | |
|--|-------------|------------------|-------------|------------------|-------------|------------------|
| | Range | Mean±SD n = 4 | Range | Mean±SD n = 4 | Range | Mean±SD n = 4 |
| OM (%) | 6.02-9.89 | 8.39±1.87 | 6.03-11.11 | 8.62±2.86 | 2.44-8.85 | 7.14±3.14 |
| Carbonate (%) | 22.46-31.29 | 26.39±3.9 | 22.53-34.55 | 26.69±5.41 | 22.62-28.9 | 25.35±2.61 |
| NO ₃ ⁻ (µg g ⁻¹) | 2.6-4.0 | 3.29±0.77 | 1.57-3.31 | 2.66±0.76 | 2.03-11.14 | 4.56±4.4 |
| NO ₂ ⁻ (µg g ⁻¹) | 0.227-0.793 | 0.501±0.24 | 0.208-0.737 | 0.449±0.26 | 0.264-1.209 | 0.567±0.43 |
| NH ₃ (µg g ⁻¹) | 67.35-338.6 | 174.9±129.9 | 41.1-291.0 | 168.8±114.7 | 52.65-260.6 | 145.1±86.95 |
| Na (mg g ⁻¹) | 27.84-70.68 | 48.19±17.55 | 14.99-97.45 | 48.46±35.92 | 20.35-85.6 | 49.24±29.11 |
| K (mg g ⁻¹) | 3.84-12.86 | 7.39±3.85 | 3.74-11.2 | 6.88±3.12 | 3.62-8.29 | 6.25±2.29 |
| Ca (mg g ⁻¹) | 44.7-168.5 | 101.1±53.6 | 56.0-205.6 | 123.6±77.9 | 148.8-563.1 | 269.5±196.9 |
| Ba (mg g ⁻¹) | 34.44-81.1 | 51.24±20.7 | 32.22-75.55 | 52.38±18.41 | 17.78-70.36 | 42.31±21.73 |
| Fe (mg g ⁻¹) | 2.35-2.84 | 2.69±0.23 | 2.52-2.92 | 2.69±0.18 | 2.17-2.94 | 2.7±0.36 |
| Mn (µg g ⁻¹) | 611-1573 | 1097.8±400 | 443-1436 | 989±411.2 | 145-1044 | 606.3±408.8 |
| Zn (µg g ⁻¹) | 103-240 | 161.3±58.5 | 65-232 | 145.5±68.7 | 41-419 | 190.3±163.7 |
| Cu (µg g ⁻¹) | 46-94 | 70.8±19.8 | 29-98 | 59.8±30.4 | 25-195 | 79.3±78.0 |
| Pb (µg g ⁻¹) | 8-80 | 37.0±30.6 | 10-121 | 52.3±48.1 | 12-105 | 64.0±43.8 |
| Cd (µg g ⁻¹) | 2-11 | 5.8±3.8 | 3-15 | 7.3±5.3 | 3-27 | 11.5±10.7 |
| Variable | Site 4 | | Site 5 | | Site 6 | |
| | Range | Mean±SD n=4 | Range | Mean±SD n=4 | Range | Mean±SD n=4 |
| OM (%) | 1.10-12.49 | 6.59±4.65 | 1.34-17.06 | 10.09±7.38 | 1.46-13.11 | 7.95±5.0 |
| Carbonate (%) | 25.52-33.82 | 27.94±3.95 | 26.15-35.64 | 29.41±4.26 | 22.9-34.23 | 27.14±5.13 |
| NO ₃ ⁻ (µg g ⁻¹) | 1.43-33.08 | 11.05±14.79 | 2.84-18.28 | 10.67±6.74 | 3.26-74.28 | 24.41±33.4 |
| NO ₂ ⁻ (µg g ⁻¹) | 0.68-4.137 | 1.573±1.71 | 0.246-4.024 | 1.431±1.74 | 0.359-1.152 | 0.789±0.34 |
| NH ₃ (µg g ⁻¹) | 42.9-270.5 | 147.5±116.4 | 13.50-255 | 133±121.2 | 54.6-275.4 | 168.2±120.9 |
| Na (mg g ⁻¹) | 22.49-60.25 | 37.02±16.36 | 18.21-50.97 | 32.29±13.75 | 14.99-84.6 | 41.23±31.22 |
| K (mg g ⁻¹) | 1.99-4.6 | 3.7±1.17 | 3.59-10.86 | 6.57±3.45 | 2.39-7.69 | 5.11±2.49 |
| Ca (mg g ⁻¹) | 143.0-559.6 | 264.9±197.2 | 48.4-599 | 225.2±252.8 | 67.0-581 | 305.5±269.3 |
| Ba (mg g ⁻¹) | 10.89-59.5 | 28.51±21.55 | 25.89-38.33 | 30.36±5.47 | 18.33-50.21 | 28.65±14.61 |
| Fe (mg g ⁻¹) | 2.46-2.72 | 2.59±0.12 | 2.32-2.96 | 2.63±0.27 | 2.29-2.97 | 2.73±0.32 |
| Mn (µg g ⁻¹) | 207-2046 | 741.8±872.4 | 184-1086 | 727.3±386.7 | 191-998 | 492.3±382.8 |
| Zn (µg g ⁻¹) | 51-368 | 143.0±150.5 | 36-202 | 115.8±67.9 | 45-194 | 131.0±65.4 |
| Cu (µg g ⁻¹) | 12-169 | 54.8±76.2 | 11-64 | 38.8±24.1 | 12-243 | 85.5±107.8 |
| Pb (µg g ⁻¹) | 13-68 | 38.5±25.5 | 12-147 | 76.8±64.1 | Sep-90 | 56.0±34.0 |
| Cd (µg g ⁻¹) | 4-16 | 9.0±5.3 | 14-Feb | 9.5±5.2 | 11-Feb | 6.0±4.2 |

Sediment Analysis

The ranges, means and SD of the studied variables in the collected sediment samples are given in Table 3. The present results indicated that there was no significant difference ($p > 0.05$) between the levels of organic matter and carbonate within sites. The OM exhibited positive correlations ($n = 24, p < 0.05$) with each of Mn ($r = 0.72$), Zn ($r = 0.62$), Cd ($r = 0.75$) and Cu ($r = 0.84$). The dominant species of nitrogen in the lake sediment is ammonia (Fig. 4a-c). Ammonia-nitrogen showed insignificant spatial variation and high significant temporal variations ($p < 0.01$). Ammonia exhibited positive correlation ($r = 0.81, n = 6, p < 0.05$) with mud percent. Sodium showed higher levels than potassium and the two elements fulfilled positive relationship ($r = 0.76, n = 24, p < 0.05$). Calcium concentrations showed wide range. The levels of barium decreased Westward far from drainage water sources. By evaluating the results obtained on a mass basis, it seems that the concentrations of studied elements in Lake Qarun sediment showed proportions of $Ca^{2+} > Na^+ > Ba^{2+} > K^+$. The collected lake sediments are mainly composed of very fine sand and mud along with minor fraction of medium and coarse sand besides some mollusca shell fragments (Table 4). As expected, trace metals concentrations in the lake sediments displayed a wide range with insignificant variations within sites. The highest levels of zinc were situated at site 3 ($419 \mu\text{g g}^{-1}$) and copper at sites 3 and 4 ($195, 169 \mu\text{g g}^{-1}$). The highest concentration of lead found with the current study was at site 5 ($147 \mu\text{g g}^{-1}$), whereas the lowest was at site 1 ($8 \mu\text{g g}^{-1}$). The

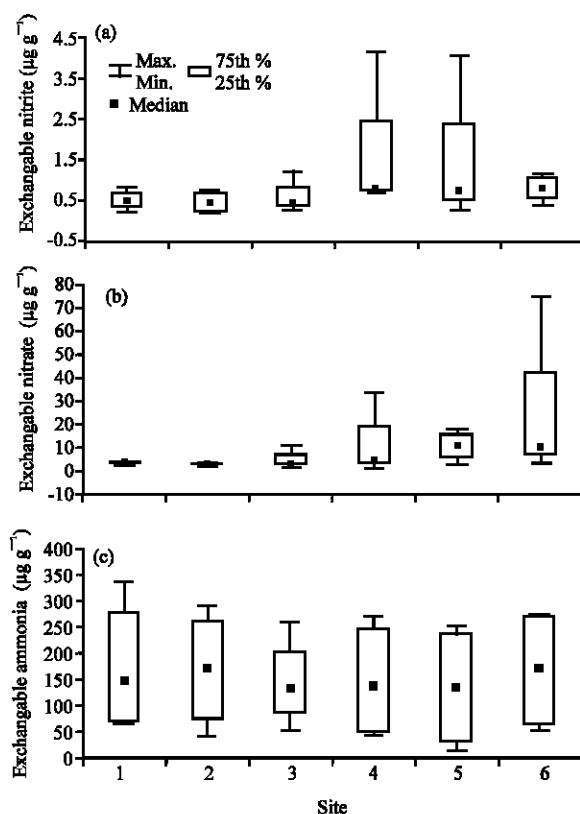


Fig. 4: Multiple box and whisker plots of exchangeable nutrient salts in lake sediment. Details as in Fig. 3 (original). (a) Exchangeable nitrite ($\mu\text{g g}^{-1}$), (b) exchangeable nitrate ($\mu\text{g g}^{-1}$) and (c) exchangeable ammonia ($\mu\text{g g}^{-1}$)

Table 4: Summary of sieve test results for sediment samples collected from the Lake Qarun during the study period

| Sites | Depth (m) | Gravel* | Sand (%) | | | | | Mud |
|-------|-----------|---------|-------------------|--------------|--------------|------------|-----------------|-------|
| | | | Very coarse* sand | Coarse sand* | Medium sand* | Fine sand* | Very fine sand* | |
| 1 | 2.4 | 2.40 | 8.30 | 1.10 | 0.89 | 3.20 | 19.05 | 27.06 |
| 2 | 2.5 | 2.50 | 14.20 | 2.30 | 1.60 | 0.40 | 12.70 | 27.30 |
| 3 | 3.0 | 3.00 | 17.20 | 2.30 | 1.90 | 0.70 | 15.10 | 19.10 |
| 4 | 5.5 | 4.55 | 6.53 | 1.10 | 0.70 | 0.40 | 15.32 | 21.20 |
| 5 | 4.5 | 4.50 | 1.20 | 0.40 | 0.12 | 0.05 | 10.30 | 27.35 |
| 6 | 4.0 | 4.00 | 30.12 | 0.72 | 0.00 | 0.00 | 6.04 | 19.03 |

*Personal communication with Mr. Hassan Farahat (NIOF)

highest Cd concentration ($27 \mu\text{g g}^{-1}$) was found at site 3 close to effluent discharges from El-Wadi Drain. Positive correlations ($n = 24, p < 0.05$) between concentrations of Zn/Cd, Cu/Zn and Cu/Cd ($r = 0.81, 0.72$ and 0.67 , respectively) were registered.

Physical and Chemical Characteristics of El-Wadi and El-Bats Drains Water

The results revealed that the effluent of El-Wadi Drain contained low total solid values, compared with El-Bats Drain (Table 5). The COD values of the two drains showed lower values than those recorded in Lake Qarun, it showed high significant difference among drains ($p < 0.01$), where, El-Wadi Drain had lower value than El-Bats Drain (Table 5). The drain's effluent are slightly enriched in Na^+ , K^+ , Ca^{2+} and Mg^{2+} , where the order of abundance on a mass basis was $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$.

Table 5: The physical and chemical variables for water samples in the drain's effluents

| Variables | Winter | | Spring | | Summer | | Autumn | |
|--|---------|---------|---------|---------|---------|---------|---------|---------|
| | El-Bats | El-Wadi | El-Bats | El-Wadi | El-Bats | El-Wadi | El-Bats | El-Wadi |
| TS (g L ⁻¹) | 10.670 | 7.770 | 1.924 | 1.180 | 2.260 | 2.768 | 4.996 | 2.056 |
| pH | 8.04 | 8.09 | 7.85 | 8.25 | 7.2 | 7.5 | 8.5 | 8.6 |
| DO (mg L ⁻¹) | 8.92 | 9.9 | 8.8 | 10.4 | 6.6 | 5.6 | 10.0 | 11.32 |
| COD (mg L ⁻¹) | 4.16 | 2.98 | 4.32 | 2.90 | 3.49 | 2.92 | 4.46 | 3.04 |
| BOD (mg L ⁻¹) | 9.21 | 6.00 | 6.40 | 9.20 | 6.04 | 5.62 | 9.32 | 4.00 |
| CO ₃ ²⁻ (mg L ⁻¹) | 4.0 | 2.0 | 8.0 | 8.0 | 14.0 | 8.0 | 0.8 | 0.0 |
| HCO ₃ ⁻ (mg L ⁻¹) | 189.0 | 226.0 | 188.0 | 224.0 | 192.0 | 220.0 | 210.0 | 228.0 |
| Cl ⁻ (mg L ⁻¹) | 2660 | 1950 | 400 | 700 | 470 | 650 | 886 | 1064 |
| SO ₄ ²⁻ (mg L ⁻¹) | 310 | 580 | 614 | 726 | 517 | 613 | 519 | 511 |
| Na (mg L ⁻¹) | 930.0 | 850.0 | 429.3 | 248.2 | 352.2 | 407.6 | 317.0 | 353.2 |
| K (mg L ⁻¹) | 43.35 | 37.15 | 35.50 | 18.78 | 24.06 | 24.50 | 21.42 | 20.1 |
| Ca (mg L ⁻¹) | 136.27 | 220.24 | 76.15 | 140.28 | 76.12 | 90.29 | 280.56 | 200.40 |
| Mg (mg L ⁻¹) | 125.3 | 203.1 | 70.50 | 98.07 | 115.33 | 68.07 | 276.81 | 182.33 |
| NO ₃ ⁻ (µg L ⁻¹) | 836.2 | 796.2 | 770.25 | 386.8 | 393.69 | 594.26 | 435.41 | 762.82 |
| NO ₂ ⁻ (µg L ⁻¹) | 526.1 | 537.8 | 661.2 | 332.5 | 267.9 | 38.54 | 229.3 | 143.9 |
| NH ₃ (µg L ⁻¹) | 384.0 | 415.0 | 876.0 | 968.0 | 540.0 | 288.0 | 356.0 | 279.0 |
| Ortho-P (mg L ⁻¹) | 1.074 | 0.571 | 0.504 | 0.251 | 0.534 | 0.235 | 0.616 | 0.334 |
| Total-P (mg L ⁻¹) | 2.925 | 1.686 | 1.519 | 0.743 | 1.967 | 1.293 | 1.171 | 1.031 |
| SiO ₃ ²⁻ (mg L ⁻¹) | 4.478 | 4.595 | 11.17 | 9.073 | 4.827 | 5.467 | 5.293 | 3.955 |
| Fe (µg L ⁻¹) | 1259 | 627 | 3259 | 2473 | 1058 | 323 | 532 | 345 |
| Mn (µg L ⁻¹) | 35 | 21 | 141 | 71 | 65 | 32 | 44 | 33 |
| Zn (µg L ⁻¹) | 66 | 68 | 68 | 45 | 88 | 49 | 90 | 56 |
| Cu (µg L ⁻¹) | 32 | 41 | 42 | 62 | 52 | 17 | 60 | 22 |
| Pb (µg L ⁻¹) | 146 | 149 | 36 | 65 | 147 | 64 | 342 | 80 |
| Cd (µg L ⁻¹) | 22 | 18 | 6 | 7 | 10 | 9 | 12 | 13 |

Original

DISCUSSION

Lakes provide a historical record of the conditions of the environments that surrounds them (Nesbeda, 2004). The increase in DO concentration in winter and spring may be due to the fall in water temperature and phytoplankton blooming (Konsowa, 2007). The distribution of major anions and cations in lake water were governed mainly by the rate of evaporation, the intrusion of drainage water and consumption of lake salts by EMISAL Company. Anthropogenic sources of nutrients coupled with modifications to the environment and climate are now so pervasive that no aquatic system can be considered as truly pristine (Edwards and Withers, 2008). Natural water have small concentrations of nitrates and phosphorus. But these nutrients increase with runoff from agricultural lands (especially intensively cultivated lands with large inputs of synthetic fertilizers) and urban wastewater, creating eutrophication (Yang *et al.*, 2003; Liu *et al.*, 2009). The obtained results revealed that ammonia accounted for the major proportion of total soluble inorganic nitrogen. Nitrite showed low levels than the corresponding values of nitrate due to the fast conversion of NO₂⁻ to NO₃⁻ ions by nitrifying bacteria (Sabae and Ali, 2004). Water level showed positive correlation (n = 4, p<0.05) with nitrite (r = 0.98) and nitrate (r = 0.84) and a negative correlation with ammonia (r = -0.94). This explains the dependence of nutrient levels on the intrusion of drainage water. Phosphorus that enters the system through anthropogenic sources, such as fertilizer-runoff, potentially could be incorporated into either inorganic or organic fractions. Once phosphorus accumulates within a lake, it can cycle through the water column and promote algal blooms indefinitely (Christophoridis and Fytianos, 2006; Mainstone *et al.*, 2008; Edwards and Withers, 2008). The Ortho-Phosphate at sites 4, 5 and 6 showed high significant seasonal variations (p<0.01), while sites 1, 2 and 3 showed irregular variation

($p = 0.36$). This reflecting the effect of drainage water, where agriculture is a major contributor of phosphorus to receiving waters (Dougherty *et al.*, 2004). The gradual decrease in silicate from winter up to autumn can explain the abundance of diatoms (75% of total phytoplankton density) from July to the end of autumn and their sharp decline in February and during the spring (Konsowa, 2007). Regionally, silicate showed higher values in the Western side than the eastern and middle area (Fig. 3), this was concurrently with diatoms abundance (Konsowa, 2007). The interference between several factors such as surrounding environment, closed basin and climatic effects may be suggest the irregular distribution patterns of metals in Qarun Lake. The concentration of Fe in water was within the values previously reported by Mansour and Sidky (2003) (average: $460 \mu\text{g L}^{-1}$). However, Pb and Zn exhibited higher concentrations (average: 209.4 and $74.5 \mu\text{g L}^{-1}$) than previously reported (average: $20 \mu\text{g L}^{-1}$), reflecting a recent pollution events. Site 1 (infront of El-Batts Drain) showed the highest value of Fe concentration ($1810 \mu\text{g L}^{-1}$), suggesting an anthropogenic source of iron input (e.g., fertilizers) (Ali, 2002). Also, the sharp increase in Cu concentration at site 3 in spring ($193 \mu\text{g L}^{-1}$) is mainly due to agricultural sewage discharge from El-Wadi Drain, where copper can be derived from a number of sources including agricultural materials, atmospheric deposition and sewage sludge (Cousins *et al.*, 2002). The trace metals concentrations exceed the marine water guidelines established by Environmental Protection Agency (1994) for Zn, Cu, Pb and Cd. However, many samples contained concentrations of Zn, Pb, Cu and Cd exceeding the chronic criteria (86, 8.5, 2.9 and $9.3 \mu\text{g L}^{-1}$, respectively). Anthropogenic influences, rather than natural enrichment of the water by metals may be the main reasons (Wasim Aktar *et al.*, 2008), where, Cd is present as an impurity in several products, including phosphate fertilizers and detergents (Greaney, 2005).

The sediments with high amounts of organic matter act as traps and reservoirs for metals of anthropogenic origin (Camusso *et al.*, 2002) this achieved by the positive correlations recorded between OM and each of Mn, Zn, Cu and Cd. Sites 4, 5 and 6 showed high carbonate content, suggesting an enrichment of sediments by mollusca and partly by calcareous fragments (Goher, 2002; Flower *et al.*, 2006).

Nutrient cycling throughout lakes is directly linked to processes operating within the lake and surrounding environs (Amirbahman *et al.*, 2003). Excess nutrient supplies from atmospheric deposition, agricultural fertilizer runoff and other anthropogenic sources, can have adverse effects on aquatic ecosystems and also influence the N and P distributions and concentrations in overlying waters and sediments (Murray *et al.*, 2005). The decrease in ammonia levels in sediment during winter and spring coincided with the increase of dissolved oxygen concentrations in the overlying water during the same seasons. The present study showed higher increase (about 413 times) of exchangeable ammonia levels than that recorded in lake water. Ammonia itself is a non-persistent and non-cumulative toxic substance, thus the high levels of ammonia released by the sediment do not cause a problem especially when the DO % is high (Johnston and Minnaard, 2003). The levels of exchangeable nitrite and nitrate in lake sediment increased Westward far from the discharging drainage sources (Fig. 4). The exchangeable NO_3^- -N concentrations are mostly higher than NO_2^- -N values suggesting the oxidized conditions of lake sediment and the two showed high increased in their levels compared with that recorded in lake water (about 243 and 88 times, respectively). These reflect the importance of internal nutrient loading when determining the trophic condition of the water body (Liikänen *et al.*, 2002).

The insignificant spatial variations of trace metals in the lake sediments reflecting the differential behavior of trace metals rich agricultural and domestic effluents draining into lake ecosystem. While there are no guidelines recommended for Fe and Mn, the present results

(average: 2671.4 and 775.7 $\mu\text{g g}^{-1}$, respectively) are higher than (about 3 times) the levels detected by Mansour and Sidky (2003) (814.5, 288.0 $\mu\text{g g}^{-1}$). This dramatic increase, which is too large to be solely caused by the weathering of sandstone, suggesting an anthropogenic source of metals input (e.g., fertilizers; pesticides) (Abdel-Satar *et al.*, 2003). The increase of the studied metals especially at sites 1 and 3 may be related to the amount of sewage entering the lake through El-Bats and El-Wadi Drains.

Lake sediments provide an archive of environmental change both within the lake ecosystem and region and therefore, have been used across the world in order to study natural environmental change or human impacts (Yang *et al.*, 2003; Sayed and Abdel-Satar, 2009). Present data support prior contamination of the sediments with metals, which were likely deposited during accidental releases from drain's sewage. Zn and Cd levels at the majority of sites were more than acute guidelines (112 and 4.2 $\mu\text{g g}^{-1}$, respectively) cited by US Environmental Protection Agency (1997). This can attributed to anthropogenic influences, rather than natural enrichment of the sediment by metal (Vest *et al.*, 2009). In addition, the levels of Cu and Pb in most samples were below the acute guidelines (108 and 112 $\mu\text{g g}^{-1}$, respectively), but exceeded the chronic criteria (18.7 and 30.2 $\mu\text{g g}^{-1}$, respectively), which have a small but negative effect on the surrounding.

The data from the drain's effluents compared with the in-lake data suggest a massive input of nutrients into the lake. The high nutrient salts concentrations in the two drains can be explained on the basis of the high amount of agricultural runoff and domestic sewage inflow from the adjacent cultivated land and neighboring villages to the drains (Sayed and Abdel-Satar, 2009). Except for COD, bicarbonate and ortho-P, the studied variables showed no significant differences ($p < 0.05$) among the two drains. This indicated that the two drains receive the same inputs from agricultural and domestic wastes.

We can conclude that municipal and agricultural sewage input into Lake Qarun causes serious pollution of its water and bottom sediments mainly by increasing the amount of nutrient and trace metals (Cu, Zn, Pb and Cd). Sediment-associated trace metals also represent a potential hazard to the aquatic environment and may be released to the water column upon disturbance. If accidental releases from drain's sewage continue, chronic accumulation of trace metals in the lake will persist, providing a continuing hazard to the lake water.

REFERENCES

- Abdel-Satar, A.M., A.A. Elewa, A.K.T. Mekki and M.E. Gohar, 2003. Some aspects on trace elements and major cations of Lake Qarun sediment. *Egypt. Bull. Fac. Sci. Zagazig Univ. Egypt*, 25: 77-97.
- Abida, B., S.H. Krishna and I. Khan, 2009. Analysis of heavy metals in water, sediments and fish samples of Madivala Lakes of Bangalore, Karnataka. *Int. J. Chem. Tech. Res.*, 1: 245-249.
- Ali, M.H.H., 2002. Impact of agricultural and sewage effluents on the ecosystem of Lake Qarun, Egypt. Ph.D. Thesis. Faculty of Science, Al-Azhar University, Egypt.
- Ali, M.H.H. and M.R. Fishar, 2005. Accumulation of trace metals in some benthic invertebrate and fish species relevant to their concentration in water and sediment of Lake Qarun, Egypt. *Egypt. J. Aquat. Res.*, 31: 289-302.
- American Society of Agronomy (ASA), 1982. *Methods of Soil Analysis. Part 2, Chemical and Microbiological Properties*. 2nd Edn., Madison, Wisconsin, USA, ISBN-10: 0891180729.

- Amirbahman, A., A.R. Pearce, R.J. Bouchard, S.A. Norton and J.S. Kahl, 2003. Relationship between hypolimnetic phosphorus and iron release from eleven lakes in Maine, USA. *Biogeochemistry*, 65: 369-386.
- APHA, AWW, WPCF, 2005. *Standard Methods for the Examination of Water and Wastewater*. 21st Edn., American Public Health Association, Washington, DC, USA.
- Anonymous, 1997. Investigation of Lake Qarun ecosystem. Final Report Submitted to USAID, National Institute of Oceanography and Fisheries, Cairo, Egypt.
- Camusso, M., S. Galassi and D. Vignati, 2002. Assessment of River Po sediment quality by micropollutant analysis. *Water Res.*, 36: 2491-2504.
- Christophoridis, C. and K. Fytianos, 2006. Conditions affecting the release of phosphorus from surface lake sediments. *J. Environ. Qual.*, 35: 1181-1192.
- Cousins, T.M., D.B. Mulquin and J.L. Pickering, 2002.. Survey of heavy metals in sediments of the Manly Lagoon Catchment. Freshwater Ecology Report 2002, Department of Environmental Sciences, University of Technology, Sydney.
- Dougherty, W.J., N.K. Fleming, J.W. Cox and D.J. Chittleborough, 2004. Phosphorus transfer in surface runoff from intensive pasture systems at various scales: A review. *J. Environ. Qual.*, 33: 1973-1973.
- Edwards, A.C. and P.J.A. Withers, 2008. Transport and delivery of suspended solids, nitrogen and phosphorus from various sources to freshwater in the UK. *J. Hydrol.*, 350: 144-153.
- Environmental Protection Agency (EPA), 1994. *Monitoring Trace Metals at Ambient Water Quality Criteria Levels: Issues, Plans and Schedule*. 2nd Edn., US Environmental Protection Agency, Washington, DC..
- EMISAL (Egyptian Company of Salts and Minerals), 1996. Qarun Lake, Abase for an Advanced Chemical Industry Complex, Investment Opportunities Based on Salt Extraction from Lake Qarun and the Integrated Industries Based on it. Egyptian Salts and Minerals Co. Ltd., London, pp: 28.
- Fathi, A.A. and R.J. Flower, 2005. Water quality and phytoplankton communities in Lake Qarun (Egypt). *Aquat. Sci.*, 67: 350-362.
- Flower, R., C. Stickleby, N. Rose, S. Peglar, A. Fathi and P. Appleby, 2006. Environmental changes at the Desert Margin: An assessment of recent paleolimnological records in Lake Qarun, Middle Egypt. *J. Paleolimnol.*, 35: 1-24.
- Goher, M.E., 2002. Chemical studies on the precipitation and dissolution of some chemical elements in Lake Qarun. Ph.D. Thesis. Faculty of Science, Al-Azhar University, Cairo, Egypt.
- Greaney, K.M., 2005. An assessment of heavy metals contamination in the marine sediments of Las Perlas Archipelago, Gulf of Panama. M.Sc. Thesis, Heriot-Watt University, Edinburgh.
- Jackson, J.F.C., A.E. Nevissi and F.B. Dervalle, 1984. *Soil Chemical Analysis*. Revised 2nd Edn., Parallel Press, Madison, Wisconsin, USA,.
- Johnston, B. and D. Minnaard, 2003. Sediment nutrient release within the Manly Lagoon catchment. Freshwater Ecology Report 2003, Department of Environmental Sciences, University of Technology, Sydney. <http://www.science.uts.edu.au/des/StaffPages/PeterJones/SedimentNutrientRelease.pdf>.
- Konsowa, A.H., 2007. Phytoplankton evolution in a shallow hypertrophic saline lake. *Al-Azhar J. Pharm. Sci.*, 32: 109-122.
- Kouadia, L. and J.H. Trefry, 1987. Saline trace metal contamination in the Ivory Air Water Soil Pollut., 32: 145-154.

- Liikänen, A., T. Murtoniemi, H. Tanskanen, T. Vaeisaenen and P.J. Martikaine, 2002. Effects of temperature and oxygen availability on greenhouse gas and nutrient dynamics in sediment of a eutrophic mid-boreal lake. *Biogeochemistry*, 59: 269-286.
- Liu, H., L. Li, C. Yin and B. Shan, 2008. Fraction distribution and risk assessment of heavy metals in sediments of Mushui Lake. *J. Environ. Sci.*, 20: 390-397.
- Liu, J., H. Wang, H. Yang, Y. Ma and O. Cai, 2009. Detection of phosphorus species in sediments of artificial landscape lakes in China by fractionation and phosphorus-31 nuclear magnetic resonance spectroscopy. *Environ. Pollut.*, 157: 49-56.
- Mainstone, C.P., R.M. Dils and P.J.A. Withers, 2008. Controlling sediment and phosphorus transfer to receiving waters-A strategic management perspective for England and Wales. *J. Hydrol.*, 350: 131-143.
- Mansour, S.A., S.S. Messeha and M.M. Sidky, 2000. Ecotoxicological Studies. 1. Qualitative and quantitative determination of salt composition in Lake Qarun water and its sources. *Egypt. J. Aquat. Biol. Fish.*, 4: 271-303.
- Mansour, S.A. and M.M. Sidky, 2003. Ecotoxicological studies. 6. The first comparative study between Lake Qarun and Wadi El-Rayan wetland (Egypt), with respect to contamination of their major components. *Egypt. J. Food Chem.*, 82: 181-189.
- Meininger, P.L. and G.A.M. Atta, 1994. Ornithological studies in Egyptian Wetlands 1989/90. WIWO-report No. 40, August 1994, Netherlands. http://en.tourduvalat.org/documentation/publications/ornithological_studies_in_egyptian_wetlands_1989_90_4327
- Mendil, D. and O.D. Uluozlu, 2007. Determination of trace metal levels in sediment and five fish species from lakes in Tokat, Turkey. *Food Chem.*, 101: 739-745.
- Murray, E.J., R.R. Haese, C.S. Smith and D.T. Heggie, 2005. Nutrient Cycling in St Georges Basin, South Coast NSW: Report on Field Survey November 2003. Geoscience Australia, Dept. of Industry, Tourism and Resources, Canberra, Australia.
- Naguib, M., 1958. Studies on the ecology of Lake Qarun (Fayoum, Egypt). Part I. *Kieler Meeresforschungen*, 14: 187-222.
- Nesbida R.H., 2004. Sedimentological and geochemical characterization of east pond, belgrade lakes watershed, central Maine. M.Sc. Thesis, Honors in Geology, Department of Colby College Faculty of the Geology, Waterville, Maine, pp: 114.
- Norton, S.A., K. Coolidge, A. Amirbahman, R. Bouchard, J. Kopáèek and R. Reinhardt, 2008. Speciation of Al, Fe and P in recent sediment from three lakes in Maine, USA. *Sci. Total Environ.*, 404: 276-283.
- Pereira, P., H. de Pablo, C. Vale, F. Rosa-Santos and R. Cesário, 2008. Metal and nutrient dynamics in a eutrophic coastal lagoon (Óbidos, Portugal): The importance of observations at different time scales. *Environ. Monit. Assess.*, 158: 405-418.
- Pertsemli, E. and D. Voutsas, 2007. Distribution of heavy metals in Lakes Doirani and Kerkini, Northern Greece. *J. Hazard. Mater.*, 148: 529-537.
- Ruiz-Fernández A.C., M. Frignani, C. Hillaire-Marcel, B. Ghaleb, M.D. Arvizu, J.R. Raygoza-Viera and F. Páez-Osuna, 2009. Trace metals (Cd, Cu, Hg and Pb) accumulation recorded in the intertidal mudflat sediments of three coastal lagoons in the Gulf of California, Mexico. *Estuar. Coasts*, 32: 551-564.
- Saad, M.A.H. and E.I. Hemeda, 2002. Distribution of nutrient species in Lake Qarun, a closed Egyptian basin. Proceedings of the International Conference on Limnology of Shallow Lakes, May 25-30, Balatonfüred, Hungary, pp: 1-309.
- Sabae, S.Z. and M.H. Ali, 2004. Distribution of nitrogen cycle bacteria in relation to physico-chemical conditions of a closed saline lake (Lake Qarun) Egypt. *J. Egypt Acad. Environ. Dev.*, 5: 145-167.

- Sayed, M.F. and A.M. Abdel-Satar, 2009. Chemical assessment of Wadi El-Rayan Lakes-Egypt. *American-Eurasian J. Agric. Environ. Sci.*, 5: 53-62.
- Singh, K.P., D. Mohan, V.K. Singh and A. Malik, 2005. Studies on distribution and fractionation of heavy metals in Gomti river sediments—a tributary of the Ganges. India. *J. Hydrol.*, 312: 14-27.
- US Environmental Protection Agency (USEPA), 1997. The Incidence and Severity of Sediment Contamination in Surface Waters of the United States, Volume 3-National Sediment Survey. USEPA, Washington, DC..
- Vest, J.L., M.R. Conover, C. Perschon, J. Luft and J.O. Hall, 2009. Trace element concentrations in wintering waterfowl from the Great Salt Lake. Utah. *Arch. Environ. Con. Toxi.*, 56: 302-316.
- Wasim Aktar, M.D., M. Paramasivam, M. Ganguly, S. Purkait and D. Sengupta, 2008. Assessment and occurrence of various heavy metals in surface water of Ganga River around Kolkata: A study for toxicity and ecological impact. *Environ. Monit. Assess.* 10.1007/s10661-008-0688-5
- Yang, Z.R., E.Y. Graham and W.B. Luons, 2003. Geochemistry of Pyramid Lake sediments: Influence of anthropogenic activities and climatic variations within the basin. *Environ. Geol.*, 43: 688-697.