Present Status and Long-Term Changes of Water Quality Characteristics in Heavily Polluted Mediterranean Lagoon, Lake Mariut, Egypt

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ABSTRACT

The present status, a long term change of water quality characteristics besides metal pollution load (Fe, Mn, Zn, Cu and Cd) in water of a heavily polluted Mediterranean Lake (Mariut Lake northwest of Egypt) were investigated. Water quality characteristics varied in a wide range among the different basins. Depending on collecting data; the agricultural and domestic sewage drained from Al-Qalaa Drain responsible for the most drastic deterioration status in main basin of the lake. Meanwhile, Aquaculture Basin has the highest values of salinity and consequently both major cations and anions. Ratio of N:P indicated of potential N limits on phytoplankton growth. Almost, the values of all studied metals are higher than standard permissible levels. The contamination index (C_d) revealed that the order of pollution increasing as WB < SB < AQB < MB. PCA analyses showed that most of nutrient salts associated with heavy metals were responsible for heavily polluted zones. Cluster analyses showed that, main basin has the most polluted aspects depending on concentration of studying parameters followed by a moderate polluted aquaculture basin then low polluted western and southern basins.

INTRODUCTION

For lake monitoring and proper management, the detection of water quality trend is often the first purpose many people have in mind (New York State Department of Environmental Conservation. 2006). Our knowledge about the response of aquatic ecosystems to changes in water quality conditions could be improved greatly by the biomonitoring programs via providing a direct measure of aquatic community status. Also, biomonitoring can serve as an "early warning" indicator by providing data and insights into incipient biological changes and long term indications of significant changes in system function or potential resource utilization. The deterioration evidence of water quality can provide a stimulus for initiating corrective actions. Water quality improvement or lack of improvement, in response to management programs is also important to demonstrate so that the effectiveness of pollution reduction efforts can be objectively evaluated

Recently, Nile delta coast had become more prominent environmental issues due to increasing population and intensifying industry (El-Rayis, 2005). The discharge of untreated wastewaters into the four coastal lagoons are causes an ecologically degradation and environment deterioration. For example, sewerage output has extended to Mariut lagoon from Alexandria on the northwestern Nile coast, where heavy metals are significantly enriched in the water and sediments. Nowadays, Mariut and Manzala lagoons are the most polluted and Idku and Burullus follow behind. Presently these two lakes are facing critical environmental pressures from local industries and urbanization with the increasing pollutants being expelled towards the lake coast (Kamal and Magdy, 2005).

The increase in population and consequently in man's activities, especially after Aswan High Dam construction constitutes the main cause of pollution in the Nile Delta lakes, mainly eutrophication, as well as occurrence of heavy metals and pesticide contaminants constituted in these lakes problems of increasing concern. Lake Manzalah occupies the second polluted level after Mariut Lake (Saad, 2003).

Over the past decades, Mariut Lake suffers from almost all possible environmental problems to an extreme degree. Anthropogenic pollutants introduced huge amounts of inorganic and organic toxic substances, different forms of nitrogen, phosphorus, heavy metals, pesticides, and pathogens (Mohammed and Ruslan, 2013). Mariut Lake becomes one of the most polluted lagoons in Egypt due to the urban expansion from the densely populated Alexandria and the uncontrolled deposition of solid wastes, complete very complicated and distressing environmental panorama.

The primary purpose of the on-going water quality and biological monitoring program will be to detect environmental change in Mariut Lake to assist in developing and supporting policy and management decisions. Additionally, these data may assist in identifying and narrowing down nutrient sources, which in turn, will help in targeting resources for nutrient reductions. Also to evaluate the levels of some toxic heavy metals (Fe, Mn, Zn, Cu and Cd) due to their health implications for human populations consuming fishes from the lake.

MATERIALS AND METHODS

Study area

Lake Mariut is one of the northern Egyptian lakes, located in the north western coast of Egypt between 31° 01´48″ and 31° 10´ 30″ North and 29° 49´48″ and 29° 57´ 00″ East. The lake extends for about 80 km along the North West coast of Alexandria and 30 km south and is divided artificially into four main basins; namely, 6000

Feddan1 Basin (Main Basin), 5000 Feddans basin (South Basin), 3000 Feddans Basin (West Basin) and 1000 Feddans Basin (Aquaculture Basin), Mariut Lake is a closed lake, not connected with the sea (Figure, 1). The main water source discharges into the lake are El-Omoum Drain, El-Qalaa Drain and El-Nubaria Canal. El-Qalaa Drain flow is consists of a mixture of East Treatment Plant effluent, raw wastewater, irrigation, drainage and runoff then passes under the Desert Road to the Main Basin. El-Omoum Drain flow is derived from a series of six pump stations. The banks of the canals and drains contain a large number of breaches which allow exchange of water between the drain and the Northwest Basin (NIOF, 2008)

Table (1). Sampling sites and its position.

Station Name	**Code**	**Latitude**	**Longitude**
Aquaculture Basin south	AQS	31^{0} 9\ 12.6\\	29^{0} 55\ 37.9\\
Aquaculture Basin north	AQN	31^{0} 7\ 37.6\\	29^{0} 54\ 1.8\\
Main Basin East	MBE	31^{0} 9\ 35.3\\	29^{0} 55\ 20.64\\
Main Basin South	MBS	31^{0} 7\ 58.1\\	29^{0} 53\ 35.52\\
Main Basin North	MBN	31^{0} 8\ 48.5\\	29^{0} 53\ 3.12\\
West Basin South	WBS	31^{0} 7\ 29.3\\	29^{0} 52\ 45.12\\
West Basin North	WBN	31^{0} 7\ 44.8\\	29^{0} 51\ 34.56\\
South Basin South	SBS	31^{0} 4\ 24.6\\	29^{0} 52\ 20.28\\
South Basin West	SBW	31^{0} 6\ 25.9\\	29^{0} 53\ 57.84\\
South Basin East	SBE	31^{0} 6\ 25.9\\	29^{0} 55\ 6.6\\

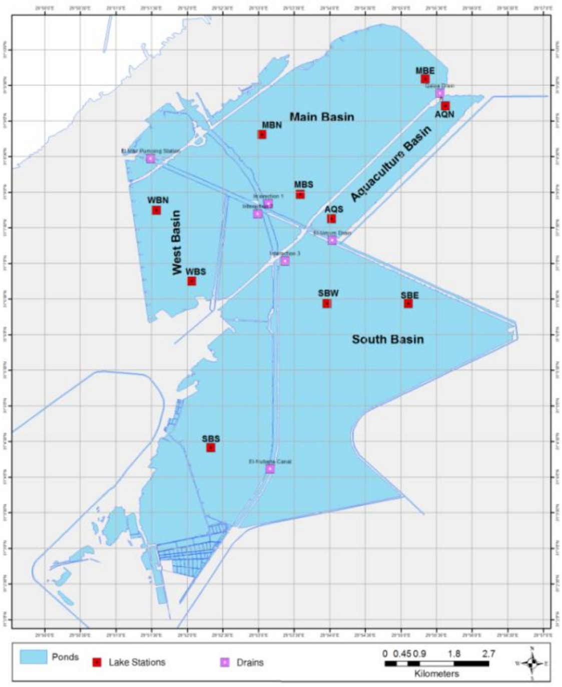

Figure (1): Map showing the location of Mariut Lake and the selected stations

Collection of samples

Ten stations were selected which covered the whole area of the lake (Table, 1 and Fig. 1). Water samples were taken seasonally using Ruttner Water Sampler bottle with capacity of 2L., the samples were preserved with a few drops of chloroform. For heavy metals determination, the samples were collected in clean plastic bottles and acidified with a few drops of concentrated nitric acid.

Methodology:

The methods described in the American Public Health Association (APHA, 2005) were used for determination of the abiotic parameters unless noted. pH values were measured during the time of sampling using Hydrolab model (Multi Set 430i WTW) after previous calibration. Dissolved oxygen was estimated by using the modified Winkler method. BOD was determined by using the 5 days method. COD was carried out using potassium permanganate method. Water alkalinity was determined immediately after collection of the samples, using phenolphthalein and methyl orange indicators. Chloride estimated using Mohr's method. Water hardness was determined using compleximetric method by EDTA. Ammonia was determined by phenate method. Nitrite was determined using colorimetric method while nitrate was determined by reduction method as described by Mullin and Riley (1956). Orthophosphate and total phosphorus were determined by using stannous chloride and acid molybdate method. Silicate was determined by using molybdate method. Total phosphorus and total nitrogen were determined according to APHA (2005).

For heavy metals, 10 ml nitric acid were added to 500 ml of mixed sample in a beaker. Slow boiling and evaporation on a hot plate were done to reach the lowest volume. Beaker walls were washed carefully with distilled water then the digested samples were transferred to a 100 ml volumetric flask and completed to the mark. For the determination of Fe, Mn, Zn, Cu and Pb in the total metals content and fractions, atomic absorption spectrometer model GBC model SavantAA AAS with Graphite Furnace GF 5000 was used.

The Contamination Index (C_d)

The relative contamination of studied metals was measured separately and manifests the combined effects of all metals as contamination index (C_d), which computed as follow (Backman et al., 1998):

$$C_d = \sum_{i=1}^{n} C_{fi}$$

Where, C_{fi} is calculated as the following equation:

$$C_{fi} = \frac{C_{Ai}}{C_{Ni}} - 1$$

Where: C_{fi} is the factor of contamination for i^{th} metal, C_{Ai} is the measured value for i^{th} metal and C_{Ni} is the upper allowable value of i^{th} metal (N refers to the normative value). C_{Ni} is considered as the standard permissible value

Statistical analysis

The results were tested for significant differences for studying parameters and sites by means of one-way ANOVA using Microsoft Excel (2007) and cluster analysis using Primer 5 progamme. Principal component analysis (PCA) a multivariate technique is usually applied to summarize the general trend and changes in chemical variables using correlation analysis. PCA was performed using CANOCO V. 4.0 (Ter Braak, 1987). In order to test the suitability of PCA for this data set, Kaiser-Meyer-Olkin (KMO) test was applied.

RESULTS AND DISCUSSION

Both of salinity and electrical conductivity (EC) in four sub-basins possessed similar distribution pattern where their values showed high significant variations ($P<0.01$) among basins, where the aquaculture basin (AQB) has the highest values of salinity and EC compared with the other basins (3.7-6.1 ppt and 7.9-10.66 mS/cm, respectively Table, 2), while, the main basin (MB) has the lowest values (1.5-3.6 ppt and 3.0-6.6 mS/cm, respectively), due to receiving drainage water from El-Qalaa and El-Omum. The basin's lake can be arranged according to their salinities and EC values as follows, Aquaculture Basin > South Basin > West Basin > Main Basin (Table, 2).

In general, the lake water was slightly alkaline during the study period with lower values in MB and WB, pH values ranged between 7.36 - 8.27 and 7.45 - 8.21 respectively (Table 2). Aquaculture basin (AQB) has the highest pH values 8.17 - 8.58. Main Basin water affected by sewage from El-Qalaa Darin especially at northern part of it, so the fermentation of organic matter and liberation of hydrogen sulphide and methane gases leads to decrease the pH values, these results coincident with that obtained by Chen et al (2010) for Lake Burullus.

Dissolved oxygen level showed high spatial significant variations ($P<0.01$) in different basin and insignificant temporal variation, which reflects the effect the sewage and industrial wastes dumping directly into lake water. Its values was completely depleted in in several lake's sites, particularly in the east and south of main basin as results of impact of sewage influx coming through Al-Qalaa Drain lead to the development of hypoxia or anoxia in water column (Cloern, 2001). The decrease in dissolved oxygen concentration in the water body directly affects survivals of fishes, migrations of higher organisms, and thus alters lake healthy ecological balance (Zheng et al., 2004). Higher dissolved oxygen concentrations were also observed at SBS (19.14 mg/l) confirming with high flourishing of macrophyte as mentioned by (Abd El-Karim, 2009) (Table, 2).

By comparing the present result with the previous works on Mariut Lake, dissolved oxygen in the main basin showed remarkable decrease than that recorded by

Aleem and Samaan, (1969), they reported that, the Main Basin showed average dissolved oxygen values ranged between 3.08-9.32 mg/l. In addition, the present results were less than that recorded by Ahdy (1982), El-Rayis et al. (1994) and El-Rayis (2005) for main basin (Table, 3).

BOD and COD values showed harmony spatial and temporal distribution pattern with considerable wide range of variations showed their highest values in MBS site (83.0 and 79.8 mg/l, respectively, Table, 2) as a result of drainage water impacts from Al-Qalaa Drain. These results agreed with that finding by Donia and Bahgat (2016) in Mariut Lake . Both BOD and COD values showed high significant spatial variations ($P<0.01$) and insignificant temporal variations for all basins except south basin, which showed high significant variation ($P<0.01$).

Bicarbonate alkalinity has relative variability range, southern basin showed lowest bicarbonate values ranged between (90 – 135 mg/l) with regional average of 123 mg/l while their values showed very narrow variability in other basins (Table, 2).

Chlorosity has elevated values in aquaculture basin ranged between (2.0 - 2.7 g/l with regional average of 2.5 g/l) due to it receives its water from drainage water of Al-Omum drain; also it seems to be closed basin. On the other hand, main basin exhibits the lowest chlorosity value (0.7 - 1.3 g/l with regional average of 1.2 g/l). These values coincide with Saad (2003) they reported the monthly chlorosity averages is 0.9 and 2.5 g/l in main basin and Aquaculture basin respectively. Calcium and magnesium showed synergistic distribution pattern showed their highest levels in the aquaculture basin followed by western basin, while main basin showed the lowest calcium and magnesium values (Table 2).

Nitrite and nitrate showed considerably wide range among four lake basins (Fig. 2 a & b), western basin showed highest NO_2 and NO_3 values with regional average of 0.5 and 1.03 mg/l respectively, followed by main basin with regional average of 0.34 and 0.76 mg/l respectively. On the other hand, Aquaculture basin has the lowest NO_2 and NO_3 values with average range of 0.04 and 0.07 mg/l respectively. The increasing nitrite and nitrate values in both western and main basins are due to the increase in the amounts of the allochthonous wastes introduced into the lake through the surrounding drains particularly in the El Qalaa Drain and the Western Water Treatment Plant (Saad, 2003).

The concentration of ammonia in the water column within the main basin showed and abrupt increase as a result of domestic sewage from El-Qalaa Drain, these values ranged between 3.4 - 12.5 mg/l with regional average of 7.5 mg/l which is above the recommended standard for surface waters of 187 – 473 depending on corresponding pH value (CCME, 2011) mg/l. The deterioration of fish production qualitatively and quantitatively in Lake Mariut especially in main basin could be reflected to the chronic exposure to elevate ammonia levels which reduce natural fish spawning and led to mass fish mortality and cause gill damage. Also ammonia reacts with chlorine to form chloramines, which is not as strong oxidant but provide longer-lasting residual free chlorine (Sentongo, 1998).

Table (2) Range and mean average concentration of some chemical variables at different selected stations in Mariut Lake .

Stations		EC (mS/cm)		Sal (ppt)		pH values	DO (mg/l)	
		Range	Mean	Range	Mean	Range	Range	Mean
aqua. Basin	AQS	6.7 - 9.4	8.4 ± 1.14	3.7 - 5.3	4.7±0.66	8.29 - 8.41	8.4 - 11.7	9.9±1.44
	AQN	10.4 - 10.7	10.5±0.15	4. 8 - 6.1	5.8±0.57	8.17 - 8.58	4.0 - 9.5	7.2±1.74
west basin	WBS	3.8 - 9	5.2±2.22	1.9 - 4.2	2.6±0.16	7.62 - 8.10	2.9 - 9.8	6.5±1.8
	WBN	5.3 - 7.1	6.2±0.74	1.1 - 1.6	2.8±0.05	7.45 - 8.21	0.9 - 3.8	2.1±0.24
main basin	MBE	3.1 - 3.3	3.2±0.09	1.5 - 1.6	1.6±0.05	7.36 - 7.90	0.0 - 3.1	1.0±0.24
	MBS	3.0 - 3.9	3.6±0.4	1.6 - 2.6	2.0±0.37	7.41 - 8.08	0.0 - 5.2	3.1±2.1
	MBN	4.9 - 6.6	5.6±0.65	2.3 - 3.6	3.0±0.48	7.44 - 8.27	3.6 - 9.9	5.4±0.54
South basin	SBS	5.3 - 6.6	6.0±0.46	2.8 - 8.6	4.2±1.1	8.17 - 8.56	5.9 - 19.1	13.6±2.53
	SBW	8.4 - 9.7	9.0±0.5	3.8 - 5.5	4.9±0.65	7.62 - 8.25	1.7 - 7.7	5.4±1.1
	SBE	8.1 - 9.4	8.8±0.54	3.2 - 5.3	4.6±0.85	7.45 - 8.15	3.8 - 11.0	7.0±1.05

Stations		BOD (mg/l)		COD (mg/l)		HCO_3^- (mg/l)		Cl^- (g/l)	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
aqu. Basin	AQS	24.4- 42.7	29.3±3.54	17.9 - 24.2	20.7±2.67	127 - 154	141±5.3	2.0 - 2.5	2.3±0.22
	AQN	21.5 - 30.0	25.7±3.61	17.5 - 23.2	20.0±2.50	129 - 156	142±5.3	2.7 - 2.8	2.7±0.07
west basin	WBS	22.9 - 49.6	29.8±3.61	18.5 - 24.5	21.3±2.50	124 - 159	145±5.2	0.9 - 2.3	1.3±0.06
	WBN	14.3 - 29.4	22.8±1.75	18.5 - 24.5	21.5±2.56	132 - 156	147±4.2	1.6 - 1.9	1.7±0.16
main basin	MBE	64.9 - 79.1	70.9±5.27	57.9 - 79.8	69.4±4.89	156 - 174	167±6.3	0.8 - 0.9	0.8±0.05
	MBS	55.1 - 83.0	74.8±2.80	55.9 - 77.1	65.8±4.57	149 - 166	157±4.0	0.7 - 0.9	0.8±0.10
	MBN	31.2 - 46.5	38.3±2.48	38.9 - 54.9	46.2±2.41	124 - 156	141±3.0	1.1 - 1.3	1.2±0.09
South basin	SBS	21.2 - 40.3	27.0±2.37	17.4 - 25.1	21.0±2.00	90 - 117	108±3.2	1.1 - 1.3	1.2±0.07
	SBW	16.8 - 42.1	23.8±2.6	18.3 - 24.9	21.2±2.78	125 - 135	131±3.0	2.2 - 2.5	2.3±0.14
	SBE	12.5 - 30.4	19.0±1.82	18.7 - 26.3	22.1±2.05	122 - 132	128±3.5	2.1 - 2.5	2.3±0.18

Stations		Ca (mg/l)		Mg (mg/l)		N:P		Si:P	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
aqu. Basin	AQS	159 - 278	229±17.62	413-631	527±12.5	2.6 - 4.5	3.7±0.66	20.1 - 26.6	24.8±6.8
	AQN	162 - 229	193±8.72	422-658	516±15.6	3.2 - 7.1	5.1±0.46	17.9 - 53.4	37.2±7.2
west basin	WBS	112 - 145	124±4.90	366-488	407±8.9	1.4 - 6.9	4.4±1.07	4.2 - 27.6	17.0±5.0
	WBN	99 - 146	115±5.65	317-462	402±8.3	5.6 - 10.5	7.7±1.91	3.4 - 12.8	7.9±4.36
main basin	MBE	46 - 71	57±2.71	190-242	207±5.25	2.6 - 6.0	4.4±1.25	1.4 - 5.7	2.9±1.6
	MBS	42 - 90	70±2.16	158-228	199±2.5	4.2 - 15.9	7.5±1.75	2.2 - 23.9	10.3±3.7
	MBN	72 - 100	84±4.51	202-248	223±2.81	2.2 - 10.0	4.7±3.02	3.6 - 15.1	11.2±3.5
South basin	SBS	75 - 129	94±4.02	334-385	362±3.59	5.2 - 11.0	8.4±2.33	1.5 - 15.0	8.4±2.56
	SBW	72 - 126	102±2.31	338-346	341±6.7	2.3 - 12.7	6.2±2.04	2.7 - 33.4	14.8±3.1
	SBE	69 - 133	88±2.23	286-391	332±5.78	2.6 - 7.3	4.5±2.14	5.6 - 21.0	12.5±3.2

Both TP and TN showed their highest values in the main basin (0.21-6.1 and 0.95-21.6 mg/l, respectively) compared with the other basins (Fig., 3d, e) while the south basin showed the lowest concentrations (0.16-0.57 and 0.78-2.99 mg/l, respectively). The increase of TP values are attributed mainly to (a) the increase in the amounts of the allochthonous phosphates introduced into the lake; (b) the increase in the rate of mineralization of the dead algae (Saad, 2003). TN and TP values fulfilled a positive relationship (r= 0.9, P<0.05). This reflecting the accidental releases from drain's sewage increase the N and P load to lake water.

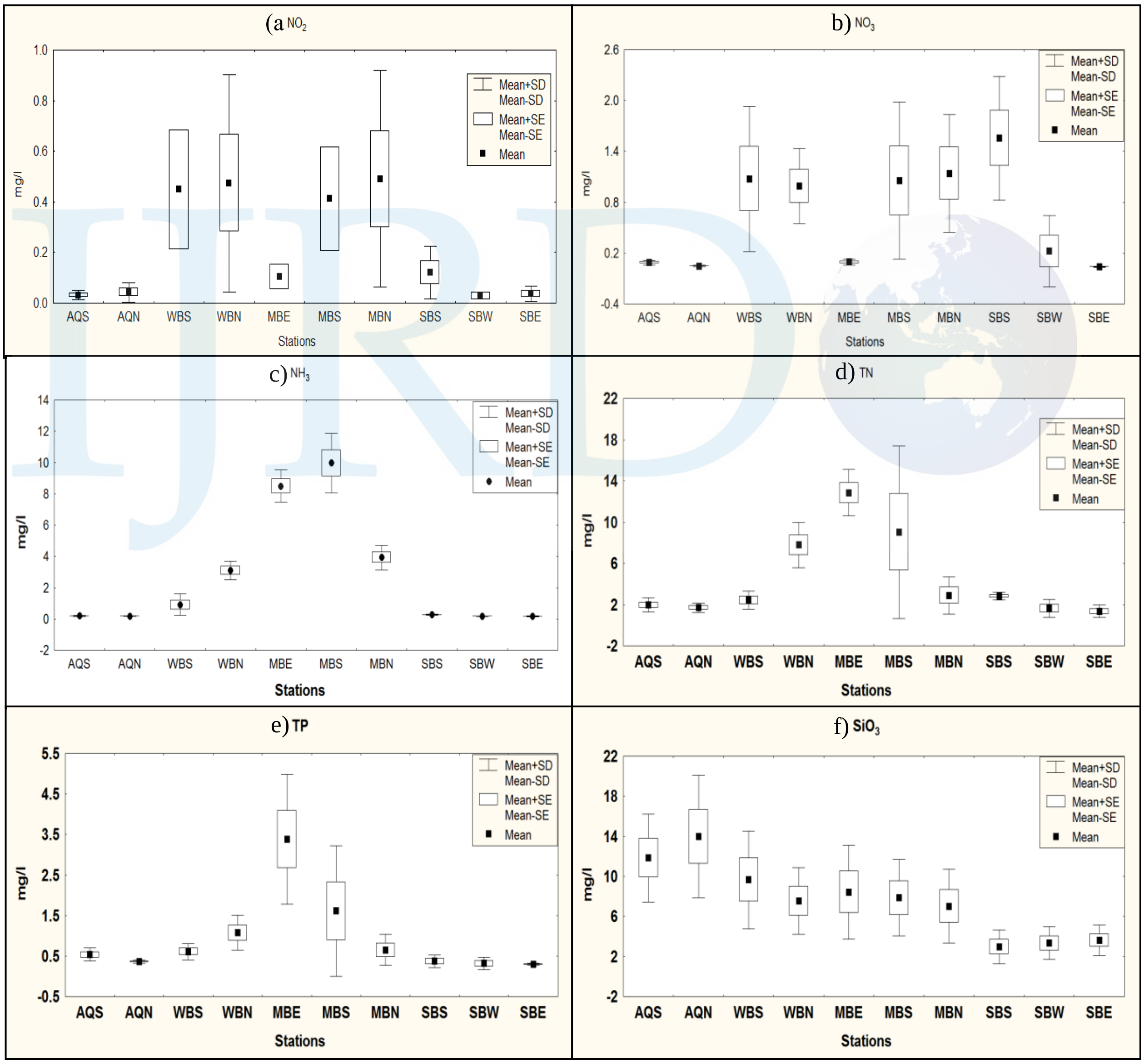

Fig. 2: Variation of a) nitrite; b) nitrate; c) ammonia; d) total nitrogen; e) total phosphorus and f) silicate in lake Mariut.

The water of aquaculture showed high increases in Si concentrations (6.0 – 22.4 mg/l) compared with others, followed by western and main basins respectively (Fig., 3f) while the south basin showed the lowest silicate concentrations (0.87-5.61 mg/l), these results coincides with that reported by Abd El-Karim (2009) who found that aquaculture basin rich with silicate values.

N: P ratio

The results of TN and TP ratios showed significant spatial variation ($P<0.05$) with highest ratio (16:1) found in the main basin followed by southern basin (12.7: 1) then western basin with value of 10.5: 1 (Table, 2). In aquatic systems nitrogen is considered potentially limiting if N:P is below 9, while phosphorus is considered potentially limiting at a N:P ratio of approx. 22 (Guildford et al., 2000). The present N:P ratios however around the values indicative of potential N limits on phytoplankton growth, or balanced growth limitation, but not P limitation.

Si: P ratios

Several other nutrients play an important role in the nutrient cycle of lakes. One of these is silicate, being an element of the skeleton of diatoms. The availability of silicate has not changed in consequence of human activities in the same way as the nitrogen and phosphorus input, but it may have changed, however, due to eutrophication, where decreased phosphorus loading has led to increased silicate concentrations due to declining abundance of diatoms and reduced silicate uptake (Barbiero et al., 2002).

The present results showed Si:P ratios at almost sites in main basin, western basin and southern basin predominantly were less than 20 except some cases exceeds than 20 but in the two sites of AQB it is exceeded 20. The increase in ratios at AQB (Table, 2), may be due to the abundance of diatoms in this baisn in comparison with other basins as illustrated by Abd El-Karim (2009) who said that diatoms and chlorophytes shared dominancy in expression in biovolume bases. However the main basin showed the lowest ratios especially in the east and south, close to the discharge points of El-Qalaa and El-Omum Drains. Enhanced diatom growth would be expected as a result of high silica concentrations. Furthermore, transition from non-diatom to diatom species occurs above Si:P from 3 to 20 (Domingues, et al., 2007).

The increase in Si: P ratio in the four basins declared the shift in phytoplankton community to increasing diatoms occurred, but this is controlled by the TN and TP concentrations (Turner et al., 2003). Finally, the present results showed that the average Si: P ratios varied significantly among different basins at $p < 0.05$.

Long term change of Chemical Characteristics of Mariut Lake

Using the available and useful aforementioned data are including comparisons between the different Mariut basins are used to indicate long term changes in two basins in Lake Mariut (Table, 3). Compares lightship data from last four decades;

1970s, 1980s and 1990s with recent data from the 2010. Main basin showed a slight increase in its salinity during recent data compared with others last four decades, while western basin showed an observed successive salinity increase (Table, 3). Dissolved oxygen contents were clearly degraded along years extend in Main basin especially in recent data which reach to complete depleted in most sites due to heavily organic load from Al-Qalaa Drain, western basin is well oxygenated during the comparison decades. The data obtained for nutrients (ammonia, nitrate, nitrite, total nitrogen and total phosphorus) showed a dramatically increase over the last four decades in main basin under the direct impacts of Al-Qalaa Drain. On the other hand, Western basin showed gradually increase in nutrients through 1970s to 1990s then an obvious increase was observed during recent data as a result of allochothonus inputs into the basin.

Table (3): Long term changes in some data of two basins of Mariut Lake

		Salinity (ppt)	DO (mg/l)	NH_4 (mg/l)	NO_3 (mg/l)	TN (mg/l)	TP (mg/l)	Ref.
Main Basin	1977-78	1.28	5.20	0.50	0.49	1.20	1.12	Ahdy (1982)
	1986-87	0.99	5.20	1.82	2.00	4.16	1.73	El-Rayis et al. (1994)
	1993-94	1.23	3.40	7.80	0.33	8.23	1.75	El-Rayis (2005)
	2009 - 10	1.90	2.70	11.50	0.21	8.90	1.90	Recent Work
Western Basin	1977-78	1.92	4.8	0.08	0.09	0.25	0.16	Ahdy (1982)
	1986-87	2.06	4.90	0.14	0.11	0.28	0.22	El-Rayis et al. (1994)
	1993-94	3.77	7.20	0.24	0.07	0.32	0.02	El-Rayis (2005)
	2009 - 10	3.30	6.40	3.23	0.47	5.00	0.80	Recent Work

Heavy Metals

In general, the heavy metals contents in Mariut Lake showed their maximal values at Main Basin especially at the discharged point of Al-Qalaa Drain at station MBE. On the other hand, the lowest values recorded at the Western Basin the lake (Fig., 3).

Iron contents in the lake fluctuated in a relatively wide range (Fig. 3a). The values incredibly increase at the eastern and southern section of main basin due to the impact of Al-Qalaa Drain which poured its sewage discharge in the area at MBE sites recording the maximum value (1952.6 µg/l), the values decreased progressively in other basin away from the drain recording the minimum value (522 µg/l) at south of western basin (WBS sites) (Fig. 3a). Manganese showed irregular fluctuation distribution in Mariut Lake, which highest value was recorded in Main Basin (84.4 µg/l) while the lowest value (20.2 µg/l) was detected at western basin (Figure 3b). On the other hand, manganese values showed considerable increase in both aquaculture and southern basins. Increasing values of manganese in Mariut Lake mainly attributed to the effect of allchothonus wastes which led to decomposition of organic debris by microbial activity (Sung and Morgan, 1981). This data is agreed with those obtained by El-Rayis and Saad (1990), they reported that heavy metals increased in the Main Basin more than the three other basin.

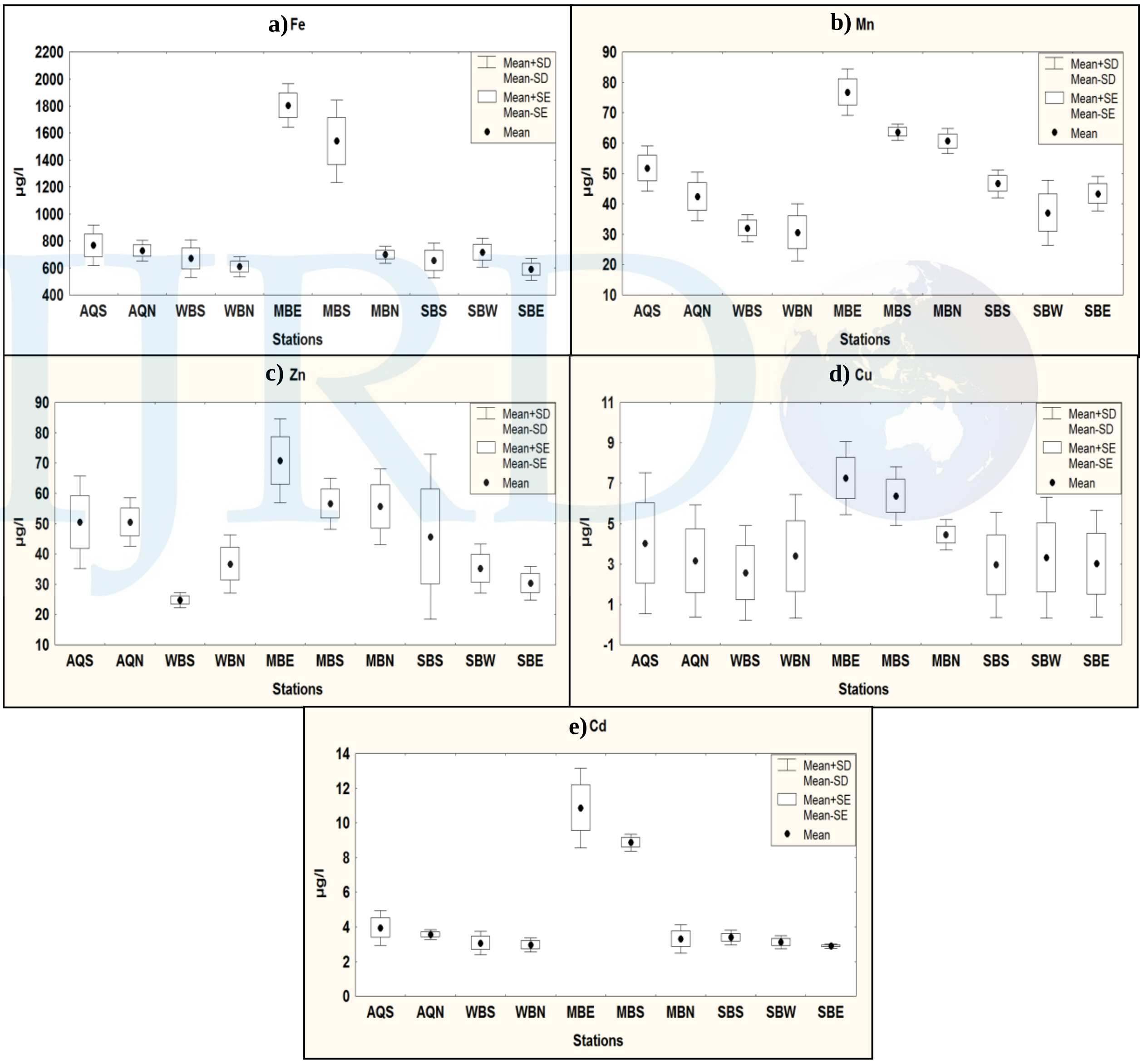

Fig. 3: Variation of a) iron; b) manganese; c) zinc; d) copper and e) cadmium in Mariut lake.

The obtained results of zinc and copper showed a relatively similar distribution pattern where there values were increased in Main Basin which was mainly attributed to the effect of allochothonus wastes from Al-Qalaa Drain recording 86.5 and 8.83 µg/l for Zn and Cu respectively, while the minimum value of 23.1 and 3.1 µg/l at western basin (Fig. 3 c&d). The results of cadmium exhibit a slight fluctuation except in Main Basin (Fig. 3e) which maintains the elevated cadmium values reached to 12.7 µg/l at MBE sites while minimum value of (2.5 µg/l) was recorded at station WBS at western basin.

The comparison between the four northern Lakes showed an observed increase of most metals values at Mariut Lake followed by Manzala except for manganese which their values were more than in Manzala Lake (Table, 4). Burullus Lake, ranked third then followed by Idku Lake. The obtained data showed that the values of all studied metals are higher than permissible levels cited by Canadian Council of Ministers of the Environment (CCME, 2007 & 2011).

Table (4): Comparison of heavy metals content (µg/l) in water of some northern Egyptian Lakes

	Fe	Mn	Zn	Cu	Cd	Ref.
Mariut	522 - 1952	20 - 85	23 - 86.5	3.0 - 8.8	2.5 - 12.7	Recent data
Manzalah	447 -1212	334 - 925	36 - 93	3 – 8	2.2 – 5.6	Ali (2008)
Burullus	25 – 60	*	18 – 55	11 – 33	2.9 – 8.5	Nafea and Zyada (2015)
Idku	80 – 1890	3 - 88	4 – 50	2 – 24	ND – 8	Saeed and Shaker (2008)
Permissible level	300	50	30	2	0.12	CCME (2007)

ND: not detected *: not available

Contamination index (C_d)

The degree of contamination (C_d) is an anthropogenic factor for each element was computed and the result presented in (Table 5). C_d factor is used to estimate the extent of metal pollution. (Al-Ami et al. 1987). Cd may be grouped into three categories as follows: high (Cd> 3), medium (Cd= 1-3) and low (Cd< 1). From the obtained results, the western and southern basins are moderate polluted sites whereas the C_d values ranged between 2.09 - 2.96 and 2.22 - 2.59 respectively. While the aquaculture basin is high polluted basin with C_d values ranged between 3.66 - 4.47. Main basin is highly polluted especially at MBS and MBE with values ranged between 10. 33 - 13.36

respectively (Table, 5). According to the C_d results of studied metals we can notice that the order of pollution increased as WB < SB < AQB < MB

Table 5. The calculated contamination index (C_d) for Mariut Lake

	C_{fi}_Fe	C_{fi}_Mn	C_{fi}_Zn	C_{fi}_Cu	C_{fi}_Cd	C_d
AQS	1.56	0.03	0.68	1.01	1.19	4.47
AQN	1.43	<0	0.68	0.58	0.98	3.66
WBS	1.23	<0	<0	0.28	0.71	2.22
WBN	1.03	<0	0.22	0.70	0.64	2.59
MBE	5.01	0.54	1.36	1.42	5.04	13.36
MBS	4.13	0.27	0.89	1.12	3.92	10.33
MBN	1.33	0.21	0.85	0.48	0.84	3.71
SBS	1.18	<0	0.52	0.48	0.88	3.06
SBW	1.38	<0	0.17	0.66	0.74	2.96
SBE	0.96	<0	0.01	0.51	0.61	2.09
min.	0.96	<0	<0	0.28	0.61	2.09
mix.	5.01	0.54	1.36	1.42	5.04	13.36

Cluster analysis

To identifying the specific contamination area, cluster analysis was used. Figure 4 shows four distinct dendrograms summarizing to large extent the four sampling basins of Mariut Lake. Two major clusters are noted (Ma and Mb). Clusters Ma including main basin sites (MBS and MBE) representing highly contaminated sites where ecotoxicological damage might be occurring. Ma cluster was located below major suspected pollution sources from Al-Qalaa Drain (i.e., large quantities of discharge of urban sewage and industrial wastewater). Accordingly, these sites should be given first priority in initial remediation efforts. Mb cluster contains three sub-cluster which represented sites of moderate (WBS, WBN and MBN) and lower (AQS, AQN, SBS, SBW and SEB) pollution sites in the lake.

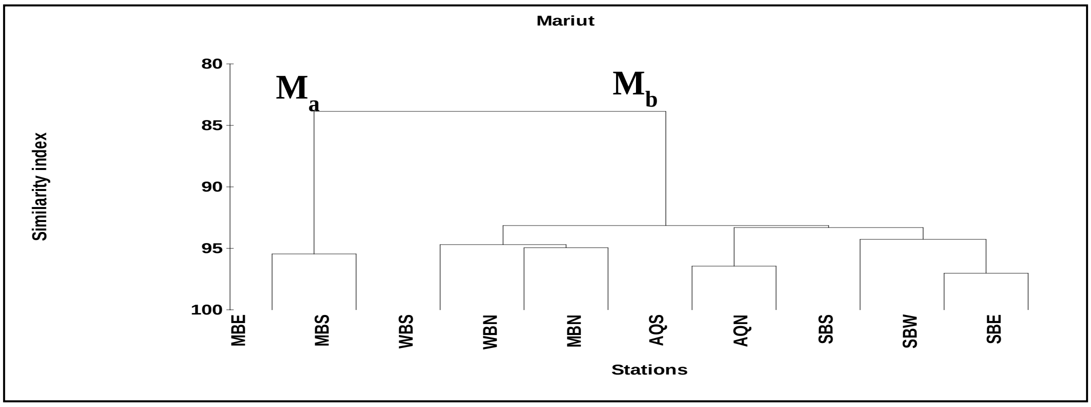

Figure 4. Dendrogram indicating linkage of sites on the basis of element concentrations

Principal Component Analysis (PCA)

PCA is a powerful technique which explains the variability of a data set by providing a new set of variables called principal components which are uncorrelated and appear in decreasing order of importance (Jollieffe 2002).

Principal component analysis (PCA) showed that, most parameters lied along X axis especially at right site (Fig. 5). The obtained KMO values ranged between (0.75 – 0.92 with $p < 0.05$) which are closer to 1 indicating that patterns of correlation are compact and should yield distinct factors (principal components) so that, the combination of highest nutrient and heavy metals associated with heavily polluted zones (Field 2009).

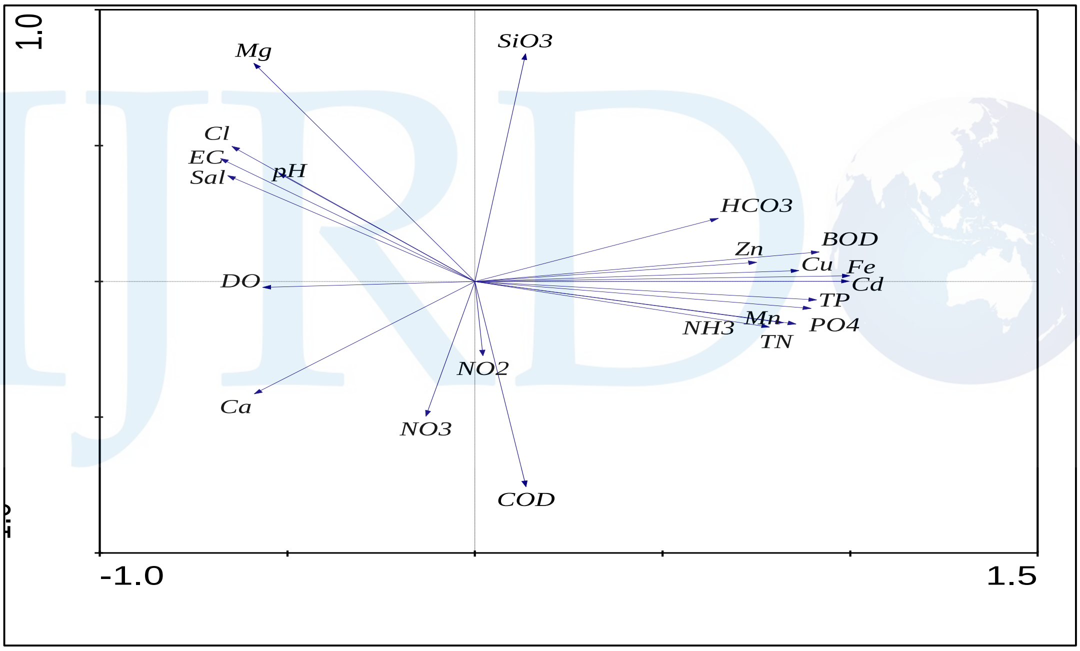

Figure (5): Principal component analysis (PCA) ordination of sampling stations based on studied parameters

Conclusion

Mariut Lake composed of four basins, suffering serious ecological problems (i.e. DO depletion, enrichment by nutrient salts causing eutrophication) which attributed to municipal, industrial and agricultural sewage especially from Al-Qalaa Drain flowing to Main Basin. The water quality parameters levels showed remarkable increase than the previous studies. On the other hand, Aquaculture Basin has the highest values of salinity. The present N: P ratios indicated a potential N limits on phytoplankton growth, or balanced growth limitation, but not P limitation. Also, the increase in Si: N and Si: P ratio in the four basins declared the shift in phytoplankton community to increasing diatoms. In general, Mariut Lake maintained high levels more than other northern Egyptian lakes. Contents of all metals exceeds than permissible levels

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