

Physicochemical Properties of Manzala Lake, Egypt

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PHYSICOCHEMICAL parameters such as temperature, total dissolved solid (TDS), pH, salinity, dissolved oxygen (DO), biological oxygen demand (BOD), permanganate index (PI), chloride and nutrient salts were measured in water samples, collected from 12 sites of Manzala Lake during winter and summer, 2015. A lot of fluctuations were observed in these parameters affected by the poor connection of water body of the lake and the diversity of the incoming flows. The pH values of water were alkaline throughout the lake and closely correlated with widely varied salinity and DO values. BOD increases in the south eastern-located sites affected mostly by Bahr El Baqur drain effluents especially during winter during the scheduled water block. PI was highly influenced by the agricultural and domestic waste effluents. Nutrients salts ranged between 5.47-249, 2.61-15.1, 0.64-24.5, and 3.47-22.9 $\mu\text{mol L}^{-1}$ for ammonia, nitrite, nitrate and phosphate, respectively. N/P ratios (2.28-12.8) in the present study indicated that nitrogen is the limiting factor for phytoplankton fluorination except for some sites in the south eastern region. The levels of total polycyclic aromatic hydrocarbons were found affected by the seawater inflows during winter. It can be concluded from obtained data that the south eastern region showed worst water quality parameters.

Keywords: Brackish water, Nutrients, Physicochemical parameters, Total polyaromatic hydrocarbons.

Introduction

Manzala Lake (Fig. 1) is the largest coastal lake in Egypt which is a shallow brackish lake extending between the Damietta Nile River branch and the Suez Canal with a maximum length of 50 km along the Mediterranean coast [1]. The northern boundary of the lake is connected with some narrow inlets such as El-Gamil canal with the sea. The eastern boundary is Suez Canal that is connected with the lake via El-Qabuty canal. Economically, Manzala Lake is considered as one of the most valuable fish sources in Egypt by about 36-50% from the total annual production of the Egyptian lakes. This contributes > 4.2% of the total country fish production; ca. 1.5 million ton [2,3].

During the last few decades, the lake has undergone obvious environmental changes due

to human activities that have a serious impact on the lake. The lake changed from a connected regenerated saline water body to semi-closed sub-basins as far as the narrow water exchange inlets are not sufficient. Also, the lake receives large amounts of untreated sewage and irrigation returns; ca. 3 milliard m³ annually [4]. Domestic, agricultural and industrial effluents are brought from urban centers along the lengths of main drains such as Bahr El Baqur through which more than 30% of the inflow passes to the lake [5]. Hydrological conditions of lake water affects the aquaculture activities resulting in a decrease in fish productivity, change in species composition avifauna, eutrophication and an overall loss of biodiversity [3,6].

Water quality monitoring is the integrated activity for assessing the physical, chemical and biological features of water in relation to human

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health, ecological conditions and designated water uses [7]. The most widely measured quality parameters are pH, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), turbidity, and chlorophyll.

In addition, the discharge of nitrogen to the lake water is of concern for a number of reasons. Excessive accumulation of nitrogen in surface waters can lead to ecological inequities that may cause overgrowth of plants and animals, leading to water quality degradation (eutrophication). Ammonia nitrogen may deplete DO in natural waters by microbial nitrification reactions. Also, high ratio of the unionized ammonia species develops at high pH that is toxic to fish and other aquatic life [7]. Nitrate and nitrite constitute a public health concern, primarily related to methemoglobinemia and carcinogenesis [8].

Recent reports encountered that Manzala Lake is contaminated with levels of organochlorines, although not higher than the maximum permissible level [9-11]. On the other hand, the highest contents of total polycyclic aromatic hydrocarbons (TPAHs) in the surface sediments along the Egyptian Mediterranean coast were found in the seashore near Manzala Lake; 4895-6338 ng g⁻¹ [12].

Fortunately, pollutants usually concentrate in the liver, kidney or gill tissue of fish species and not to the same extent in the body muscles that make it safe food if these organs are discarded [13,14]. However, continuous assessment of water quality parameters is necessary to monitor and understand the effect of different water resources on water quality of Manzala Lake. The aim of the present study is to assess the physicochemical properties of water in Manzala Lake during winter and summer 2015.

Materials and Methods

Study area

Manzala Lake is located on the northeastern edge of the Nile Delta within three governorates; Dakahlia, Damietta and Port Said, and separated from the Mediterranean Sea by a sandy beach bridge [15]. It is located between latitudes 31°07'N and 31°30'N and longitudes 31°48'E and 32°17'E (Fig. 1). Over 1,000 islands of different sizes are scattered throughout the lake, some of them are inhabited. Large areas in the north-west of the lake have been changed into fish farms, while much of the southern part of the lake

is being prepared for its conversion to agricultural use. Wastewater effluents are flowing into Manzala Lake from nine major drains and canals. Faraskur, Al Sarw, Baghous, Abu Garida and Bahr El Baqur are the most important of them. The last drain is the most polluted which carries mostly untreated wastewater originating from Cairo and contributing much to the deteriorating water quality of the lake. The samples were collected two times during a 1-year period (10/2/2015 and 15/9/2015) as described below.

Samples collection

Surface water samples were collected from 12 sampling sites along Manzala Lake using Nansen bottles at a 50 cm depth during the period of study. Sampling sites were covering different criteria of the lake as detailed in Table 1 and Fig.1. The water samples were filtrated through a Whatmann filter paper in order to remove debris and particulates. The filtrated water samples were then kept at -15 °C until further analysis.

Procedures

Results were averages of 5 replicates with RSD below 2%. Samples have been subjected to various analyses at the time of sampling including water temperature (T) using a digital thermometer, depth by standard meter, pH value and EC by using portable devices (pH meter model HI 8314 and digital conductivity meter HI2300 Hanna Ins. Romania).

TDS, DO, biochemical oxygen demand (BOD₅), permanganate index (PI), chloride content (Cl), alkalinity, ammonia, nitrite, nitrate, dissolved reactive phosphate and total polyaromatic hydrocarbons (TPAHs) were analyzed in the laboratory by following standard methods [16].

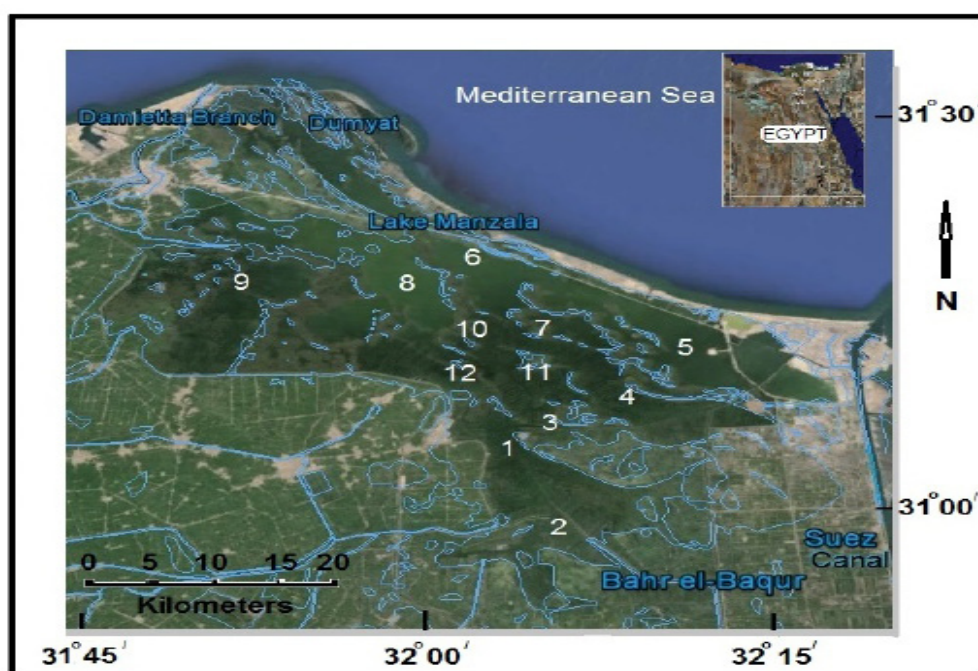
The pH value was confirmed in laboratory by Consort C860 (Parklaan), 36 B-2300 Turnhout. TPAHs were measured by digital spectrofluorometer model 450 from Sequioa-turner Corporation. Nutrient salts; NH₃, NO₂⁻, NO₃⁻ and PO₄³⁻ were determined by using Beckman Du-6-UV-Visible single beam spectrophotometer.

Statistical analysis

Pearson correlation bivariate two-tailed test were used to evaluate the significant difference in water quality parameters of different study sites. A probability at level of 0.05 or less was considered significant [17].

TABLE 1. Sites of water samples collected from Manzala Lake and their influencing effluents

Site	Latitude			Longitude			Nearest effluent	Type of effluent	Mean inflow, m ³ /s
	°	'	"	°	'	"			
1 (El-Matteriah)	31	09	23	32	05	17	Ramsis Hadus	agricultural waste agricultural waste	19. [4] 5.44 [15]
2 (Genka)	31	06	06	32	06	41	Ramsis Hadus	agricultural waste agricultural waste	19.1 [4] 5.44 [15]
3 (Ras Set Elbanat)	31	10	55	32	05	56	Ramsis Hadus	agricultural waste agricultural waste	19.1 [4] 5.44 [15]
4 (Elbashtir)	31	1	40	32	09	24	new Bahr Elbaqur	mixed wastes	50.4 [15]
5 (El-Gamil)	31	14	31	32	11	50	El- Qabuty El-Gamil Alhuria-Port Said	seawater seawater sewage	- - -
6 (Temsah)	31	19	48	32	02	53	El-Dibah Rattama	seawater brackish water	- -
7 (Kassab)	31	16	24	32	05	49	-	-	-
8 (Alhomra)	31	18	49	32	00	04	-	-	-
9 (Elzarka)	31	19	09	31	54	25	Inania Faraskour El-Serw	agricultural waste agricultural waste agricultural waste	9.81 [4] 1.64 [4]
10 (Bahr Kromlos))	31	15	51	32	03	23	-	-	-
11 (Legan)	31	13	13	32	05	41	-	-	-
12 (Deshdy)	31	13	40	32	03	08	El-Gamaliyah El-Matariya	agricultural waste agricultural waste	- -

**Fig. 1. Map of Manzala Lake showing sampling station.**

Results

Physicochemical parameters

Table 2 shows the physicochemical parameters of Manzala Lake during 2015. The temperature ranged between 14 and 27.5. The pH of water was found to be slightly alkaline throughout the year with the range of 7.65 to 8.88.

EC strongly varied between the values 1.78 and 29.2 mmhoS/cm with average values 10.3 and 3.36 mmhoS/cm during winter and summer, respectively. However, the corresponding median values were 3.71 and 3.15 mmhoS/cm and the relative standard deviation (RSD) 97.5 and 46.8%, respectively. Also, TDS and salinity varied widely throughout the lake. During winter season, maximum values of TDS and salinity were 18.5 and 19.8 g/L, in site 5 and minimum values were found to be 1.19 and 1.10 g/L, respectively, in El Matteria area (site 1). During summer, their maximum values were 4.73 and 4.6 g/L in site 6, respectively, and minimum values were 1.11 and 1.0 g/L, in site 1, respectively.

The DO of surface water in Manzala Lake varied widely throughout as can be concluded from its RSD along Manzala Lake. Maximum values of DO during winter and summer were 11.8 and 8.6 mg/L in site 6 whereas minimum values were 1.6 and 1.25 mg/L in site 4.

Maximum values of BOD were 56.8 and 52.8 mg/L during winter and summer, respectively in site 1; whereas minimum amounts of BOD were found to be 5.76 and 5.2 mg/L in sites 7 and 6 during winter and summer, respectively. High BOD values (34.2–56.8 mg/L) and low DO levels (1.25–5.2 mg/L) were observed in sites 1–4. Average BOD values were 32.1 and 28.9 mg/L in water and summer, respectively.

Permanganate index of water of Manzala Lake had minimum values of 1.28 and 12.0 mg/L in sites 12 and (1 & 6); whereas maximum values were 4.0 and 22.0 mg/L in sites (4 & 5) and 5 during winter and summer, respectively. Mean PI values during summer were remarkably higher than during winter.

TABLE 2. Physicochemical parameters of Manzala Lake during 2015.

Parameter Site	T, °C		pH		EC mmhoS/cm		TDS g/L		Salinity ‰		DO		BOD		PI		Chloride (g L ⁻¹)		Alk (mg CaCO ₃ L ⁻¹)	
	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S
	(mg L ⁻¹)																			
1	14	25	7.71	7.88	2.02	1.78	1.19	1.11	1.10	1.00	5.2	1.76	56.8	52.8	3.60	12	0.440	0.355	178	186
2	14	25.5	7.80	7.78	3.39	2.82	2.02	1.63	1.90	1.50	2.64	1.68	48.0	44.24	3.60	14.8	0.900	0.655	256	228
3	14	26	7.70	7.93	3.59	3.50	2.16	2.08	2.00	1.90	4.4	3.84	55.5	51.2	3.84	18.8	1.02	0.910	174	207
4	14	26	7.65	8.7	3.59	3.53	2.15	2.13	2.00	1.90	1.6	1.25	42.5	34.2	4.00	17.2	1.01	0.885	196	193
5	14	26	7.83	8.46	29.2	3.73	18.5	2.20	19.8	2.10	9.2	4.00	18.0	17.5	4.00	22.0	13.0	0.995	127	198
6	14	26	8.88	8.48	26.0	7.90	16.4	4.73	17.3	4.60	11.8	8.60	11.2	5.20	2.80	12.0	11.9	2.63	123	208
7	14	26.5	7.71	8.51	16.8	3.72	10.4	2.24	10.8	2.10	8.0	7.20	5.76	6.60	1.60	18.8	5.20	0.945	159	211
8	14	27	7.86	8.52	20.4	3.35	12.7	1.99	13.4	1.80	10.4	8.00	10.9	6.30	1.60	16.0	7.40	0.825	147	214
9	14	27	7.90	8.45	9.40	2.94	6.60	1.76	6.50	1.60	10.8	2.92	40.5	42.0	2.40	18.8	3.40	0.690	174	180
10	14	27.5	7.75	8.15	3.83	2.68	2.27	1.57	2.10	1.40	4.02	2.60	30.5	22.5	3.52	16.8	0.700	0.585	177	192
11	14	27.5	7.98	7.97	3.29	2.44	1.96	1.44	1.80	1.30	7.64	5.01	12.48	9.72	2.00	15.8	0.400	0.525	179	208
12	14	27.5	7.70	7.76	2.21	1.95	1.31	1.14	1.20	1.10	8.90	1.28	6.66	6.40	1.28	16.0	0.540	0.395	178	182
Mean	14	26.5	7.87	8.22	10.3	3.36	6.47	2.00	6.66	1.86	7.12	4.36	32.1	28.9	2.85	16.6	3.83	0.866	172	201

W, S and Alk denote winter, summer and Alkalinity, respectively.

Chloride concentration varied widely throughout the lake. Maximum values were 13.0 and 2.63 g/L in sites 5 and 6 during winter and summer, respectively. Minimum amounts (0.4 and 0.355 g/L) were recorded in sites 11 and 1 during winter and summer, respectively.

Alkalinity maximum values (256 and 228 mg/L) were recorded in site 2 during winter and summer, respectively. Minimum values (123 and 180 g/L) were recorded in sites 6 and 9 during winter and summer, respectively.

Nutrient levels

Table 3 shows the variation of major nutrient salts in Manzala Lake during 2015. Ammonia ranged from 6.31 $\mu\text{mol L}^{-1}$ at site 11 to 81.9 $\mu\text{mol L}^{-1}$ at site 4 during winter and from 5.47 $\mu\text{mol L}^{-1}$ at site 9 to 249 $\mu\text{mol L}^{-1}$ at site 5 during summer. The ammonia levels were concentrated in the eastern sites of Manzala Lake.

Nitrite ranged from 2.61 $\mu\text{mol L}^{-1}$ at site 4 to 13.8 $\mu\text{mol L}^{-1}$ at site 3 during winter and from 4.26 $\mu\text{mol L}^{-1}$ at site 9 to 15.1 $\mu\text{mol L}^{-1}$ at site 5 during summer. Nitrate ranged from 3.3 $\mu\text{mol L}^{-1}$ at site 8 to 24.5 $\mu\text{mol L}^{-1}$ at site 12 during winter

and from 0.64 $\mu\text{mol L}^{-1}$ at site 2 to 2.84 $\mu\text{mol L}^{-1}$ at site 6 during summer. Average nitrite level during winter was slightly higher than summer. In contrast, average nitrate level in winter is much higher than summer.

Dissolved reactive phosphate ranged from 6.34 $\mu\text{mol L}^{-1}$ at site 6 to 17.7 $\mu\text{mol L}^{-1}$ at site 4 during winter and from 3.47 $\mu\text{mol L}^{-1}$ at site 9 to 22.9 $\mu\text{mol L}^{-1}$ at site 5 during summer. Average PO_4 level during winter is slightly higher than summer and the fluctuations during summer are apparently higher than winter.

Total Polycyclic aromatic hydrocarbons.

Figure (2a and b) shows the TPAHs levels which were generally high in sites close to open seawater inlets during winter and low during summer. Maximum value of TPAHs during winter was 4.75 $\mu\text{g/L}$ in site 11 whereas minimum value was 0.512 $\mu\text{g/L}$ recorded in site 2. Maximum value of TPAHs, during summer, was 2.68 $\mu\text{g/L}$ in site 1 whereas minimum value was 0.25 $\mu\text{g/L}$ in site 5. Average TPAHs values during winter (2.39 $\mu\text{g/L}$) was higher than during summer (1.85 $\mu\text{g/L}$).

TABLE 3. Nutrient salts of water collected from Manzala Lake during 2015.

Parameter Site	ammonia		nitrite		nitrate		phosphate	
	$\mu\text{mol L}^{-1}$							
	W	S	W	S	W	S	W	S
1	67.0	41.2	9.23	4.96	19.9	2.08	9.03	9.50
2	59.9	48.1	10.9	5.05	16.9	0.64	14.7	12.5
3	41.7	89.9	13.8	4.63	24.0	1.00	10.1	9.79
4	81.9	248	2.61	4.96	8.63	1.44	17.7	19.9
5	28.2	249	3.98	15.1	4.43	2.20	11.7	22.9
6	8.19	14.8	3.49	5.01	4.43	2.84	6.34	5.86
7	10.4	9.07	7.13	6.36	19.6	2.20	9.79	6.07
8	14.7	6.97	3.86	4.91	3.30	1.20	8.92	4.87
9	12.2	5.47	5.45	4.26	8.16	1.44	11.3	3.47
10	13.8	7.51	8.59	4.68	20.7	0.96	9.55	5.37
11	6.31	5.89	3.60	6.55	23.0	1.24	9.76	5.16
12	33.6	23.4	8.18	8.28	24.5	1.44	8.79	7.19
Mean	31.5	62.4	6.74	6.23	14.8	1.56	10.6	9.38

W and S denote winter and summer, respectively.

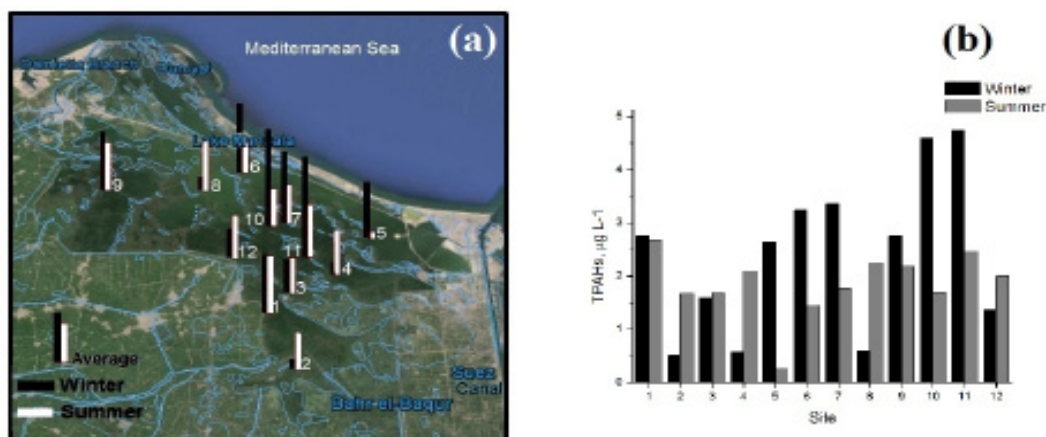


Fig. 2. Relative variation of TPAHs ratio in Manzala Lake during winter (black) and summer (gray).

Statistical correlation

The Pearson correlation co-efficient (PC) among various water quality parameters are given in Table 4. Matrix analysis showed that there were highly significant positive correlations ($P \leq 0.01$) between EC vs. TDS, salinity and chloride; TDS vs. salinity and chloride; salinity vs. chloride; and ammonia and TIN during the studied seasons. Also, significant positive correlations ($0.01 < P < 0.05$) were found between DO vs. EC, TDS, salinity and Cl during the same period. On contrary, significant negative correlations were detected between DO and BOD during winter and summer.

During winter, highly significant positive correlations were detected between PO_4 vs. ammonia and TIN whereas a highly significant negative correlation was observed between nitrite and TPAHs.

During summer, the bi-variants PI vs. BOD and TIN vs. BOD were highly positively correlated whereas alkalinity vs. EC, TDS, salinity; DO and Cl; DO vs. ammonia and TIN; and nitrate vs. EC, TDS, salinity and Cl were highly negatively correlated.

Significant positive correlations ($0.01 < P < 0.05$) were found between the parameters nitrite vs. PO_4 ; DO and nitrate vs. EC, TDS, salinity and chloride during winter and between the parameters: pH vs. chloride; alkalinity vs. TIN and PO_4 ; and ammonia vs. BOD, PI and PO_4 during summer. Moreover, significant inverse correlations were detected between DO vs. BOD, PI and PO_4 ; ammonia vs. TPAHs; and TIN vs. EC, TDS, salinity and chloride during summer.

Discussion

Manzala Lake receives large amounts of untreated sewage and irrigation returns (ca. 3 milliard m^3 annually) from five major governorates located in the northern of Egypt; Damietta, Dakahlia, Sharkiya, Ismailia and Port Said [4]. In addition, the gross area of the lake was reduced as estimated by satellite images during 1973 - 2013 from 1,100 km^2 in 1973 to 1052 km^2 in 1984, to 720 km^2 in 2003 and finally became 385 km^2 in 2013 [5, 18]. They attributed this shrinking to the reclamation activities and to the construction of the coastal highway. This is affirmed by the gradual decrease in wet lands pictured by goggle maps within the period 1972 - 2015 (Fig. 3). This continuously changing morphology of Manzala Lake has direct impact on its water quality and may lead to many side effects to the consumers which made continuous monitoring of water quality a mandate.

Physicochemical parameters

The pH of water samples was within the prescribed limits, *i.e.* 6.5 to 9.0 [19,20]. The pH values were generally high in northern sites influenced by the inflows from the seawater inlets especially during winter. It is known that during winter, a water block of fresh water flow during January is annually scheduled causing inflows from seawater to be highly effective [21]. However, pH in sites 6 (during winter), 4, 7 and 8 (during summer) were slightly higher than common pH values in coastal seawater (8-8.5) indicating a probable state of eutrophication [20]. This can be supported by the observation of higher average pH value during summer than winter as the growth of aquatic organisms flourishes in warm weather at pH values ranging from 6.5-8.5 [20]. So the water was conducive for growth of water organisms.

TABLE 4. Pearson bivariate correlation co-efficient of water quality parameters in Manzala Lake during 2015.

		Winter correlations														
		pH	EC	TDS	Sal	DO	BOD	PI	Cl	Alk	Amm	NO ₂	NO ₃	TIN	PO ₄	TPAHs
pH	PC		0.52	0.53	0.50	0.48	-0.32	0.33	0.47	-0.03	0.35	0.08	0.44	0.35	0.20	-0.24
	Sl2		0.086	0.080	0.098	0.117	0.309	0.294	0.121	0.923	0.264	0.806	0.153	0.266	0.540	0.445
EC	PC			1.00**	1.00**	0.67*	-0.35	-0.18	0.997**	0.31	0.05	-0.03	0.61*	0.05	0	-0.41
	Sl2			0.000	0.000	0.017	0.269	0.577	0.000	0.325	0.876	0.939	0.035	0.870	0.999	0.180
TDS	PC				1.00**	0.67*	-0.34	-0.19	0.997**	0.30	0.05	-0.03	0.63*	0.05	-0.00	-0.40
	Sl2				0.000	0.017	0.279	0.561	0.000	0.346	0.874	0.918	0.030	0.869	0.995	0.197
Sal	PC					0.67*	-0.36	-0.20	0.999**	0.29	0.04	-0.01	0.65*	0.04	-0.01	-0.41
	Sl2					0.018	0.256	0.543	0.000	0.361	0.900	0.983	0.023	0.891	0.988	0.181
DO	PC						-0.62*	-0.07	0.65*	0.48	-0.33	-0.02	0.47	-0.32	-0.38	-0.14
	Sl2						0.031	0.828	0.021	0.114	0.300	0.941	0.119	0.314	0.228	0.665
BOD	PC							-0.03	-0.34	-0.15	0.21	-0.33	-0.36	0.19	0.23	0.20
	Sl2							0.927	0.282	0.646	0.519	0.300	0.254	0.555	0.466	0.545
PI	PC								-0.23	-0.10	0.48	0.55	-0.14	0.49	0.39	-0.55
	Sl2								0.478	0.748	0.115	0.065	0.657	0.108	0.208	0.063
Cl	PC									0.29	0.03	-0.02	0.64*	0.04	-0.01	-0.40
	Sl2									0.368	0.918	0.946	0.027	0.910	0.975	0.198
Alk	PC										-0.10	-0.09	-0.18	-0.11	0.02	-0.18
	Sl2										0.748	0.774	0.577	0.742	0.960	0.571
NH ₄	PC											0.55	0.11	1.00**	0.96**	-0.52
	Sl2											0.065	0.729	0.000	0.000	0.082
NO ₂	PC												0.33	0.57	0.60*	-0.73**
	Sl2												0.298	0.051	0.037	0.007
NO ₃	PC													0.13	0.09	-0.28
	Sl2													0.694	0.772	0.374
TIN	PC														0.96**	-0.54
	Sl2														0.000	0.071
PO ₄	PC															-0.57
	Sl2															0.054
TPAHs	PC															
	Sl2															

PC: Pearson Correlation. P=St₂: Sig. (2-tailed). ** =very significant. * =moderate significant.

		Summer Correlations														
		pH	EC	TDS	Sal	DO	BOD	PI	Cl	Alk	NH ₄	NO ₂	NO ₃	TIN	PO ₄	TPAHs
pH	PC		0.54	0.54	0.54	0.57	-0.35	-0.11	0.59*	-0.47	-0.45	-0.40	-0.45	-0.56	-0.49	0.28
	Sl2		0.071	0.069	0.072	0.054	0.271	0.744	0.043	0.126	0.147	0.203	0.147	0.058	0.106	0.382
EC	PC			1.00**	1.00**	0.68*	-0.54	-0.10	0.989**	-0.76**	-0.47	-0.52	-0.75**	-0.68*	-0.31	0.07
	Sl2			0.000	0.000	0.016	0.069	0.769	0.000	0.004	0.123	0.086	0.005	0.015	0.333	0.839
TDS	PC				1.00**	0.69*	-0.53	-0.09	0.99**	-0.76**	-0.47	-0.52	-0.76**	-0.69*	-0.30	0.07
	Sl2				0.000	0.014	0.075	0.770	0.000	0.004	0.118	0.083	0.004	0.013	0.338	0.832
Sal	PC					0.68*	-0.53	-0.09	0.99**	-0.76**	-0.47	-0.52	-0.76**	-0.68*	-0.30	0.07
	Sl2					0.014	0.074	0.781	0.000	0.004	0.125	0.084	0.005	0.015	0.339	0.841
DO	PC						-0.66*	-0.62*	0.66*	-0.73**	-0.75**	-0.46	-0.44	-0.83**	-0.67*	0.24
	Sl2						0.019	0.031	0.019	0.007	0.005	0.135	0.157	0.001	0.017	0.453
BOD	PC							0.73**	-0.49	0.55	0.69*	0.56	0.18	0.72**	0.45	-0.27
	Sl2							0.007	0.108	0.066	0.013	0.060	0.582	0.009	0.141	0.389
PI	PC								-0.01	0.21	0.60*	0.24	-0.12	0.52	0.49	-0.11
	Sl2								0.971	0.510	0.039	0.450	0.722	0.084	0.104	0.741
Cl	PC									-0.76**	-0.41	-0.51	-0.76**	-0.63*	-0.30	0.05
	Sl2									0.004	0.182	0.093	0.004	0.027	0.349	0.873
Alk	PC										0.57	0.47	0.45	0.68*	0.61*	-0.35
	Sl2										0.055	0.121	0.145	0.016	0.033	0.257
NH ₄	PC											0.27	0.10	0.93**	0.68*	-0.61*
	Sl2											0.392	0.764	0.000	0.015	0.034
NO ₂	PC												0.68*	0.55	-0.06	-0.14
	Sl2												0.015	0.066	0.847	0.657
NO ₃	PC													0.45	-0.13	0.26
	Sl2													0.146	0.693	0.407
TIN	PC														0.55	-0.48
	Sl2														0.064	0.117
PO ₄	PC															-0.49
	Sl2															0.103
TPAHs	PC															
	Sl2															

PC: Pearson Correlation. P= St₂: Sig. (2-tailed). ** =very significant. * =moderate significant.

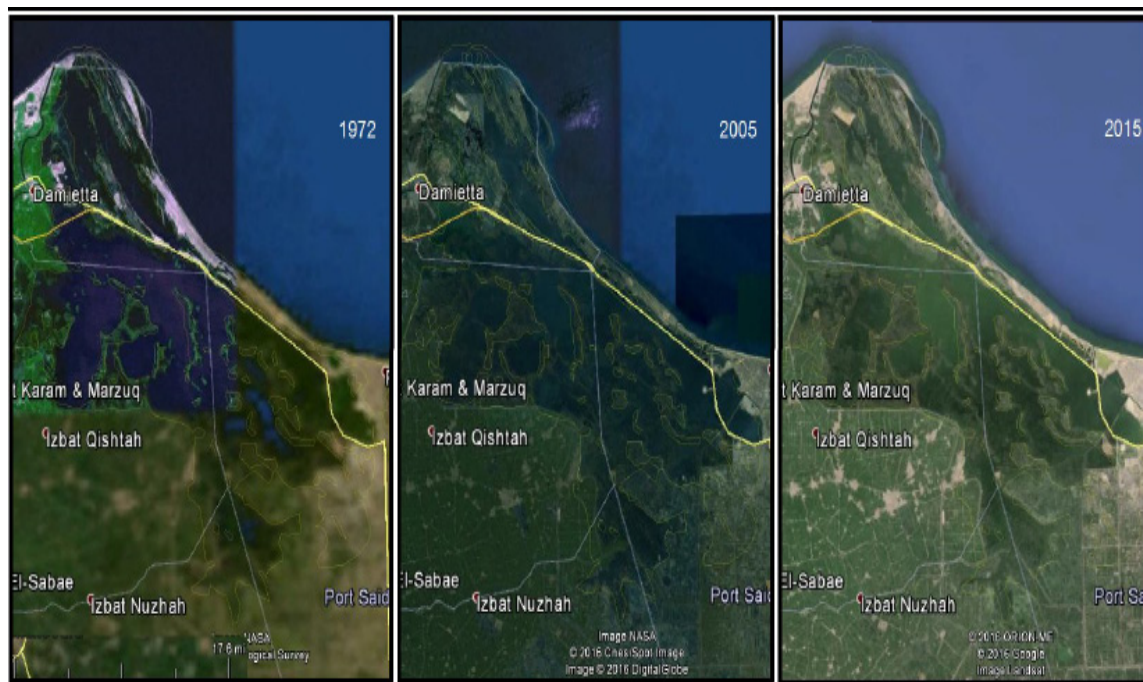


Fig. 3. Variation of vegetation in Manzala Lake during the period 1972-2015.

The RSD values of EC indicate that the levels of EC and their fluctuations during winter were more than summer due to the river block during winter. For the same reason, the northern sites were strongly influenced by the seawater inflows during winter as shown in Fig. 4. Also, TDS and salinity were affected by the sea inlet area at El Gamil. The degree of salinity of lake water indicated that it was brackish all over the lake according to 'Phocaides' classification [22].

The highly significant positive correlations ($P \leq 0.01$) observed between EC, TDS, salinity and chloride concentration approaching unity confirm the credibility of EC and salinity measurements as they are mathematically correlated. Also, these highly significant correlations may indicate that the source of chloride content is mainly the seawater as concluded from their high values in sites near seawater inlets (Fig. 4). Moreover, the highly significant correlation between EC and TDS indicated that the dissolved solids were mainly ionic.

DO is the extent of the quantity of oxygen freely available in water. It figured out the possibilities for flora and fauna living in the water system. The concentration of DO is controlled by its consumption by aerobic organisms and plants which is reproduced during photosynthesis. Also,

DO levels may change by variations in natural reiteration, temperature, flow, and depth. Level of DO was found to be mainly affected by the type of nearest water effluents (Fig. 5). In DO-poor sites such as near outlets of Bahr El Baqur drain, anaerobic conditions should set in and remaining organic matter may undergo anaerobic decomposition to yield products such as methane and ammonia [7]. That may also explain the observed high concentration of ammonia in the eastern region of the lake especially site 4 (Fig. 6). At temperatures 14–28 °C, the maximum detected level of DO (11.8 and 8.6 mg/L) is 111–113% supersaturated that means a potential sign of a mild unhealthy eutrophication. Mean values of DO was within the recommended limits (≥ 4 mg/L or 30% saturation) for most Manzala Lake fish species although it was less than optimum value (≥ 5 mg/L)[19].

Average BOD values were high compared to the adopted limits in Europe (BOD of salmonid waters should be ≤ 3 mg O₂ l⁻¹, and ≤ 6 mgO₂ l⁻¹ for cyprinid waters [7]). High BOD values in the eastern sites of Manzala Lake may suggest an anaerobic decomposition of ammonia and organic materials in industrial and municipal effluents and production of organic material in the lake itself that may be lethal for fish [23].

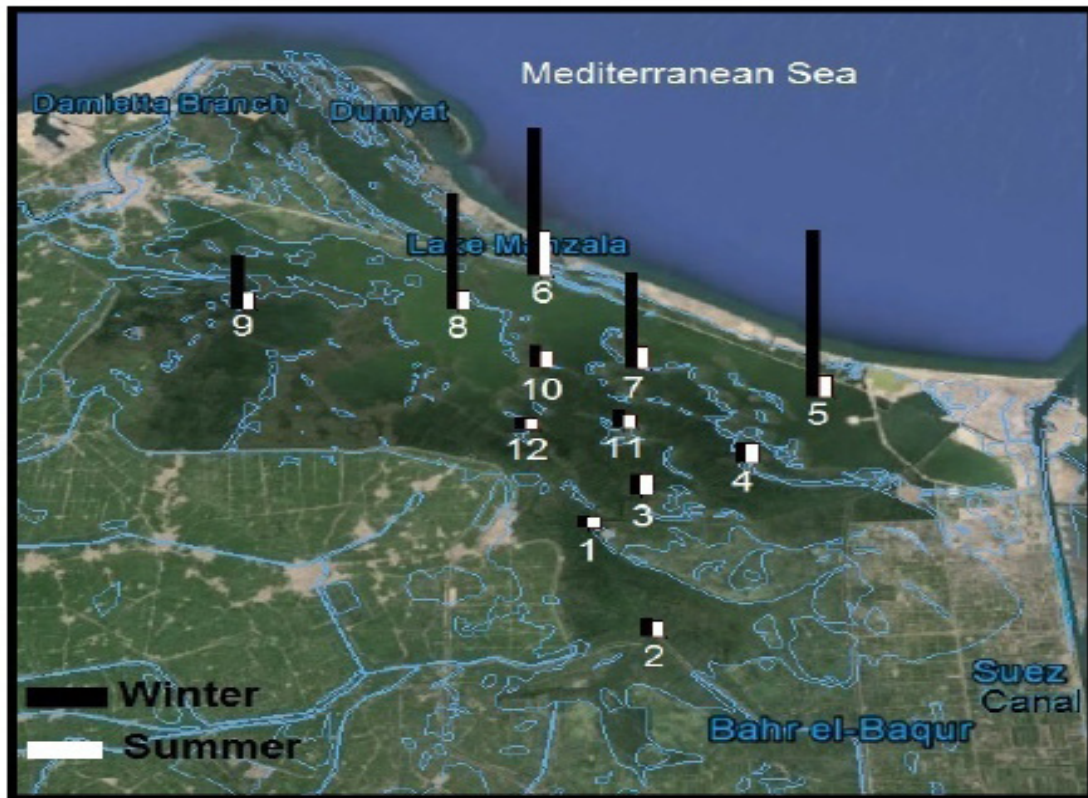


Fig. 4. Relative variation of EC in Manzala Lake during winter and summer, 2015.

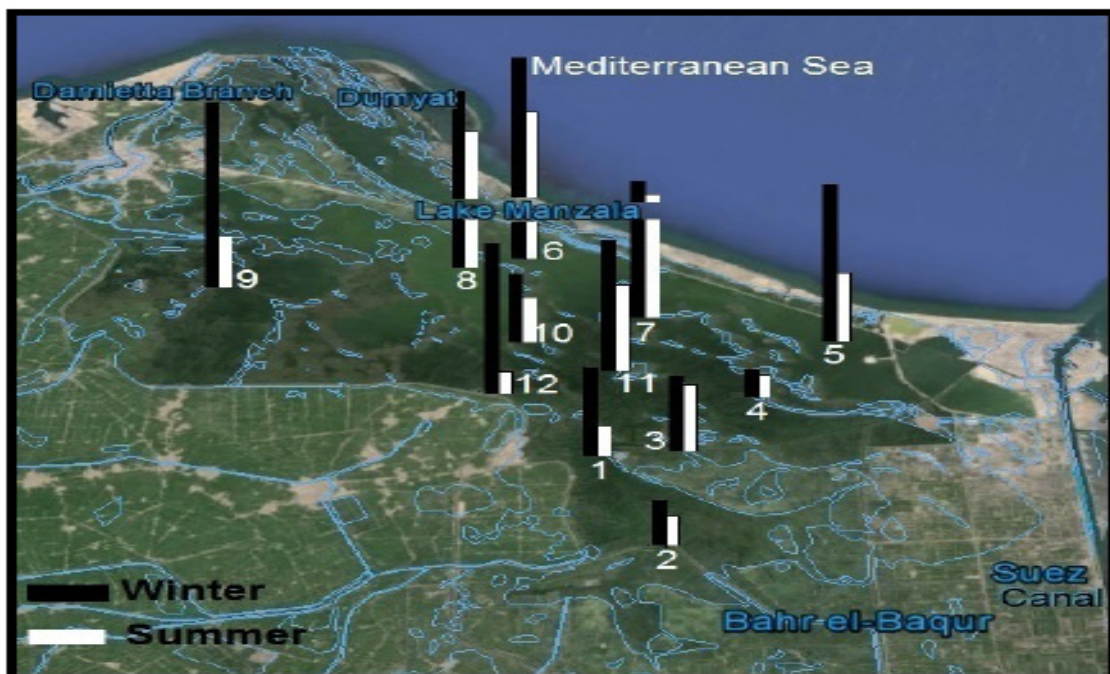
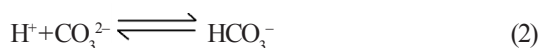
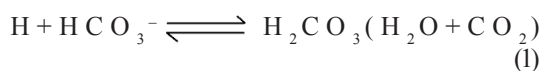


Fig. 5. Relative variation of DO in Manzala Lake during winter and summer, 2015.

As PI refers only to 40% of the total of chemical oxygen demand (COD) [24], the presence of its maxima at site 5 during winter and summer may be related to the presence of high chloride contents which may interfere with the oxydisable organic matter. The observed increase of PI average during summer, in comparison to winter, may be attributed to the influence of large drain loads during summer compared with winter due to water block of river Nile during winter.

Alkalinity is involved in the consequential effects of eutrophication of waters. Wherever a high degree of photosynthesis occurs, a high consumption of carbon dioxide is expected by algae and pH increases via left-right shifts of a series of related chemical equilibrium reactions, as follows [20]:



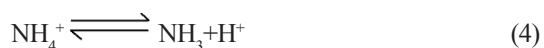
Consequently, the relative increase in alkalinity during summer, compared with winter and in the south and south eastern sites in Manzala Lake, may be attributed to a state of eutrophication processes. This

was also confirmed by the significant correlations ($0.01 < P < 0.05$) found between alkalinity vs. DO, chloride, EC, TDS, salinity, TIN and PO_4 which is attributed to a state of eutrophication during winter.

Nutrient levels

The observed higher average ammonia level during summer compared with winter is attributed to the higher inflows of nutrient-rich effluents and the relatively higher evaporation rate during summer compared with winter affected with water block [21]. The high ammonia levels in the eastern sites of the lake is influenced by the domestic and agricultural effluents of the major drains such as Bahr El Baqur, El Mattered, Hadus and Ramsis (Fig. 6).

The maximum allowed limit of total ammonia decreases with increasing temperature and pH values as illustrated in Table 5. The release of the toxic free ammonia increases with pH ($-\log[\text{H}^+]$) according to the equation [20]:



Consequently, total ammonia concentration in Manzala Lake can be considered tolerable during winter. On contrary, during summer, sites 2 – 6 exceeded the allowed limits especially in site 4 that reached ca 30 times the allowed limit, influenced

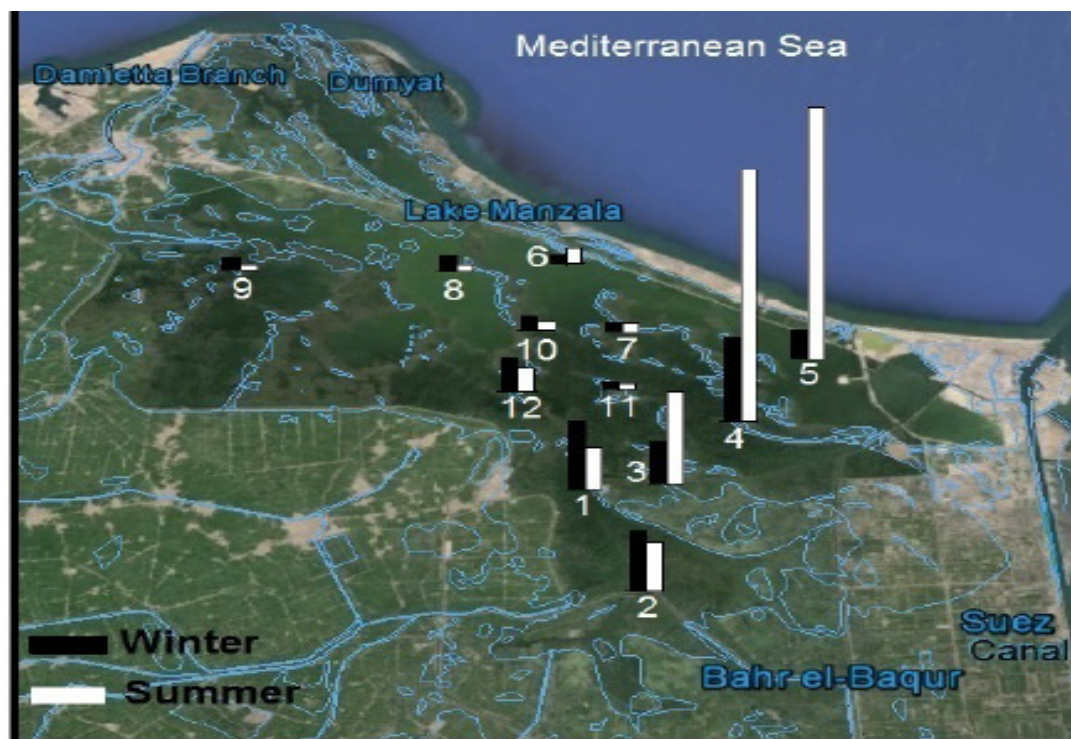


Fig. 6. Relative variation of ammonia in Manzala Lake during winter and summer 2015.

TABLE 5. Maximum allowed limits of ammonia ($\mu\text{mol L}^{-1}$) for an aquatic life at different water pH and temperatures within present study parameters [20]

pH	10°C	15°C	25°C	30°C
7.50	129	129	61.8	43.5
7.75	124	118	58.2	41.8
8.00	80.6	78.2	38.8	27.6
8.25	45.9	44.7	22.9	16.5
8.50	26.5	25.9	13.5	10
8.75	15.3	15.9	9.41	6.47

by Bahr El Baqur effluents. This should be fatal for fish and aquatic life as a whole in this sector.

Most NO_2^- levels including average value were higher than the maximum allowed maximum nitrite concentration; $4.35 \mu\text{mol L}^{-1}$ [19]. All nitrate levels were much lower than the allowed maximum nitrate concentration; $48.4 \mu\text{mol L}^{-1}$ [19].

Comparing the annual average concentration of N-ions, a sequence of decrease of them was observed to be ammonium \gg nitrate $>$ nitrite, which may suggest an oxygen-deficiency state.

Most PO_4 levels were higher than the maximum allowed concentration; $4.35 \mu\text{mol L}^{-1}$ [19]. A comparison between the levels of ammonia, nitrite, nitrate and PO_4 in Manzala Lake (Fig. 6-8) indicated that the sources of pollution are drains found in the eastern and south eastern sectors of the lake especially Bahr El Baqur during summer.

The observed higher averages of oxygenated nutrients during winter compared with summer may be correlated with the shortage in fresh water inflows concomitant with winter block. The winter block cannot actually be correlated with these ions but it just discloses their main sources which are apparently agricultural waste effluents.

The average total inorganic nitrogen (TIN) values (53.0 and $70.2 \mu\text{mol L}^{-1}$) during winter and summer, respectively; indicated that Manzala Lake was Class III eutrophic, according to Standard Statistical Classification of Surface Freshwater Quality for the Maintenance of Aquatic Life [25]. Concentrations of hazardous substances in Class III can be detected but the concentrations should be below chronic and acute values.

As the principal nutrients entering the Manzala Lake are inorganic phosphorus and nitrogen, their ratio is necessary to be controlled for the development of the undesirable growths associated with eutrophication [26]. Therefore, the N/P ratio has been calculated from the lake data for total inorganic nitrogen as ammonia, nitrite and nitrate and

phosphorus (as orthophosphate) which was found to be within 2.28-10.6 during winter and 2.46-12.8 during summer. The relative importance of nitrogen and phosphorus to phytoplankton productivity was reported [27]. It is well known that the growth and proliferation of aquatic plants is a result of the utilization and assimilation of organic materials through the photosynthesis. Thus the plant biomass increases by the uptake of available phosphorus and nitrogen from the water. It was also found that the nutrient that will control the maximum amount of plant biomass is the nutrient that "runs off" or reaches a minimum before other nutrient. Therefore under a certain condition, nitrogen may reach a minimum value before phosphorus and, as a result, control the maximum amount of plant biomass and vice versa. This situation depends on the relative amount of nitrogen and phosphorus required by aquatic plants and their availability in water body. Accordingly, a mass ratio of available forms of inorganic nitrogen and phosphorus (N/P) were used to calculate the limiting nutrient in water. In this respect, different ratios were suggested by many authors [28-30]. The most conservative ratio suggests that when N/P ratio is between 5 and 10, either nutrient could be limiting and if less than 5, nitrogen is the limiting for plant growth. The N/P ratio in Manzala Lake was below 5 indicating that nitrogen is the limiting nutrient except for sites 2-4 and 12 during winter, 1 and 3 during summer that were within 5 and 10. This may explain the significant correlation between TIN and BOD during summer. Also, sites 1 during winter, and 4 and 5 during summer were slightly higher than 10, that means that phosphorous in these sites is the limiting nutrient. However, average N/P ratios were 5 and 7.48 during winter and summer, respectively. As most lake sites are characteristic with low N/P ratios, it may favor green algal dominance, macrophytes and zooplankton [31,32].

Total Polycyclic aromatic hydrocarbons

TPAHs has been defined as the concentration of six specific compounds: fluoranthene, 3,4-benzofluoranthene, 1,12-benzofluoranthene, 3,4-benzopyrene, 1,12-benzoperylene and indeno (1,2,3-cd)pyrene which are carcinogens of greater or lesser potency [7]. TPAHs are higher than permitted value ($<1 \mu\text{g/L}$) [7]. The observed high TPAHs levels in sites of Manzala Lake close to open seawater inlets during winter (Fig. 2) indicated that its main source may be harbor activities. The inverse of this behavior occurring during summer may indicate that the TPAHs loads of the lake drains have greater effect than the harbor activities despite the finding of the TPAHs average during summer is lower than during winter. This should be attributed to the dilution effect of effluent inflows during summer compared with winter during which a block of water flow is regularly scheduled [21].

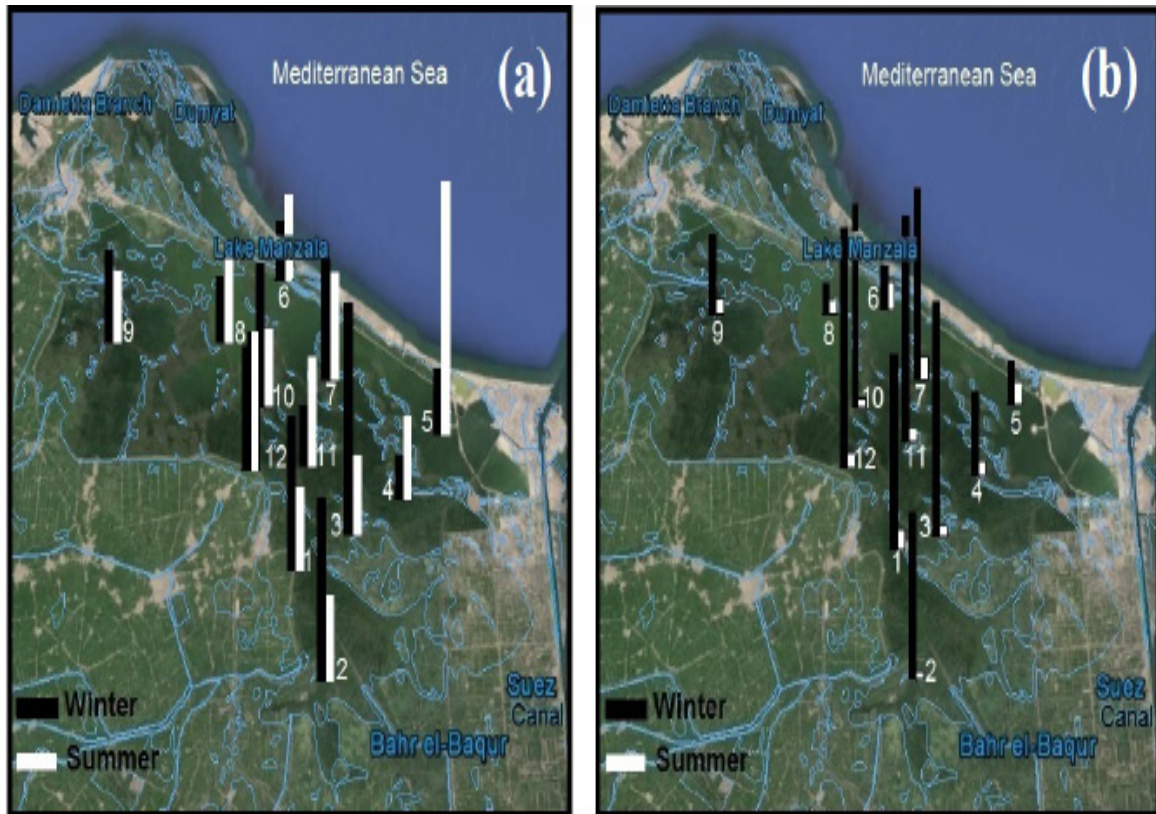


Fig. 7. Relative variation of nitrite (a) and nitrate (b) in Manzala Lake during 2015.

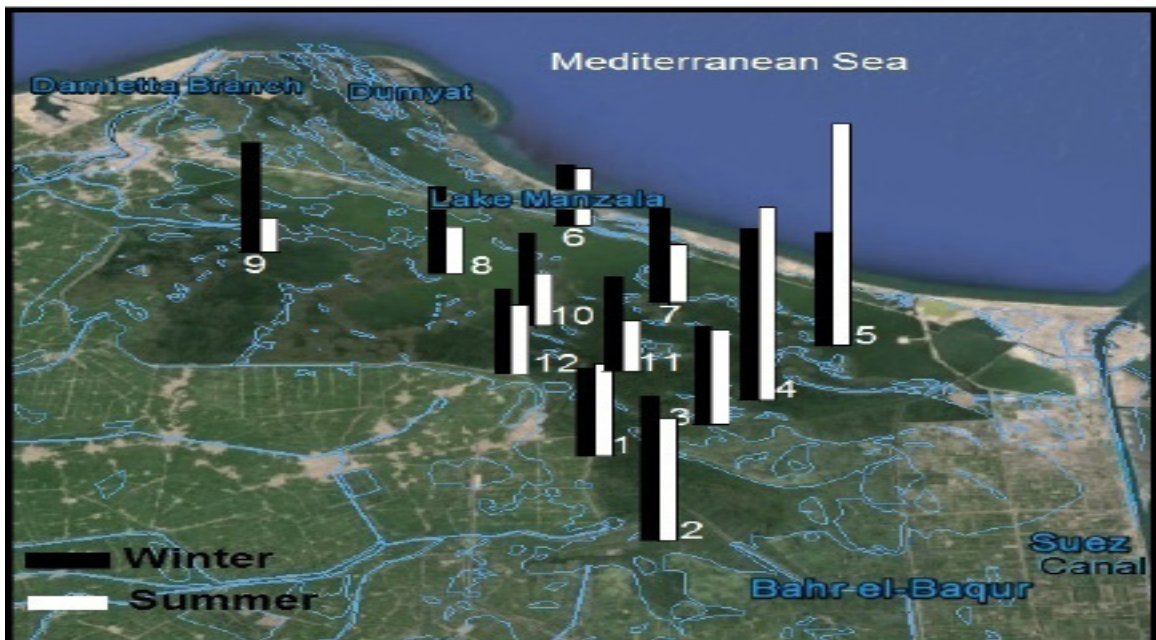


Fig. 8. Relative variation of PO₄ in Manzala Lake during 2015.

Statistical correlation

Matrix analysis (Table 4) showed that significant correlations could be detected between the studied parameters during summer more than during winter which may be due to the influence of winter water block that decreases the homogeneity of water of the Manzala Lake which transforms to isolated ponds-like during winter [21]. The highly significant correlation between ammonia and TIN indicated that ammonia was the major component of TIN.

The observed significant positive correlations between DO vs. EC, TDS, salinity and Cl are unexpected as they do not obey Henry's law; the higher the salinity level, the lower the dissolved oxygen concentration [33]. This may be explained in view of the observed inverse correlation between DO and BOD which is attributed to the consumption of DO by microorganism such as aerobic bacteria in presence of high organic matter, ammonia and/or eutrophic conditions [20]. Due to the existence of oxygen-consuming materials in fresh water inflows much more than in seawater inflows, [4,12] DO is consumed in water of low salinity more than in that of high salinity. Moreover, during summer, considering the highly significant positive correlations found between BOD vs. PI and TIN; and ammonia vs. TIN whereas highly significant negative correlations found between DO vs. ammonia and TIN; and nitrate vs. EC, TDS, salinity and Cl, it may be concluded that ammonia was the main O_2 consumer via bio-oxidation to nitrate in lower salinity water.

The highly significant correlation between nitrite vs. TPAHs; PO_4 vs. ammonia and TIN; and

significant correlations between nitrite vs. PO_4 during winter and between the parameters PO_4 vs. ammonia during summer, indicated that these pollutants were from the same source which is Bahr El Baqur drain as discussed above.

Variation of some reported water quality parameters in Manzala Lake

Figure 9 shows comparisons of some important water quality features; pH, salinity, DO, BOD, ammonia, nitrite, nitrate and PO_4 values, of Manzala Lake and their linear fittings at different periods within the period 1920-2015. It can be concluded that pH, salinity, DO, nitrite and nitrate values are in a state of decreasing with different rates; whereas BOD, ammonia and PO_4 are increasing. A good sign was the apparent decrease in nitrite concentration that reflects some improvement towards pollution treatment in Manzala Lake. However, the decrease in pH, DO and salinity which was accompanied with a rising up of BOD, ammonia and PO_4 is apparently alarming us to keep efforts for improving the water quality of the lake. This is affecting directly the quality and diversity of fish as it was reported that marine catch species such as *Mullet* decreased constantly during the period 1920-1980 whereas fresh water species such as *Tilapia* increased [3,19] and the total fish catch of the lake was reported to decrease from 68 thousand tons in 2001 to a minimum value of 46.5 thousand tons in 2008 until it raised again [34]. Fortunately, the increase in ammonia concentration is accompanied by a decrease in pH that reduce its threat to aquatic life as illustrated in Table 5. The details of these studies are shown in Table 6.

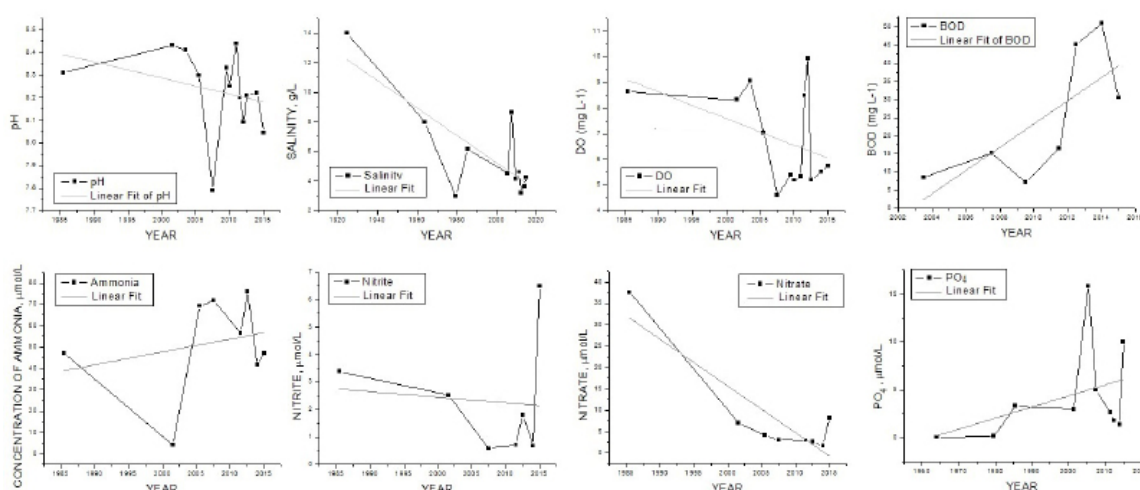


Fig. 9. Comparison of pH, salinity, DO, BOD, ammonia, nitrite, nitrate and PO_4 concentrations of Manzala Lake during the period 1920-2015.

TABLE 6. Comparison of some water quality parameter of Manzala Lake during the period 1920-2015.

Year	1920-1929	1962-1966	1979 / 1980	1985 / 1986	2001/2002	2003/2004	2005	2007/2008	2009 / 2010	2010	2011	2011/2012	2012	2012/2013	2014	2015
pH	-	-	-	8.31*	8.43*	8.41	8.30*	7.79	8.33	8.25*	8.44*	8.20	8.09*	8.21	8.22*	8.05
Salinity- (‰)	14.00	8.00	3.00	6.14*	-	-	4.52*	8.64	4.15	-	-	4.60	-	3.22	3.65*	4.26
DO (mg L ⁻¹)	-	-	-	8.65*	8.32*	9.06	7.03*	4.59	5.38	5.19*	5.32*	8.50	9.95*	5.2	5.51*	5.74
BOD (mg L ⁻¹)	-	-	-	-	-	8.57	-	15.27	7.16	-	-	16.5	-	45.1	51.0*	30.5
Ammonia (μmol L ⁻¹)	-	-	-	46.9*	*4.15	-	69.2*	71.8*	-	-	-	56.5*	-	75.9	41.8*	47.0
Nitrite (μmol L ⁻¹)	-	-	-	3.39*	2.52*	-	-	0.578*	-	-	-	0.71*	-	1.79	0.689*	6.49
Nitrate (μmol L ⁻¹)	-	-	-	37.6*	7.00*	-	4.07*	3.06*	-	-	-	2.90*	-	2.58	1.74*	8.18
PO ₄ (μmol L ⁻¹)	-	0.063*, **	0.172*, **	3.28*	2.98*	-	-	5.02*	-	-	-	2.61*	-	1.79	1.39*	9.99
Reference	[35]	[35]	[35]	[36]	[37]	[38]	[39]	[40]	[41]	[4]	[4]	[42]	[4]	[43]	[44]	Present work

* = recalculated. ** = total phosphate.

TABLE 7. Comparison of some water quality parameter of Manzala Lake with some principal drain effluents during the period 1998 - 2013

Year	1998/1999	2001-2010	2001-2010	2004-2006	2006	2005-2008	2010	2011	2012	2013	2010	2011	2012	2013	2015
pH	7.6	7.48	7.52	-	-	7.3-7.6	7.30	7.49	7.72	7.69	7.73	7.65	7.92	7.86	8.05
EC (mmhoS/g)	1.78	-	-	0.41 - 6.92	-	-	4.01	3.9	3.6	2.97	3.04	2.13	2.23	1.22	6.83
Salinity- (‰)	0.75	-	-	-	-	-	-	-	-	-	-	-	-	-	4.26
DO (mg L ⁻¹)	4.78	2.27	1.58	-	0.2	1.0-2.1	1.18	1.42	1.62	1.98	1.62	2.34	1.80	1.70	5.74
BOD (mg L ⁻¹)	14.5	-	-	4.05 - 68.5	-	28 -100	-	-	-	-	-	-	-	-	30.5
Ammonia (μmol L ⁻¹)	47.2	-	-	-	821	100 -250	-	-	-	-	-	-	-	-	47.0
Nitrite (μmol L ⁻¹)	2.17	-	-	-	-	-	-	-	-	-	-	-	-	-	6.49
Nitrate (μmol L ⁻¹)	3.29	-	-	17.7 -635	-	-	-	-	-	-	-	-	-	-	8.18
PO ₄ (μmol L ⁻¹)	7.22	0.92	0.79	-	80.1	8.25 -23.7	-	-	-	-	-	-	-	-	9.99
Source of water	S	BB	H	BB	BB	BB	BB	BB	BB	BB	H	H	H	H	ML
Reference	[45]	[15]	[15]	[46]	[47]	[48]	[4]	[4]	[4]	[4]	[4]	[4]	[4]	[4]	Present work

.BB, H and S denote Bahr El Baqur, Hadus and El-Serw drains, respectively

Table 7 shows a comparison of some water quality parameter of Manzala Lake with principal drain effluents during the period 1998 – 2013. Bahr El Baqur drain clearly shows the worst water quality parameters which indicate that it has been the key problem and the key solution of most Manzala Lake issues. Also, this may explain why the south eastern region of the lake hosted the most deteriorated sites.

Conclusion and recommendations

Manzala Lake is suffering environmental changes where human activity such as construction of fish farms, roads and drying up large areas from the lake for agricultural purposes have changed the lake from a connected water body to semi-closed sub-basins, that are connected partially by narrow inlets. The northern portion of Manzala Lake differs much more than the southern portion along the whole year. The southern portion of the lake contains a relatively higher organic matter influenced by large waste effluents from different drains in particular Bahr El Baqur drain. On the

other hand, the northern portion of the lake has a relatively higher salinity due to its nearness and impact of the Mediterranean Sea on it. The lake is highly eutrophic with nutrients and other toxic compounds such as petroleum hydrocarbons having access to people via the food chain beginning from algae and weeds to various kinds of fish and sea birds. It is highly recommended to continue efforts for effective treatment of waste effluents from different drains especially Bahr El Baqur drain. Also, the diffusion of seawater along the lake should be improved. Finally, it is advised to prohibit illegal land reclamation and intensive fishery especially with illegal methods to keep biological diversity of the lake.

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الخصائص الفيزيوكيميائية لبحيرة المنزلة، مصر

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تم قياس المعاملات الفيزيائية والكيميائية مثل درجة الحرارة ومجموع المواد الصلبة الذائبة ودرجة الحموضة والملوحة والأكسجين الذائب والطلب الأكسجيني البيولوجي ومؤشر البرمنجنات والكلوريد وأملاح المغذيات في عينات المياه التي تم جمعها من ١٢ موقعا من بحيرة المنزلة في الشتاء والصيف، ٢٠١٥. وقد لوحظت الكثير من التقلبات في هذه المؤشرات المتضررة من سوء اتصال الجسم المائي للبحيرة وتنوع التدفقات الواردة. وكانت قيم الرقم الهيدروجيني للمياه قلوية في جميع أنحاء البحيرة وترتبط ارتباطا وثيقا مع الملوحة على نطاق واسع والأكسجين الذائب. وقد لوحظ زيادة الطلب الأكسجيني البيولوجي في المواقع الواقعة في جنوب شرق البحيرة والتي تأثرت في معظمها بمياه مصرف بحر البقر وخاصة في فصل الشتاء خلال سدة المياه المقررة. وقد تأثر معامل البرمنجنات بشكل كبير بالنفايات السائلة الزراعية والمنزلية. تراوحت أملاح المغذيات بين ٢٤٩-٥,٤٧ و ٢٤٦-١,٥١ و ٢٤,٥-٠,٦٤ و ٢٢,٩-٣,٤٧ ميكرومول للتر للأمونيا والنترت والنترات والفوسفات على التوالي. أشارت نسب النيتروجين / فوسفور (١٢,٨-٢,٢٨) في هذه الدراسة إلى أن النيتروجين هو العامل المحدد في عملية النمو في البحيرة باستثناء بعض المواقع في المنطقة الجنوبية الشرقية. تم العثور على الهيدروكربونات العطرية متعددة الحلقات متأثرة بتدفقات مياه البحر في فصل الشتاء. وأظهرت المنطقة الجنوبية الشرقية أدنى معايير نوعية المياه.