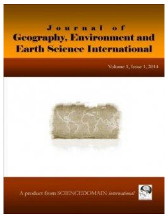

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Spatial Assessment of Water and Sediment Quality in Burullus Lake Using GIS Technique

Yasser A. El-Amier[1], Hoda Abd El-Azim[2] and Muhammad A. El-Alfy[2*]

[1]Department of Botany, Faculty of Science, Mansoura University, Mansoura, Egypt.
[2]Department of Marine Pollution, National Institute of Oceanography and Fisheries (NIOF), Suez, Egypt.

Authors' contributions

This work was carried out in collaboration between all authors. Author YAEA designed the study, monitored the experimental process and reviewed results. Author MAEA carried out the experiments of the study and wrote the draft of the manuscript and author HAEA designed the study and reviewed the results of the study. All authors read and approved the final manuscript.

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ABSTRACT

The Egyptian northern Deltaic lakes including Burullus Lake suffer from pollution of intensive agri culture, domestic and industrial activities. The objective of this research was to evaluate water and sediment quality in Burullus Lake based on certain physical and chemical characteristics. Mapping the spatial distribution of these parameters will be done using ordinary Kriging method to reveal the link with potential pollution sources. Geo-referenced water and sediments samples were collected from 34 and 37 representative sites in the lake, respectively. The obtained results indicated that the quality of both water and sediments in receiving drainage water of the southern parts of the lake were relatively inferior compared to that of the northern parts. So we recommended that wastewater from different drains should be treated before being drained into the Lake.

Keywords: Burullus Lake; GIS; pollutants; water; sediment quality.

**Corresponding author: E-mail: muhammad.elalfy@yahoo.com;*

1. INTRODUCTION

Five natural lakes are located length with the Mediterranean coast of Egypt, are: Mariut (Western Coast), Edku, Burullus and Manzala (Deltaic Coast) and Bardawil (Eastern Sinai Coast) [1]. In this study, Burullus Lake was selected as it is one of the most conspicuous wetland habitats in Egypt. It was taken into consideration according to Ramsar convention in 1971 that known as an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources [2].

The coastal lakes are suffering from excessive amounts of pollutants due to increasing human activities and urbanization. The lakes are directly or indirectly affected by pollutants linked to human activities, namely: Industry, sewage and/or agricultural drainages. The agricultural drainage water and industrial effluents and sewage discharges supply water and sediment with excessive amounts of organic pollutants and heavy metals [3].

Water pollution leads to alteration in physical, chemical and biochemical properties of water bodies as well as that of the environment. It directly or indirectly affects the life processes of aquatic flora and fauna [4,5]. The aim of this research was to determine and map different water and sediment quality parameters of Burullus Lake using geographic information system (GIS) technology.

2. MATERIALS AND METHODS

2.1 Study Area

Burullus lake is located at the middle northern part of Nile-Delta in Kafr El-Sheikh governorate (30°22` - 31°35`N; 30°33` - 31°08`E) with an area of about 460 km^2 (Fig. 1). The lake receives about 4.1 billion m^3 annually through a system of eight drains namely: West El-Burullus, Gharbia Drain, El-Kashaah Drain, Tirrah Drain, Drain 7, Drain 8, Drain 9, El-Hoks Drain and Brinbal Freshwater Canal [6].

2.2 Climatology

The records for climatic conditions from meteorological station data in the study area were obtained as follows; the minimum air temperature varies from 11.2°C in January to 23.6°C in August with mean annual temperature of about 17.3°C. The maximum air temperature is in the range of 17.4°C to 29.7°C in January and August, respectively with mean annual temperature of 24°C. The relative humidity ranges between 65% in March and 73% at July with a mean value of about 69%. The total

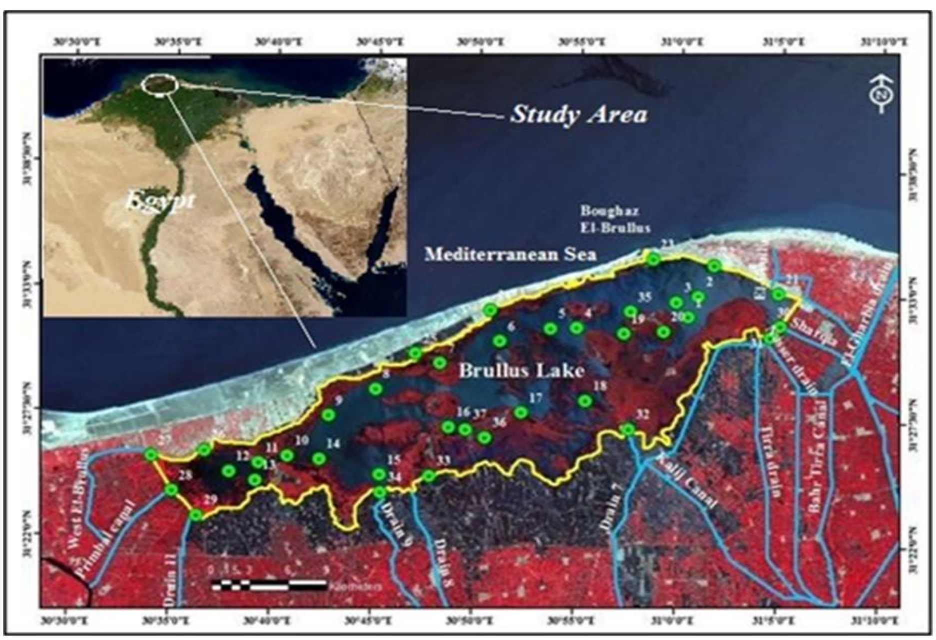

Fig. 1. Map of the study area (Burullus Lake) showing sampling locations

annual rainfall attained a value of 175.2 m. The evaporation rate increases from north to south and reach its maximum during summer seasons and minimum during winter period. The evaporation rate ranges between 3.3 mm/day in January and 5.6 mm/day in June at the study area.

2.3 Analytical Methods

2.3.1 Water samples

Water samples were collected from 34 locations. Four liters of each sample were filtered through CF/C glass fiber filters. The first one liter was discarded and others were stored at 4°C in dark to be used for chemical analysis.

2.3.1.1 Field measurements

A Secchi disc reading is used to determine the depth of light penetration into a body of water. Water temperature and dissolved oxygen (DO) were measured using the DO meter (Lutron YK-22 DO meter); water depth and transparency were measured as methods described by APHA [7]; the values of pH were recorded using a (pH-meter) and the electrical conductivity using EC-meter (Thermo, Orion 150 A+ advanced conductivity).

2.3.1.2 Lab measurements

Water samples were transported to the laboratory in the same day of collection and filtered through CF/C glass fiber filters. The following methods were adopted for chemical analyses. For biological oxygen demand (BOD) was carried out using the conventional Winkler method and chemical oxygen demand (COD) using the dichromate reflux method [8]; total alkalinity (T. Alk) measured by using the titration method [7]. Determination of nutrients in water samples was carried out according the methods described by Grasshoff [9]. The developed colors were measured at spectrophotometer and all concentrations were expressed as µg/l.

2.3.2 Sediment samples

Sediment samples were collected from the different locations representing 37 samples in Burullus Lake. All samples were carried to the laboratory in plastic bags shortly after collection. These samples were air dried, thoroughly mixed, sieved using a 2 mm sieve to remove gravel and debris and stored in plastic bags for subsequent physical and chemical analyses.

2.3.2.1 Physical analyses

Texture of samples was determined by using the hydrometer method, porosity and Water-holding capacity (WHC) were determined according to the method described by Piper [10].

2.3.2.2 Chemical analyses

Soil pH was measured by using the pH-meter (Model Lutron YK-2001, pH meter) and Electrical conductivity by using the Electrical conductivity meter (YSI Incorporated Model 33) in 1:5 soil suspensions as described by Jackson [11]. Carbonates and bicarbonates were determined by titration method as described by Pierce et al. [12]. The calcium carbonate content was determined according to Jackson [11]. Chlorides, sulphates and organic carbon were determined as described by Piper [10]. Available phosphorus was determined according to the method described by Watanabe and Olsen [13], available nitrogen in soil samples was determined by Kjeldahl method [14]. The method of extraction of different elements (Na^+, K^+, Ca^{+2} and Mg^{+2}) was described by Allen et al. [15].

2.4 Geostatistical Analysis

The Geostatistical analyst in ArcGIS (ver. 10.1) software package [16] was used to develop the semivariogram between each pairs of points versus their separation distances. This semivariogram was used in predicting the studied parameters in both water and sediment samples.

3. RESULTS

3.1 Water

The physicochemical characteristics of the waters from three ecological sites namely; drains, lake open water and lake shores are shown in Table 1. Dissolved oxygen showed the highest significant correlations ($P < 0.05$) among these different ecological habitats. The lowest mean value of DO was recorded in the drains habitat (4.78 mg/l), while the highest mean value was observed in the lake open water habitat (12.3 mg/l). There are other parameters which showed moderate significant correlations such as; transparency, pH, EC, alkalinity, Ca^{+2} and SAR. The lowest mean values of transparency and pH were recorded in the drains habitat (25.7 cm and 8.28), while the highest mean values of both were obtained in the lake shores habitat (27.6 cm and 8.71) for transparency and pH, respectively. For alkalinity, the highest mean value was recorded in the lake shores habitat (342 mg/l), whereas the lowest mean value was recorded in the lake open water habitat with a value of 209 mg/l. for Ca^{+2} and SAR, the highest mean values were obtained in the lake shores habitat (60.66 mg/l and 152.53), the lowest mean values were recorded in the lake open water habitat for Ca^{+2} (28.1 mg/l) and in the drains habitat for SAR (114.03). The other parameters such as nutrients showed low to non-significance correlations between the different ecological habitats. The spatial distributions of these parameters were shown in Fig. 2 (a-c).

3.2 Hydrosoils

The physical and chemical characteristics of the sediments collected from four ecological sites of the Lake Burullus are shown in Table 2. Electrical conductivity, pH, chlorides, sulphates and sodium showed the highest significant correlations ($P < 0.05$) among these different ecological habitats. All those parameters showed highest mean values (46.9 ms/cm, 8.6, 115.3 meq/100 g, 44.67 meq/100 g and 5202.4 ppm) in the lake islet habitat. While the lowest mean value of these parameters were (3.5 ms/cm, 3.63 meq/100 g, 1.53 meq/100 g, 344.18 ppm) in the lake shore habitat for EC, Cl^-, SO_4^{-2} and Na^+, respectively. For pH, the lowest mean value was recorded in the lake open water habitat (7.87). The highest mean value of sand texture was recorded in the lake shore habitat with a value of 59.2%, whereas it's showed low value in the lake open water habitat of 45.9%. For silt, the highest mean value was obtained in the lake open water habitat (34.07%), but the lowest mean value was recorded in the lake shores habitat (25.4%). Clay recorded high value in the lake islets habitat (27.7%) and low value in the lake shores habitat. The spatial distribution of hydrosoil parameters were as shown in Fig. 3 (a-c).

4. DISCUSSION

4.1 Water

Conductance measurement represents rapid and practical parameter for the variation of dissolved nutrients and micro-nutrients contents of water samples. The highest mean value of EC was recorded nearby El-Boughaz and at the northern part of the lake as a result of sea water intrusion, but the lowest mean value was recorded nearby drains and the southern part of the lake. This agreed with results obtained by Darwish [17] and Basiony [18] for the lake Burullus.

The pH of water is important because it affects the solubility and availability of nutrients, and show how they can be utilized by aquatic organisms [19]. The values of pH ranged from 7.76 to 8.86 in Burullus Lake. So, it was neutral to moderately alkaline, but was above the upper limit defined by guidelines of WHO [20] (6.5-8.5).

The depth of water is one of the physical factors which act as a controlling factor for determining the water quality [21]. The depth was in the range between 0.4 to 2.5 m. This result agreed with the findings of Hereher et al. [22] and Basiony [18]. Transparency in Burullus Lake varied from 7 to 50 cm. The lowest value in Burullus Lake is recorded in El-Shaklouba drain. The results indicated that the lowest values of transparency were recorded in drains which contain high organic load and suspended materials that could lower the penetration of light and affect the aquatic life. The highest transparences were recorded in sites with low suspended matter with low organic pollutants. In fact, it is known that the water transparency is generally low at the Egyptian northern Deltaic lakes. This may be attributed to their shallowness and the continuous disturbance of the mud bottom by wind action (Shakweer [23]).

High alkalinity may cause a physiological stress on the aquatic organisms and lead to loss of biodiversity [24]. The highest water alkalinity (360 mg $CaCO_3$/l) was observed at El-Shakhlouba drain, this value is higher than (307 mg/l) recorded by El-Nemr [25] and Radwan [26]. While the lowest water alkalinity was (110 mg $CaCO_3$/l) at the northwestern part of this lake.

The highest concentration of chloride was analyzed at the northern parts of the lake. This result agrees with Ahmed et al. [27] who revealed that the increase of chloride concentrations toward the north to the Mediterranean Sea is obviously clear, whereas the lowest concentrations of chloride were distributed at the southern and western parts of the lake. These parts of the lake were affected more with fresh water from different drains. These results agree with the findings of Nayak et al. [28] and Patra et al. [29].

Table 1. Mean values and standard errors of water characteristics collected from different three ecological sites of Burullus Lake (*P ≤ 0.05*)

Water variables		Ecological sites			Mean (n =34)	F-Value	$LSD_{0.05}$
		Open water (n = 20)	Lake shores (n = 5)	Drains (n = 9)			
Depth (m)		0.9^{a}±0.05	1.1^{a}±0.15	1.3^{a}±0.24	1.10±0.15	0.49	0.39^{ns}
Transparency		11.51^{b}±1.17	27.6^{a}±1.50	25. 7^{a}±4.48	21.60±2.38	10.74	11.52^{**}
pH		8. 5^{a}±0.28	8.71^{a}±0.43	$8.29^{b\pm}$0.56	8.50±0.42	8.01	0.29^{**}
EC ms/cm		18.6±3.4^{b}	27.5^{a}±4.9	$11.4^{b\pm}$3.0	19.17±3.77	4.91	13.14^{*}
Alkalinity	mg/l	209^{b} ±12	342^{a}±30.2	303.3^{a}±13.3	284.77±18.50	10.39	73.72^{**}
HCO_3^-		269^{a} ±13	253^{a}± 31.4	309^{a}±16.2	277.00±20.20	1.07	92.27^{ns}
Cl^-		6373^{b}±1275.6	9930.3^{a}±1879	3759.8^{b}±1111.3	6687.7±1421.97	5.27	4902.67^{*}
SO_4^{-2}		53.4^{a}±8.6	$86.3^{a\pm}$15.7	99.7^{a} ±13.9	79.80±12.73	0.34	54.64^{ns}
NH_3^+	µg/l	114a ±17.9	$64.20^{a\pm}$6.60	$767.3^{a\pm}$272.4	315.17±98.97	1.92	69.88^{ns}
NO_2^-		35.5^{a}±25.4	35.48^{a}±27.7	122.21^{a}±31.8	64.39±28.30	1.69	84.84^{ns}
NO_3^-		187.1^{a}±40.6	$173.1^{a\pm}$97.39	337.18^{a}±69.67	232.46±69.22	0.26	233.67^{ns}
SiO_4^-		550.6^{a}±137	289.6^{a}±70.6	2927.2^{a}±774.2	1255.80±327.27	1.75	1951.75^{ns}
DO	mg/l	12.3^{a}±0.70	7.02^{b}±0.47	4.78^{b}±0.33	8.03±0.50	38.02	2.74^{***}
BOD		10.9^{a}±0.95	7.8^{a}±1.51	8.53^{a}±2.24	9.08±1.57	0.14	8.03^{ns}
COD		251^{a}±9.48	358^{a}±55.1	474.1^{a}±67.1	361.03±43.89	1.93	210.85^{ns}
Na^+		1231.9±272.2	1874.6±238.12	709.60±158.48	1272.03±222.93	8.98	740.64^{**}
K^+		50.94^{a}±8.98	72.56^{a}±11.87	31.54^{a}±8.03	51.68±9.63	4.14	35.45^{*}
Ca^{++}		28.1^{b}±5.47	$60.66^{a\pm}$9.42	52.03^{a}±4.82	46.93±6.57	11.83	20.17^{**}
Mg^{++}		167.7^{a}±31.17	239.77^{a}±29.78	109.42^{a}±31.96	172.30±30.97	3.23	125.89^{ns}
SAR		114.2^{b}±14.16	$152.53^{a\pm}$12.68	75.37^{b}±8.86	114.03±11.90	7.25	51.99^{**}
PAR		4.8^{a}±0.45	5.82^{a}±0.63	3.30^{a}±0.46	4.64±0.51	3.42	2.14^{ns}

EC = Electrical Conductivity, DO = Dissolved Oxygen, BOD = Biological Oxygen Demand, COD = Chemical Oxygen Demand, SAR = Sodium Adsorption Ratio, PAR = Potassium Adsorption Ratio and NS: Non-significant

Table 2. Mean values and standard errors of hydrosoil characteristics collected from different four ecological sites of Burullus Lake (*P* ≤ *0.05*)

Hydrosoil variables		Ecological habitats				Mean (n =37)	F-Value	$LSD_{0.05}$
		Open water (n = 20)	Lake Shores (n = 5)	Drains (n = 9)	Lake Islets (n= 3)			
Sand		45.9^{bc}±0.8	59.2^{a}±4.5	53.90^{ac}±2.6	39.3^{c}±0.5	49.58±2.10	6.78	10.2^{**}
Silt	%	34.07^{a}±0.44	25.4^{c}±2.6	29.00^{bc}±1.4	33^{ab}±0.2	30.37±1.16	5.34	5.77^{**}
Clay		20.03^{b}±0.87	15.4^{b}±1.8	17.10^{b}±1.4	27.7^{a}±0.4	20.06±1.12	8.22	5.73^{**}
EC (ms/cm)		6.77^{b}±0.87	3.5^{b}±1.3	4.77^{b}±1.1	46.9^{a}± 23.2	15.49±6.62	13.78	21.09^{***}
pH		7.87^{b}±0.0	7.9^{b}±0.07	8.17^{b}±0.1	8.6^{a}±0.3	8.14±0.12	6.09	0.42^{**}
WHC		37.8^{b}±1.6	37.4^{b}±4.2	53.9^{ab}±3.1	52.2^{a}±0.7	45.33±2.40	3.46	11.99^{*}
$CaCO_3$		5.02^{ab}±0.28	6.64^{b}±0.02	6.21^{ab}±0.4	6.67^{a}±1.9	6.14±0.65	2.32	3.09^{ns}
OC	%	17.13^{b}±2.62	29.3^{ab}±3.3	43.33^{a}±5.9	33.8^{ab}±5.7	30.89±4.38	3.01	19.49^{ns}
Cl^{-}		17.03^{b}±2.06	3.63^{b} ±0.08	11.84^{b}±2.7	115.3^{a}±56.9	36.95±15.44	14.01	7035.94^{***}
SO_4^{-2}		6.93^{b}±0.92	1.53^{b}±0.02	4.08^{b}±0.9	44.67^{a}±22	14.30±5.96	14.28	20.02^{***}
HCO_3^{-}		505.5^{a}±35	359^{a}±72	494.8^{a}±66	386^{a}±14	436.33±46.75	0.59	268.05^{ns}
Av. N.		68.9^{b}±3.0	54.6^{b}±6.5	61.2^{b}±4.8	95.7^{a}±1.4	70.10±3.93	7.81	19.52^{**}
Av. P.		13.95^{b}±0.58	11.08^{b}±1.3	12.27^{b}±0.9	19.12^{a}±0.29	14.11±0.77	7.93	3.78^{**}
Na^{+}	ppm	689.14^{b}±79.78	344.18^{b}± 141.7	502.23^{b}±198.4	5202.4^{a}±2583	1684.49± 750.77	13.78	2361.25^{***}
K^{+}		54.52^{b}±5.15	23.56^{b}±5.7	32.87^{b}±8.4	244.8^{a}±137	88.94±34.06	8.21	136.73^{**}
Ca^{+2}		48.39^{a}±4.80	28.5^{a}±3.3	73.34^{a}±15.7	44.7^{a}±30.9	48.73±13.68	0.87	45.07^{ns}
Mg^{+2}		46.16^{b}±5.83	27.8^{b}±6.5	73.14^{b}±13.1	406.6^{a}±325	138.43±87.61	3.57	353.04^{*}
SAR		101.11^{b}±8.54	61^{b}±22.8	56.41^{b}±20.8	440.1^{a}±295.2	164.66±86.84	5.06	309.18^{*}
PAR		8.02^{b}±0.56	4.3^{b}±0.7	3.71^{b}±0.6	23.7^{a}±17.7	9.93±4.89	3.26	19.26^{*}

EC = Electrical Conductivity, WHC = Water Holding Capacity, OC = Organic Carbon, AP = Available Phosphorus, AN = Available Nitrogen, SAR = Sodium Adsorption Ratio, PAR = Potassium Adsorption Ratio, ns = Non-significant

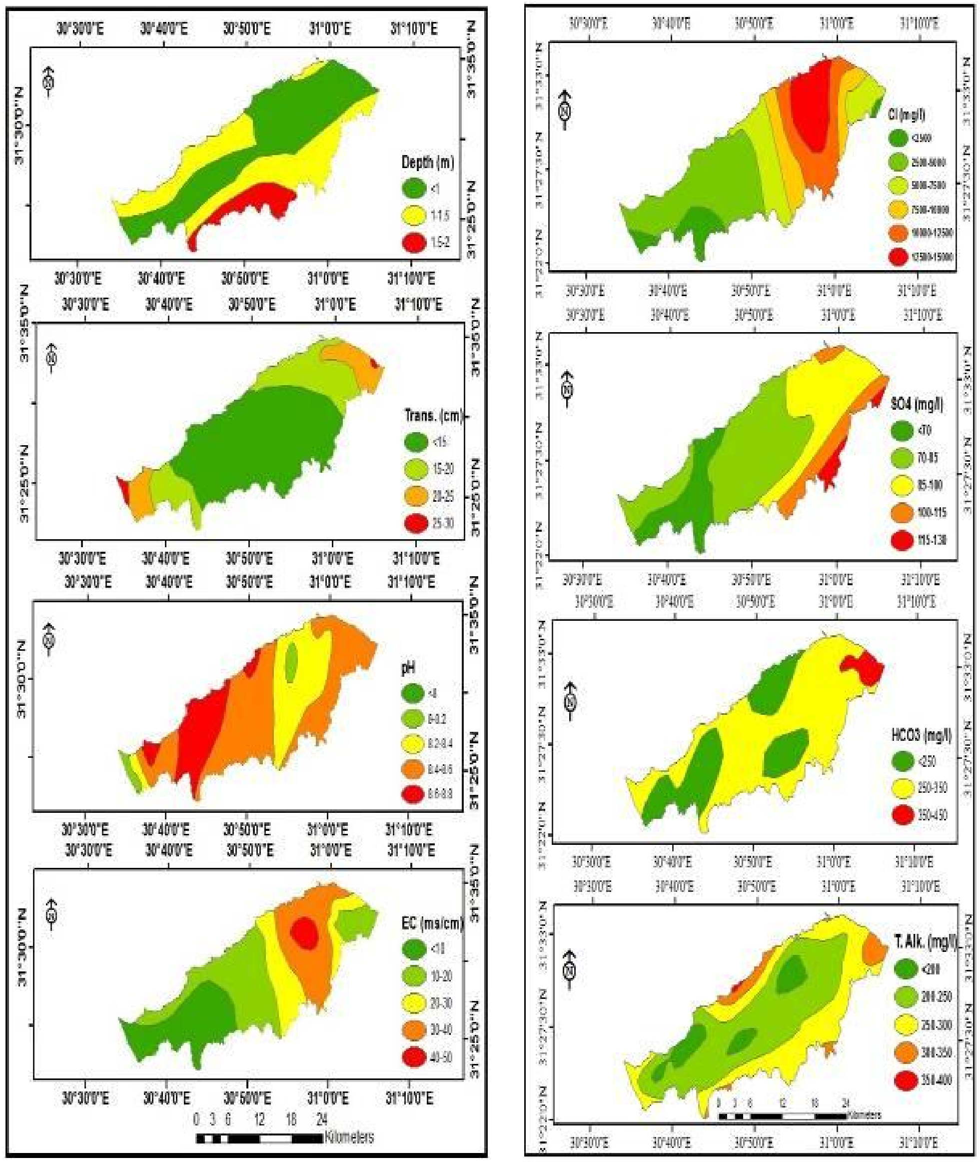

Fig 2(a). The spatial distribution of water variables (depth, transparency, EC, Cl^-, SO_4^{-2}, HCO_3^- and alkalinity as ($CaCO_3$) in Burullus Lake using GIS technique

Regarding the cations in the lake, Na^+ is the most abundant cation in the lake water samples, followed by Mg^{+2}, Ca^{+2} and K^+. High levels of sodium and magnesium were recorded nearby El-Boughaz and the northern parts of lake as a result of sea water intrusion. Also, the values of cations were high nearby drains due to agricultural wastes. The anions and cations are naturally very variable in surface waters due to climatic and geographical conditions and their distribution depends on the evaporation rate and the drainage water from different drains [30].

Dissolved oxygen in the water is necessary for respiration, and thus, is necessary for aquatic life to exist. The highest value of DO was recorded nearby El-Boughaz, this value is more than those recorded by Okba and Hussien [31] and Ayyad et al. [32], but lower than those recorded by Basiony [33,18]. The lowest value of dissolved oxygen in Burullus Lake was recorded in West El-Burullus drain that may be attributed to sewage and agricultural drainage. From these results and according to the permissible limits (4.0-5.0 mg/L) [34], so water in the northern sites of the lake does not pose any threat to aquatic life except in sites nearby drains.

BOD is a direct indicator to the extent of pollution in water body. The maximum BOD value was recorded nearby Baltim City close to the different drainage water. This value is more than those recorded by Basiony [33,18] on his study on El-Burullus Lake but lower than what obtained by Younes and Nafaa [35]. The lowest value of BOD (1.4 mg/l) was recorded at open water far from drains. BOD values of 3 mg/l indicated pure water, but values which reach 5 mg/l gives an indication of doubtful purity of water [36].

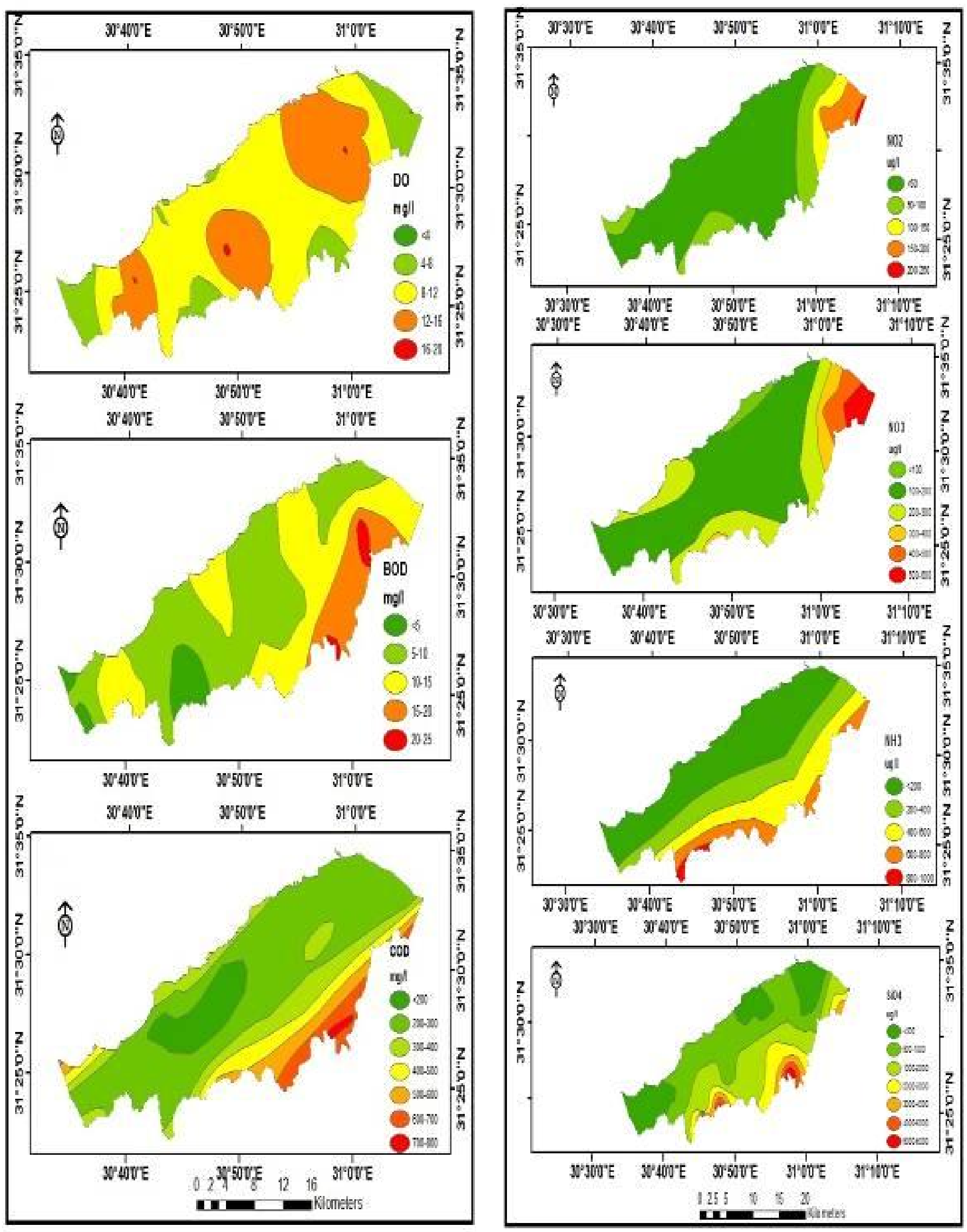

Fig. 2b. The spatial distribution of water variables (DO, BOD, COD, NO_2^-, NO_3^-, NH_3^+ and SiO_4^-) in Burullus Lake using GIS technique

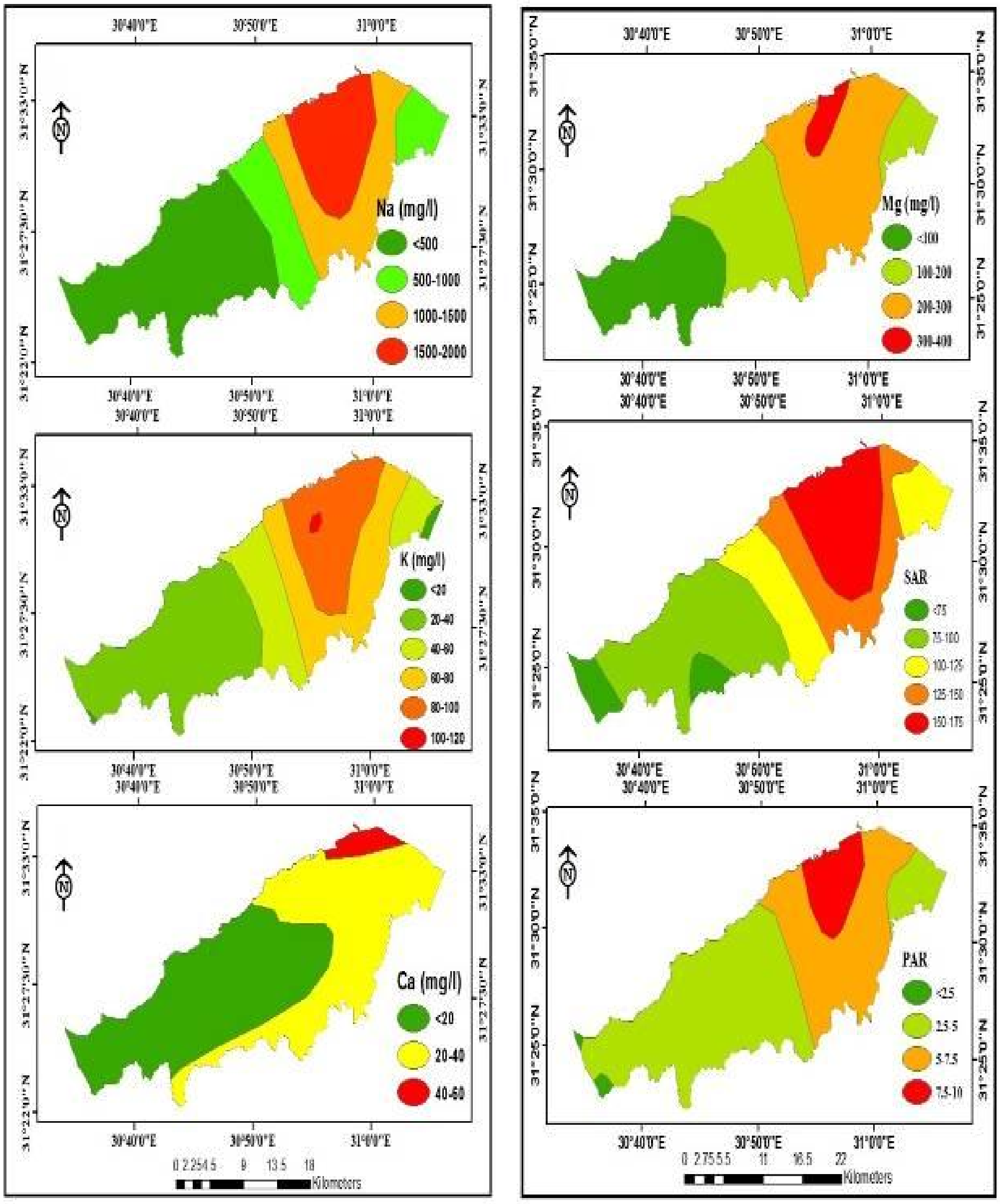

Fig. 2(c). The spatial distribution of water variables (Na^+, K^+, Ca^{+2}, Mg^{+2}, SAR and PAR) in Burullus Lake using GIS technique

COD is a measure of the oxygen equivalent of the organic matter content of water that is susceptible to oxidation by a strong chemical oxidant. The highest value is recorded in the southern part of the lake nearby drains especially drain no.7, this may be due to the high load of organic matter. But the lowest mean value is obtained at the middle part of the lake at El-Zanka area as if far from the drains. The present results agreed with Basiony [18].

The over use of artificial inorganic fertilizers containing nitrogen is the main source of nitrate ions in the water sources. Also, the complete oxidation of nitrogen from the decaying of organic materials in the surface water and in the sediment is an important factor in producing ammonia, nitrate and nitrite [37]. Ammonia (NH_3-N) showed different distribution patterns in Burullus Lake depending on the drainage areas that drain into the lake. The highest ammonia-nitrogen concentration was recorded in El-Shakhlouba. This result is comparable with those obtained by Al-Sayes et al. [38] and Basiony [18]. Ammonia in higher concentrations is harmful to fishes and other aquatic life, but the level of toxicity is based on water temperature and pH [39]. The Illinois Pollution Control Board (IPCB) [40] stipulates an ammonia nitrogen (NH_3-N) limitation of 15 mg/L. The maximum values of ammonia in Lake Burullus were exceeding the WHO permissible limits for surface water bodies which must be lower than 0.2 mg/L.

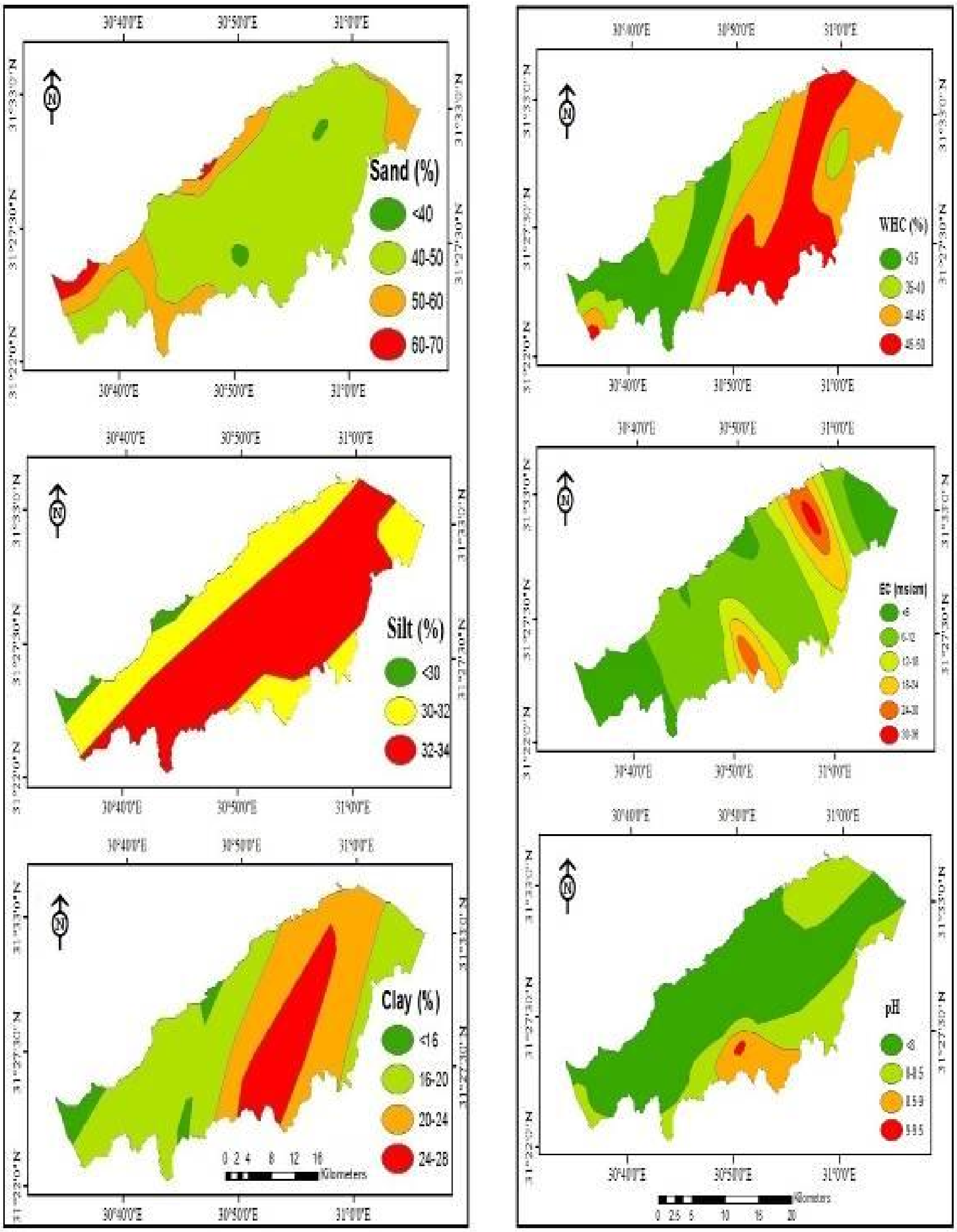

Fig. 3(a). The spatial distribution of hydrosoil variables (soil texture, WHC, EC and pH) in Burullus Lake using GIS technique

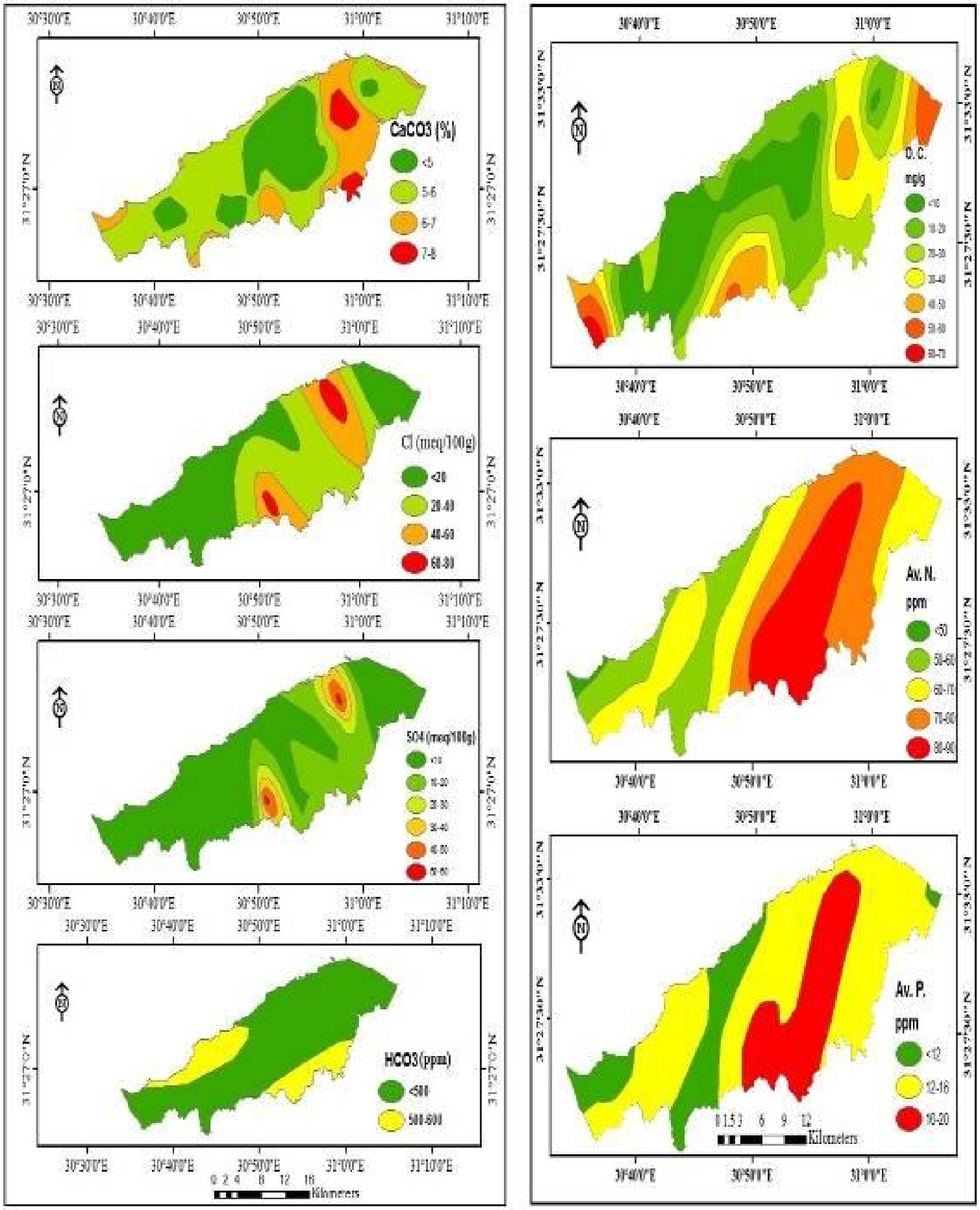

Fig. 3(b). The spatial distribution of hydrosoil variables (Cl^-, SO_4^{-2}, HCO_3^-, OC, available nitrogen and available phosphorus) in Burullus Lake using GIS technique

The highest value of nitrates (884.3 µg/l) was observed at Baltim city nearby drainage area, while the lowest value (12.6 µg/l) was recorded at Bar Bahry area far away from drains. The concentration of nitrate-nitrogen was higher than those reported by Okba and Hussein [31], Darwish [17] and Basiony [18]. The IPCB [40] has set standards for nitrate not to exceed 10 mg/L as nitrogen for the purpose of public water-supply and food processing waters.

The highest concentration of nitrite (517.08 µg/l) was recorded nearby Baltim City as a result of huge amount of wastes near this area, this value is more than (39.2 and 99.4 µg/l) that obtained by Al-sayes et al. [38] and Darwish [17] and

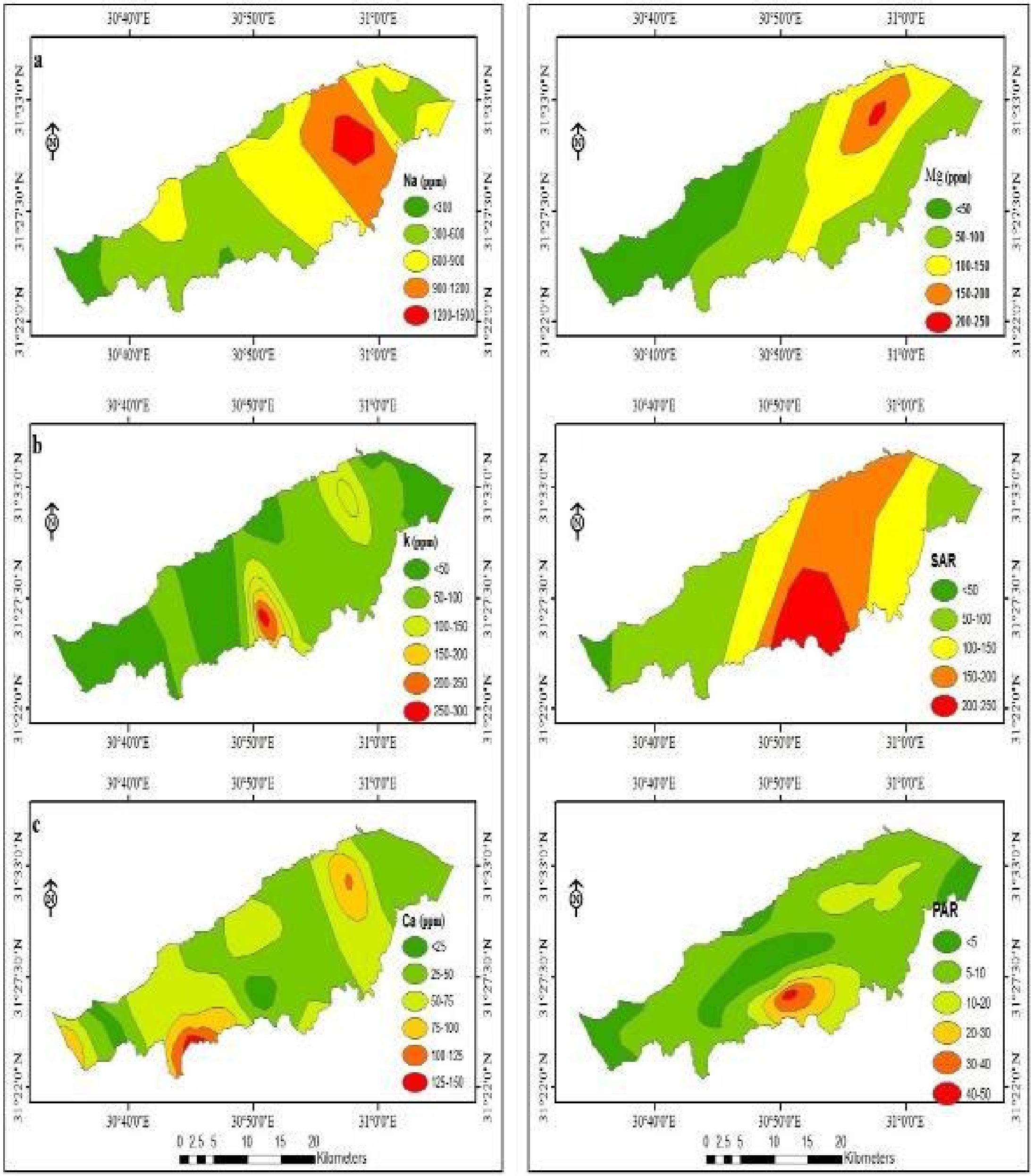

Fig. 3(c). The spatial distribution of hydrosoil variables (Na^+, K^+, Ca^{+2}, Mg^{+2}, SAR and PAR) in Burullus Lake using GIS technique

lower than that recorded by Basiony [33] which was 810.9 µg/l. The lowest value (5.32 µg/l) was recorded nearby Brinbal canal area (at the western part of the lake). If the sum of NO_2 and NO_3 nitrogen concentrations exceeds 0.30 mg/L, it may stimulate algal growth.

The highest value of silicate (5999 µg/l) was recorded at Drain.7 which contains different types of wastes. This value is higher than that recorded by Radwan [41] (865.8 µg/l), but lower than (9531.2 µg/l) estimated by Okba and Hussien [31]. The lowest value (63 µg/l) is recorded at El-Burullus area. It's clear that the highest concentrations of silicates were distributed at the southern parts especially nearby drains as a result of different drainage waters [42].

4.2 Hydrosoils

Sediment quality is a good indicator of water pollution, where it tends to concentrate and accumulate the trace metals and other organic pollutants. Contaminated sediments can pose a threat to human health, aquatic life and the environment [43]. In the study area, soil texture varies from sandy in the northern part to sandy silt and sand muddy in the southern parts. This finding agreed with Samy and El-Bady [44] who revealed that Lake Burullus sediments are texturally classified to three classes: sandy silt, sandy mud, and mud. Radwan and Lotfy [45] reported that sediments of Lake Burullus have a complex nature. The sediments change from coarse particles-sand, usually abundant in the northern coast and at the coast of islets, whereas it's muddy in the southern parts of lake.

Hydrogen ion concentration (pH) plays an important role in many life processes and living organisms in the aquatic environment. The values of pH in the hydrosoils of different habitats were in the range of 7.2 to 9.2. Relatively low pH values occur in drains; this could be attributed to the decay of organic matter and release of organic acids into these sediments [46].

Water holding capacity and clayey soils exhibited the same trend and distribution, this finding is in agreement with Valdes and Real [47] who reported similar results. The higher concentration of $CaCO_3$ was recorded at the northern parts and at the islets of the Lake. This could be attributed to the accumulation of large amounts of shell remains overspreading at the sediments of Lake Burullus.

The distribution of the highest concentrations of available nitrogen and available phosphorus were observed nearby drains at the eastern sector, this may be attributed to the agricultural wastes or the accumulation of deposits containing dead planktons which increase the percent of phosphorus in the sediments [48]. The lowest concentrations were determined in the western section at Brinbal canal that represents the fresh water resource.

The highest concentrations of organic carbon were recorded at the western, southern and eastern parts of the lake; this agrees with Masoud [49] who found that the organic carbon content of sediments was higher at the eastern and western parts where those areas are mostly affected by drainage water. The south parts of lake are characterized by fine particles which contain high amount of organic carbon unlike sandy soils which are very poor with organic matters at the northern parts of the lake [50]. However, the lowest concentrations of organic carbon in the lake were recorded far away from the drainage areas. Organic carbon is strongly correlated with clayey sediments than other soil types.

5. CONCLUSION AND RECOMMENDATIONS

- The northern parts of Burullus Lake characterized by good water and sediment quality than these in the southern parts
- Wastewater must be treated before being drained into Lake water
- Regular evaluation and monitoring of water and sediment quality is important to keep the biodiversity of Lake Burullus.
- Great efforts and cooperation between different authorities are needed to protect the biodiversity in Burullus Lake
- The geospatial tools "i.e. ordinary Kriging'' could be very helpful in monitoring and studying the spatial distribution of different physico-chemical characteristics of water and sediment in the Lake.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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