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Nutrient Salts and Eutrophication Assessment in Northern Delta Lakes: Case study Burullus Lake, Egypt

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ABSTRACT

This study was designed to assess the levels of nutrient salts and eutrophication status in Burullus Lake water. Most of the physicochemical characteristics showed wide variations among the sites and seasons ($p<0.01$). The water of the lake was in the alkaline side, and pH value fluctuated in the range (7.47-8.96). The lake water was oxygenated around the year (2.10 and 13.40 mg/l). The nutrient salts showed a lot of fluctuations, often occurring in high concentrations, with a remarkable spatial and temporal difference ($p<0.001$). As a result of nutrient enrichment, Chlorophyll-a (Chl-a) recorded abnormal high concentrations up to 648.3 µg/L. TN:TP ratio implied that phosphorus is the limiting factor for phytoplankton growth in Burullus Lake. The high levels of nutrient salts and Chl-a together serve as a good indicator of hypertrophic levels in the lake water. This observation was confirmed by the data of the Trophic State Index (TSI) using Chl-a, TP, TN, and Secchi depth that indicated the hypereutrophic state of Burullus Lake associated with poorly of its water quality. Our results indicated the existence of dramatic deterioration in Burullus Lake because of human activities and the discharge of wastewater to the lake.

INTRODUCTION

Lake ecosystems are vital resources for aquatic wildlife and human needs, and any alteration of their environmental quality and water renewal rates has wide-ranging ecological and societal implications (Vincent, 2009). They are the most fertile, productive and interactive ecosystems in the world, unfortunately, lakes today have reached a point of crisis due to unplanned industrialization and urbanization (Rangnekar, 2016).

The lakes fisheries play an important role in the Egyptian economy. In the past, they provided more than 50% of harvested fish in Egypt but now their contribution to the Egypt fish production decreased to only about 10.0 % in 2016. Egyptian northern coastal lakes (Mariout or Mariut, Edku or Edko, Burullus or Borollus, Manzala and Bardawil) provide about 77% of the harvested fish from the Egyptian lakes (GFARD, 2018), the first four lakes represent the Nile Delta lakes.

Burullus Lake is considered as a valuable source for fish yield in Egypt (Mohsen *et al.*, 2018). In the present time, it is the largest producer of fish production in all Egyptian lakes. Its production has increased gradually from 7,349 tonnes in 1963 to 67.577 tonnes in 2016, in addition to about 670.000 tonnes from the aquaculture processes around it, the production of the lake and its aquaculture ponds represented about 42.5 % from the total fish production in Egypt (GFARD, 2018).

Burullus Lake is the second largest natural lake in Egypt, is situated close to the Mediterranean between two main branches of the Nile. It has been listed in 1998 as a Ramsar site because of its importance for migratory foraging, refuge, and breeding of water birds (Goher, 2009). It covers an area of 410 km^2 (Shaltout, 2018) of which 220 km^2 are open water in 2015 (Mohsen *et al.*, 2018). It is obvious that the lake’s open water surface had reduced from 1092 Km^2 in 1801 (Shaltout and Khalil, 2005) to 434.6 Km^2 in 1972 and 220 Km^2 in 2015 with shrinkage about of 80.0 % of the water area (Mohsen *et al.*, 2018; SWOS, 2018). The loss in the water area of the lake returns to the infringement of large areas of the southern and southwestern parts of the lake for reclamation activities and transformation of the lakes to fish farms along their southern regions. Moreover, discharging of the drained wastewater from the drains into the lake leads to increase in number and area of islands inside the lake and to the progressive growth of aquatic plants (El-Khayat *et al.* 2018; Mohsen *et al.*, 2018). Because of the huge amount of rich nutrient wastes discharged to the lake, nitrogen and phosphorus up to elevated levels causing dense algal blooms and eutrophication phenomenon.

Lake Eutrophication is one of the major environmental anxieties over the world in recent times. Most of the wetlands and lakes suffer from the deterioration of water quality and environmental imbalance related to the increasing anthropogenic activities, particularly in developing countries, that may threaten water resource eco-function and human health (Bhagowati and Ahmed, 2018; Xie, *et al.,* 2019. The most eutrophication markers in water bodies include increase rates of primary productivity (the production of plant matter through photosynthesis) to excessive levels, leading to overgrowth of vascular plants (e.g. water hyacinth), algal blooms, and the depletion of dissolved oxygen in the water column, which can stress or kill fish and aquatic organisms (Palaniappan *et al.*, 2012; Bhagowati and Ahmed, 2018). Understanding the trophic status of lakes provides an indication of an ecosystem's current structure and function, which facilitates the prediction of future trends in an ever-changing environment, and this information can be used to formulate appropriate mitigation strategies (Wang *et al.*, 2019).

Eutrophication problems related to the continuous enrichment of nutrients from different sources. Consequently, human-induced eutrophication is in a way related to the increase in human population De Jonge *et al.* (2002). Nutrient enrichment has become the planet’s most widespread water-quality problem. Most often associated with nitrogen and phosphorus from agricultural runoff, but also caused by human and industrial waste. (Palaniappan *et al.*, 2012).

Due to the importance of Burullus Lake, which has economic importance for fish yield in Egypt and suffering from nutrient enrichment and eutrophic phenomena. Moreover, any marked change in water quality is reflected both directly and indirectly in the health, growth, and structure of the fish population (Svobodová, *et al.* 1996). Therefore, the main objective of the current study is to assess the status of Burullus Lake water quality using Trophic State Index and to evaluate the levels and the distribution pattern of different forms of nitrogen and phosphorus in the lake water.

MATERIALS AND METHODS

Study area:

Burullus Lake is a lagoon extending along the Deltaic Mediterranean coast of Egypt. It lies between longitudes 30º 30´ and 31º 10´ E and latitudes 31º 21´ and 31º 35´ N. (Fig. 1). It has an oblong shape extends for a distance of 47 km along the NE-SW axis with width varies between 4 and 14 Km (Okbah, 2005; Shaltout and Khalil, 2005). The depth of the lake ranges between 0.40 and 2.0 m (Goher, 2009). The deepest parts are in the middle sector of the lake where the depth reached 200 cm, and also the southern parts of the western sector (west of Doshimi islet). The eastern sector is the shallowest where the depth does not exceed 20 cm near the shore, but increases westwards until it reaches about 70 cm (Shaltout and Khalil, 2005).

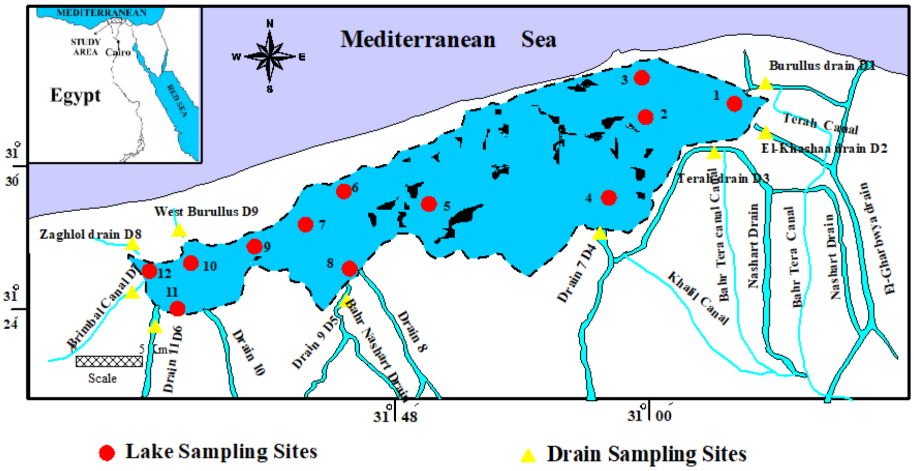

Fig. 1: Map of Burullus Lake demonstrated the selected stations, the black areas represent the islets scattered inside the lake

Sea water enters freely during periods of low inflows of Nile water because the eastern sector of the lake opens to the Mediterranean Sea by a short canal, El Boughaz, 250 m wide and 5m deep, and kept open by dredging to prevent it from silting up (Doumont and El-Shabrawy, 2007; Goher, 2009). It receives approximately 4 billion m^3 of drainage water per year from the Nile Delta agricultural lands (El Shinnawy, 2002), which accounts 97% of the water inflow (Shaltout and Khalil, 2005; Eid, 2012), the remaining 3% is precipitation and groundwater (Oczkowski and Nixon, 2010). Burullus lagoon is affected mainly by agricultural drainage water mixed with different types of wastes from fish farms, industrial and domestic wastewaters effluents via a lot of drains. Many drains connected directly to the lake including (Burullus east Drain, El-Khashaa Drain, Terra, Drain 4, Drain 7, Drain 8, Drain 9 (Nashart), Drain 10, Drain 11, Zaghloul Drain, and Burullus west Drain); in addition to Brimbal (Brinbal) canal that was transferred Nile water from Rosetta Branch to Burullus Lake. Currently, Brimbal canal receives small amounts from Nile water (due to the shortage of freshwater in Egypt), but it receives different wastewaters from minor drains. Also, when the canal water level drops than the lake level, the water return from the lake to the canal. On the other side, there are drains do not connect directly to the lake but they discharge their water via lateral drains as El-Gharbia Drain discharges its water through El-Khashaa Drain. Annex (1) showed details of the descriptions and the annual wastewater inflow of the main Drains into the Burullus Lake.

Water sampling:

Twelve stations and nine drains were selected along Burullus Lake (Fig.1). Water samples were collected seasonally from spring 2016 to winter 2017 by a polyvinyl chloride Van Dorn bottle (2 L), and kept in an icebox on the spot. Burullus lagoon is classified to three basins; eastern, central and western, each one has some sort of homogeneity in geomorphological, hydrological and biological characteristics. The eastern basin comprised three stations (1-3) and three drains, the central basin (five stations; 5-8) received discharged water through several drains, while the western basin (represent four stations; 9-12) receives water from Brimbal canal and from four drains. Details of the sampling sites with their longitude and latitude are provided in Table 1.

Table 1: The details of the sampling locations.

Burullus Lake				The Drains			
No.	Name	Latitude	Longitude	No.	Name	Latitude	Longitude
1	Eastern the lake	31°32'44.10"	31° 4'8.08"	D1	Burullus east	31°33'44.52"	31° 4'40.48"
2	Balaa	31°32'55.74"	30°59'22.38"	D2	El-Khashaa	31°31'22.15"	31° 5'51.36"
3	El-Boughaz	31°34'6.08"	30°58'51.19"	D3	Tera	31°30'54.30"	31° 4'2.54"
4	Infront Drain7	31°27'20.19	30°58'0.91	D4	Drain 7	31°24'9.74"	31° 2'0.65"
5	El-Zanga	31°28'55.35"	30°50'7.74"	D5	Drain 9	31°24'10.90"	30°45'46.90"
6	Mostro	31°28'59.66"	30°45'38.66"	D6	Drain 11	31°21'48.68"	30°35'47.02"
7	El Tawella	31°27'35.04"	30°44'53.12"	D7	Bimbal	31°23'57.36"	30°34'54.05"
8	El-Shakhloba	31°24'54.59"	30°45'36.09"	D8	Zaghloul	31°25'51.28"	30°33'49.09"
9	Abo Ameer	31°25'57.36"	30°42'45.50"	D9	Burullus west	31°25'29.49"	30°35'0.68"
10	ElBerka middle	31°25'28.69"	30°38'15.75"				
11	El-Houkes	31°23'54.51"	30°38'0.30"				
12	Brimbal	31°24'28.38"	30°35'56.00"				

Methods of analysis:

The American Public Health Association standard methods (APHA 2005) was used to determine the water parameters. Water temperature, electrical conductivity and pH value were measured in situ, using the Hydrolab model (Multi Set 430i 126 WTW). The transparency was measured using the Secchi-disk (diameter 30 cm). Water samples were kept in 2-L polyethylene bottles in an ice box and analyzed in the laboratory. TS (total solids) were measured by evaporating a known volume of well-mixed sample at 105°C. TDS was determined by filtering a known volume of sample by (GF/C) and evaporating it at 180°C. TSS was directly obtained by (TS–TDS) (American Public Health Association). For DO and Biochemical oxygen demand (BOD) determination, the samples were filled carefully in glass stopper oxygen bottles with 300 ml capacity. The samples of DO were fixed immediately by $MnSO_4$ and alkaline KI while the bottles of BOD samples were kept far from the light and incubated at 20 ^oC. BOD was determined by using the 5-day method. Chemical oxygen demand (COD) was analyzed using the dichromate method. Dissolved inorganic nitrogen forms NO_2-N, NO_3-N, and NH_4-N were determined using colorimetric techniques with the formation of reddish purple azo-dye, copper-hydrazine sulphate reduction and phenate methods, respectively. Reactive soluble phosphate (RSP) or dissolved inorganic phosphorus (DIP) in filtrated sample and total inorganic phosphorus (TIP) in unfiltrated sample (after hydrolysis by dilute HCl) was determined using ascorbic acid molybdate method. and Chlorophyll-*a* in the surface water were determined according to the method by Strickland and Parsons (1972). Total nitrogen (TN) and total phosphorus (TP) in unfiltered samples and total dissolved nitrogen (TDN) and total dissolved phosphorus (TDP) in filtered water were determined as NO_3 and PO_4 after simultaneous persulfate digestion (Valderrama *et al.*, 1981).

To estimate the PON, DON and TON mathematically as follows :

PON=[TN]- [TDN] & DON = [TDN]- [DIN] and TON=[PON] + [DON]

and also PIP, TPP, DOP, POP, and TOP was calculated as follows:

PIP=[TIP]-[DIP] & TPP= [TP]-[TDP]

DOP=[TDP]-[DIP] & POP= [TPP]-[PIP] and TOP = [DOP] + [POP]

The concentration of nitrogen and phosphorus forms were determined colorimetrically, using Shimadzu double beam spectrophotometer UV-150-02.

Statistics analysis:

One-way ANOVA analysis, followed by a post-hoc comparison using Tukey's test, was applied to identify significant differences in all parameters among sites and sampling time. Significance levels of tests were taken as $p<0.05$ and highly significant as $p<0.01$. ANOVA tests were undertaken using the Excel-Stat software. Pearson's correlation analysis was performed to evaluate potential relationships between the different variables.

Trophic State Index:

Trophic State Index (TSI) was calculated according to (Carlson and Simpson, 1996) scheme, which combines the Carlson (1977) and Kratzer and Brezonik (1981) schemes and calculates Trophic State Index (TSI) values for four key variables depended on the inter relationships of secchi depth reading in meter (TSI_{SD}), Chlorophyll-a concentration, µg/l (TSI_{Chl-a}), total phosphorus, µg/l (TSI_{TP}) and total nitogen, mg/l (TSI_{TN}). TSI calculation was done as follows:

TSI_{SD} =60 – 14.41 ln (SD) SD in m

TSI_{Chl-a} =30.6 + 9.81 (ln Chl-a) Chl-a in µg/l

TSI_{TP} =4.15 + 14.42 ln (TP) TP in µg/l

TSI_{TN} = 54.4 + 14.43 ln (TN) TN in mg/l

TSI= 1/4 [SI_{SD} + TSI_{Chl-a} + TSI_{TP} + TSI_{TN}]

RESULTS AND DISCUSSION

Physicochemical characteristics of water:

Water Temperature:

Temperature is one of the most important factors in aquatic environment. In general, most of the biological and chemical processes occurring in natural water bodies are greatly dependent on temperature. Its measurements in natural water bodies are subjected to great variations due to several factors such as, the latitude, sun altitude, season, wind, depth of water, waves, gain or loss of heat in shallow waters close to the land, etc.(Saad *et al*., 2017)

In Burullus Lake, the temperature was ranged in normal values (13.6 - 32.20◦C) around the year, which is suitable for fish survival, with a slight increase during summer. ANOVA data shows a highly temporal significant difference ($p< 0.01$). Temperature is positively correlated ($n=48$, $p<0.01$) ($r=0.42$) with BOD, ($r=0.43$) with TSS, ($r=0.45$) with Fe, ($r=0.54$) with Mn, ($r=0.50$) with Zn, and ($r=0.56$) with Pb and negatively correlated ($r= -0.37$, $n=48$, $p<0.01$) with Transparency, this results are in agreement with those obtained by (Goher *et al.*, 2018) in Qarun Lake.

Water Transparency:

Transparency relates to the depth that light will penetrate water that influences the primary productivity, it depends on the amount of inorganic particles (suspended solids and sediment from erosion) and organic particles (such as, organic detritus, algae, and phytoplankton) (Goher *et al.,* 2018). Our results indicated the high turbidity of Burullus Lake water that showed a high temporal and spatial significant difference ($p< 0.01$), It was ranged from 15cm in spring at (St. 4) to 70 cm in winter at (St. 3) with an annual average of 25.63 cm. The low transparency value related to the massive amounts of wastewater, which is heavily loaded with suspended and organic matter, in addition to the phytoplankton bloom (Okbah, 2005). As shown in Fig.2, the transparency decreased in the middle sector which is affected by the agricultural, industrial and domestic drains especially drain 8 and 9, while the high transparency was recorded at the north part as it receives water from the sea through Al-Boughaz out-let. In drains, transparency ranged between (15-60 cm). Based on the annual averages, the maximum value 45 cm was recorded at Brimbal Canal, while the minimum one 15 cm was recorded at drains 3, 7 and 9 Table (2).

Table 2: The ranges and annual means of physicochemical characteristics and nutrient salts content in water of the main drains of Burullus Lake

parameter	Dr1	Dr2	Dr3	Dr4	Dr5	Dr6	Dr7	Dr8	Dr9
Temp °C	14.9-33.70 23.08	15.10-29.60 22.63	15.4-29.0 22.63	16-28.2 22.25	16.3-28.5 22.45	16.20-3.02 23.53	16.3-2.01 23.83	15-28.1 22.05	15.6-29.30 22.2
Trans. Cm	30-40 35	20-40 28.75	15-30 21.25	15-30 25	15-25 18.75	20-30 23.75	30-60 45	20-30 25	20-30 27.50
EC ms/cm	5.54-9.72 7.08	4.26-5.80 4.95	4.52-8.89 5.86	4.24-5.01 4.74	2.54-3.32 2.81	1.02-1.74 1.42	3.50-9.84 6.63	6.38-9.65 7.79	2.2-2.67 2.42
TDS mg/l	3.75-6.71 4.84	2.91-3.96 3.36	3.08-6.05 4	2.89-3.38 3.2	1.75-2.26 1.91	0.70-1.17 0.96	2.36-6.71 4.50	4.35-6.57 5.31	1.51-1.81 1.6
pH	7.55-7.90 7.74	7.99-8.36 8.13	7.72-8.02 7.86	7.07-8.03 7.77	7.30-8.47 7.93	7.54-8.25 7.88	8.16-8.94 8.56	8.09-8.73 8.36	7.66-8.59 7.97
DO mg/l	4.16-4.62 4.46	6.36-7.80 6.84	4.6-6.72 5.58	4.0-9.84 5.75	2.4-5.28 4.24	3.6-7.44 4.77	5.24-6.12 5.64	4.12-5.26 4.67	4.16-6.12 5.17
BOD mg/l	13.52-16.19 14.93	11.71-17.44 15.35	10.46-15.68 13.78	10.54-18.1 13.53	20.24-30.17 23.78	11.18-21.92 14.54	12.71-17.72 14.51	10.10-15.32 13.36	12.54-15.86 13.62
COD mg/l	39.73-56.4 44.95	40.45-49.8 44.07	27.55-36.66 33.24	29.49-49.97 39.32	37.27-53.83 46.51	31.85-38.60 35.69	26.62-38.27 33.66	37.17-44.54 41.31	28.77-42.70 33.18
NO_3-N µg/l	237.4-925.9 557.2	232.59-1060.1 665.6	208.9-1328.8 708.38	171.59-1227.7 503.7	478-984.9 711.7	205.6-715 409.02	329.6-806.7 473.2	386.4-1444.2 871	251.80-1432.3 779.7
NO_2-N µg/l	63.7-306.8 223.4	89-316.52 240.4	40-456.20 235.7	86.6-237.8 142.4	83.1-504.3 251.9	32.9-129.42 85	16.9-313.1 128.1	30.7-344.1 225.9	44.23-588.85 284.79
NH_4-N µg/l	2159-4563.1 3066.8	2323.7-4186 3345.7	2355.9-4593 3265.9	1953.7-6235.5 4137.4	2500-25931 11443.2	4666.3-10054 6739.3	1469-3826 2348.7	1280.3-5464 2417.5	687.5-2572.3 1192.1
DIN µg/l	2491.3-5107.4 3847.5	2645.2-5562.7 4251.7	2604.7-6377.9 4209.6	2291.1-6547.9 4783.6	3090.8-27108 12406	5040.9-10293 7233.5	1904.3-4207.2 2950	1697.4-6837.7 3514.4	1000.2-3101 2196.5
PON µg/l	414.3-2827.8 1563.1	482.3-3096.4 1982.6	761.4-3396 1950.8	619.4-2488.4 1408.5	956.2-3796.1 2118.2	781.3-2279.4 1355	1416.7-1929 1605	346..3-1874 888.9	394.2-1137 872.9
DON µg/l	675.4-951.8 770.8	347.1-712.7 512	497.4-810.8 657.1	386.2-762.1 556.9	416.9-1187.8 809.8	534.7-842.9 700.4	379.1-646.7 492	268.8-547.2 403.2	287.4-614.2 273
TON µg/l	1089.7-3779.6 2333.9	829.5-3478.5 2494.6	1293.2-4206 2607.9	1121.7-3250.6 1965.4	1849.4-4983.9 2928	1478.2-3122.3 2055.4	1877.5-2576 2097.1	615.1-2301.2 1292.2	681.6-1721.4 1345.9
TN µg/l	3581-8887 6181.3	3474.7-9041.2 6746.3	3897.9-9827.6 6746.3	3412..8-8832.3 7648.9	4940..2-32092.6 15334.7	6519.1-13415.5 9289	3881.8-6783 5047.1	2312.5-9183.9 4806.6	1681.8-4798.1 3542.3
DIP µg/l	278.2-384.1 335.3	117.5-473.5 341.8	153.7-611.1 415.7	110.8298.7 200.6	121.2-819.9 441.7	105.5-643.1 338	134.7-301.8 185	121.8-282.3 192.7	108.7-286.7 192.7
TIP µg/l	349.2-463.1 403.9	141-565 408.3	208.7-737.9 504.9	131.4-348.6 241.2	229.2-1018.7 260.4	115.9-785.1 412.4	161.2-344.1 223.1	147.5-350.6 241.1	126.4-345 262.5
DOP µg/l	129.9.3-212.7 181.29	46.7-250.6 155.01	122.8-241.3 178.9	102.7-157.1 126.5	72.3-439.5 215.1	148.3-423.9 245.1	66.1-249.8 154.9	79.3-214.5 140.4	54.7-108 85.6
TOP µg/l	190.3-370.9 281	86.1-335.2 236.6	156.2-296 238.5	165.6-230.6 186.7	128.8-556.3 289.5	176.4-428.2 305.3	116.1-339.3 210.6	104.5-235 181.3	85-590.3 236.7
TDP µg/l	449.6-593.17 516.59	164.22719.8 496.8	276.49-764.13 496.8	213.46-455.8 327.02	216.35-1259.4 656.7	293.14-1067 583.09	201.72-551.6 339.9	226.7-496.7 333.14	179.8-789.4 414.3
TPP µg/l	127.8-215.4 168.4	62.9-247.3 148	88.4-238.1 148.7	83.2-123.5 100.9	69.5-315.6 168.1	90.2-215.4 137.1	40.2-131.8 93.8	58-110.9 89.3	58-145 84.8
TP µg/l	577-787 685	227-898 644.8	364-1002 743.1	308-579 427.9	285-1575 824.8	289-1213 720.2	280-683.4 433.7	337.6-585.9 422.5	451.4-935.4 499.1

Electrical conductivity (EC) and Total dissolved solid (TDS):

Water electrical conductivity (EC) is the ability of water to conduct an electrical current, and the dissolved ions are the conductors. The EC in the Burullus Lake ranged between 2.14 to 54.8 mS/cm with high spatial significant difference ($p< 0.01$). The high EC were recorded at the eastnorth side of the lake due to the pass of seawater through El Boughaz outlet (Ali, 2011; EL-Zeiny and EL-Kafrawy, 2016). On the other side, the increase of EC during winter due to lack of fresh water input during the drought period and periodic intrusion of sea water through El-Boughaz outlets. The EC decreases in southern and western sectors due to the mixing with the wastewater from drains 9, 11, and west Burullus, which characterized by a relatively low of EC values.

TDS followed the distribution approach of EC (Fig. 2), the obtained results showed high positive correlation between EC and TDS (r= 0.99, P< 0.01), because EC is sensitive to variations in dissolved solids, mostly mineral salts (Kumar and Parita, 2014). TDS showed its maximum value (34.10 g/l) during winter at St. (3). On the other hand, the lowest value (1.44 g/l) was recorded at St. (11) in summer, may be attributed the dilution effect of drain 11, which is distinguished with low TDS contents. In the drains, EC and TDS reneged between 1.02 - 9.84 ms/sec and 0.7 – 6.71 g/l at drain 11 and Brimbal Canal, respectively (Table 2). It is worth mentioning, the abnormal increase of EC and TDS in Brimbal Canal, (was supposed to transfer Nile water to the lake), may be attributed to the significant reduction discharge of the Nile water to the canal, on the contrary, the canal became receives water from the lake and minor drains, in addition to the stagnation of water in the canal most of the time.

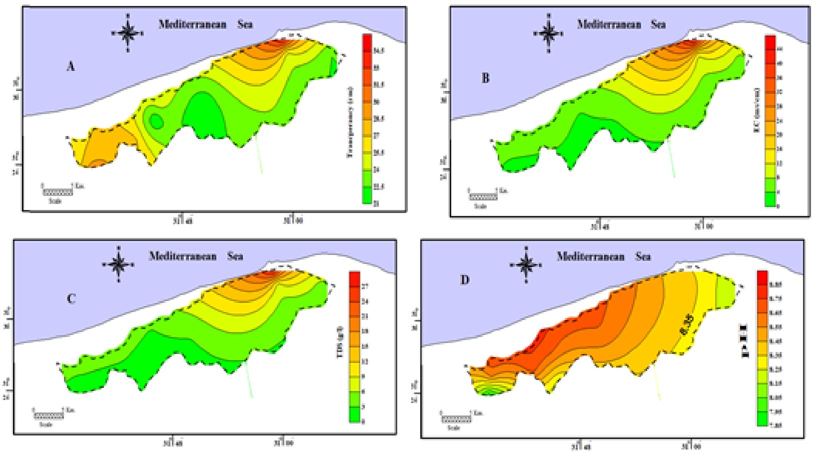

Fig. 2: Contour map of the mean value of A: transparency (cm) , B :EC (ms/cm), C: TDS (g/l) and D: pH in Burullus Lake water.

Hydrogen ion concentration (pH):

Hydrogen ion concentration (pH) is the master control parameter in the aquatic environment for the chemical and biological transformation of water (Goher *et al.*, 2017). The results showed that the pH values tended to the alkaline side and ranged between (7.55-8.95) with remarkable difference among sites and seasons ($p< 0.01$), that may be due to the increase of photosynthetic activity of planktonic algae (Fathi and Kobbia, 2000). It is noted that the pH decreased in west southern part due to the effect of drains 8 and 9 (Fig. 2), these results in agreement with those reported by (Okbah and Hussein, 2005; El-Alfy *et al.*, 2017). According to the regional average values, the hot seasons (summer and spring) recorded higher pH levels than the cold seasons (winter and autumn), which is related, mainly, to the increase of CO_2 uptake due to the increase of the photosynthetic activity, which leading to high pH values (Goher, 2002). The correlation coefficient matrix showed a positive correlations between pH and CO_3^{2-} ($r = 0.82$, n=48, $p< 0.01$), DO ($r = 0.44$, n=48, $p< 0.01$). The pH values in drain water exhibited a minimum mean value (7.74) in East Burullus Drain, while the highest mean value (8.56) was recorded in Brimbal Canal Table (2).

Dissolved Oxygen (DO):

Dissolved Oxygen is one of the key parameters and factors in the chemical and biological systems of natural waters that effect on fish production and the biological processes of almost all aquatic organisms and its survive (Goher *et al.*, 2018; El Zokm *et al.* 2018). Water of Burullus Lake was oxygenated during the entire sampling period (Fig. 3), it was found in the range of (2.1–13.4 mg/l) with high spatial and temporal significant difference ($p < 0.01$). The lowest value was recorded at station 8 in winter season may be attributed to the direct effect of the discharged effluents heavily loaded with organic and inorganic wastes from the agricultural and domestic waste drain (drain 7) combined with the low photosynthesis activity during winter, this result agreed with that obtained by Hereher *et al.* (2010). While, the highest value of DO 13.40 mg/l was found at St. 6, in the north side, the most station far from the effluent wastes during summer. This may be attributed to the increase of photosynthetic activity during this season, which liberates a significant amount of oxygen to the surrounding water ecosystem, since the photosynthetic process was regarded as the main source of oxygen in the aquatic environment (Mahmoud, 2002).

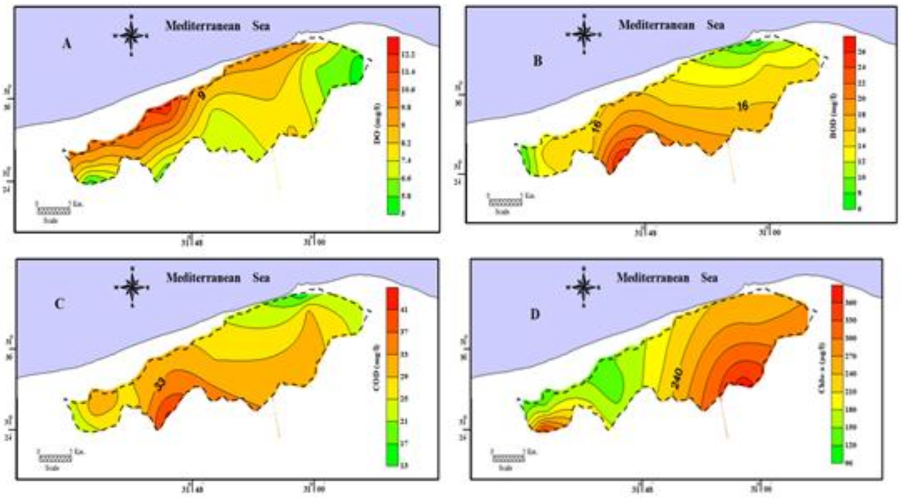

Fig. 3: Contour map of the annual mean values of A: DO, B: BOD, C:COD concentrations (mg/l) and D: Chl-a (µg/l) in Burullus Lake water

It is notable that the DO in Burullus Lake showed a wide variation among sites and seasons. Where, DO exhibited high contents in the western part compared with the middle and the eastern regions, and it decreased from north to south. This finding may be related the discharges of different wastewater via founding a lot of drains, especially at south side, which in turn correlated with the load of organic matters discharge into the lake, this result agreed with that reported by Younis and Nafea (2012). According to the drains, DO ranged between a minimum value (2.4 mg/l) at drain 9 and a maximum value (9.48 mg/l) at drain 7 (Table 2).

Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD):

BOD and COD refer to the organic matter contents in water that is degradable by biological action (microorganisms' activity) or by the chemical process, respectively (Goher *et al.*, 2017). They are a good indicator for the pollution of water bodies with organic substance (El Zokm *et al.* 2018). Concerning to our study, the levels of both BOD and COD in Burullus Lake water were higher than the international permissible levels. ANOVA data showed BOD and COD results had a high spatial and temporal significant difference ($p < 0.01$), they fluctuated in the ranges of (5.82-29.16) and (10.29-48.51) mg/l, respectively. It is noticeable that, based on the annual average, St.3 (facing to El Boughaz outlet) recorded the low contents of BOD and COD due to the dilution effect of low organic matter loaded seawater, on the side, the highest values were recorded at St.8, infront of drains 8&9 where pouring heavily loaded drainage wastewater these results are in agreement with those obtained by EEAA (2017).

According to the regional averages, the hot seasons, in particular summer, exhibited the high BOD and COD concentrations, as result of the increase of bacterial activity at high temperature, as well as, the increase discharging of organic matter loaded wastewater after the drought period. In the drains, BOD varied in the range of 10.1-30.17 mg/l in Zagloul Drain and Drain 9, respectively. While COD changed between 26.62 and 56.42 mg/l at Brimbal Canal and West Burullus Drain, respectively.

Chlorophyll-a (Chla):

Chlorophyll-a can be used as an indicator parameter for the quality and the health of the water bodies. It is essential to the phytoplankton growth, and a measure of the productivity of the water body. The current study revealed that the chlorophyll-a content varied significantly among the sites, it fluctuated in the ranges of 95.0-648.3 µg/l with descending order of summer > spring > autumn > winter. The value of chlorophyll-a decreased during winter in response to the winter closure policy, i.e. no pumping of drain-water into the lake (El-Shinnawy, 2002), the water level falls to about 26 cm below sea level. This permits approximately 110 million m^3 of nutrient-poor seawater to enter the lake. These saline and colder inflows could be a reason for the pronounced reduction in phytoplankton in winter (Ali, 2011). Spatial distribution of chlorophyll-a is shown in Fig.3, where, the maximum values of chlorophyll-a were recorded at the southern part of the lake, this may be attributed to a dense population of phytoplankton due to the huge amounts of discharged wastewater that is heavily loaded with nutrient.

Nutrient Salts:

Nutrients, the fuel of life, are a variety of chemical elements and compounds are essential to the growth and survival of living organisms that all plants and animals require for growth. In aquatic ecosystems, nitrogen and phosphorus are the most important, as they are most often in short supply relative to the needs of plants, algae, and microbes (Unknown, 2016). Fig. 4 represents the contour map of the annual means levels for the different nitrogen forms in Burullus, including; ammonia NH_4-N, nitrite NO_2-N, nitrate NO_3-N, total inorganic nitrogen (TIN), dissolved organic nitrogen (DON), particulate organic nitrogen (PON), total dissolved nitrogen (TDN), total organic nitrogen (DON), and total nitrogen (TN).

Inorganic Nitrogen:

Nitrogen enters water in numerous forms, including both inorganic and organic forms. The primary inorganic forms of N are ammonia, nitrate, and nitrite. Organic-nitrogen (organic-N) is found in proteins, amino acids, urea, living or dead organisms (i.e., algae and bacteria) and decaying plant material (Wall, 2013).

The present results demonstrated that the dissolved inorganic nitrogen content (the sum of NO_2-N, NO_3-N, and NH_4-N) in the lake water is relatively high. Generally, high levels of DIN were found at Shakhloba (St. 8) and El-Hoksa (St. 11) compared with that recorded in the other sites, which is related to that these stations are closed to drains 8&9 and drain 11, reactively, and are affected directly by the discharge of the effluents that mainly contain amount of agricultural fertilizers, in addition to domestic and fish farms wastes (Darwish *et al.*, 2018), this result agrees with the result obtained by Okbah and Hussien (2006). Fig. 4 showed that the concentration of the DIN increased from north to south because the northern part of the lake is close to the sea but the southern part is surrounded by agricultural and industrial drains.

Ammonia, nitrate, and nitrite in the upper lake were found in wide variations in the ranges of 115.6–11350, 36.3–1241.1, and 14.3–247.9 µg/l, respectively with a highly significant difference among sites and seasons ($p < 0.01$). Ammonia in Burullus Lake, that represents 81 and 44.86 % of DIN and TN, respectively, exist in high levels that may become toxic and lethal (depend on pH value) for fish and other aquatic organisms.

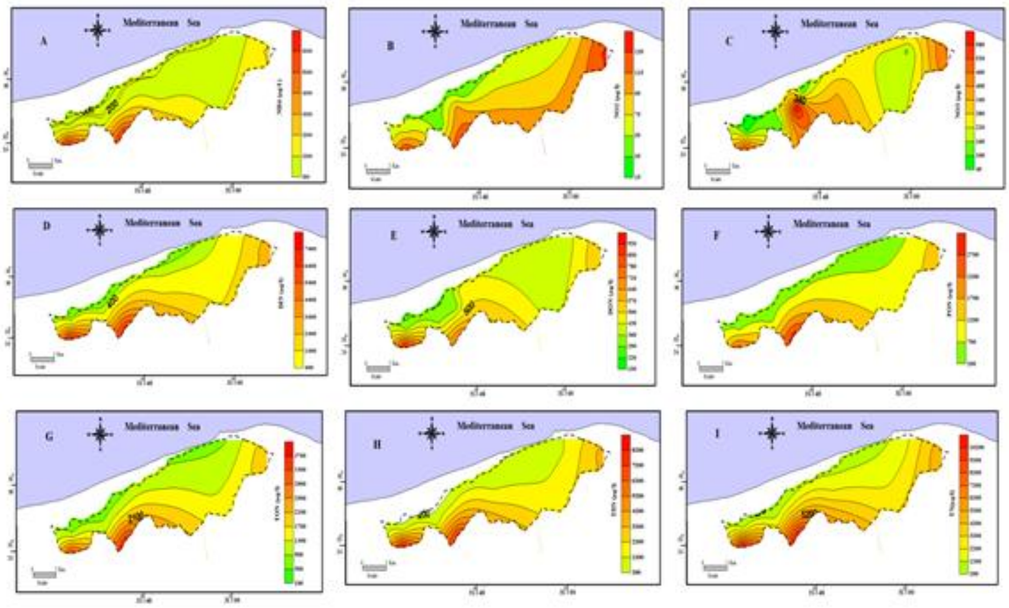

Fig. 4: Contour map of the mean value of A: NH_4-N , B: NO_2-N, C: NO_3-N, D:D1N , E: DON, F: PON, G: TON, H: TDN and I: TN concentrations (µg/l) in Burullus Lake water

In a similar trend, nitrate showed a high spatial and temporal difference ($p < 0.01$), it ranged between 36.1 and 1241.1 µg/l, where the lowest value was recorded at St. 2 during winter and the highest one at St. 11 in autumn. On contrast to ammonia and nitrate, the distribution dynamics of nitrite did not show any significant variations among seasons and locations ($p > 0.10$), although it changed in a wide range of 14.3 µg/l in autumn at St. 9 and 247.9 µg/l in winter at St. 1. In general, the increasing levels of DIN in hot seasons compared to those in cold period, may be attributed to the increase of the effluent from the different drains after the winter closure policy (drought period) these finding in opposite to those obtained by Okbah (2005), who recorded that the highest values of DIN were recorded in the winter season. In the drains, NH_4-N, NO_2-N, and NO_3-N changed in the ranges of 687.52-25931, 16.91-588.58, and 36.3-1241.1 µg/l, respectively.

Organic and Total Nitrogen:

Organic nitrogen (ON) in aquatic environments consists of truly dissolved organic nitrogen (DON) and particulate organic nitrogen (PON). DON is defined as material that can pass from 0.2-mm filter, while PON is the material that is retained on the filter. This means that PON includes both dead organic matter and living organisms that are larger than 0.2 mm (Jørgensen, 2009). Dissolved organic nitrogen (DON) can be one of the important sources of nitrogen for phytoplankton growth (Otsuki *et al*., 1993). According to the current study, the TON, DON, and PON were found in the ranges of 667.4-4679.2, 204-1146.1, and 208.1-3769 µg/l, respectively with a high significant spatial difference ($p < 0.01$) and irregular distribution with time. The maximum values were recorded at St.8 due to the effect of demotic, industrial and agricultural wastes through drains 8&9, while the minimum concentrations were recorded at station 7, 3, and 6, respectively.

It is noticeable that the lake water contains a considerable amount of particulate nitrogen associated with organisms and products of their metabolism and decay (Okbah, 2005). On the other hand, the concentration of DIN (55.45% of TN) was much higher than DON (13.13 % of TN) (Table 3), this may be attributed to the high amounts of agricultural wastes that is discharged from the surrounding drains. This result disagrees with that obtained by (Okbah, 2006). It is obvious that the contents of organic nitrogen (DON and PON) were lower in winter compared to the other seasons due to the entrance of poor nitrogen seawater during the winter closure policy.

Table 3: The ranges and means concentrations of Nitrogen and Phosphorus (µg/l) forms in Burullus Lake water

					Nitrogen contents				
	NH_4	NO_2	NO_3	DIN	TN	TDN	PON	DON	TON
MIN.	115.6	14.3	36.3	275.3	204	507.6	208.1	667.4	1001.5
Max	11350	247.9	1241.1	11536.5	1146.1	12371.7	3769.5	4915.6	16452.2
Mean	1636.2	86.64	302.7	2025.5	479.0	2504.5	1142.7	1621.7	3647.2
±SD	±2593.4	±64.9	±282.8	±2686.6	±214.3	±2186.9	±879.2	±1021	±4007
% 0f TN	44.86	2.38	8.30	55.54	13.13	68.67	31.33	44.46	100.00
					Phosphorus contents				
	DIP	PIP	TIP	DOP	POP	TOP	TDP	TPP	TP
MIN.	11.6	1.8	13.6	6.79	4.1	10.91	18.4	6.1	24.6
Max	413.3	44.8	434.0	176.1	171.6	335.2	576.92	192.3	769.2
Mean	150.5	19.2	169.7	85.6	60.9	146.5	236.08	80.1	316.2
±SD	±86.12	±12.4	±95.4	±40.1	±35.7	±76.3	±126.63	±44.8	±170.66
% of TP	47.60	6.07	53.67	27.07	19.26	46.33	74.66	25.33	100.00

The total nitrogen showed the same distribution pattern of DIN, it varied significantly among sites and time with a remarkable increase during the hot seasons in comparing to the cold seasons. It showed a wide range of variation along the study area (1001.5 – 16452.2 µg/l) with remarkable high levels at the locations closed to drains 8&9 and 11. Our results agree with El-Zeiny and El-Kafrawy (2016), they found that the highest concentrations of TN have detected in southeastern and western part of the lake, especially at the parts polluted by fertilizer, run-off animal wastes, and domestic sewage. Finally, all nitrogen forms in Burullus Lake were found in high levels due to the nitrogen loaded wastes that are poured into the lake through the different sources. In the drains, the TON and TN ranged between 615.1-4983.9 and 1681.8-32092.6 µg/l, respectively (Table 2).

Organic and Total Phosphorus:

Organic phosphorus in water bodies exists either as dissolved or particulate, A portion of particulate phosphorus is contained in organic matter such as algae, plant and animal tissue, waste solids, or other organic matter; or precipitates of phosphorus and phosphorus adsorbed to particulates. The dissolved organic phosphorus, to a somewhat lesser extent, is usable by microorganisms (Ellison and Brett, 2006) and it supports a significant amount of the annual primary production in highly stratified, phosphate depleted waters (Unknown, 2014). However, this bioavailability may be reduced at the association of DOP with humic acids (Ellison and Brett, 2006). In the present study, DOP ranged between (6.79-171.6 µg/l) with high significant difference among season and locations, the maximum value was recorded at St. 8 while the minimum was recorded at St.3 (Fig. 5). In spite of DOP contributes a significant fraction of the total phosphorus, 27 %, it is relatively low compared to DIP (Table 3).

There was significant variation in the content of POP ($p < 0.01$), it ranged between 4.1 and 171.6 µg/l, the maximum value was recorded at St.8 in summer, while the lowest one was recorded at St. 3 in winter. POP represented 76 % of TPP while PIP represented 24%. The high level of TPP (40.2-315.6 µg/l) may have resulted from phosphorus that is associated with the suspended particulate matter and organic detritus, in addition to the debris of dead algae and aquatic organisms carried by the wastewater inflows into the lake.

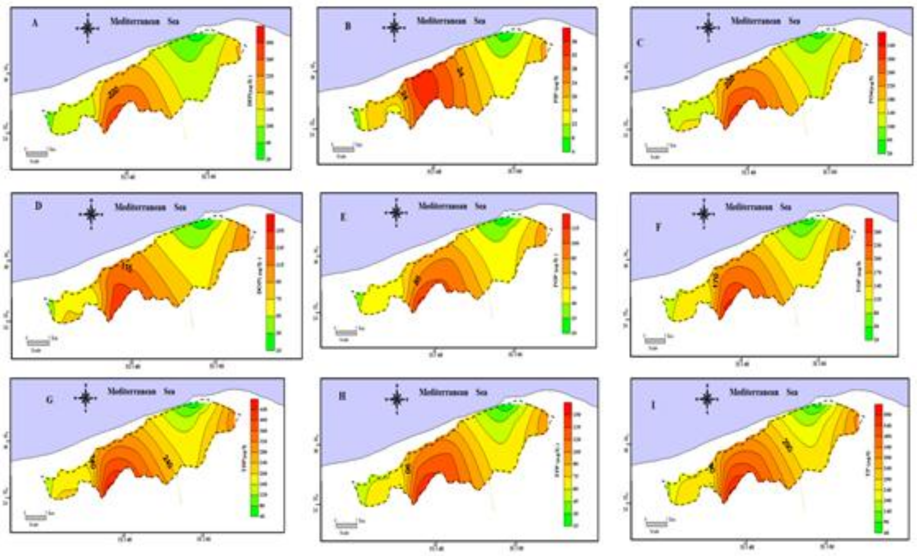

Fig. 5: Contour map of the mean value of A: DIP, B: PIP, C: PO_4/P, D: DOP, E: POP, F:TOP, G: TDP, H: TPP and I: TP concentrations (µg/l) in Burullus Lake water

As the same trend TIP and TOP distribution, the total phosphorus (TP) showed a wide range of variation with high spatial and temporal significant difference (p <0.01). The absolute value of total phosphorus was fluctuated between the low value (24.6 µg/l) at St. 3 in winter and the maximium one (796.2 µg/l) at St.8 in summer. Generally, the concentration of total phosphorus was relatively high; this may be related to the huge amounts of wastewater drainage into the lake. As shown in Fig.5, the concentration of TP increased in western, southwestern and eastern parts of the lake, this result is in agreement with that obtained by El-Zeiny and El-Kafrawy (2017).

According to the drains, TDP, TDP, and TP varied in the ranges 164.22-1259.4, 85.0-590.3, and 227. 1-1575.0 µg/l, respectively (Table 2), these results confirmed that the bulk amounts of the phosphorus introduced to the lake in inorganic forms.

N: P Ratio:

The N: P ratio provides an indication of the limiting factor responsible for controlling eutrophication in the aquatic environment. It is calculated from the concentrations of nitrogen as total nitrogen and phosphorus as total phosphate at the sampled stands in a different site. Although the ratio between dissolved nutrient has been found to be a better indicator of phytoplankton growth limitation, the ratio between total nitrogen and total phosphorus (TN:TP) is commonly used ratio to determine the limiting nutrient in lakes (Romarheim, 2012). Lakes with a TN:TP molar ratio < 10 are considered to be N limited, whereas those with TN:TP molar ratios >20 are considered to be P deficient (Muhid and Burford, 2012; Ratliff, 2018). While aquatic ecosystems with TN:TP molar ratio between 10 and 20 are a dual limitation of phytoplankton growth by both phosphorus and nitrogen. Table 4 showed that TN:TP molar ratios have ranged between 10.9 and 110.4, indicating that the different sites of Burullus Lake are either P limited or N and P co-limited. It was noticed that the maximum TN:TP ratio was recorded at station 3 (infront the outlet to the Mediterranean sea, which may be attributed to the effect of phosphorus-poor seawater. On the other hand, the lowest N:P ratio was recorded at station 5 (in the middle of the lake).

Table 4: N/P molar ratio of Burullus Lake water.

Station	TN µM/l	TP µM/l	TN/TP ratio	Limitation
1	339.2	12.73	26.7	P
2	130.4	6.89	18.9	N and P
3	181.4	1.64	110.4	P
4	198.2	8.01	24.7	P
5	170.3	15.69	10.9	N and P
6	194.4	13.81	14.1	N and P
7	181.1	15.12	12.0	N and P
8	754.3	19.97	37.8	P
9	125.4	7.67	16.3	N and P
10	100.4	8.21	12.2	N and P
11	724.9	8.94	81.1	P
12	182.2	5.42	33.6	P
Whale Area	273.7	10.3	26.4	P

Generally, Burullus Lake may be considered P limited for Phytoplankton growth based on the mean value of TN:TP molar ration in the whole area of the lake (Table 4). The high values of TN/TP ratio were consistent with a number of other studies where phosphorus was found to be the limiting nutrient (Sterner *et al*., 2008; Romarheim, 2012; Fink *et al*., 2018; Khellou *et al*., 2018). In contrast, our results are disagreement with those obtained by El Zokm *et al*., (2018), they recorded that the nitrogen is the limiting factor in Mariout Lake. High concentrations of DIN, which were in the range of 0.27-11.54 mg/l around the year, indicate sufficient nitrogen for phytoplankton growth. Nitrogen may, therefore, be excluded as a limiting factor for phytoplankton dynamics (Romarheim, 2012).

Trophic State Index:

The trophic state index (TSI) is a good indicator to assess the health and quality of the water bodies. It is a classification system designed to "rate" individual lakes, ponds, and reservoirs based on the amount of biological productivity occurring in the water (Unknown, 2018). Good to mention, the more the water eutrophy, the less the water quality. The lakes are usually classified to three possible classes: oligotrophic, mesotrophic or eutrophic. Lakes with extreme trophic indices are known as a hypereutrophic. Table 5 shows the relationships between the ranges of TSI values associated with water quality conditions.

Table 5: Trophic Classes of lakes and their attributes according to Trophic State Index*

TSI value	Attributes	Trophic Class	WQ
< 30	**Oligotrophic; clear water; high DO throughout the year in the entire hypolimnion**	**Oligotrophic**	**Good**
30-40	**Oligotrophic; clear water; possible periods of limited hypolimnetic anoxia (DO =0)**		
40-50	**Moderately clear water; increasing chance of hypolimnetic anoxia in summer; fully supportive of all swimmable/aesthetic uses**	**Mesotrophic**	**Fair**
50-60	**Mildly eutrophic; decreased transparency; anoxic hypolimnion; macrophyte problems; warm-water fisheries only; supportive of all swimmable/aesthetic uses but "threatened"**	**Eutrophic**	**Poor**
60-70	**Blue-green algae dominance; scums possible; extensive macrophyte problems**		
70-80	**Heavy algal blooms possible throughout summer; dense macrophyte beds; hypereutrophic**	**Hypereutrophic**	**Very Poor**
> 80	**Algal scums; summer fish kills; few macrophytes due to algal shading; rough fish dominance**		

* After (Carlson and Simpson, 1995)

According to the Carlson's trophic index and based on our data, all Stations of Burullus Lake were found in the hypereutrophic state during the different seasons except St3 that may be classified as eutrophic in winter due to the effect of entry of poor-nutrient sea water. Table 6 indicates that the mean value of trophic state index around the year ranged between (73.62-86.1) with a high spatial and temporal significant difference ($p < 0.001$), where the minimum TSI value was recorded infront El-Boughaz out-let. While the maximum value was found at St.8 that receives high loaded nutrient wastewater from drain 8 and drain 9. Our results are consistent with a number of other studies indicating the hypereutrophy of Burullus Lake (Okbah and Hussien,2005; Ali, 2011); In addition to the results are in harmony with those reported by Farag and El-Gamal, (2011), they have created a eutrophication profile of Burullus Lake using remote sensing approach and found hyper-eutrophic conditions in the lake.

Table 6: Trophic state index of Burullus Lake water during 2016

St.	Trophic state value					TSI Ranke	WQ
	Spring	Summer	Autumn	Winter	annual average		
1	83.84	83.29	84.64	80.83	83.28	Hyper eutrophic	Very Poor
2	82.96	78.81	79.97	73.62	79.36	Hyper eutrophic	Very Poor
3	74.89	75.71	70.43	65.16	73.29	Hyper eutrophic	Very Poor
4	79.73	82.46	76.19	72.86	78.74	Hyper eutrophic	Very Poor
5	83.40	80.82	75.07	76.68	79.47	Hyper eutrophic	Very Poor
6	83.67	77.55	79.33	80.15	80.24	Hyper eutrophic	Very Poor
7	77.64	79.78	80.67	79.60	79.66	Hyper eutrophic	Very Poor
8	87.28	88.71	84.97	81.41	86.10	Hyper eutrophic	Very Poor
9	80.43	81.00	74.59	75.32	79.07	Hyper eutrophic	Very Poor
10	77.10	74.92	74.28	74.68	75.36	Hyper eutrophic	Very Poor
11	83.00	81.44	73.73	76.98	79.85	Hyper eutrophic	Very Poor
12	78.46	80.66	81.88	76.59	79.51	Hyper eutrophic	Very Poor
Average	82.48	82.83	80.85	77.30	81.96	Hyper eutrophic	Very Poor

CONCLUSION

Although, the great importance of Burullus Lake for the economic and fish supply of Egypt. It receives a massive amount of different discharged waste. This huge amounts of agriculture, demotic, aquaculture, and industrial wastes have affected, dramatically, on the aquatic system of the lake, which is categorized as a brackish shallow turbid lake. Our results revealed that the nutrients in Burullus Lake were at high levels and showed a lot of fluctuations with a remarkable spatial and temporal difference. The Lake is rich with organic matter and phytoplankton. The nitrogen: phosphorus ratio established that the phosphorus was the limiting factor for phytoplankton dynamics in Burullus Lake. Based on the Trophic State Index (TSI), Burullus Lake is classified as hypereutrophic water body that is characterized by poor and deteriorating water quality.

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Annex 1: The main drains description and their annual water volume (million m^3) inflow into Lake Burullus

Drain	Water Volume	Description
Burullus East	**65.75**	It is located at the eastern side of the lake, this drain extends parallel to the sea, collecting drainage water from Baltim area.
Khashaa	**485.76**	It is considered as one of the most important drains in the North Delta, it collects both the agricultural drainage water as well as the sewage and industrial waste water from El-Gharbia and El-Dakahlia Governorates, although El-Gharbia main drain does not discharge its water directly in the lake, it has insidious harmful effects on the water quality of Burullus lake through the lateral drains
Tera Drain	**609.67**	It is leading to daily input of industrial, agricultural and domestic sewage to Burullus lake.
Drain No.7	**476.10**	It collects the waste water of Kafr El-Sheikh and El-Gharbia provinces which are mixed from agricultural industrial and domestic wastes.
Drain No.8	**425.67**	It is located on the southern side and is leading to daily input of industrial, agricultural and domestic sewage to Burullus lake.
Drain No.9 (Nashart)	**780.0**	It is located at Shakhloba village on Burullus Lake coast on the southern side and is leading to daily input of industrial, agricultural and domestic sewage to the lake.
Drain No.10	———	Located in the western sector of the lake and leading to daily input of industrial, agricultural and domestic sewage to the lake.
Drain No.11	**723.0**	Located in the western sector of the lake and leading to daily input of industrial, agricultural and domestic sewage to the lake.
Brimbal Canal*	**198.93**	It is located in the western side of the lake which receives fresh water directly from Rosetta branch during the flood periods.
Zaghloul	———	Located in the northwestern side of the lake which discharges aquaculture and domestic sewage to the lake.
Burullus west	**139.75**	Located on the northwestern side of the lake and leading to daily input of aquaculture, agricultural and domestic sewage to the lake.
Reference	**Ali, (2011)**	Darwish *et al.,* (2018)

* This value has been significantly reduced in the current time, but, many times, the canal receives the water from the lake.