



Investigation of Eutrophication State of Manzala and Burullus Lakes in Egypt by Using Remote Sensing and GIS

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ABSTRACT

Eutrophication causes many problems for aquatic organisms as it makes water degrade. This research, focused only on three parameters, which are: chlorophyll "a", phosphate and nitrate in the evaluation of the eutrophication state in both Manzala and Burullus lakes. Trophic state index (TSI) was also calculated in this work and it was used in the lake ranking according to the eutrophication state throughout both lakes. Satellite data and GIS techniques were used in the classification and mapping the trophic state. The obtained results indicated that the TSI in Manzala Lake varied from mildly eutrophic in the northern parts of the lake to oligotrophic and hyper-eutrophic in the southern parts. On the other hand, Burullus Lake ranged between oligotrophic nearby El-Boughaz and hyper-eutrophic at the outlets of drains. The results also revealed that the southern parts in both lakes were enriched with nutrients that are considered as the most important limiting factors for phyto-organisms growth. The N/P ratio indicated that P was the limiting factor nearby El-Boughaz area. However, N was the limiting factor in the southern parts close to drains, which dump both agricultural and sewer waste waters into the lakes. Accordingly, it is recommended to treat wastewater before being dumped into the studied lakes to protect the aquatic environment and sustain biodiversity in these lakes.

1. Introduction

Coastal lakes and lagoons represent an important water resource across many parts of the world. They serve as reservoirs and contribute to the fishery and aquaculture industries. In economic terms, El-Manzala Lake provides one of the most important Egyptian farmed fish resources [1, 2]. Water quality problems in lagoons are commonly linked to the increase in phosphorus content. There are many cases to illustrate the link between the increased in phosphorus levels and the accelerated eutrophication and concomitant deterioration of water quality [3]. Total phosphorus inputs to lagoon lead to hypolimnetic dissolved oxygen depletion and loss of cold water fish habitat [4, 5].

The enrichment of water bodies by nutrients is often followed by a heavy growth or even blooming of the resident algal communities. Accordingly, eutrophication has become a problem receiving a great psychological concern. It has been reported elsewhere that, eutrophication stimulate profuse growth of blue-green algae [6]. Eutrophication is a widespread problem in rivers, lakes, estuaries, and coastal oceans, caused by over enrichment with P and N and nonpoint pollution. A major source of P and N to surface waters results primarily from agricultural, industrial and urban activities. Inputs of P and N to agriculture area in the form of fertilizers often exceed the outputs [7]. Eutrophication can also result in detrimental effects on the biological stability of a lake or reservoir ecosystem, virtually affecting all the biological populations and their interactions in the water body [8].

Eutrophication (the over enrichment of aquatic ecosystems with nutrients leading to algal blooms and anoxic events) is a persistent condition of surface waters and a widespread environmental problem. Some lakes have recovered after sources of nutrients were reduced [9].

Anthropogenic activity has greatly enhanced the inputs of nitrogen (N) and phosphorus (P) to lakes, causing widespread eutrophication. Algal or cyanobacterial blooms are among the most severe consequences of

eutrophication, impacting aquatic food webs and humans that rely on lakes for ecosystem services [10].

The main objective of this work was to evaluate the eutrophication state in both Manzala and Burullus Lakes based on the measurement of chlorophyll "a", phosphate and nitrate in addition to calculating the Trophic State Index (TSI).

2. Experimental Methods

2.1 Study Area

Manzala Lake is located at the eastern margin of Damietta branch between 31°00' - 31°30' N latitude and 31°45' - 32°30' E longitude. The area has been reduced from 407×103 feddans to about 213×103 feddans during the early 1990's and to about 192×103 feddans in 1993. This was due to the extensive agricultural reclamation activities, especially in the southern and south western sides of the lake [5, 11]. Fig. 1 illustrates the location of El-Manzala Lake and sample distribution within the lake.

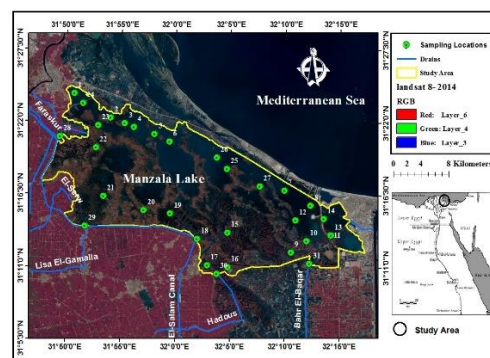


Fig. 1 Location of El-Manzala Lake and sample distribution within the lake

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Burullus Lake is located in Kafr El-Sheikh Governorate between 30°22' - 31°35'N and 30°33' - 31°08'E, with an area of about 460 km². It is located in the eastern side of Rosetta branch as illustrated in Fig. 2. It occupies a central position along the Mediterranean coast of the Nile Delta. It also represents the second largest natural lake in Egypt after Manzala. It is totally located in the northern part of Kafr El-Sheikh Governorate and extends at El-Burullus (Baltim) district from the east; El-Hamool, El-Riad and Sidi Salim districts from the south and Motobas district from the west [12].

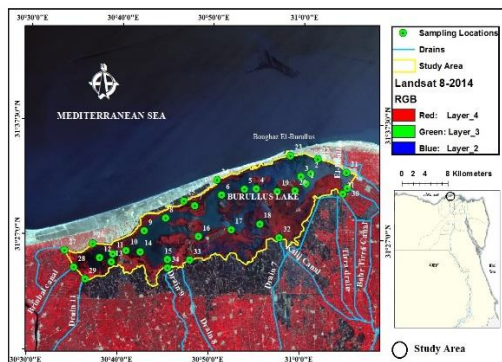


Fig. 2 Location of Burullus Lake and sample distribution within the lake

2.2 Carlson Trophic State Index (TSI)

Carlson Trophic State Index (TSI) is used to provide a single assessable index for classifying lakes according to the trophic state of the lake. Recently, Carlson Index is accepted in the limnological community as a reasonable approach for this problem. It is used as a measure of the trophic status for a water body using some water quality parameters including: transparency or turbidity (using the concentrations of Secchi disk depth (SD), chlorophyll-a (Chl "a") and ortho-phosphate (PO₄) levels [13].

The TSI values range between zero and 100 depending on the relationship between secchi disk (SD) or transparency and concentrations of both chlorophyll and total phosphorus or ortho-phosphorus in surface water. This is based on the assumption that the suspended particulate materials in the water control secchi depth (algal biomass is the major source of particulates). Accordingly, TSI values less than 40 are used to represent oligotrophic conditions and TSI values greater than 60 represent eutrophic conditions. TSI values between 40 and 50 represent a mesotrophic condition; values between 50 and 60 represent a moderately eutrophic and values greater than represent a hyper-eutrophic.

The following equations were used in this work to describe these relationships. The higher values correspond to the increase in fertility, which indicates more eutrophic conditions. Each increase in TSI by 10 units corresponds to a reduction in the secchi desk (SD) (transparency) by half and an increase in the phosphorus concentration by double. The spatial distribution of the TSI values was mapped by using the ordinary Kriging approach.

$$TSI (Chl_a) = 10 \left(6 - \frac{2.04 - 0.68 \ln(Chl_a)}{\ln(2)} \right), (Chl_a \text{ in } \mu\text{g/L}) \quad (1)$$

$$TSI (PO_4) = 10 \left(6 - \frac{\ln(\frac{21.67}{PO_4})}{\ln(2)} \right), (PO_4 \text{ in } \mu\text{g/L}) \quad (2)$$

$$TSI (\text{average}) = [TSI (Chl_a) + TSI (PO_4)]/2 \quad (3)$$

where, TSI is the trophic state index, chl "a" is chlorophyll a, and PO₄ is phosphate.

2.3 N/P Ratio

The N/P ratio provides an indication of the limiting factor responsible for controlling eutrophication in aquatic environment. It is calculated from the concentrations of nitrogen as nitrate and phosphorus as phosphate at the sampled stands in both lakes. Values below 5 indicate nitrogen limiting conditions, values between 5 and 10 reveal that either nitrogen or phosphorus could be the growth limiting factors, and values above 10 indicate phosphorus limiting conditions [14].

2.4 Chlorophyll Estimation from Landsat Data

Chlorophyll values could be extracted from satellite data by subtraction the reflectance of band 3 from band 1 and normalizing by the reflectance of band 2 as in Equ. 4 according to Brivio et al. [15].

$$Chl = 0.098 \times (\text{band 1} - \text{band 3}) / (\text{band 2}) \quad (4)$$

The ratios between the reflectance of band 2 and band 3 or between band 1 and band 3 are used to make an estimation of chlorophyll-a according to Akbar et al. [16] as follow (Eqs. 5 and 6):

$$Chl = B2 (\text{green}) (0.5-0.6 \mu) / B3 (\text{red}) (0.6-0.7 \mu) \quad (5)$$

$$Chl = B1 (\text{blue}) (0.4-0.5 \mu) / B3 (\text{red}) (0.6-0.7 \mu) \quad (6)$$

2.5 Statistical Analysis for Chlorophyll Estimation

A 3x3 window was used to collect data from the raster layers of the studied bands and indices at the sampling stands. The average value was calculated for each of the studied parameters at each location to get better representation. Pearson's correlation was used to study the relationships between each pairs of these studied parameters. The statistical analyses were carried out by using the SPSS software package (SPSS, ver.16).

3. Results and Discussion

3.1 Eutrophication State of Manzala Lake

Data in Table 1 include the values of the main parameters used in investigating the eutrophication conditions in Manzala Lake. The correlation coefficients of the relationship between chlorophyll at the different studied locations in Manzala Lake and PO₄, NO₃ band reflectance and band ratios are represented in Table 2. The obtained results indicated highly significance correlations between chlorophyll "a" and nutrients as NO₃ and PO₄, (r = 0.9 with each). Also chlorophyll "a" had highly significant correlations with band reflectance and band ratios extracted from the Landsat image (r = 0.9). A multi-regression model was developed from the obtained results to be used in making an estimation of chlorophyll "a" in Manzala Lake as follow:

$$Chl "a" = -61.22 + 0.52(PO_4) - 1.5(B4)$$

where, Chl "a" is measured chlorophyll, PO₄ is phosphate and B4 is the spectral reflectance at band 4 in the Landsat image.

Table 1 Trophic state index (TSI) and N/P ratio at the sampled locations within Manzala Lake

Site No	NO ₃ (μg/L)	PO ₄ (μg/L)	Chl	N/P Ratio	TSI (Chl_a)	TSI (PO ₄)	TSI General
1	294.1	8.6	92.3	34.28	83.99	46.63	65.31
2	37.2	2.8	23.3	13.46	70.47	30.27	50.37
3	61.1	2.5	22.3	24.93	70.07	28.55	49.31
4	22.4	6.7	34.5	3.32	74.34	43.15	58.74
5	14.5	3.7	33.2	3.94	73.97	34.42	54.20
6	16.4	3.1	35.2	5.36	74.53	31.76	53.14
7	13.2	3.4	33.5	3.93	74.03	33.15	53.59
8	512.5	5.5	113.3	93.00	86.00	40.24	63.12
9	403.1	65.2	29.0	6.18	72.62	75.90	74.26
10	121.7	123.4	35.2	0.99	74.54	85.10	79.82
11	203.0	115.8	33.6	1.75	74.07	84.17	79.12
12	352.0	83.6	62.5	4.21	80.17	79.48	79.82
13	290.7	56.0	75.0	5.19	81.96	73.70	77.83
14	356.2	48.1	85.2	7.41	83.20	71.50	77.35
15	309.3	79.6	59.6	3.88	79.70	78.78	79.24
16	227.4	56.4	31.0	4.03	73.28	73.79	73.53
17	196.9	59.4	20.3	3.31	69.13	74.55	71.84
18	286.6	58.8	27.7	4.87	72.19	74.40	73.30
19	225.7	59.7	29.4	3.78	72.78	74.63	73.70
20	466.7	60.3	56.4	7.73	79.16	74.77	76.97
21	387.8	45.9	22.9	8.44	70.32	70.84	70.58
22	168.1	18.1	28.4	9.30	72.42	57.38	64.90
23	56.6	23.3	38.3	2.43	75.36	61.03	68.20
24	26.8	8.0	16.4	3.37	67.02	45.55	56.29
25	71.7	8.6	17.6	8.36	67.74	46.63	57.19
26	29.2	8.3	10.8	3.53	62.98	46.10	54.54
27	28.2	20.2	12.2	1.40	64.17	58.99	61.58
28	301.5	41.7	1.6	7.24	43.90	69.43	56.66
29	651.3	40.4	55.1	16.11	78.94	69.00	73.97
30	348.8	117	6.5	2.98	57.98	84.33	71.15
31	114.1	162	64.6	0.70	80.49	89.11	84.80

Table 2 Correlation Matrix between the studied water parameters, landsat bands and band ratios at the sampled locations within Manzala Lake

Factor	b1	b3	b4	b5	b6	b3/b1	b4/b3	NO ₃	PO ₄	Chl "a"
b1	1									
b3	0.99**	1								
b4	0.99**	0.99**	1							
b5	0.99**	0.99**	1.00**	1						
b6	0.99**	0.99**	0.99**	0.99**	1					
b3/b1	0.12	0.15	0.15	0.15	0.15	1				
b4/b3	-0.38*	-0.38*	-0.36*	-0.37*	-0.36*	-0.37*	1			
NO ₃	0.97**	0.97**	0.97**	0.97**	0.97**	0.14	-0.33	1		
PO ₄	0.99**	0.99**	0.99**	0.99**	0.99**	0.19	-0.43*	0.97**	1	
Chl "a"	0.99**	0.99**	0.99**	0.99**	0.99**	0.098**	0.15	-0.42*	0.96**	1

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

Abbreviations: b= Landsat band and Chl "a": Chlorophyll "a"

The spatial distribution for the trophic state index of Manzala Lake based on Phosphate, Chlorophyll "a" and the calculated average value between the two variables is illustrated in Fig. 3. According to the TSI (PO₄), the trophic state of Manzala Lake was ranged between oligotrophic and moderately clear water in the northern parts of the lake. It was eutrophic in the southern parts of the lake nearby the drains and hyper-eutrophic with the presence of algal scums close to Bahr El-Baqar drainage area. Likewise, the eutrophication state in Manzala Lake was classified into three classes based on the TSI (chl "a"). These classes were: 1) eutrophic in the northern and western parts, 2) hyper-eutrophic conditions in the southern parts of the Lake and 3) algal scums nearby the Biological Treatment Project south to Port Said city area. The average TSI for chlorophyll and phosphate indicated that eutrophication state in Manzala Lake was increased in the direction from north to south especially at the drainage areas nearby Hadous and Bahr El-Baqar drains.

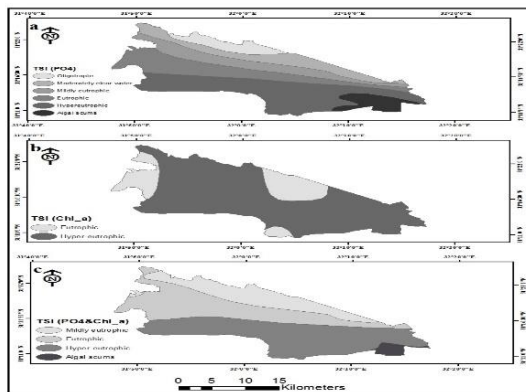


Fig. 3 Spatial distribution of the trophic state index within Manzala Lake according to a) PO₄, b) Chl "a" and c) the average between (PO₄ & Chl "a")

According to the N/P ratio P was the limiting factor for plant growth in the northern parts of the Lake (nearby El-Boughaz and Port Said city) and at the western part (nearby Damietta city, Faraskur and El-Serw drains) as shown in Table 1 and illustrated in Fig. 4. On the other hand, N or P was the limiting factor for plant growth in the middle part of the Lake and N was the limiting factor in the south-eastern parts of the lake (at Bahr El-Baqar and Hadous drainage areas).

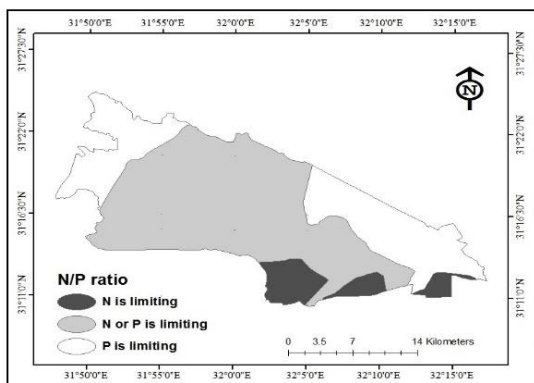


Fig. 4 Spatial distribution of N/P ratio in Manzala Lake

3.2 Eutrophication State of Burullus Lake

The values of the studied parameters in Burullus Lake are represented in Table 3. Data in Table 4 represent the correlation coefficients between the measured chlorophyll at the studied stands in Burullus Lake PO₄, NO₃, band reflectance and band ratios. These data revealed highly significance correlation between chlorophyll NO₃, and PO₄ (r = 0.92 and 0.68, respectively). Also, significant correlations were observed between chlorophyll band ratios (b3/b2 (r = 0.64) and b3/b1 (r=0.54)) extracted from the Landsat image. It was found that chlorophyll (a) can be estimated in Burullus Lake by using the following equation:

$$\text{Chl "a"} = -53.09 + 1.6(\text{PO}_4) - 0.012\left(\frac{\text{b3}}{\text{b1}}\right) + 0.08\left(\frac{\text{b3}}{\text{b2}}\right)$$

where, Chl "a" is the measured chlorophyll, PO₄ is phosphate and b1, b2 and b3 are the spectral reflectance at bands 1, 2, and 3, respectively.

Table 3 Trophic state index (TSI) and N/P ratio at the sampled locations within Burullus Lake

Site No	PO ₄ (µg/L)	NO ₃ (µg/L)	Chl.	N/P Ratio	TSI (PO ₄)	TSI (Chl _a)	TSI General
1	21.6	884.26	72.11	40.94	59.95	81.57	70.76
2	22.1	255.58	19.51	11.56	60.28	68.74	64.51
3	11.6	150.07	10.69	12.94	50.98	62.85	56.915
4	8.78	214.86	16.11	24.47	46.97	66.86	56.915
5	7.77	238.86	18.12	30.74	45.20	68.01	56.605
6	9.35	94.06	6.00	10.06	47.87	57.18	52.525
7	12.5	189.6	14.00	15.17	52.06	65.49	58.775
8	18.3	251.2	19.15	13.73	57.56	68.59	63.075
9	25.7	330.82	25.81	12.87	62.46	71.49	66.975
10	14.3	208.19	15.55	14.56	54.00	66.49	60.245
11	11.3	117.29	7.95	10.38	50.61	59.94	55.275
12	8.36	82.15	5.01	9.83	46.26	55.41	50.835
13	8.31	80.03	4.83	9.63	46.17	55.05	50.61
14	9.14	58.61	3.04	6.41	47.55	50.51	49.03
15	7.89	57.99	2.99	7.35	45.42	50.34	47.88
16	11.9	86.15	5.34	7.24	51.35	56.03	53.69
17	15.3	133.6	9.31	8.73	54.98	61.49	58.235
18	12.9	138.9	9.75	10.77	52.52	61.94	57.23
19	5.36	94.39	6.03	17.61	39.85	57.23	48.54
20	1.53	74.97	4.41	49.00	21.76	54.16	37.96
21	9.99	514.42	41.17	51.49	48.83	76.07	62.45
22	7.31	489.26	39.06	66.93	44.32	75.56	59.94
23	7.05	27.27	39.06	3.87	43.80	31.09	37.445
24	7.11	12.55	40.00	1.77	43.92	36.91	40.415
25	14.1	22.2	0.76	1.57	53.80	70.95	62.375
26	14	314.2	24.42	22.44	53.70	70.95	62.325
27	12.4	210.61	15.75	16.98	51.95	66.65	59.3
28	11.2	80.86	4.90	7.22	50.48	55.19	52.835
29	10	177.36	12.97	17.74	48.84	64.74	56.79
30	18.4	497.61	39.76	27.04	57.64	75.73	66.685
31	21.9	661.67	53.49	30.21	60.15	78.64	69.395
32	4.8	92.14	5.84	19.20	38.25	56.91	47.58
33	18.5	477	38.04	25.78	57.72	75.30	66.51
34	14.7	322.98	25.15	21.97	54.40	71.24	62.82

The spatial distribution of the trophic state index of Burullus Lake depending on Phosphate, Chlorophyll "a" and the average between the two parameters is demonstrated in Fig. 5. According to TSI (PO₄) the eutrophication state of Burullus Lake can be classified into two classes: 1) oligotrophic nearby El-Boughaz and the northern parts of the Burullus Lake and 2) moderately clear water nearby Drains and fish farms. On the other hand, eutrophication state can fit into three categories according to the TSI (Chl "a"): 1) moderately clear water nearby El- Boughaz, 2) mildly eutrophic in the middle part and 3) eutrophic to hyper-eutrophic in the southern parts closer to the drains. Also, TSI (Chl "a" and PO₄) took the same distribution pattern in the lake as the TSI (Chl "a"), where it ranged between moderate clear water at El-Boughaz area and eutrophic to hyper-eutrophic in the areas nearby drains.

From the N/P ratio in Burullus Lake, it was found that N was the limiting factor for bio-growth in the northern section of the Lake (N/P ratio < 5). However, N or P was the limiting factor in the western parts of the Lake and (N/P ratio >10) and P was the limiting factor in the eastern parts of the Lake (N/P ratio from 5 to10), as illustrated in Fig. 6.

Eutrophication and organic pollutants are still the major pollution problems in aquatic environments. Eutrophication is the process by which

lakes are enriched with nutrients, increasing the production of rooted aquatic plants and algae to levels considered to be an interference with desirable water uses such as recreation, fish maintenance and water supply [17]. Eutrophication has detrimental effects on the biological stability of lake and reservoir ecosystems, affecting virtually all the biological populations and their interactions in the water body. Consequently, eutrophication of the lakes and reservoirs has significant negative ecological, health, social and economic impacts on human use of

a primary and finite resource [18]. In studied lakes, when the degree of pollution increases southwards, the concentrations of three parameters namely; dissolved oxygen, pH and salinity decrease. Eutrophication conditions occur as a result of the decrease of dissolved oxygen [19]. Some authors as Rosernberg [20]; Meybeck et al. [21]; Pathak and Pathak [22] reported that water quality degraded and soil nitrate content increases as a result to eutrophication. This leads to undesirable changes in vegetation composition.

Table 4 Correlation Matrix between the studied water parameters, landsat bands and band ratios at the sampled locations within Burullus Lake

Factor	b1	b2	b3	b4	b5	b6	b1_b2	b1_b3	b2_b3	b3/b1	b4/b3	b3_b2	Chl_a	NO ₃	PO ₄
b1	1.00														
b2	0.97**	1.00													
b3	0.99**	0.984**	1.00												
b4	1.0**	0.967**	0.99**	1.00											
b5	0.02	-0.013	0.02	0.02	1.00										
b6	0.38*	0.33	0.38*	0.38*	0.92**	1.00									
b1_b2	-0.6**	-0.84**	-0.7**	-0.68**	0.07	-0.15	1.00								
b1_b3	-0.8**	-0.93**	-0.9**	-0.87**	0.01	-0.29	0.88**	1.00							
b2_b3	-0.9**	-0.83**	-0.9**	-0.89**	-0.06	-0.38*	0.54**	0.87**	1.00						
b3/b1	0.94**	0.98**	0.97**	0.98**	-0.01	0.33	-0.85**	-0.98**	-0.9**	1.00					
b4/b3	-0.9**	-0.94**	-0.9**	-0.88**	0.03	-0.28	0.88**	0.99**	0.87**	-0.98**	1.00				
b3_b2	0.93**	0.86**	0.93**	0.93**	0.06	0.39*	-0.55**	-0.87**	-0.9**	0.91**	-0.87**	1.00			
Chl_a	0.63**	0.55**	0.62**	0.63**	0.41*	0.61**	-0.27	-0.49**	-0.6**	0.54**	-0.49**	0.64**	1.00		
NO ₃	0.67**	0.57**	0.65**	0.67**	0.412*	0.62**	-0.25	-0.51**	-0.6**	0.56**	-0.49**	0.68**	0.92**	1.00	
PO ₄	0.43*	0.37*	0.428*	0.427*	0.10	0.19	-0.18	-0.34*	-0.5**	0.39*	-0.36*	0.48**	0.68**	0.63**	1.00

**Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed)

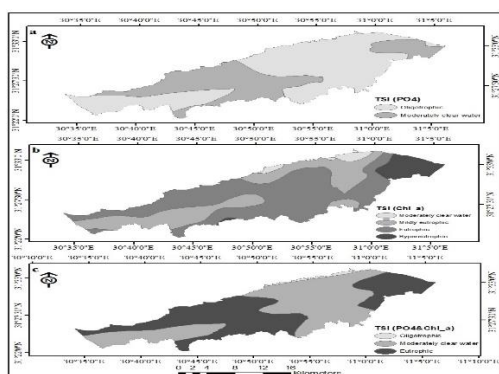


Fig. 5 Spatial distribution of the trophic state index (TSI) within Burullus Lake according to a) PO₄, b) Chl "a" and c) the average between (PO₄ and Chl "a")

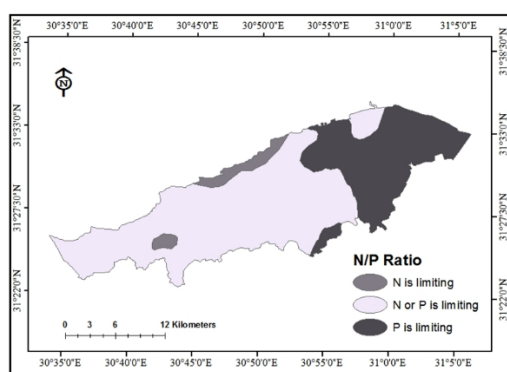


Fig. 6 Spatial distribution of N/P ratio in Burullus Lake

The trophic state index is an important factor to evaluate water quality conditions in water bodies especially those which receive huge amounts of nutrients [13]. The trophic state of Manzala Lake was either moderately clear water in the northern part, mildly eutrophic in the middle part, algal scums or hyper-eutrophic in the south eastern part nearby Hadous and Bahr El-Baqar drains. This result agrees with what was estimated by El-Naggar et al. [23]; Donia and Hussien [17]; Ahmed et al. [18]. They reported that water in Manzala Lake ranged between eutrophic and

hyper-eutrophic conditions. Khedr [24] found that eutrophication increases in the western and southern parts of the lake nearby drains.

The trophic state of Burullus Lake was divided into three categories; oligotrophic nearby El-Boughaz and the northern part, moderately clear water in the western part and in the middle part and eutrophic in the south eastern part of the lake near drains and near El-Shakhlouba area. The results of the trophic state index in Burullus Lake agreed with those reported by Farag and El-Gamal [25] and Ali [26]. They have created an eutrophication profile of Burullus Lake using remote sensing approach and found hyper-eutrophic conditions in the lake.

Generally, in the aquatic ecosystems that are receiving high N inputs, phosphorus may be the limiting factor as the N/P loading ratio tends to increase. Also nitrogen and phosphorus are indicators for productivity [27-29]. Our study revealed that in Manzala Lake, especially in the area where Bahr El-Baqar and Hadous drain, N was the limiting factor because of the decrease in N/P ratio. This is in agreement with the results obtained by Wakeel and Wahby [30] who observed that the areas of the lake are directly affected by drainage water enriched with phosphate.

In Burullus Lake, it was noticed that its eastern parts were enriched with nitrogen (the N/P ratio was high); therefore the limiting factors for plant growth were related to the concentration of phosphate. At the El-Boughaz area and the western parts of the lake, the N/P ratio indicated that N or P was the limiting factors for growth. In the northern parts of the lake, where there are fish farms and drainage water from agricultural areas containing high amounts of phosphate, nitrate was the limiting factor.

4. Conclusion

It could be concluded that eutrophication state in both Manzala and Burullus lakes can be effectively studied through measuring chlorophyll "a", phosphate and nitrate in these lakes. Also, the application of remote sensing data and GIS techniques could provide a great help in classifying, mapping, highlighting trophic state areas in both lakes.

The Trophic state index (TSI) varied from mildly eutrophic to eutrophic and hyper-eutrophic in Manzala Lake; however it ranged between oligotrophic and hyper-eutrophic in Burullus Lake. Hyper-eutrophic conditions were dominant at the southern parts of both lakes, which receive wastewater from agricultural and sewer drains. It was also found that P was the limiting factor for plant growth nearby El-Boughaz areas, whereas N was the limiting factor at the southern parts of both lakes. Close to drains, which dump both agricultural and sewer waste waters into the lakes.

The eutrophication state in both lakes was mainly affected by the continuous dump of wastewaters from agricultural, industrial and other human activities in these lakes. Accordingly, it is highly recommended to treat these wastewaters before dumping into the studied lakes. Also, it is recommended to develop a monitoring system in these lakes that employs both remote sensing and GIS technology. This is to protect the aquatic environment from pollution and keep the biodiversity in these lakes.

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