Original article

Assessing water quality and classifying trophic status for scientifically based managing the water resources of the Lake Timsah, the lake with salinity stratification along the Suez Canal

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Abstract

Lake Timsah is considered as the biggest water body at Ismailia City with a surface area of 14 km². It is a saline shallow water basin lies approximately mid-way between the south city of Suez and the north city of Port Said at 30°35′46.55″N and 32°19′30.54″E. Because it receives water with high and low salinities, salinity stratification is producing in the Lake Timsah, with values of 14–40‰ for the surface water and over 40‰ for the bottom water. The temperature of the lake water decreased to below 19 °C in the winter and rose to above 29 °C in the summer; the concentration of dissolved oxygen ranged between 6.5 and 12.2 ml/l and the pH fluctuated between 7.9 in its lower value and 8.2 in its higher value. Water transparency was very low as indicated by Secchi disc readings recorded during this study and varied between 0.3 and 2.7 m. The main chemical nutrient (phosphorus) reached its highest levels of 96 µg/l during winter and their lowest values of 24 µg/l during summer. This nutrient concentration is high especially by comparing with those of unpolluted marine waters, but is typical of the more eutrophic coastal waters worldwide. The composition and abundance of phytoplankton with dominancy of diatoms and increased population density (20,986 cell l⁻¹) reflect the eutrophic condition of the lake. The intensive growth of phytoplankton was enriched by high concentration of chlorophyll a with annual values ranged between 6.5 and 56 µg l⁻¹. The objective of the present work was quantitative assessment of the quality of the water of the Lake Timsah using different approaches. During the present study, three different approaches were applied for the quantitative assessment of Lake Timsah water quality: the trophic state index (TST); trophic level index (TLI) and water quality index (WQI). Application of the trophic state and trophic level indices (TSI & TLI) revealed that the Lake Timsah has trophic indices of 60 and 5.2 for TSI and TLI, respectively. Both indices reflected the eutrophic condition of the lake waters and confirmed that the eutrophication is a major threat in the Lake Timsah. On the other hand, the WQI calculated for the Lake Timsah during the present study with an average of 49 demonstrated that the water of the Lake Timsah is bad and unsuitable for main and/or several uses. Moreover, WQI allows accounting for several water resource uses and can serve a more robust than TSI and/or TLI and can be used effectively as a comprehensive tool for water quality quantification. In conclusion, the three subjective indices used for the assessment process for the lake water are more suitable and effective for needs of the sustainable water resources protection and management of the Lake Timsah.

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1. Introduction

Water is more critical than energy because we have alternative source of energy, but with water there is no other choice. Thus, it is necessary to find ecologically sound ways to conserve and protect valuable water resource of the lakes. Actually, the continuous monitoring and the assessment of lake’s water quality are a key issue for the sustainable protection and management. Lakes are often

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subjected to sudden environmental changes caused by various anthropogenic (industrial, agricultural, water supply, recreational, etc.) and touristic activities along their shores. This is the case in the Lake Timsah, which receives a tremendous amount of untreated waste discharges (domestic, industrial and agricultural), and exhibits rapidly developing touristic activities along its shores. Unfortunately and for the previously mentioned reasons, the Lake Timsah is suggested to exhibit serious water quality problems.

Water quality (WQ) is a term used to describe the condition, as well as, the suitability of water for use, and is therefore likely to be subject for perceptions and biases of the observer (Parparov et al., 2006). In other words, the term quality is being subjective rather than absolute term and often reflects the assessment of the user himself for the different uses of the water. For simple explanation, the “oligotrophic lake” which can be considered to have good water quality for swimming on one hand is a lake with poor water quality for fishing on the other.

Different approaches were used for assessing the water quality of lakes worldwide: the water quality index (WQI) was developed by Horton (1965) in United States, and has been widely applied and accepted in European, African and Asian countries. In 1977 Carlson developed a numerical rather than nomenclature classification for the trophic status of the lakes (TSI). A modification for the trophic state index developed by Carlson into a trophic level index (TLI) has been established by Burns et al. (2005). Actually, the assessment of water quality of lakes is especially relevant when there is a need to balance ecological and socio-economic interests. Because water quality indices characterize and describe forcing factors, such as external nutrients load, consumption of water and climate change in relation to the aquatic ecosystem of the lakes they can be used as a key task for water resources management on scientific bases. (Directive 2000/60/EC; Parparov and Hambright, 2007).

Many researchers investigated the water quality of Lake Timsah (AWRC, 1994; SLTDS, 1994; ETPS, 1996; Donia, 2005; 2011; Ahmad and Kaiser, 2014). All of these studies confirmed that the deterioration of the lake ecosystem & water lake quality has been extended to a serious level, and thus an urgent action is immediately required to restore the Lake Timsah ecosystem and its water resources. Therefore, the present work aims at assessing quantitatively the water quality of the lake through the biologically nomenclature phytoplankton index and through the numerically mathematical indices of Trophic State Index (TSI), Trophic Level Index (TLI), and Water Quality Index (WQI) and to evaluate the suitability of these indices for the needs of sustainable water resources management of the Lake Timsah.

2. Materials and methods

2.1. Description of the study Lake

Lake Timsah which has a surface area of 14 km² can be considered as the biggest water body at Ismialia City, and is a saline shallow water basin with salinity stratification along the Suez Canal. It lies approximately mid-way between the south city of Suez and the north city of Port Said at 30°35’46.55”N and 32°19’30.54”E (Fig. 1). It has an irregular shoreline giving it approximately a triangular shape with elongated sides extending roughly 5 km from east to west, excluding peripheral lagoons; and 4.5 km from north to south with a maximum depth of more than 25 m in the vicinity of the navigational pass way of the Suez Canal. Most of the floor of the Lake Timsah is muddy; with an apparently anaerobic black mud in the deeper areas and aerobic grey mud in shallower areas (El-Serehy and Sleighb, 1992). Its shores, shallow water and some dredged areas are more sandy but with few rocky outcrops. The Lake Timsah receives saltwater mainly from the Suez Canal; and freshwater from different sources (including: Ismailia canal; rare seasonal streams; and from sewage outlets) creating salinity stratification in the lake water. Chemical analysis and nutrient concentrations in the water of the Lake Timsah were given by many investigators (for example Fox, 1926; Morcos, 1967, 1968; El-Serehy and Sleighb, 1992). The sea-grasses (Halophila stipulacea & Ceratophyllum demersum) and the green algae (Enteromorpha intestinalis & Ulva sp.), as well as, the red algae (Nitophyllum punctatum, Acanthophora delilei and Spyridia claoata) grow in the Lake Timsah and contribute with phytoplankton in the oxygenisation of its water (El-Serehy and Sleighb, 1992). Different limnological variables and characteristics of the Lake Timsah are presented in Table 1.

2.2. Lake monitoring

A total of 144 water samples were collected from four stations selected in the Lake Timsah. The four sampling stations were cho-

| Parameters          | Lake Timsah                  |
|---------------------|------------------------------|
| Location            | Ismialia City on the Suez Canal |
| Origin              | Natural                      |
| Latitude            | 30°35’46.55”N               |
| Longitude           | 32°19’30.54”E              |
| Surface area (km²)  | 14                           |
| Water volume (m³)   | 80 x 10⁶                     |
| Average depth (m)   | 2–28                         |
| Catchment area (km) | 4.5                          |
sen to represent different ecological conditions prevailing in the lake. Each station was visited monthly, through complete year, from January to December 2016. The locations of the sampling stations are shown in Fig. 1, while coordinates and descriptive features of anthropogenic activities of the four sampling stations are shown in Table 2.

The salinity and temperature of the near-surface water (50–75 cm) were recorded monthly using a portable electronic salinometer (MC Salinity/Temperature Bridge). The pH values were recorded using pH meter (model 201/digital pH meter). The transparency of the Lake Timsah water was measured using Secchi disc (SD) with 30 cm in diameter and painted with two contrasting black and white colours.

In the field, the collected water samples were subdivided into glass and plastic bottles. The parts of water sample being stored in glass bottles usually contained 1 ml chloroform as preservative for analysis of N and P; while the water sample parts stored in plastic bottles were kept with few drops of hydrochloric acid as preservative for analysis of silicates (APHA, 2005). In the laboratory, colorimetric methods for nutrients analysis were used and the results were being measured using a Pye SP 500 spectrophotometer (Parsons et al., 1984). For determination of chlorophyll a concentration, the acetone extraction method (Golterman, 1969) was applied.

Samples of phytoplankton were collected by horizontal hauls with a net of a mesh size of 33 μm, and fixed with acetic Lugol’s iodine solution with final concentration of 1% (Throndsen, 1978). Phytoplankton taxa were identified using an inverted microscope (Nikon TMS, magnification: 200x, 400x and 600x). The most commonly used literatures were consulted to ascertain the taxonomy of the phytoplankton species (Krammer and Lange-Bertalot, 1986; 1988; Sournia, 1986; Popovski and Pfiester, 1990; Cox, 1996; Komarek and Anagnostidis, 1999; John et al., 2002). Taxa and author names were confirmed following standardized databases for phytoplankton taxonomy (Guiry and Guiry, 2013).

### 2.3. Assessment of Lake Timsah water quality

Trophic State Index (TSI) was calculated using a logarithmic transformation (Ln) of the chlorophyll a concentration (Chl. a) in microgram per liter, Secchi disc depth (SD) in meters and the total phosphorus (TP) in microgram per liter according the following equation (Carlson, 1977):

\[ CTSI = \frac{[TSI(SD)] + [TSI(CHL)] + [TSI(TP)]]}{3} \]

where,

\[ TSI(SD) = 60 - \frac{14}{41} \ln(SD)(m) \]

\[ TSI(CHL) = \frac{9}{81} \ln(chl.a) + \frac{30}{6} (\mu g/L) \]

\[ TSI(TP) = \frac{14}{42} \ln(TP) + \frac{4}{15} (\mu g/L) \]

Burns et al. (2005) modified TSI developed by Carlson (1977) into TLI (trophic level index). Both indices (TSI & TLI) use values of chlorophyll a concentration (Chl), the depth of Secchi disc (SD) and the concentration of total phosphorus (TP), while the TLI index also includes total nitrogen (TN). The numerical values of the trophic level index (TLI) for the Lake Timsah water were calculated using the following equation (Burns et al., 2005):

\[ TLI = \frac{1}{4}(TLCHL + TLSD + TLP + TLN) \]

Where,

\[ TLCHL = 2.22 + 2.54 \log(Chl) \]

### Table 2

| Sampling sites | Coordinates of sampling sites | General features of anthropogenic activities |
|---------------|-------------------------------|---------------------------------------------|
| (Station I)   | 30°33’18”N-32°17’69”E       | -Recreational beach along the lake shore  |
|               |                               | -Sediments have grey colour               |
|               |                               | -Sediment texture are dominated by median sand |
|               |                               | -Vegetation:                              |
|               |                               |   - Few seaweeds                          |
|               |                               |   - Macrofaunal abundance:                |
|               |                               |     - High abundance                      |
| (Station II)  | 30°34’45”N-32°16’87”E       | -Freshwater intrusion                      |
|               |                               | -Agricultural discharge                   |
|               |                               | -Wastewater discharge                     |
|               |                               | - The floor of the lake is covered with sand and rocks |
|               |                               | -Vegetation:                              |
|               |                               |   - Filamentous and thalloid algae        |
|               |                               |   - Blue green algal mats                 |
|               |                               |   - Macrofaunal abundance:                |
|               |                               |     - High abundance of copepod and amphipod crustaceans |
| (Station III) | 30° 35’ 46”N-32° 18° 25”E   | -Recreational beach along the lake shore  |
|               |                               | - Industrial workshop for shipyards        |
|               |                               | - Domestic outfall areas                   |
|               |                               | - Oil contamination                       |
|               |                               | - Concrete platform floor covered with mud |
|               |                               | - Vegetation:                             |
|               |                               |   - Filamentous and thalloid algae        |
|               |                               |   - Blue green algal mats                 |
|               |                               |   - Macrofaunal abundance:                |
|               |                               |     - High abundance of polycheate, acidians and barnacles |
| (Station IV)  | 30°35’64”N-32°19’30”E       | -Recreational beach along the Suez Canal shore |
|               |                               | - Sediment texture are dominated by median sand |
|               |                               | - Vegetation:                             |
|               |                               |   - Rich growth of brown, red and blue-green algae |
|               |                               |   - Macrofaunal abundance:                |
|               |                               |     - High abundance                      |
Wunderlin (2000), as following:

\[
T_{LO} = 5.10 + 2.60 \log (1/SD - 1/40)
\]

\[
T_{LP} = 0.218 + 2.92 \log (TP)
\]

\[
T_{LN} = -3.61 + 3.01 \log (TN)
\]

Vollenweider’s method for assessing a water body’s trophic state (1989), accepted by the Organization for Economic Co-operation and Development (OECD, 1982); Environment Canada (2004); MDDEP (2007) was also applied to classify the trophic status of the lake.

To develop an overall status of the Lake Timsah water, the values recorded for the physico-chemical parameters of pH, dissolved oxygen, phosphate, silicate, nitrate, nitrite and ammonia, were mathematically transformed into a single number that represents the water quality level according to (Sánchez, et al., 2007). A range extended from 0 to 100 was assigned to give the quality value to each parameter. Each Q value was multiplied by a weighting factor based on the importance of the parameter, and summation of the weighted Q value yielded the water quality index (WQI) characterizing the water as very bad (0–25), bad (25–50), intermediate or good (71–90), or excellent (91–100). The (WQI) was determined using the equation given by Pesce and Wunderlin (2000), as following:

\[ WQI = k \sum CiP_i \]

Where,

k is a subjective constant with a value of (0.25) for bad water; and a value of (1) for good quality water. \( C_i \) is the normalized value of the parameter while \( P_i \) is the relative weight assigned to each parameter (Smith, 1990).

3. Results

3.1. Physico-chemical conditions of the Lake Timsah

The minimum and maximum values of different physical and chemical parameters measured at the four sampling sites chosen at the Lake Timsah are shown in Table 3. The surface water temperature varied between 16 °C in winter months at station IV and 30 °C in summer months at station I. Salinity levels ranged between 17‰ (During Winter, at station II) and 40‰ (During Summer at station I) and with an average of 36‰. The dissolved oxygen values in the Lake Timsah water ranged between 6.5 mg l⁻¹ during summer and 12.2 mg l⁻¹ during winter for minimum and maximum values, respectively; while the nutrient concentration (P) remained extremely high, fluctuating between 24 and 96 μg l⁻¹ at the four sampling stations with no apparent differences. The present study recorded slightly alkaline mean values for pH and with 7.8 for minimum and 8.4 for maximum values, respectively. The high concentration of chlorophyll a showed pronounced temporal and spatial variations with minimum values of 6.5 μg l⁻¹ during summer at station IV, and maximum values of 56 μg l⁻¹ during spring at station II. Total nitrogen concentration ranged between 430 and 780 μg l⁻¹ for the minimum and the maximum values, respectively. The dissolved nitrate in the lake water fluctuated between 6.7 μM and 17.8 μM for its minimum and maximum values, respectively. During the present study, the reactive silicate showed its maximum concentration during summer and with being values of 4.1 μM. The maximum values of 1.2 μM were recorded for the dissolved ammonium during summer and the minimum values of 0.2 μM during autumn.

### 3.2. Phytoplankton species composition and community structure of the Lake Timsah

The present study recorded and identified a total of 164 species of phytoplankton in the Lake Timsah belonging to 5 families: Bacillariophyceae (95 species); Dinophyceae (31 species); Chlorophyceae (11 species); Cyanophyceae (13 species); Euglenophyceae (14 species) (Table 4). The percentage contribution of 58, 18.9, 6.7, 8 and 8.5 % to the phytoplankton community was recorded for Bacillariophyceae, Dinophyceae, Chlorophyceae, Cyanophyceae and Euglenophyceae, respectively. Characteristic phytoplankton groups and algal indicator species for the trophic status classification of the Lake Timsah are shown in Table 5. The standing crop of species was generally high reaching a highest density of 20,986 cell l⁻¹ at station II, and a visible decreasing in the algal density reaching 11,115 cell l⁻¹ at station IV. Overall, the Bacillariophyceae was the most abundant group of phytoplankton, followed by the Dinophyceae rank and the Euglenophyceae and the Cyanophyceae. While the Bacillariophyceae formed the largest group in almost every month, the Dinophyceae group represented a large part of the phytoplankton community during the study period, although the population varied during the sampling seasons. The members of the family Euglenophyceae were recorded largely around the year. On the other hand, members of Cyanophyceae were present

| Parameter                          | Min  | Max  | Average | SD   |
|-----------------------------------|------|------|---------|------|
| Secchi disc transparency (m)¹      | 0.5  | 2    | 1       | ±0.30|
| Temperature (°C)                  | 16   | 30   | 22      | ±2.40|
| Salinity (‰)                      | 17   | 40   | 36      | ±4.80|
| pH¹                               | 7.8  | 8.4  | 8.2     | ±0.01|
| Total Phosphorus (μg l⁻¹)         | 24   | 96   | 48      | ±7.00|
| Total Nitrogen (μg l⁻¹)           | 430  | 780  | 720     | ±76.8|
| Chlorophyll a (μg l⁻¹)            | 6.5  | 56   | 20      | ±5.70|
| TN/TP ratio                       | 15.5 | 16.7 | 16      | ±4.30|
| Phosphate (μM)                    | 63.6 | 85.2 | 81.4    | ±6.20|
| Nitrate (μM)                      | 6.7  | 17.8 | 9.75    | ±5.40|
| Silicate (μM)                     | 1.4  | 4.1  | 3.4     | ±0.70|
| Ammonia (μM)                      | 0.2  | 1.2  | 0.8     | ±0.10|
| Dissolved oxygen (mg l⁻¹)         | 6.5  | 12.2 | 9.4     | ±3.00|
| Nitrite (μM)                      | 0.08 | 0.8  | 0.6     | ±0.03|
| TSI                               | 50   | 70   | 60      | ±9.30|
| TLI                               | 4.1  | 6.3  | 5.2     | ±0.87|
| WQI                               | 27   | 67   | 49      | ±8.83|

¹ Measured parameters used for calculating TSI.
² Measured parameters used for calculating TLI.
³ Measured parameters used for calculating WQI.
| S. | Taxon                                                                 | Abundance |
|----|----------------------------------------------------------------------|-----------|
| 1. | Asterionella compressa                                                | 70.       |
| 2. | A. japonica                                                           | 71.       |
| 3. | A. paludosa                                                           | 72.       |
| 4. | A. bacillaris                                                         | 73.       |
| 5. | A. brevipes                                                          | 74.       |
| 6. | A. constricta                                                         | 75.       |
| 7. | A. formosa                                                           | 76.       |
| 8. | A. globosa                                                           | 77.       |
| 9. | A. microreticulata                                                   | 78.       |
| 10.| A. obtusa                                                            | 79.       |
| 11.| A. pacifica                                                          | 80.       |
| 12.| A. plicatilis                                                        | 81.       |
| 13.| A. pseudopunctulata                                                  | 82.       |
| 14.| A. quillensis                                                        | 83.       |
| 15.| A. subquadrata                                                       | 84.       |
| 16.| A. subrotunda                                                        | 85.       |
| 17.| A. subula                                                            | 86.       |
| 18.| A. trachypneum                                                       | 87.       |
| 19.| A. triungula                                                         | 88.       |
| 20.| A. truncata                                                           | 89.       |
| 21.| A. unifrons                                                          | 90.       |
| 22.| A. variabilis                                                        | 91.       |
| 23.| A. veneta                                                            | 92.       |
| 24.| A. viridis                                                           | 93.       |

### Bacillariophyceae

1. Achnanthes brevipes Agardh
2. Amphiprora alata Kützing
3. A. paludosa Smith
4. Amphora marina Smith
5. Asterionella japonica Cleve
6. Bacillaria paraodoxa (Müller) Grunow
7. Bacteriastrium delicatulum Cleve
8. B. hyalunum Lauder
9. Bellerocca malleus Brüg
10. Biddulphia aurita (Lyng.) Breb.
11. B. favus (Ehrenberg) Van Heurck
12. B. longicirris Greville
13. B. mobilensis (Bailey) Grunow
14. B. obtusa (Kützing) Ralfs
15. B. smithii Van Heurck
16. Campylocystis noricus var. hibernicus (Ehrenberg) Grunow
17. Ceratium bergonii (Peragallo) Schütt
18. Chaetoceros afnifi Lauder
19. C. arctica Grunow
20. C. compressus Lauder
21. C. curvisetus Cleve
22. C. decipiens Cleve
23. C. densus Cleve
24. C. lorenzianus Grunow
25. C. peruvianus Cleve
26. C. radicans Schütt
27. C. tetrachon Cleve
28. C. tortissimus Gran
29. Cladocordium biconvexum Cleve
30. C. braunfeldianum Grunow
31. Climacocystis moniliger Ehrenberg
32. Cocconis placenta Ehrenberg
33. Coscinodiscus excentricus Ehrenberg
34. C. granii Gough
35. C. marginatus Ehrenberg
36. C. radians Ehrenberg
37. Cyclotella meneghiniana Kützing
38. Cymbella ventricosa Kützing
39. Diploneis interrupta (Kützing) Cleve
40. Fragilaria capucina Desmazières
41. Guinardia flaccida (Castracane) Peragallo
42. Gyrosigma attenuatum (Kützing) Rabenhorst
43. G. balticum (Ehrenberg) Rabenhorst
44. Hemiaulus hebergii Cleve
45. Lauderia borealis Gran
46. Leptocylindrus danicus Cleve
47. Licmophora abbreviata Ehrenberg
48. L. flabellata (Greville) Agardh
49. L. grossis.gracilis (Ehrenberg) Grunow
50. Lithodesmium undulatum Ehrenberg
51. Melosira granulata (Ehrenberg) Ralfs
52. M. sulcata (Ehrenberg) Kützing
53. M. varians Agardh
54. Navicula cancellata Donkin
55. Navicula cryptcephala Kützing
56. N. cuspidate Kützing
57. N. denticula Ehrenberg
58. N. gracilis Cleve
59. N. placenta Ehrenberg
60. Nitzschia closterium (Ehrenberg) Smith
61. N. kützingiana Hilse
62. N. longissima (Brébisson) Ralfs
63. N. obtuse Smith
64. N. pacifica Cupp
65. N. palea (Kütz) Smith
66. N. pungens var. atlantica Cleve
67. N. seriata Cleve
68. N. sicula (Castracane) Hustedt
69. N. sigma (Kützing) Smith

### Cyanophyceae

1. Chroococcus turgidus (Kützing) Nägeli
2. Coongeophora aponina Kützing
3. Lyngbya minor Meneghinii ex Gomont
4. Merismopedia punctata Meyen
5. Oscillatoria constricta Sazlfer
in the samples received in some seasons and the numbers tend to remain high, a fact contrary to the other groups of phytoplankton. For example, presence of the members of blue-green algae was recorded in summer and autumn months only. Algal blooms were frequent in the samples received in some seasons and the numbers tend to remain high, a fact contrary to the other groups of phytoplankton.

### 3.3. Lake Timsah water quality

The numerical trophic state index (TSI), trophic level index (TLI) and water quality index (WQI) for the Lake Timsah were given in Table 3. The average numerical values calculated for TSI, TLI and WQI in the water of the Lake Timsah with population density of 60 and 5.2 for each assessment scale, respectively show clearly the eutrophic conditions of the lake water. The internationally accepted criteria of the OECD (1982), Environment Canada (2004), MDDEP (2007), Nürnberg (2001), and University of Florida (1983) for the trophic status classification of lakes were applied for the current assessment and also confirmed the eutrophic conditions in the Lake Timsah water (Table 6). On the other hand, the numerical WQI in the water of the Lake Timsah with an average rank of 49 classify the Lake Timsah water with characteristics of bad water for use by humans. Descriptions corresponding to use with ranks and descriptors of water quality index (WQI), trophic level index (TLI) and trophic state index (TSI) applied for the Lake Timsah and its water during the present study are shown in Table 7.

### 4. Discussion

The need for the present study aroused because of the significance of the fragile ecosystem of the lakes of the Suez Canal (Bitter Lakes & Lake Timsah) and the proposed development activities in the canal area (El-Serehy et al., 2014; El-Serehy et al., 2018). The lake Timsah is under an increasing human population density pressure, and the increase in human population is associated with decreasing water resources and increasing organic pollution in the Lake Timsah water. The human population of the area increased to one million and five hundred populations by 2017 (Central Agency for Public Mobilization and Statistics, CAPMAS, 2017). The study of the flora and fauna of the Lake Timsah is very valuable to understand the composition of its biota for purposes of exploitation and conservation, and also because it is one of the lakes of the Suez Canal which is the main link between the Red Sea and the Mediterranean. Moreover, quantitative assessment of the water of the Lake Timsah using different approaches as an integral part of water resources management is very important to characterize the water quality problems in the biggest water body along the Suez Canal at Ismailia City for sustainable water resources management.

During the present study, a total of 164 phytoplankton species were identified, corresponding to diatoms, dinoflagellates, green microalgae, cyanobacteria and euglenoids. The phytoplankton community of the Lake Timsah was characterized by higher population density with maximum values (20,986 cell l⁻¹) during summer and lower density (11,115 cell l⁻¹) during winter, and the dominancy of the diatom group. Phytoplankton structure and abundance are result of spatial and temporal changes in physical, chemical and biological variables (Roy & Chattopadhyay, 2007; Pacheco et al., 2010; Zhang et al., 2011; Demir et al., 2014; Napiórkowska-Krzejbietke, and Hutorowicz, 2014). Among the algal communities, diatom taxa are considered as a group sensitive to water chemistry and specific ecological conditions, and thus are used as an indicator for water-quality in many aquatic systems (Stevenson and Smol, 2003; Zhang et al., 2011). The diatom species are also useful parameters to monitor changes temporally and spatially. Moreover, diatoms can be used as one of the tools for assessing water quality (Mariacristina and Antonio, 2006). During the present study, Diatoms formed the dominant component of phytoplankton in the Lake Timsah with population density of 17,838 cell l⁻¹ and representing 85 % of the total phytoplankton counts. Owing to the relatively short life cycle, the diatoms respond rapidly to the physico-chemical changes and eutrophication thus indicating information on nutrient changes (Rahmati et al., 2011; Darling 2015). They can indicate rapidly a change in water quality and can be used successfully in biomonitoring pro-
grams (Stevenson and Pan, 1999). Moreover, diatoms are strongly correlated to total phosphorus (TP) concentrations (Wang et al., 2014). In the Lake Timsah water with higher concentration of phosphorus (TP: 24–96 μg l\(^{-1}\)), diatom species such as *Asterionella japonica* Cleve, *Chaetoceros lorentzianus* Grunow, *Nitzschia. pungens* var. *atlantica* Cleve, *Rhizosolenia alata* Brightwell, *R. alata* f. *gracilima* (Cleve) Grunow, *Schroederella delicatula* (Peragallo) Pavillard, *Skeletonea costatum* (Greville) Cleve, *Thalassionema nitzschioides* (Grunow) Meschikowsky were the dominant diatom species. These dominant diatom species can be suggested as indicators to eutrophic status of the Lake Timsah ecosystem, a phenomenon used as potent indicator of trophic status in the water of many lakes (Demir et al., 2014). Moreover, the utility of phytoplankton quotients with particular reference to diatom quotient, which can be derived from dividing the number of species of Centrales over that of Pennales can indicate the trophic status of the aquatic ecosystem, with being 0.0 to 0.2 for oligotrophy, and 0.2 to 3.0 for eutrophy (Nygaard, 1970). The data provided in Table 5, with diatom quotient of 1.2 can support the presence of eutrophic diatom algal indicators and confirm the eutrophy of the Lake Timsah.

### Table 6
Internationally accepted criteria for trophic status classification of the water bodies with comparison applied to the Lake Timsah.

| Trophic status       | Chlorophyll \(a\) (μg l\(^{-1}\)) | Transparency\(^a\) (m) |
|----------------------|---------------------------------|-----------------------|
| OECD criteria\(^b\)  |                                 |                       |
| Ultra-oligotrophic   | <4                              | <1                    |
| Oligotrophic         | 10–35                           | 2.5–8                 |
| Mesotrophic          | 35–100                          | 8–25                  |
| Eutrophic            | >100                            | >25                   |
| Hyper-eutrophic      |                                  |                       |
| **Canadian criteria\(^c\)** |                      |                       |
| Ultra-oligotrophic   | <4                              | <1                    |
| Oligotrophic         | 10–30                           | 3–8                   |
| Mesotrophic          | 30–100                          | 8–25                  |
| Eutrophic            | >100                            | >25                   |
| Hyper-eutrophic      |                                  |                       |
| **Quebec criteria\(^d\)** |                      |                       |
| Oligotrophic         | 4–10                            | 1–3                   |
| Mesotrophic          | 10–30                           | 3–8                   |
| Eutrophic            | 30–100                          | 8–25                  |
| Hyper-eutrophic      |                                  |                       |
| **Nürnberg criteria\(^e\)** |                      |                       |
| Oligotrophic         | <10                             | <3.5                  |
| Mesotrophic          | 10–30                           | 3.5–9                 |
| Eutrophic            | 31–100                          | 9.1–25                |
| Hyper-eutrophic      |                                  |                       |
| **Swedish criteria\(^f\)** |                      |                       |
| Oligotrophic         | <15                             | <3                    |
| Mesotrophic          | 15–25                           | 3–7                   |
| Eutrophic            | 25–100                          | 7–40                  |
| Hyper-eutrophic      | >100                            | >40                   |
| **Lake Timsah results\(^g\)** | |                       |
| Ultra-oligotrophic   |                                  |                       |
| Oligotrophic         |                                  |                       |
| Mesotrophic          |                                  |                       |
| Eutrophic            | 24–96                           | 20                    |
| Hyper-eutrophic      |                                  |                       |

\(^a\) Transparency by Secchi disk depth.

\(^b\) Ryding and Rast (1994).

\(^c\) Environment Canada (2004).

\(^d\) MDDEP (2007).

\(^e\) Nürnberg (2001).

\(^f\) University of Florida (1983).

\(^g\) Present study.

### Table 7
Descriptions corresponding to the use of water quality index (WQI) [modified from Smith, 1990], trophic level index (TLI) [modified from Burns et al., 2005] and trophic state index (TSI) [modified from Carlson, 1977] applied for the Lake Timsah.

| Water quality | WQI Rank | Descriptor | TLI Rank | Descriptor | TSI Rank | Descriptor |
|---------------|----------|------------|----------|------------|----------|------------|
| Excellent     | 91–100   | Eminently usable for all purposes | 2–3 | Oligotrophic | <40 | Oligotrophic |
| Good          | 71–90    | Suitable for all uses | 3–4 | Mesotrophic | 40–50 | Mesotrophic |
| Intermediate  | 51–70    | Main use and/or some uses may be jeopardized | 4–5 | Meso-eutrophic | 50–60 | Eutrophic |
| Bad           | 25–50    | Unsuitable for main and/or several uses | 5–6 | Eutrophic | 60–80 | Eutrophic |
| Very Bad      | 0–25     | Totally unsuitable for main and/or many uses | 6–7 | Hyper-eutrophic | >80 | Eutrophic |

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On the other hand, the phytoplankton euglenoid forms, represented by fourteen species and constituting 8.5% of the total algal community, are rightly represented in this manner owing to the increasing of organic matters contamination in the Lake Timsah water. The amount of the discharging effluents to the Lake Timsah as recorded by the International Center for environmental and development (ICDE, 1998) were 1.3 \times 10^5 \text{m}^3/\text{day}. Euglenoids are the more dominant protists in aquatic habitats usually rich in organic matter (Sleigh, 1989).

Pattern of the spatial and temporal distribution and taxonomic composition of phytoplankton in the study area was generally uniform, a phenomenon reflecting more homogenous hydrographic characteristics of the four sites. The amount of the standing crop of planktonic algae attained a higher population density of between 11,115 cell l$^{-1}$ and 20,986 cell l$^{-1}$ (Table 5), a fact attributed to the high nutrients availability (24–96 \mu g l$^{-1}$), environmental factors and the ongoing eutrophication process caused by anthropogenic activities in the lake area (Table 2). The phytoplankton community in the Lake Timsah, therefore, is characterized by high population density, higher number of algal species diversity (164 species), a combination that can be associated with high levels of nutrients, high values of chlorophyll a, high productivity, thus suggesting the eutrophication nature of the Lake Timsah.

Many efforts have been made to establish an accepted criteria and levels to classify lakes based on trophic status, nutrients, total phosphorus as well as on certain other physical (e.g., water transparency, oxygen dissolved in the water) and biological (e.g., algal pigments) characteristics (OECD, 1982; Vollenweider, 1989; Galvez-Cloutier and Sánchez, 2007; Zebe, 2009; Ferreira et al., 2011). A nutrient ratio (N/P) has been used to explain phytoplankton populations, or identify a nutrient limiting factor (Redfield, 1958; Hecky and Kilham, 1988). Redfield Ratio (Nitrogen to Phosphorus in molecular weights: 224/30 = 7.46) is considered as an established baseline for nutrient availability (Wetzel, 1983) and it has been suggested that Phosphorus becomes limiting nutrient in water bodies containing TN/TP value greater than 7, whereas a ratio below 7 is a reflection of nitrogen as limiting factor for algal growth (Meybeck et al., 1989; Chapman, 1996). For practical purposes, TN/TP value less than 10 indicates a nitrogen shortage, and value higher than 20 as phosphorus shortage. Lower TN/TP ratios are observed in eutrophic lakes and high in mesotrophic and oligotrophic lakes. The present study reports TN/TP ranging between 8.13 and 17.9, while the average ratio is 15, a fact indicating that in the Lake Timsah, nitrogen remains the limiting nutrient (Table 3).

The blooming of blue green algae (cyanobacteria) is frequently associated with eutrophic conditions; a situation had been encountered during the present study where algal blooms were detected in the study area. The blue green algae dominate at low TN/TP ratios, and become rare when the TN/TP ratio is greater than 29 (Smith 1983). Based on the results of the present investigation, Lake Timsah can be considered as eutrophic and presented TN/TP as more lower than 29. Apart from the TN/TP ratios, the individual concentrations of TP and TN can also be correlated with the flourishing and dominancy of cyanobacteria in the aquatic ecosystem. The probability of cyanobacteria blooming is 40% for TP concentration of 30–70 \mu g l$^{-1}$, but this probability rises to reach 80% when the TN concentration in the water is 100 \mu g l$^{-1}$ (Downing et al., 2001). Thus, using of various protocols is largely determined by the scope of the work and the objectives of such analyses to interpret the summer algal blooming detected in the lake during the present work.

Scientific Studies have been carried out to establish a quality criteria and thresholds for classification of lakes according to their trophic status on the basis of nutrient concentrations, and certain physical and biological characteristics (OECD, 1982; Galvez-Cloutier and Sánchez, 2007; Hutorowicz et al., 2011; Hutorowicz and Pasztaleniec, 2014; Phillips et al., 2013). Moreover, estimation of trophic level using protocols largely based on the phytoplankton biomass and measurement of chemical constituents and/or combination of both seems effective, especially over the past decades these protocols were refined, standardized and modified. But the results are hard to compare especially when the information originates through the use of different methods and sampling gear (Kasprzak et al., 2008). In the present study, the applying of the internationally accepted criteria of OECD (1982), Environment Canada (2004) and MDDEP (2007) for classifying the trophic status indicated that the eutrophic condition for the Lake Timsah. The classification—in respect to the trophic conditions reported through the present study is given in Table 6, these data indicate that the Lake Timsah can be considered as eutrophic. The microscopic evaluation of phytoplankton samples and calculation of algal biomass remain significant in studies focusing on biological parameters but are, however, labour-intensive as well as demanding taxonomic skills of the investigators. An alternate is chlorophyll a concentration, though with limitations, has gained interest of the researchers as a quick and easy-to-measure index of phytoplankton biomass.

The present study employs Carlson’s Trophic State Index (TSI) and Burns et al.’s Trophic Level Index (TLI) with the understanding that both indices are a well-tested robust quantitative method and replicable methodology considering biological and physical parameters and the findings are presented in Table 3. A TSI value between 40 and 50 is usually associated with mesotrophic (moderate productivity); values greater than 50 are associated with eutrophic (high productivity), and values less than 40 are associated with oligotrophic nature (lower productivity) of the water body (Murthy and Shivalingaiah, 2008). A TLI values between 3 and 4 is usually associated with mesotrophic (moderate productivity); values greater than 5 are associated with eutrophic (higher productivity), and values less than 4 are associated with oligotrophic nature (lower productivity) of the water body (Burns et al., 2005). If the TSI and TLI are calculated using Carlson’s method and Burns et al.’s method, measuring Secchi disk depth, chlorophyll a and total phosphorous and nitrogen values, the present study reveals that the Lake Timsah of the Suez Canal has an average Index of 60 and 5.2 for the two trophic indices of TSI and TLI, respectively and confirming the eutrophication problem as a serious threat in the Lake Timsah. Water quality assessed with the TSI and TLI is more suitable for needs of natural water resources management if eutrophication is a major threat (Parparov et al., 2010).

Moreover, different physical and chemical factors can be used to assess water quality of the aquatic ecosystems (Sarganoor and Deshpande, 2003). The mathematical rating reflecting the composite effects of these factors on the overall water quality of the lake water can suggest the valuable approach for quantitative assessment in the form of WQI. During the present study, seven parameters vise: pH, dissolved oxygen, nitrate, nitrite, ammonia, phosphate and silicate were selected to calculate the WQI of the Lake Timsah. The results indicated that the water quality of the lake ranged between intermediate (67%) and bad (27%) waters with being average of 49% (Table 3) on one hand, and report the unsuitability of the Lake Timsah waters for main and/or several human uses on the other (Table 7). The water quality index (WQI) allows the reduction of big amounts of physical, chemical, and biological data to a single number in a simple reproducible manner. So, the WQI is suggested to be the most helpful tool to enable waterbody managers, policy makers, and even public to evaluate the water quality. Many researchers adopted the use of The WQI as one of the simplest effective methods used in assessing
the overall water quality of the lakes worldwide (Hamilton and Parparov, 2010; Parparov et al., 2010; Tyagi et al., 2013).

5. Conclusions

Lake Timsah can be classified as eutrophic lake in respect to greater species diversity and higher population density of its phytoplankton community. The eutrophication status of the Lake Timsah water has been confirmed by other numerical indices rather than nomenclature phytoplankton index. Away from the eutrophication conditions, the Lake Timsah suffering from water quality problems due to different anthropogenic activities as it receives a tremendous amount of untreated domestic and industrial waste discharges and agricultural drainage. The water quality problems of the Lake Timsah are suggested to affect the health and the different components of the aquatic ecosystem, and also affect the people living around the lake, as well as, the health of the highly increased inhabitants in the area. During the present study, three different approaches were applied for the quantitative assessment of Lake Timsah water quality: the trophic state index (TST); trophic level index (TLI) and water quality index (WQI). Application of the trophic state and trophic level indices (TSI & TLI) revealed that Lake Timsah has indices of 60 and 5.2, respectively and confirm eutrophic status of the lake waters. Water quality assessed with both indices is more suitable for lake management needs if eutrophication is a major threat. The WQI calculated for the Lake Timsah with an average of 49 demonstrated that the water of the Lake Timsah is bad and unsuitable for main and/or several uses. In conclusion, WQI allows using of several parameters for measuring water quality and can serve a more robust than TSI and/or TLI for measuring water quality and can serve a more robust than TSI and/or TLI

In conclusion, WQI allows using of several parameters for measuring water quality and can serve a more robust than TSI and/or TLI and can be used effectively as a comprehensive tool for water quality assessment method by the Q assemblage index in Lake Mogan (Turkey). Turkiye J. Fish. Biol. 38, 169–175.

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