OPEN ACCESS
Asian Journal of Biological Sciences

ISSN 1996-3351
DOI: 10.3923/ajbs.2019.808.819

Research Article
Spatiotemporal Changes of Plant Diversity and Trophic Level in Idku Lake, Egypt: Integrating Remote Sensing and GIS

[1]Muhammad Abdul-Hady El-Alfy, [2]Yasser Ahmed El-Amier and [3]Manar Mohamed Nofal

[1]Department of Marine Pollution, National Institute of Oceanography and Fisheries, Alexandria, Egypt
[2]Department of Botany, Faculty of Science, Mansoura University, Mansoura, El-Gomhouria Street, Egypt
[3]Egyptian Environmental Affairs Agency, Mansoura, Egypt

Abstract

Background and Objective: Wetlands are described as the kidneys of the landscape because they function as downstream receivers of wastewater from both natural and human sources. This research study the plant diversity and eutrophication process in Idku lake. **Materials and Methods:** The methodology is based on collection and analysis of water samples collected from 12 locations with known coordinates using a GPS technology. Landsat data and Geographical Information System (GIS) approaches were used for developing trophic level maps as indication to eutrophication process in wet and dry conditions of Idku lake. **Results:** The results showed dense diversity of vegetation in south parts than those in north part. The produced trophic maps indicated oligotrophic conditions in summer (<40) and hyper-eutrophic conditions in winter (>80). The extracted data from Landsat images integrated with tools in GIS proved the field and lab analysis approaches. The statistical predicted models may aid in tracking these environmental problems and support decision makers with more information. **Conclusion:** This study showed that the lakes' environments need for periodical monitoring programs using new technologies as remote sensing (RS) and GIS for sustaining its biodiversity.

Key words: Plant diversity, lakes, eutrophication, landsat and GIS

Citation: Muhammad Abdul-Hady El-Alfy, Yasser Ahmed El-Amier and Manar Mohamed Nofal, 2019. Spatiotemporal changes of plant diversity and trophic level in Idku lake, Egypt: integrating remote sensing and GIS. Asian J. Biol. Sci., 12: 808-819.

Corresponding Author: Yasser Ahmed El-Amier, Department of Botany, Faculty of Science, University of Mansoura, Mansoura, El-Gomhouria Street, Egypt Tel: 01017229120-01280288892, +2 050 2223786 Fax: +2 050 2246781

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Wetlands are described as the kidneys of the landscape because they function as downstream receivers of wastewater from both natural and human sources[1]. The Nile Delta is characterized by the presence of several lakes occupying a significant percentage of the delta surface area. The northern lagoons of the Nile Delta of Egypt are exposed to two types of environmental alarms which are actual threats, such as drying of substantial areas of the lagoons, significant shoreline erosion and disposal of untreated wastes and potential threats, such as drowning by the seawater due to the eustatic sea level rise; tectonic lowering and removal of coastal sand dunes[2].

Macrophytes are aquatic plants, growing in or near water that are emergent, submerged or floating. They are considered as important component of the aquatic ecosystem not only as food source for aquatic invertebrates and fishes, but also act as an efficient accumulator of nutrients elements and heavy metals[3]. Macrophytes are known as good indicators of heavy metal contamination in aquatic ecosystems and they act as biological filters by accumulating heavy metals from the surrounding environments[4,5]. The distribution and abundance of aquatic plants are influenced by many factors. Nutrients are the most important factor for the submerged plant growth and distribution, although, nutrient enrichment in water could inhibit the growth of some aquatic plants[6,7].

Water is one of the most important natural resource available to manhood. Knowing the importance of water for sustenance of life, the need for conservation of water bodies is being recognized everywhere in the world[8,9]. So, water pollution is the prevalent threat of urbanization, industrialization and modern agricultural practices. It leads to alteration in physical, chemical and biochemical properties of water bodies as well as that of the environment. It directly or indirectly affects the life processes of flora and fauna of the water body, surrounded by chemical toxicants[10,11].

Water eutrophication in lakes, reservoirs, estuaries and rivers is widespread all over the world and the severity is increasing, especially in the developing countries. The major influencing factors on water eutrophication include nutrient enrichment, hydrodynamics, environmental factors such as temperature, salinity and microbial and biodiversity[12].

Remote sensing techniques are widely applied in studies of water quality nowadays, for example, measuring water clarity, surface temperature and chlorophyll-a (Chl a). Due to the relationship between absorption and scattering of the visible spectrum and Chl a concentrations, consequently it is more effective to use a ratio between two bands that have such interaction with the spectra[13,14]. The use of remote sensing in lake management is based on the fact that the causes of eutrophication and an increase in productivity will be associated with a change in the water optical properties Increases in chlorophyll-a are associated with a decrease in the relative amount of energy in the blue wavelength (0.45-0.52 μm) and increases in the green wavelength (0.52-0.60 μm)[15]. Landsat imagery with a fine spectral resolution increases the accuracy of quantifying Secchi disk depth and chlorophyll-a[16].

The GIS capability can be used to link ecological information with the management decisions of these waters. Remote sensing provides useful information in the form of satellite images and aerial photographs that can be integrated and analyzed in GIS to provide useful spatial information and temporal changes over large geographic areas affecting the structure and function of tropical waters[17]. The application of GIS to the field of aquatic botany has been more often proposed as a good method that has been awarded over a decade[18].

Idku lake receives huge amounts of drainage water from three main drains (Berzik, Idku and El-Boussili), which attach the eastern basin of the lake. The maximum influx from all drains is recorded during summer, while the minimum is in winter. An amount of 3.3×106 m^3 per day of brackish water is introduced into Abu Qir Bay from lake Idku through Boughaz El-Maadiya[19]. Idku lake exposed to pollution from different point and non-point sources which effect the water quality of it. Also, huge amount of nutrients that make the lake mostly atrophied may aid in changing the plant diversity. The aim of this research is to detect areas more correlated to trophic conditions within Idku Lake in two different seasons (winter and summer) integrating Remote Sensing and GIS technologies.

MATERIALS AND METHODS

The collection of samples in this study begin at September, 2016 for summer season and at February, 2017 for winter season, then samples were sent to laboratory for determination of different parameters.

Study area: Idku lake is the 3rd largest coastal water body northwest of the Nile delta located within El Beheira Governorate. Since mid-1950s, over 30% of Idku lake was dried to create new agricultural lands[20]. The lake is located between 30 10'E and 30 14' E and 31 13'N and 31 16'N. There are many sources for drainage water in the lake mostly from El-Khairy, Damanhur and Bersik drains.

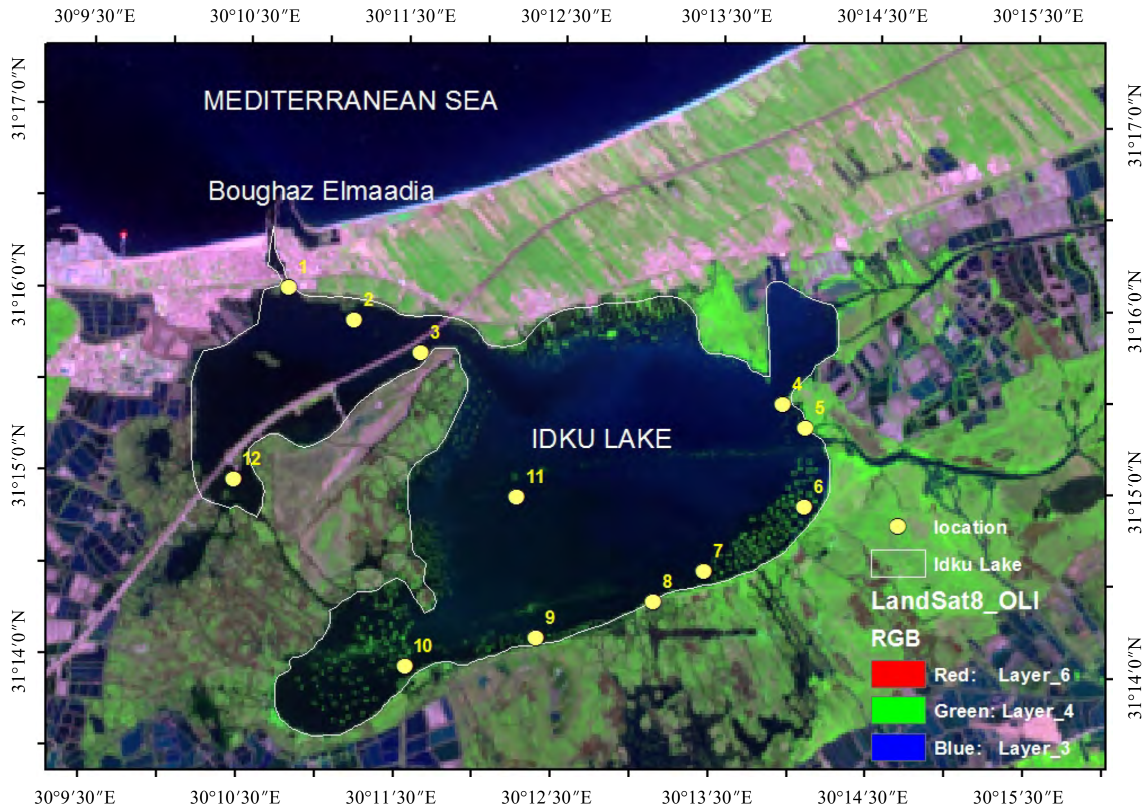

Fig. 1: Location map showing the selected sites in Idku lake

Table 1: Latitudes and longitude for samples locations in Idku lake

Site No.	North	East	Description
1	31.26711	30.1795	Boughaz El-Maadia
2	31.26433	30.1865	North to the international coastal road
3	31.2615	30.19361	Bab Harb (south to coastal Road)
4	31.25761	30.23206	El-Berka
5	31.2555	30.2345	El-Khairy drain
6	31.24828	30.23467	El-Barsik drain
7	31.24225	30.22414	Fish Farms drainage area
8	31.23939	30.21886	Southern part of lake
9	31.23581	30.20656	Bab Elkanais
10	31.23297	30.19272	Bab Kanfur
11	31.24861	31.20417	Middle part of Lake
12	31.24965	30.17406	Drainage area at northern part

Hydrophytes distribution: Hydrophytes were collected from different sampling sites, during summer (9/2016) and winter (2/2017) trips. The identification, classification and floristic composition were according to Tackholm[21] and Boulos[22]. Plant life forms were identified according to the scheme of Raunkiaer[23].

Sampling and analysis: Twelve georeferenced samples were taken from whole lake representing different sectors of the lake (Table 1). All precautions and accuracy were considered in water sampling. Samples were filtered through CF/C glass fiber filters then stored at 4°C in the refrigerator for further chemical analysis.

Water depth and Secchi disk depth (Transparency) are measured as the methods of APHA[24]. Nutrients (NH_4, PO_4, SiO_4 and TP) were analyzed according to Grasshoff *et al.*[25]. The phytoplankton biomass was estimated as chlorophyll a according to the procedure given by Strickland and Parsons[26].

Digital image processing: The selected landsat images were downloaded from this site (http://earthexplorer.usgs.gov) with path 177 and row 38 of OLI sensor type at acquisition dates of 8/2016 for dry conditions and 2/2017 for wet conditions. The image digital number values (DN) were converted to reflectance using image metadata according to model created using ERDAS imagine ver.14.

Eutrophication investigation methodology using landsat data and GIS: A 3×3 window was used in ArcGIS program ver. 10.1 to gather data from the raster layers of the studied bands and indices at the sampling locations. The average values were calculated for 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). The multiple regression models for phosphate estimation in the two different periods were occurred using Excel program. Then the trophic conditions in both dry and wet conditions calculated according the trophic state index based on PO_4.

Calculation of trophic state index (TSI): The Carlson's trophic state index (CTSI) was calculated using the following formulae, the category of CTSI is as Table 2:

$$TSI\ (SDT) = 10\ [\ 6\text{-In SDIn}\ 2]$$

$$TSI\ (Chl\text{-}a) = 10\ [\ 6\text{-}2.04\text{-}0.68\ \text{In}\ (Chl\text{-}a)\text{In}\ 2]$$

$$TSI\ (TP) = 10\ [\ 6\text{-In}\ 48\text{TPIn}\ 2]$$

$$TSI(PO_4) = 10\left(6 - \frac{\text{Ln}\left(\frac{21.67}{PO_4}\right)}{\text{Ln}(2)}\right), [PO_4\ (\mu g\ L^{-1})]$$

Table 2: Categories of trophic state according to Carlson classification

No.	CTSI value	Attributes	Trophic level
1	<30	Clear water	Oligotrophic
2	30-40	Will still exhibit oligotrophy	
3	40-50	Water moderately clear	Mesotrophic
4	50-60	Lower boundary of classical eutrophic	Eutrophic
5	60-70	Dominance of blue-green algae	
6	70-80	Hypereutrophic	
7	>80	Algal scum	

Statistical analysis: The mean of the results was calculated using Excel. Multiple regression equations also were created using Excel program ver.10. The correlation between different parameters were made using SPSS ver.16.

RESULTS

Plant distribution: Floristically, the total number of the recorded plant species in the present study is 15 species (two submerged, 4 floating and 9 emergent hydrophytes) belonging to 13 genera and related to 9 families. Figure 2 shows that, the family Cyperaceae comprises 4 species (26.67%) of the total recorded plant species, followed by Poaceae 3 species (20.0%). The remaining families which include Azollaceae, Ceratophyllaceae, Lemnaceae, Polygonaceae, Pontederiaceae, Potamogetonaceae and Typhaceae comprise only one species each (6.67%). On the other hand, the floristic analysis of Idku lake as shown in Fig. 3 reveals that 6 species or about 29.4% of the total number of recorded species are cosmopolitan taxa. Other taxa are either paleotropical and pantropical (4 species = 23.5%, each), Mediterranean and neotropical (two species = 11.8 %, each).

According to the life-span the major bulk of the recorded species in the present study was mainly represented by perennials (93.33%) and partly by annuals (6.67%). On the basis of life-forms, species recorded classified under four types as follows: Therophytes (one species = 5.26%), geophytes (7 species = 36.84%), hydrophytes (5 species = 26.32%) and helophytes (6 species = 31.58%). It is also obvious that, the majority of the recorded species are geophytes followed by helophytes (Table 3).

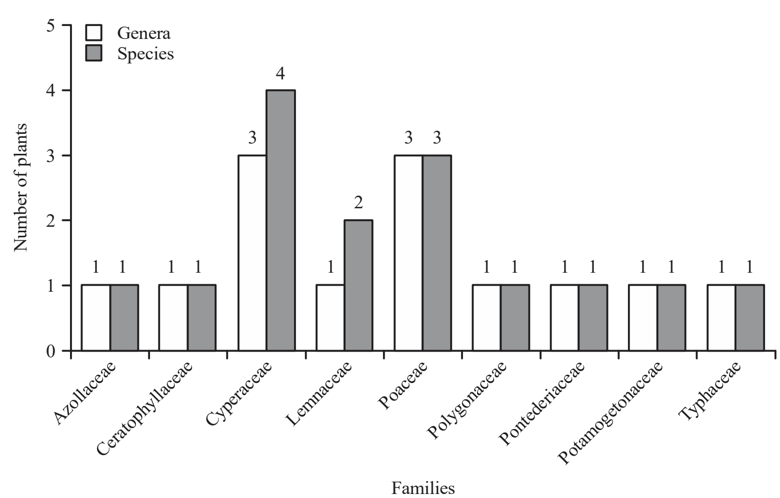

Fig. 2: Total number of recorded plant genera and species in the families

Table 3: Floristic composition of the plant life in the study area

No.	Taxon	Ecological groups	Families	Life-span	Life-form	Floristic category
1	*Azolla filiculoides* Lam	Floating	Azollaceae	Ann	Th	NEO
2	*Bolboschoenus glaucus* (Lam.) S.G. Smith	Emergent	Cyperaceae	Per	G	COSM
3	*Ceratophyllum demersum* L.	Submerged	Ceratophyllaceae	Per	Hy	COSM
4	*Cyperus alopecuroides* Rottb.	Emergent	Cyperaceae	Per	He	PAN
5	*C. articulatus* L.	Emergent	Cyperaceae	Per	G, He	PAN
6	*Echinochloa stagnina* (Retz.) P. Beauv.	Emergent	Poaceae	Per	G, He	PAL
7	*Eichhornia crassipes* (C. Mart.) Solms	Floating	Pontederiaceae	Per	Hy	NEO
8	*Lemna gibba* L.	Floating	Lemnaceae	Per	Hy	COSM
9	*L. minor* L.	Floating	Lemnaceae	Per	Hy	COSM
10	*Persicaria salicifolia* Brouss. ex Willd.	Emergent	Polygonaceae	Per	G	PAL
11	*Phragmites australis* (Cav.) Trin. ex Steud.	Emergent	Poaceae	Per	G, He	COSM
12	*Potamogeton pectinatus* L.	Submerged	Potamogetonaceae	Per	Hy	PAN
13	*Saccharum spontaneum* L.	Emergent	Poaceae	Per	G, He	ME+PAL
14	*Schoenoplectus litoralis* (Schrad.) Palla.	Emergent	Cyperaceae	Per	G	ME+PAL
15	*Typha domingensis* (Pers.) Poir. ex Steud	Emergent	Typhaceae	Per	He	PAN

Ann: Annual, Per: Perennials, Th: Therophytes, G: Geophytes, Hy: Hydrophytes, He: Helophytes, COSM: Cosmopolitan, NEO: Neotropical, PAL: Palaeotropical, PAN: Pantropical, ME: Mediterranean

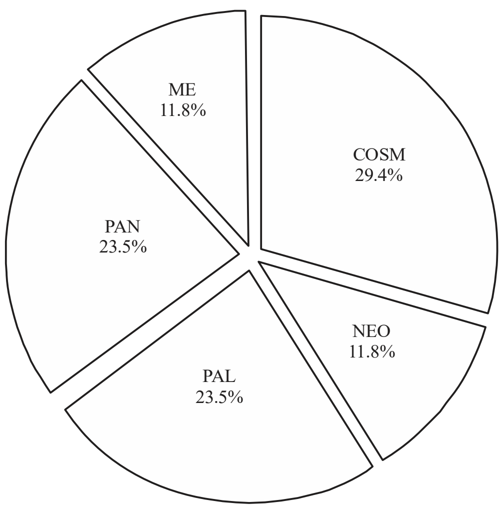

Fig. 3: Principal floristic categories of the recorded species in the study area

COSM: Cosmopolitan, NEO: Neotropical, PAL: Palaeotropical, PAN: Pantropical, ME: Mediterranean

Full data about spatial and seasonal variation in species composition in hydrophytes collected from different stations along Idku lake are given in Table 4. Fifteen different hydrophyte plants were recorded during this study and the distribution of these hydrophyte species along Idku lake varied from site to another and from summer to winter (Table 4). The highest numbers of hydrophyte species (8 and 7 species) were recorded at the sampling stations 4, 6, 10, 12, 3 and 2 during summer, respectively (Table 4). The most dominant species which were recorded almost during summer and winter seasons were *Eichhornia crassipes*, *Echinochloa stagnina*, *Phragmites australis* and *Typha domingensis*. Other hydrophytes were restricted to a particular sampling site, for example *Azollaf iliculoides*, *Lemna gibba* and *L. minor*, *Persicaria salicifolia*, *Potamogeton pectinatus* and *Saccharum spontaneum* were recorded at stations in south part of lake. It must be highlighted that, in winter at station 2, 3 and 11 not any hydrophyte species recorded.

Concentrations of nutrients in Idku lake: Table 5 indicates the concentrations of different nutrients in Idku lake. Mean values of phosphate ranged between 0.049 and 0.030 mg L^{-1} for summer and winter season, respectively. While ammonia mean value varied from 0.18 mg L^{-1} in summer season to 0.258 mg L^{-1} in winter season. Mean values of silicates fluctuated between 0.960 and 0.426 mg L^{-1} in summer and winter seasons, respectively. Finally, mean values of total phosphate varied between 1.12 and 1.08 mg L^{-1} for summer and winter seasons, respectively.

Trophic level in Idku lake: Results of Carlson tropic state index indicated eutrophic conditions in summer season to blue green algae formation in winter season (Table 5).

As shown in Table 6 and Fig. 4, in summer season, N/P ratio ranged between 1.5 in site 3 and 7.39 in site 6. In winter season, this ratio ranged from 5.03 in site 10 and 11.65 in site 11. In summer, N is the limiting factor from site 1 to site 5 and from site 8 to site 12 as percent of N/P ratio<5 and N or P is the limiting factor in sites 6 and 7. While, in winter season, P is the limiting factor in sites 1, 2, 4, 6 and 11, but N or P is the limiting factor in other sites.

Table 4: Distribution of hydrophytes at different sampling sites along the study area during summer and winter seasons

	Sampling sites																							
	S. 1		S. 2		S. 3		S. 4		S. 5		S. 6		S. 7		S. 8		S. 9		S. 10		S. 11		S. 12	
Plant species	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W
Azolla filiculoides Lam	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-
Bolboschoenus glaucus (Lam.) S.G. Smith	-	-	-	-	-	-	+	-	-	-	+	+	-	-	-	-	-	-	+	-	-	-	-	-
Ceratophyllum demersum L.	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	-	+	-	-	-	+	-	-	-
Cyperus alopecuroides Rottb.	-	-	-	-	-	-	+	+	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-
C. articulatus L.	-	-	-	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+
Echinochloa stagnina (Retz.) P. Beauv.	-	-	+	-	+	-	-	-	+	+	+	+	+	-	+	+	-	+	-	+	-	-	+	+
Eichhornia crassipes (C. Mart.) Solms	+	+	+	-	+	-	+	+	+	+	+	-	+	-	-	-	+	+	+	+	+	-	+	-
Lemna gibba L.	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
L. minor L.	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Persicaria salicifolia Brouss. ex Willd.	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+
Phragmites australis (Cav.) Trin. ex Steud.	+	+	+	-	+	-	+	+	+	+	+	-	+	+	+	+	+	+	+	+	-	-	+	+
Potamogeton pectinatus L.	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-	-	+	-	-	-
Saccharum spontaneum L.	-	-	-	-	-	-	-	+	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-
Schoenoplectusl itoralis (Schrad.) Palla.	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	+	-	+	+	+	-	-	+	+
Typha domingensis (Pers.) Poir. ex Steud	-	-	+	-	+	-	+	-	+	+	+	+	-	+	+	+	+	+	+	+	-	-	+	+
Number of different species at each site	2	2	4	0	7	0	8	5	7	4	8	4	5	4	5	4	4	5	7	5	3	0	8	6

S: Summer, W: Winter, +: Present, -: Absent

Table 5: Concentrations of nutrients and Carlson trophic state index values

			Nutrients (mg L^{-1})					Calculated TSI				
No.	Season	SD	NH_4	SiO_4	PO_4	TP	Chl-a	SD	TP	Chl-a	Av.	Condition
1	S	60.00	0.023	0.22	0.009	0.58	10.01	0.93	95.95	53.17	50.02	E
	W	20.00	0.384	0.711	0.036	1.21	nd	16.78	106.56	nd	61.67	E (b/g al.)
2	S	25.00	0.112	0.714	0.054	1.15	55.25	13.56	105.82	69.93	63.10	E (b/g al.)
	W	10.00	0.359	0.433	0.032	1.56	25.86	26.78	110.22	62.48	66.49	E (b/g al.)
3	S	25.00	0.06	0.338	0.04	1.77	43.64	13.56	112.05	67.61	64.41	E (b/g al.)
	W	20.00	0.266	0.595	0.035	0.85	144.47	16.78	101.46	79.36	65.87	E (b /g al.)
4	S	35.00	0.316	0.719	0.077	1.45	11.84	8.71	109.17	54.82	57.56	E
	W	20.00	0.384	0.484	0.032	0.61	28.67	16.78	96.68	63.49	58.98	E
5	S	30.00	0.295	0.734	0.064	1.02	nd	10.93	104.09	nd	57.51	E
	W	20.00	0.236	0.47	0.028	1.13	21.24	16.78	105.57	60.55	60.97	E (b/g al.)
6	S	30.00	0.503	1.693	0.068	0.93	nd	10.93	102.76	nd	56.85	E
	W	10.00	0.28	0.504	0.028	1.45	33.36	26.78	109.17	64.98	66.98	E (b/g al.)
7	S	26.00	0.556	0.507	0.095	1.53	nd	13.00	109.94	nd	61.47	E (b/g al.)
	W	25.00	0.258	0.344	0.027	0.77	23.4	13.56	100.04	61.5	58.37	E
8	S	25.00	0.058	0.697	0.031	1.65	nd	13.56	111.03	nd	62.3	E (b/g al.)
	W	10.00	0.192	0.398	0.028	1.05	77.78	26.78	104.51	73.28	68.19	E (b/g al.)
9	S	25.00	0.068	0.933	0.039	0.69	nd	13.56	98.45	nd	56.01	E
	W	15.00	0.159	0.154	0.028	1.37	70.51	20.93	108.35	72.32	67.20	E (b/g al.)
10	S	22.00	0.06	3.753	0.02	0.46	nd	15.41	92.61	nd	54.01	E
	W	12.00	0.146	0.217	0.029	0.7	44.77	24.15	98.66	67.86	63.56	E (b/g al.)
11	S	30.00	0.064	0.459	0.029	1.37	nd	10.93	108.35	nd	59.64	E
	W	20.00	0.303	0.476	0.026	0.96	139.96	16.78	103.22	79.05	66.35	E (b/g al.)
12	S	30.00	0.06	0.748	0.026	0.81	nd	10.93	100.77	nd	55.85	E
	W	20.00	0.134	0.32	0.026	1.29	118.82	16.78	107.48	77.44	67.23	E (b/g al.)
Mean	S	30.25	0.18	0.96	0.046	1.118	30.185	11.33	104.25	61.38	58.23	E
	W	16.38	0.258	0.426	0.03	1.08	66.36	19.97	104.33	69.3	64.32	E (b/g al.)

SD: Secci desk, S: Summer, W: Winter, Chl-a: Chlorophyll-a, TP: Total phosphorus, TSI: Trophic state index, Av.: Average, E: Eutrophic, (b/g al.): Blue/green algae, nd: Non-detected

Regression model for trophic estimation: The Pearson correlation for estimation phosphate regression model in winter and summer seasons were shown in Table 7 and 8. The predicted regression equations of phosphate with different seasons were; in summer season, PO_4 correlated with b2 (r = -0.6) and showed positive significant correlation with b5 (r = 0.59) and this regression equation is as follow:

$$PO_4 = 0.7*b2-0.6*b5+0.11*NH_4 \text{ (adjusted } R^2 = 0.8)$$

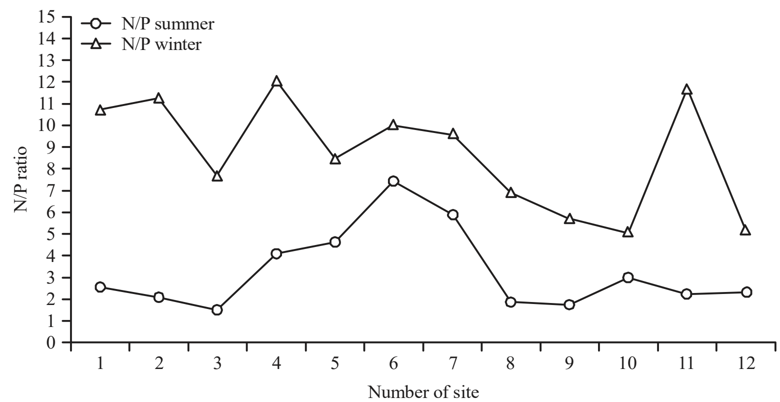

Fig. 4: Distribution of N/P ratio in different locations for winter and summer seasons in Idku lake

Table 6: N/P ratio in different locations for winter and summer seasons in Idku lake

	Summer				Winter			
Site No.	NH_4	PO_4	N/P	Limiting factor	NH_4	PO_4	N/P	Limiting factor
1	0.023	0.009	2.56	N	0.384	0.036	10.67	P
2	0.112	0.054	2.07	N	0.359	0.032	11.25	P
3	0.06	0.04	1.50	N	0.266	0.035	7.60	N or P
4	0.316	0.077	4.10	N	0.384	0.032	12.00	P
5	0.295	0.064	4.61	N	0.236	0.028	8.43	N or P
6	0.503	0.068	7.39	N or P	0.28	0.028	10.00	P
7	0.556	0.095	5.85	N or P	0.258	0.027	9.56	N or P
8	0.058	0.031	1.88	N	0.192	0.028	6.86	N or P
9	0.068	0.039	1.74	N	0.159	0.028	5.68	N or P
10	0.06	0.02	3.00	N	0.146	0.029	5.03	N or P
11	0.064	0.029	2.21	N	0.303	0.026	11.65	P
12	0.06	0.026	2.31	N	0.134	0.026	5.15	N or P

N/P: Red field ratio

Table 7: Pearson correlation between extracted band values from Landsat image in summer season and different water quality parameters

Var.	B2	B3	B4	B5	B6	B7	TP	TN	NH_4	NO_2	NO_3	SiO_4	PO_4	Chl-a
B2	1													
B3	0.854**	1												
B4	0.986**	0.883**	1											
B5	-0.293	-0.129	-0.251	1										
B6	0.443	0.408	0.395	0.52	1									
B7	0.676*	0.640*	0.613*	0.064	0.769**	1								
TP	-0.358	-0.302	-0.34	0.187	-0.168	-0.27	1							
TN	-0.363	-0.298	-0.344	0.213	-0.136	-0.282	0.996**	1						
NH_4	-0.5	-0.177	-0.435	0.663*	0.049	-0.292	0.223	0.251	1					
NO_2	-0.342	-0.074	-0.294	0.306	-0.185	-0.434	0.316	0.35	0.791**	1				
NO_3	-0.372	-0.306	-0.353	0.218	-0.147	-0.281	0.998**	0.999**	0.259	0.36	1			
SiO_4	-0.111	-0.34	-0.124	-0.142	-0.253	-0.356	-0.529	-0.528	0	-0.138	-0.54	1		
PO_4	-0.623*	-0.368	-0.572	0.599*	-0.048	-0.455	0.444	0.473	0.898**	0.826**	0.486	-0.164	1	
Chl	0.193	0.117	0.165	-0.35	-0.271	-0.246	0.315	0.32	-0.231	0.332	0.325	-0.255	0.033	1

**Correlation is significant at the 0.01 level (2-tailed), *Correlation is significant at the 0.05 level (2-tailed), Var.: Variables

In winter season, it showed positive correlation with b2, b4 (r = 0.7and 0.6), respectively and this regression equation is as follow:

$$PO_4 = -0.008+0.6*b2-0.2*b4+0.004*SiO_4$$
$$(\text{adjusted } R^2 = 0.\ 44)$$

From the developed models using Landsat data, it gives indication to low degree of trophic conditions in dry conditions, while in wet conditions, it showed high degree or expression to formation of algal blooms in the lake. Figure 5 and 6 showed the category of trophic condition based on developed predicted equation of phosphate.

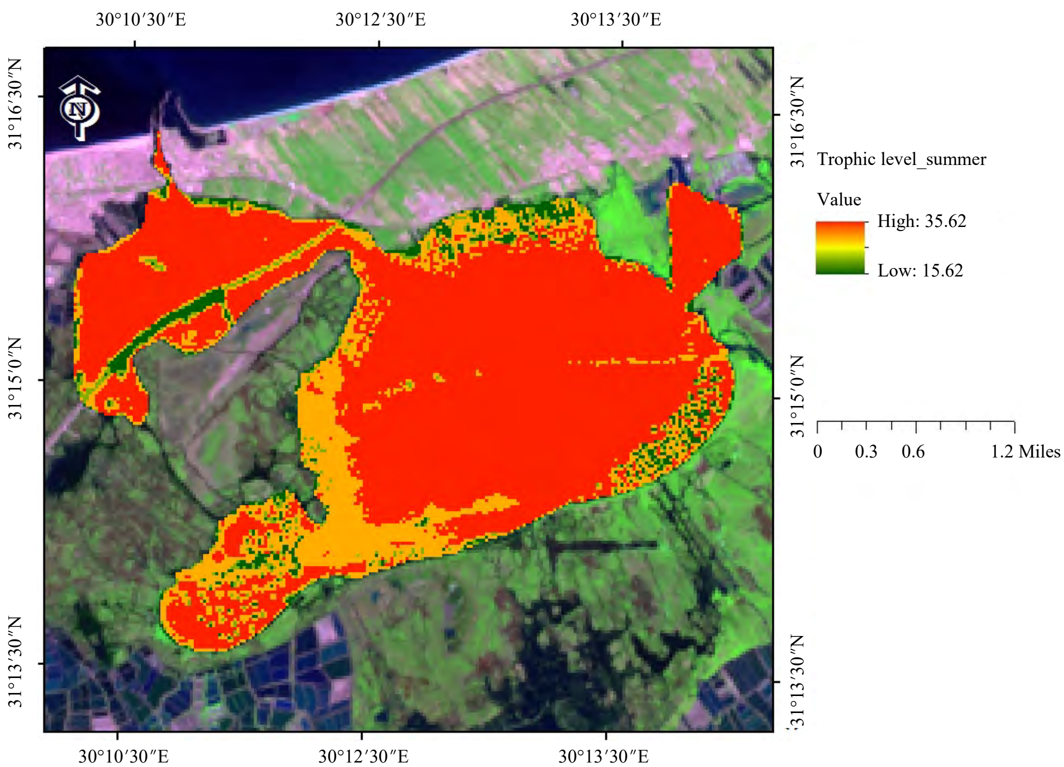

Fig. 5: Developed map indicate the trophic level of Idku lake in summer season

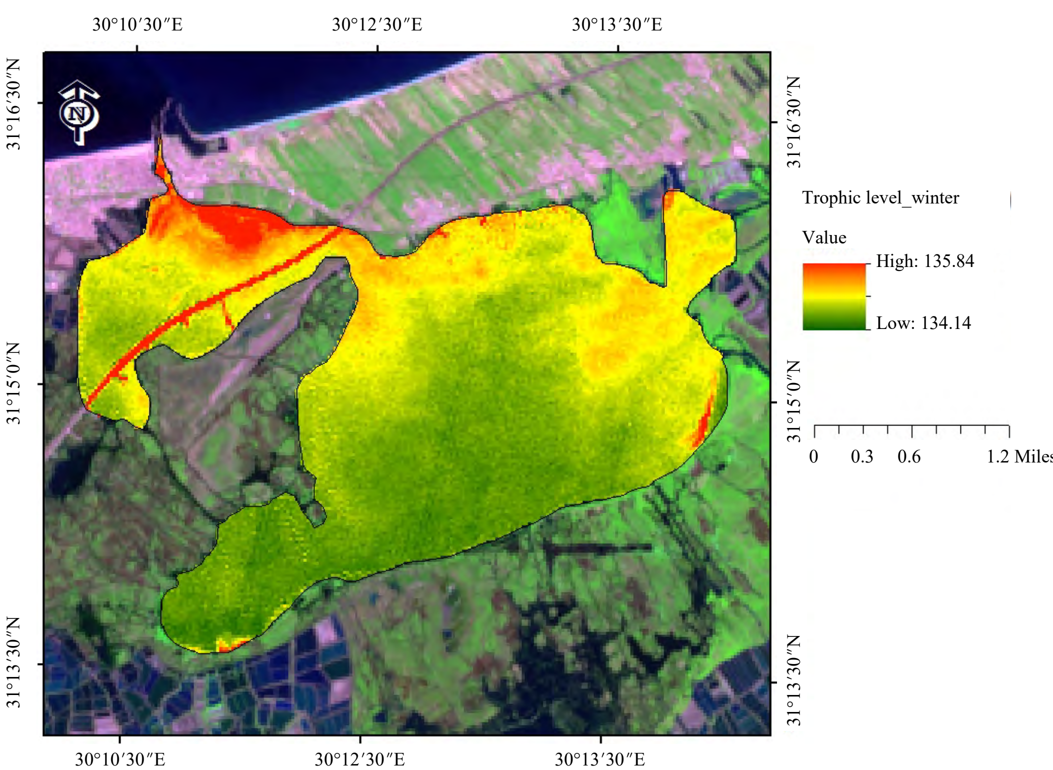

Fig. 6: Developed map indicate the trophic level of Idku lake in winter season

Table 8: Pearson correlation between extracted band values from Landsat image in winter season and different water quality parameters

Variables	B2	B3	B4	B5	B6	B7	TP	SiO_4	PO_4	Chl-a
B2	1									
B3	0.975**	1								
B4	0.976**	0.984**	1							
B5	0.648*	0.710**	0.734**	1						
B6	0.760**	0.784**	0.831**	0.893**	1					
B7	0.812**	0.803**	0.859**	0.810**	0.975**	1				
TP	0.462	0.518	0.454	0.405	0.231	0.21	1			
SiO_4	0.746**	0.681*	0.710**	0.422	0.624*	0.672*	0.007	1		
PO_4	0.736**	0.608*	0.677*	0.349	0.512	0.605*	-0.067	0.652*	1	
Chl a	0.660*	0.575	0.634*	0.368	0.654*	0.782**	0.119	0.601*	0.588*	1

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

DISCUSSION

In the last decades, the reduction in Idku lake area occurred as a result of the development of drainage and irrigation schemes in the eastern portion. It is obvious that, all drainage water of the Nile delta from different sources either agricultural, sewage or industrial wastewaters were drained into the southern parts of these lakes which now considered as polluted areas[16,27].

The aquatic weeds of northern lakes (48 species) represent about 55% of the total aquatic macrophytes in Egypt (87 species as reported by Zahran and Willis[28]). Field observations revealed that, the emergent plant species e.g., *Phragmites australis*, *Saccharum spontaneum*, *Echinochloa stagnina* and *Typha domingensis* have dense growth in lake. Furthermore, the floating hydrophytes e.g., *Eichhornia crassipes* and *Lemna* spp., as well as the submerged hydrophytes e.g., *Ceratophyllum demersum* and *Potamogeton pectinatus* are collectively growing in all ecological sites. These weeds are growing and forming either pure or mixed community types. It observed that, the floating macrophytes are mixed with the emergent vegetation types along shore lines of lake. The worsen of aquatic environments is attributed to industrial, agricultural and municipal wastes which directly added to the water bodies especially those lakes which considered as important habitat of organisms i.e., fishes[29-31].

The floristic diversity of the study Lake included 15 species, through 12 sites. More than 45% (7 species) of the recorded species belong to two families; these are the species-rich families: Cyperaceae and Poaceae. These families represent the most common in the Mediterranean north African flora[32]. Comparing the results of floristic diversity in Idku lake in the present study with other studies[7,33,34] are more or less similar due to time of field trip during summer and winter. On the other hand, decreased numbers of hydrophytes in the northern part of the Idku lake can be attributed to the water salinity which plays an important role in reducing floral diversity.

In comparison with the other lakes, the highest number of aquatic weeds was recorded in Manzala lake (35 species), the lake that receives large amounts of nutrients through the drainage water[35], a condition that favours the growth of the floating and emergent hydrophytes. Shaltout and Galal[36] reported that lake Bardawil contributed the highest number of natural plants (104 species) and the lowest numbers of aquatic weeds (4 species).

Lake Idku receives two different types of input water, saline water from the Mediterranean Sea through Boughaz El-Maadia and drainage water from minor and major drains terminating in the lake along the eastern and southern shores (e.g., El-Khairy, Barsik, El-Boussili, Damanhour drains, etc.). The external loading of nutrients is decisive for primary productivity in the lake. However, nutrient overloading from external sources can lead to the creation of dense plant cover in the lake[28,37].

The largest numbers of hydrophyte species (8 and 7 species) were recorded at the sampling stations in south part during summer. Species diversity increases with decreasing salinity and increasing eutrophication near the mouths of the drains in the southern parts of the lake[37]. The northern part of the lake with relatively low depth and high salinity, while southern part of the lake receives large amounts of nutrients through the drainage water, this condition favours the growth of floating and emergent hydrophytes, particularly *Eichhornia crassipes*, *Echinochloa stagnina*, *Phragmites australis* and *Typha domingensis*. The decline of submerged vegetation near the mouths of these drains may be due to light limitation due to turbidity[38,39]. Other hydrophytes were restricted to a particular sampling site, for example *Azolla filiculoides*, *Lemna gibba*, *L. minor*, *Persicaria salicifolia* and *Potamogeton pectinatus* in south part of lake. The recent changes in species distribution can be attributed to the effects of salinity, water depth and drainage water[37].

According to the description and classification of life-forms[23], the life-forms of the species recorded in the present study are grouped under four types as follows: therophytes (5.26%), geophytes (36.84%), hydrophytes (26.32%) and helophytes (31.58%). In the present investigation, the floristic structure agrees more or less, with findings of Quezel[32] concerning the floristic structure of the Mediterranean Africa, El-Sheikh[40] on the canal-drain vegetation in the middle Delta region, El-Amier[41] on phytosociological and autecological studies on the canal bank vegetation in Egypt, Shaltout *et al.*[42] studied the plant life in the Nile delta and El-Alfy[33] on the vegetation analysis on El-Manzala and Burullus Lakes.

Chronologically, Egypt is the meeting point of the floristic elements belonging to at least four phytogeographical regions: The African Sudano-Zambesian, the Asiatic Irano-Turanian, the Afro-Asiatic Sahro-Sindian and the Euro-Afro-Asiatic Mediterranean[43]. In Idku lake most of recorded species are cosmopolitan taxa (29.4%). Other taxa are either paleotropical and pantropical (4 species = 23.5%, each), Mediterranean and neotropical (two species = 11.8 %, each).

The highest mean values of total phosphorus TP were recorded in sites (2 and 3) in the north sector beside drainage area attributed to anthropogenic activities of different fish farm wastewaters, this agreed with El-Alfy[44]. The concentration of these nutrients is more in winter than those of summer may attributed to anthropogenic and different change activities in the lake of this period. Also, the results of TP are more than those recorded by El-Alfy[44] in the north part of Manzala lake area. Silicates varied according to water salinity. The highest concentration of silicates were recorded in summer season may attributed to waste water, While in winter season, the highest concentration of SiO_4 was recorded in site 3 may attributed to sea water intrusion.

The enrichment of water bodies by nutrients is often followed by a heavy growth or even blooming of the resident algal communities and therefore, eutrophication has become a problem receiving a great psychological concern. It has been reported elsewhere that, eutrophication stimulate profuse growth of blue-green algae[45]. Abd El-Hamid *et al.*[46] mentioned that excessive nutrients, especially nitrogen and phosphorus, the northern lakes are able to support an abundance of undesirable aquatic plants causing eutrophication and deterioration of their water quality.

The calculated trophic state index for SD, TP and Chl-a in Idku lake in summer was ranged between Eutrophic to algal formation conditions, where these algae increased in different sectors in winter season, may attributed to the decrease of water depth, distribution of macrophytes and the increase of nutrients concentration. From results, the general state of the lake is eutrophic.

These results agreed with that estimated by El-Amier *et al.*[47], who found similar trophic condition especially in drainage areas in Manzala and Burullus lakes based on TSI (PO_4 and Chlorophyll). The results of TSI based on SD, PO_4 and Chl classified lake Idku into eutrophic to hypereutrophic conditions, this is agreed with Abd El-Hamid *et al.*[46].

The ratio of N/P in the water body (referred to as the "Redfield ratio") is an important indicator of which nutrient is limiting eutrophication[48]. The role of N/P ratio should be strictly considered in order to predict the algal growth potential of a water body from the field measurements of either nitrogen or phosphorus. In summer, nitrogen is the limiting for plant and algae growth, in contrast with winter conditions, P showed more limitation conditions. The N/P ratio increases in winter than those in summer season may attribute to decrease of water amount and increase of drainage waters, N or P is the limiting factors in most sites as a result of different waste types. This result is agreed with Okbah *et al.*[49], who found that the phosphorus is limiting nutrient factor ($N/P>5$) in the investigated area during winter, but during summer ($N/P<5$), nitrogen is limiting nutrient factor for plant growth. El-Wakeel and Wahby[50] observed that the areas of the lake are affected directly by drainage water enriched with phosphate. Eutrophication condition of Idku lake was assessed and integrated from the band extracted values from Landsat/OLI-8. As using Landsat images play an important role in mapping the coastal lake's water quality and Chl-a[51]. The relationship between the extracted values from Landsat images and nutrients measured data has been verified in winter and summer seasons. It's indicated high positive relation between nutrients especially PO_4 (limiting for algal blooms formation) and band values. Systems with high amounts of phosphorus tend to be highly productive or highly trophic and aid in formation of algal blooms[52]. Band values from the OLI Landsat image and this was obvious more in winter, may due to huge amounts of agricultural wastes from different drains. This is agreed with what estimated by El-Alfy[33].

According to Lillesand and Kiefer[53], it's obvious that chlorophyll and PO_4 were correlated with band 2 (Blue chlorophyll absorption area), Band 3 (Green), band 4 (Red chlorophyll absorption area). So, this relation proved the analytical methods when being integrated with remote sensing data and that area of Idku lake is eutrophic. Also, chlorophyll and phosphate highly correlated with bands more related to high dense vegetative areas. A regression predicted model for phosphate in the two different seasons proved this. This regression can be indication for the trophic state in Idku lake within studied seasons in future periods based on data from Landsat images integrating technique of GIS.

CONCLUSION

The lakes' environments need for periodical monitoring programs using new technologies as RS and GIS for sustaining its biodiversity. The drainage water should be remediate to reduce the level of pollutants to acceptable limits. Cleanses of unwanted water plants may aid in reducing eutrophication process in the lake. The depth of lake should be increase especially in El-Boughaz area to renew water of the lake.

SIGNIFICANCE STATEMENT

This study discussed a serious problem of Egyptian lakes namely; eutrophication which affect badly on the aquatic biota. Also, it referred to two important techniques for modeling the trophic level. Monitoring the plant species by the seasonal periods aid in the identification of flora in lake. This study will help the researchers to detect areas with more nutrients for further remediation processes. Also huge data base for flora of the lake would be available for future studies.

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