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Water quality assessment of the Nile Delta Coast, south eastern Mediterranean, Egypt.

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ABSTRACT

The physical characteristics (temperature, salinity, pH and dissolved oxygen), turbidity, phytoplankton biomass (Chlorophyll-*a*) and nutrients in the coastal waters of a stressed area of the Nile Delta were studied biweekly from January to December 2007. The results indicated that the discharged waste waters caused pronounced changes in the water quality. The surface salinity recorded a minimum of 0.3 ‰ at site IV and a maximum of 38.1 ‰ at site I. pH ranged from 7.25 at site V to 8.55 at site II, while dissolved oxygen attained the lowest concentration (0.5 mg/l) at sites IV and V, and the highest concentration (10.82 mg/l) at site II. The water turbidity demonstrated wide fluctuation between 0.2 NTU at site II and 117 NTU at site III. The nutrient salts experienced great variation throughout the area of study as well as on the time scale; nitrate showed a range of 3 – 1682 µg/l, nitrite: 0.42-1106.2 µg/l, ammonia displayed undetectable level as well as high concentration (1646.6 µg/l), while the total phosphorus fall within a range of 10-8260 µg/l and silicate of 40 – 40800 µg/l. High phytoplankton biomass was recorded over the whole area (chl. *a*: 0.4 - 197.4 µg/l). The trophic state of the study area calculated by trophic index (TRIX) appeared to be widely different, reflecting degraded and very high trophic water, except at site I which contained moderate quality and high trophic water in significant part of the year.

INTRODUCTION

The rapid development of human activities, especially industrial and agricultural activities, large quantities of nutrients and other pollutants to the coastal sea water of this area, and consequently lead to high eutrophication in some parts of the Egyptian Mediterranean Coast.

Accelerated eutrophication has become one of the world's most serious environmental problems (**Nyenje *et al.* 2009**). The terrestrial nutrient enrichment represents an important anthropogenic pressure affecting estuarine and coastal waters worldwide (e.g.**Nixon, 2009; Ferreira *et al.* 2011**), whereas eutrophication dominates in such areas, causing a shift of biological regime (**Scheffer *et al.* 2001; Carpenter, 2003**), promotes toxic and nontoxic algal blooms, and subsequently leads to ecological deterioration and economic loss.

Several mechanisms have been developed by many countries to minimize the effect of eutrophication through the reduction of nutrient input to the coastal areas (**Bricker *et al.* 2007; Borja *et al.* 2010**).

For characterizing eutrophic state, a trophic index (TRIX) was developed by **Vollenweider (1998)** for the coastal area of northern Adriatic Sea and was confirmed by **UNEP (2007a, b)** to be also used in the Mediterranean (c.f. **Primpas and Karydis, 2011**).

Although the main body of the Eastern Mediterranean Sea was well documented as oligotrophic area (e.g. **Souvermezoglou *et al.* 1996; Ignatiades, 1998**), eutrophic conditions have been reported along the Egyptian Mediterranean coast due to great amount of nutrients brought from the coastal lakes which are considered as storage basins for sewage, agricultural and industrial wastes (**Dorgham, 2011, 2014**). Recreation, fishing activities, natural gas extraction, and other human activities are other factors affecting the trophic state of the Nile Delta coast.

During the last few decades, the northern part of the Nile Delta has been subjected to extensive unplanned development projects, which accelerated hazardous changes in the Nile delta coast. Several studies have been conducted on the physical chemical characteristics of the waters and sediments in the Delta coastal lakes (e.g. **Deyab and El-Katony, 2015; El-Gammal *et al.* 2015**) and in the Nile Delta coast (**Said and Hamed, 2006; El-Matary, 2006; El-Ghobashi *et al.* 2006; El-Ghobashi, 2009; Faragallah *et al.* 2009; El-Serehy *et al.* 2012; El-Tohamy, 2015; Soliman *et al.* 2015; El-Zeiny *et al.* 2016**).

Other studies have been done on some heavy metals in the water, sediment and/or animals of coastal sea area off the Delta region (**Soliman *et al.* 2015; El-Serehy *et al.* 2012**), while others were concerned with total pesticides and petroleum hydrocarbons (**Said and Hamed, 2006**) and COD (**El-Gammal *et al.* 2015; El-Zeiny, 2010**).

Despite of the large number of studies on the ecological characteristics of the Nile Delta coast, the majority of them were based on a few number of satellite images, which were taken intermittently once or twice a year or in different years for certain parts of the area, and consequently do not provide the actual dynamic of the coastal ecosystem. Some of the previous studies concerned with different types of pollutants that brought to the sea through the discharged wastes, but a few were done on the physical chemical characteristics of sporadic water fragments along the Delta coast, depending on seasonal sampling.

The present study aims to provide a more detected configuration of the ecological characteristics of the Nile Delta coast measurement of physical chemical parameters through biweekly sampling over a year. It also aims by using the TRIX index to assess the water quality and trophic state of the study area, particularly the part receiving different volumes of discharged wastes.

MATERIALS AND METHODS

Study area

The area of study lies on the eastern part of the Nile Delta, between 31°10 and 32°05 E and 31°20 and 31°35 N. It has particular ecological and economical importance as it is highly fertile and exposed to different environmental stress resulting from the Damietta Branch of the River Nile, different types of land based effluents, fishing and fish culture activities.

The present study was carried out through biweekly sampling during the period January - December 2007 at five ecologically different sites with a 2 m depth range (Fig. 1).

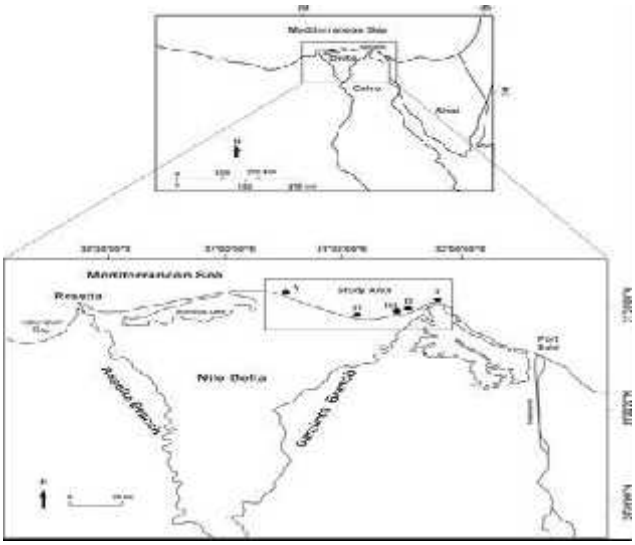

Fig. 1: A map of the study area showing the positions of the sampling sites

Site I lies at the connection between the Lake Manzalah and the Mediterranean Sea, and is affected by fresh water from the Damietta Branch of the River Nile, domestic wastes from surrounding villages, industrial wastes from a sardine factory, and wastes of fish farms. This site receives also polluted waters from Lake Manzalah, which receives daily about $20.5x10^6$ m^3 of untreated industrial and agricultural wastes as well as sewage (**Abdel-Rasheed, 2011**) from Cairo, Port Said, Damietta, and other surrounding cities (**Khalil, 1990**) with high loads of nutrients (**El-Sherif and Gharib, 2001**). The sediments of Lake Manzalah contained high value of organic matter (up to 12.2%) and were categorized as moderately to heavily polluted with heavy metals (**Abu Khatita *et al.* 2016**). On the other hand, a total of 9503.2×10^6 m^3/yr of the Lake waters are discharged annually to the Egyptian Mediterranean Sea, with seasonal variations given in Table 1.

Table 1: Monthly of discharge (10^6 m^3) from Lake Manzalah to the Mediterranean Coast, Egypt (**Al Saharty, 2014**)

Month	Runoff	Month	Runoff
January	441.97	July	1948.28
February	334.95	August	2007.25
March	502.86	September	916.41
April	489.78	October	644.68
May	551.23	November	537.64
June	558.42	December	569.76
		Total	9503.23

Site II lies at the connection between the Mediterranean Sea and the Damietta Harbour, which receives fresh water from the River Nile, sewage, agricultural wastes, industrial wastes from fertilizer and methanol producing factories, and a natural gas liquefaction laboratory. Unfortunately, there is no record for the volume of discharged wastes at this site.

Site III lies west to the Damietta Branch of the River Nile and receives approximately 6×10^6 m^3 day^{-1} of untreated agricultural, industrial wastes and sewage from New Damietta City.

Site IV is located west to site III at the mouth of Gamasa Drain, which transfers to the sea coast 13.1×10^6 m^3 day^{-1} of untreated domestic and agricultural wastes.

Site V lies at the mouth of El-Kassara Drain, west to the River Nile Branch farther than site IV, and receives about 8.6×10^6 m^3 day^{-1} of industrial, agricultural and sewage wastes, in addition to waste waters from adjacent fish farms.

Samples collection and analysis

All the parameters of the present study were measured in water samples collected from 50 cm below the sea surface. The water temperature was measured by an ordinary thermometer graduated to 0.1ºC, water turbidity by the Nephelometric method **(APHA, 1998)**, and pH by a pocket digital pH meter (Orion research Model 201). Salinity was measured argentometrically according to **Strickland and Parsons (1972**) and the dissolved oxygen (DO) by the Winkler method (**APHA, 1998)**.

For nutrient determination, 500 ml of the sea water from each site was filtered through the membrane filter (pore size 0.45 µm) and was frozen at -20 ^oC until analysis. The inorganic nitrogen forms (ammonia, nitrite, nitrate) and silicate were determined according to **Strickland and Parsons (1972)**. The total phosphorus (TP) was measured in unfiltered water samples according to **APHA (1998).**

The phytoplankton biomass (chlorophyll *a*) was determined according to **Strickland and Parsons (1972)**, using the SCORE UNESCO equation [(11.64×E663)−(2.16×E645)+(0.1×E630) ×10]/V.

The trophic state of the water was estimated using the trophic index, proposed by Vollenweider *et al.* (1998), following the equation:

TRIX = [log10 (Cha × aD% × Oxygen × N × P) + 1.5] /1.2.

where:

Cha: chlorophyll-*a* (μgL^{-1});

aD% oxygen: (absolute % derivate for saturation);

N: mineral nitrogen ($N{-}NO_3$ + $N{-}NO_2$ + $N{-}NH_4$; as μgL^{-1}); and

P: total phosphorus (μgL^{-1}).

Statistical analysis

The similarity index **(Bray and Curtis, 1957)** was used between stations and months for hydrographic conditions, applying the statistical design "Hierarchical clustering" by using Statsoft Statistica 8.0.

RESULTS

Hydrographic conditions

The physical chemical parameters (Table 2) demonstrated conspicuous variations on both spatial and temporal scales. The water temperature fluctuated between 12.5 ºC in winter (February) and 31 ºC in summer (July and August), with negligible differences among the sampling stations. The surface salinity experienced wide range of variations (0.3-38.1‰), whereas the water could be classified as moderately or high brackish at sites I, II and III, with annual average salinity of 25.03‰, 16.43‰ and 18.55‰ respectively, and low brackish at sites IV and V (average salinity: 1.4‰ and 4.0‰ respectively). The biweekly salinity at site I was mostly between 23.4‰ and 28.6‰, except the two high values (35.0 ‰ and 38.1 ‰) in August and September respectively. At site II, it fell within the range of 17.0 - 27.7‰ most of the year, and markedly dropped to 1.6 – 4.6 ‰ from September to

November. At site III, salinity fluctuated mostly between 21.5 ‰ and 25.4 ‰, against < 1 ‰ at sites IV and between 2.5 - 4.6 ‰ at Site V (Fig. 2).

Table 2: Minimum, maximum, mean and standard deviation of physical chemical parameters along the Nile Delta coast.

Parameter	St I		St II		St III	
	Mean+SD	Min-Max	Mean+SD	Min-Max	Mean+SD	Min-Max
Temp (°C)	22.1±5.26	12.5-31	22.17±5.14	15-31	22.17±5.17	14 - 31
Sal. (‰)	25.03±6.26	9.3 -38.1	16.43±9.61	1.6 – 27.7	18.55±7.58	3.1 – 32.9
pH	7.9±0.16	7.4-8.1	7.97±0.2	7.6-8.55	7.73±0.2	7.4-8.3
DO (mg/l)	6.36±1.5	2.7- 9.5	7.35±2.07	3.2-10.82	5.56±1.94	1.7 – 9.0
Turb. (NTU)	18.63±24.81	1 – 91	3.86±3.49	0.2 – 13.4	44.84±36.02	3.6 – 117.0
NO_3(µg/l)	26.33 ±22.39	3 – 98	51.5±45.88	6 – 174	66.79±50.07	9 – 204
NO_2 (µg/l)	11.26±10.86	0.42-56.5	26.41±31.87	3.2-131.64	34.93±30.31	8.0 – 117.1
NH_4 (µg/l)	4.9±6.45	0.0-21.7	19.33±23.76	0.0 –67.0	77.11±65.49	0.0-191.9
TP (µg/l)	1113.8±2022.83	30 -5770	1380.8±2416.25	10 – 6780	1595 ±2498	30 - 8260
Silicate (µg/l)	4814.6±6310.7	40 -23500	3652.9±2345.4	130 – 9000	9790 ±8296	1210 - 38000
Chl *a* (µg/l)	7.04±10.38	0.4-49.0	12.55±9.67	2.4 – 34.0	8.12±6.63	0.6-26.5

Parameter	St IV		St V	
	Mean+SD	Min-Max	Mean+SD	Min-Max
Temp (°C)	22.31±5.09	14-31	22.27±5.28	13-31
Sal. (%0)	1.37±1.86	0.3 – 9.4	4.02±1.02	2.5 – 6.3
pH	7.59±0.21	7.3-8.1	7.74±0.2	7.25-8.05
DO (mg/l)	2.63±1.77	0.5-7.54	4.42±3.15	0.5 – 9.24
Turb. (NTU)	34.65±11.89	13.4-57.0	32.32±10.61	10.9 -50.0
NO_3(µg/l)	602.33±348.15	120 – 1682	212.33±171.53	36 – 763
NO_2 (µg/l)	343.39±229.75	24.1 -1106.2	121.16±110.68	15.3-410.1
NH_4 (µg/l)	561.93±396.82	38.2-1646.6	73.04±59.31	0.0 – 219.7
TP (µg/l)	1489.57±2160.6	160 - 7880	1588.8 ±2294.4	50 - 6980
Silicate (µg/l)	13746.7±6166.4	4500 - 26500	23562.5±7384.2	14400 - 40800
Chl *a* (µg/l)	8.77±4.29	1.7-17.1	80.56±49.73	7.6-197.4

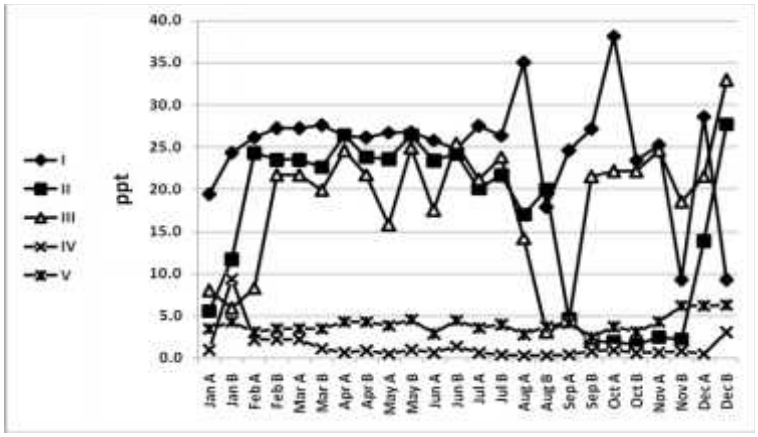

Fig. 2: Biweekly variations of salinity at the sampling sites.

The water turbidity appeared the lowest (annual average: 13.4 NTU) at site II and the highest (annual average: 117.4 NTU) at site III, displaying different temporal patterns throughout the study area (Fig. 3). At sites I and II turbidity fluctuated monthly between 0.2 NTU and 13.4NTU, while at site III, it sustained values of 3.6 - 11.2 NTU from May to August, increased to 26 NTU up to 117 NTU during the rest of the year. At sites IV and V, turbidity showed approximately close variation ranges (13.4 - 57, 10.96 - 50.0 NTU)**.** The pH varied from a minimum of 7.73±0.2 at site III to a maximum of 7.97±0.2 at site II.

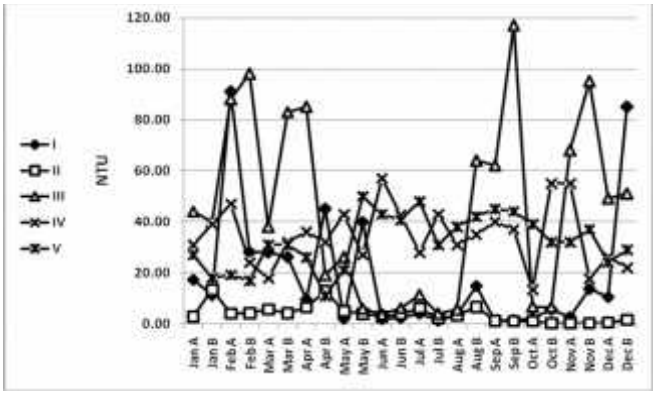

Fig. 3: Biweekly variations of turbidity at the sampling sites

The DO experienced pronounced variations between the sampling stations, falling within a range of 0.5 - 10.8 mg/l. However, the biweekly values (Fig. 4) were higher than 5 mg/l most of the year at sites I and II, decreased below 5 mg/l from May to September at sit III and dropped to anoxic level (<2 mg/l) from May to November at site V. In contrast, dissolved oxygen was either at anoxic level or critical level (2-4 mg/l) most of the year at site IV.

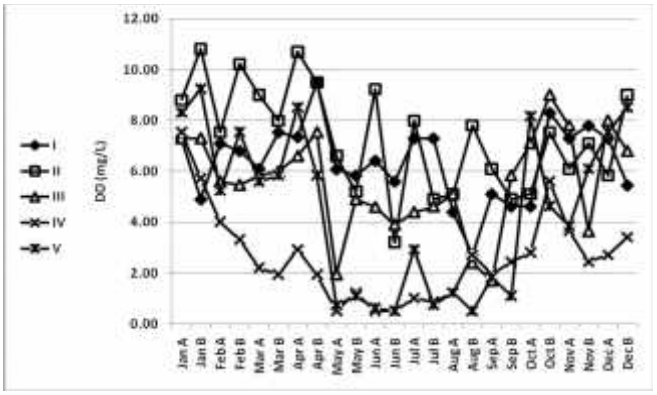

Fig. 4: Biweekly variations of dissolved oxygen at the sampling sites

Nutrients

The nutrient concentrations reflected wide different fertility along the study area (Table 2). Nitrate was the lowest at site I (26.33 ± 22.39 µg/l) and the highest (602.33±348.2 µg/l) at site IV. The biweekly distribution of nitrate displayed different patterns throughout the study area (Fig. 5). At site I, it remained high (20 - 40 µg/l) from January to May and in August, increased to 55, 62.8 and 98 µg/l in late December, early February and early June respectively, but it decreased below <20 µg/l during the rest of the year. At site II, nitrate showed the lowest values from February to May and in August (<20 µg/l), exceeded 20 µg/l during most of the year, but it sometimes attained values of 70 - 174 µg/l. Except occasional low values the concentration of nitrate was mostly > 50 µg/l at site III, reached to 100 - 204 µg/l in July, June and January. At site IV, it was exceptionally high (mostly > 500 µg/l), increased to 1430-1682 µg/l in June, while at site V, the value exceeded 200 µg/l most of the year, reached a maximum of 763 µg/l in December and 503 µg/l in January, but it decreased to < 100 µg/l from May to September.

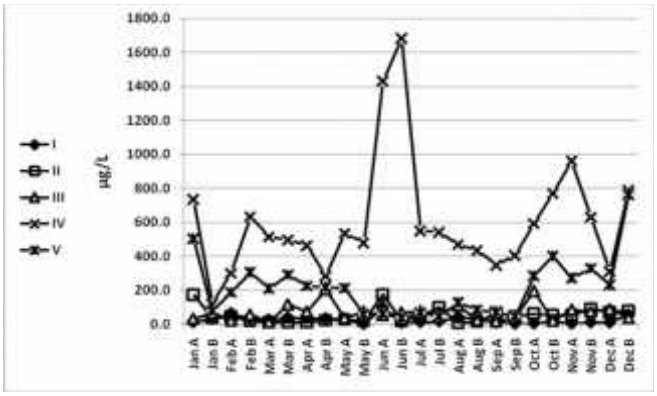

Fig. 5: Biweekly variations of nitrate at the sampling sites.

Nitrite was considerably low (11.26±10.86– 34.93±30.31 µg/l) at sites I, II and III as compared to sites IV and V (343.39±229.8 and 121.16±110.7 µg/l respectively). On the biweekly scale (Fig. 6), site I contained nitrite < 10 µg/l from May to January and between 10 and 17 µg/l during the other months, reaching a maximum of 56.5 µg/l in June. At site II, the concentration was < 10 µg/l from January to August, 20 - 39.2 µg/l from September to December, increased to 99.8, 60.4 and 131.6 µg/l in June, July and January respectively.

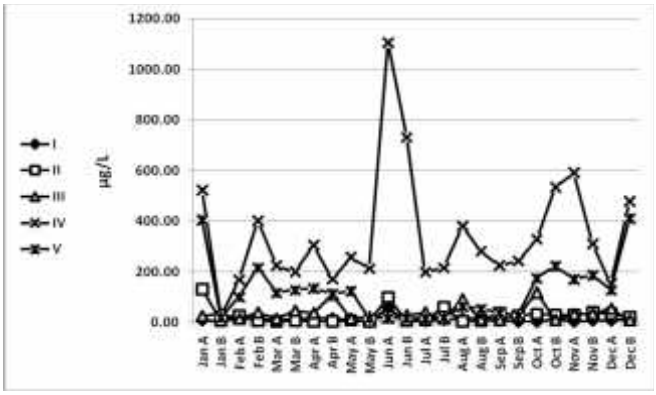

Fig. 6: Biweekly variations of nitrite at the sampling sites

Ammonium concentration fluctuated between 5.77±6.05 µg/l and 561.93±396.8 at site IV, displaying pronounced temporal variations at the sampling sites. At site I, it was under the detectable level from late April to early July, became < 10 µg/l during the rest of the year, and recorded 20.6, 21.7 and 15.2 µg/l in January, February and March respectively (Fig. 7). At site II, undetectable level was observed from early May to early July, followed by < 10 µg/l in March and August, 10 - 30 µg/l during February, July and September - October, with a maximum of 56.9 - 67 µg/l in January, February and November-December. At site III, ammonium frequently showed concentrations between 100 µg/l and 191.9 µg/l, and decreased below 100 µg/l during intermittent months. The ammonium concentration at site IV was the highest over the whole area (mostly > 200 µg/l), increased to 1646.6 µg/l in February, however, it dropped to 38.2 -107.7 µg/l during April and early May. At site V, it showed approximately similar temporal distribution to that occurred at site III.

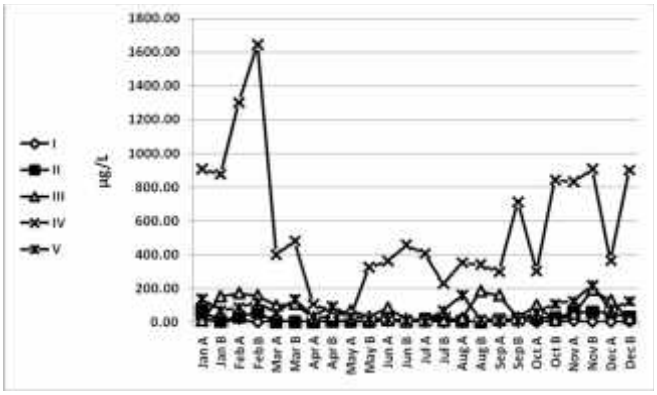

Fig. 7: Biweekly variations of ammonium at the sampling sites

The total phosphorus (TP) amounted to 1113.8±2022.8 µg/l at site I, and 1380.8±2416.3 µg/l at site II, 1595 ±2498 µg/l and 1588.8 ±2294.4 µg/l at sites III and V respectively, and 1438.3±2127.9 µg/l at site IV (Table 2). In contrast to all other nutrients, the TP demonstrated approximately similar temporal distribution throughout the area of study. It was low most of the year at all the sampling sites, except the abnormally high values from late May to the end of July at sites II and III and during June and July at sites I, IV and V (Fig. 8).

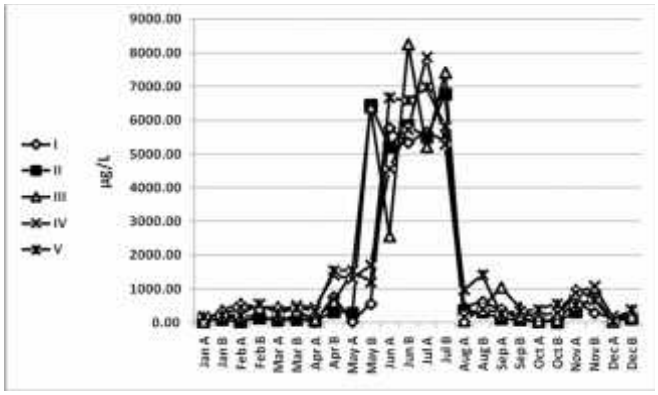

Fig. 8: Biweekly variations of total phosphorus at the sampling sites.

Silicate recorded pronouncedly high concentrations over the whole area of study, varying between 3652.9±2345.4 µg/l at site II and 23562.5±7384.2 µg/l at site V (Table 2). Figure 9 shows that site I contained silicate < 4700 µg/l most of the year, increased to 12000 – 23500 µg/l in February, August, November and December. At site II, silicate was lower than 1000 µg/l in April and May, >1000 - 4000 from January to early March, and exceeded 4000 µg/l during summer. At site III, the lowest silicate (< 2000 µg/l) occurred intermittently in April, October and December, increased to 15000 µg/l in early winter, spring and summer, while its maximum (38000 µg/l) was observed in early February. With the exception of values (<10000 µg/l) in some months of summer and autumn silicate at site IV showed high concentrations over the year, attaining values of 20000 µg/l - 26500 µg/l in late winter and early spring. Site V was characterised by the highest silicate (mostly > 15000 µg/l), and increased to 31200 - 40800 µg/l in early January, late February, late March, early June and late September (Fig. 9).

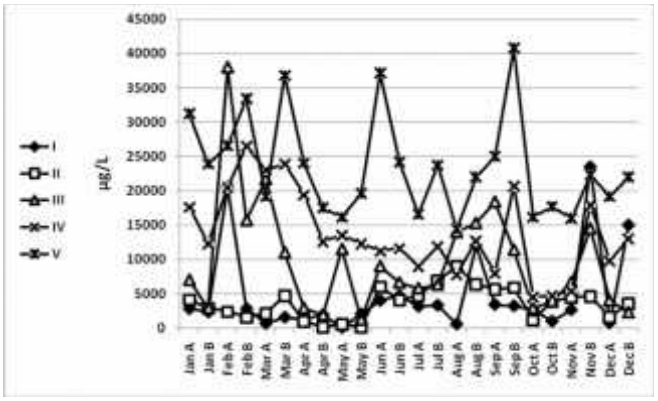

Fig. 9: Biweekly variations of silicate at the sampling sites

Phytoplankton biomass (Chlorophyll *a*)

The concentrations of chlorophyll *a* indicated high phytoplankton biomass in the study area, but with pronouncedly spatial differences, where it recorded 7.05±10.4 µg/l and 8.12±6.63 µg/l at most sites, and increased dramatically to 80.56±49.73 µg/l at site V. As shown in Figure 10 chlorophyll *a* in winter and spring was lower than in summer and autumn, recording pronouncedly high values of 49 µg/l in late June, 23.4 µg/l in early October and 16.4 µg/l in lateNovember. At site II, chlorophyll *a* was < 5 µg/l during most winter and spring, increased to around 15 µg/l in late June, late July, late August and late December, and amounted to 23.2 - 34.0 µg/l in early April, early June, early July, early August and late November. At site III, chlorophyll *a* exhibited values of < 6 µg/l during winter and early spring, increased to 11.3 µg/l from April to July, and reached 17.3 – 26.5 µg/l in late August, late September, early October and early November. At site IV, chlorophyll *a* recorded concentrations < 6 µg/l from January to March, 6 µg/l - <12 µg/l in most months and 12 - 17.1 µg/l in early April, Early June, late August and late December. Site V contained high chlorophyll over the year, with values between 40 - 66.5 µg/l during winter and spring, increased to 80.5 - 98.9 µg/l in late May and June, and reached the maximum of 121.5 - 197.4 µg/l from early August to early November.

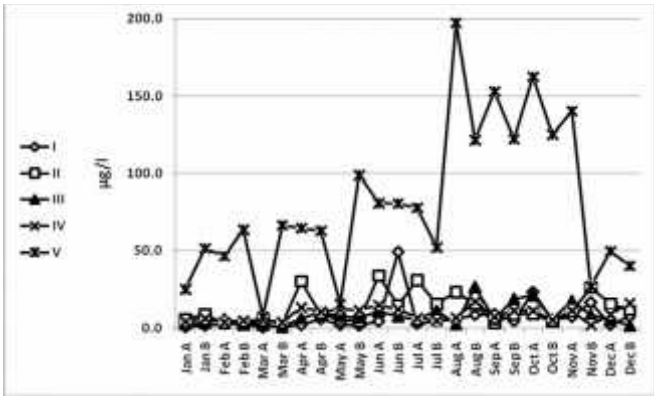

Fig.10 Biweekly variations of chlorophyll *a* at the sampling sites

The statistical analysis (Table 3) indicated that salinity had negative correlation with all nutrients except the total phosphorus, while pH and dissolved oxygen were negatively correlated with all nutrients. On the other hand, chlorophyll *a* showed negative correlation with salinity, and dissolved oxygen and positive correlation with temperature and silicate.

Table 3: Correlation matrix of biweekly physical chemical parameters.
(**Significant at P <01, N = 120, * Significant at P <05, N = 109)

	Temp.	pH	Turbidity	Salinity	DO	Chl a
Salinity		0.391**	-0.22*			
Turbidity		-0.319**				
DO	-0.453**	0.596**	-0.263**	0.498**		
Chl a	0.206*			-0.34**	-0.232*	
Silicate		-0.33**	0.399**	-0.601**	-0.371**	0.471**
NO3		-0.369**		-0.55**	-0.372**	
NO2		-0.318**		-0.532**	-0.324**	
NH4	-0.203*	-0.352**		-0.456**	-0.283*	
TP	0.587**				-0.315**	
TRIX	0.362**	-0.486**	0.236*	-0.643**	-0.671**	0.446**
	Silicate	NO3	NO2	NH4	TP	
NO3	0.23*					
NO2	0.219*	0.963**				
NH4	0.249*	0.608**	0.588**			
TRIX	0.552**	0.541**	0.499**	0.357**	0.479**	

The TRIX values ranged monthly from 4.39 - 7.77 at sites I, 5.07 – 8.91 at site II, 5.48 – 8.31 at site III, 7.53 - 9.81 at site IV and 6.95 - 9.38 at site V. The Bray-Curtis similarity dendrogram showed great similarity in the trophic state (~ 97%) between sites IV and V, and slightly so (~ 93%) between sites I and II, while site III appeared as independent area (Fig. 11).

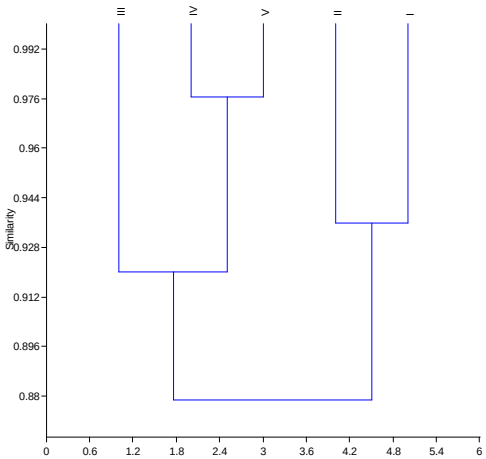

Fig. 11: Bray-Curtis similarity dendrogram for TRIX at the sampling sites.

Cluster analysis

With respect to environmental parameters versus stations (Fig. 12), the cluster analysis divided the environmental parameters into three groups. The first group showed a higher similarity between silicate and chlorophyll *a* than between turbidity and temperature. Three variables (DO, pH and Salinity) combined to form the second group with a strong correlation between DO and pH. The third group included total phosphorus and a single cluster of nitrate, nitrite, and ammonium.

The biweekly variations of environmental parameters (Fig. 13) demonstrated four clustered periods: the first one extended from January to March, the second included early April and October, the third represented by August, September and November, and the fourth period extended from late April to July. Such pattern reflected clear temporal variations in the environmental parameters. Throughout the

stations (Fig. 14), two clusters can be distinguished, the first one included sites I and II and the second cluster was represented by sites III, IV and V.

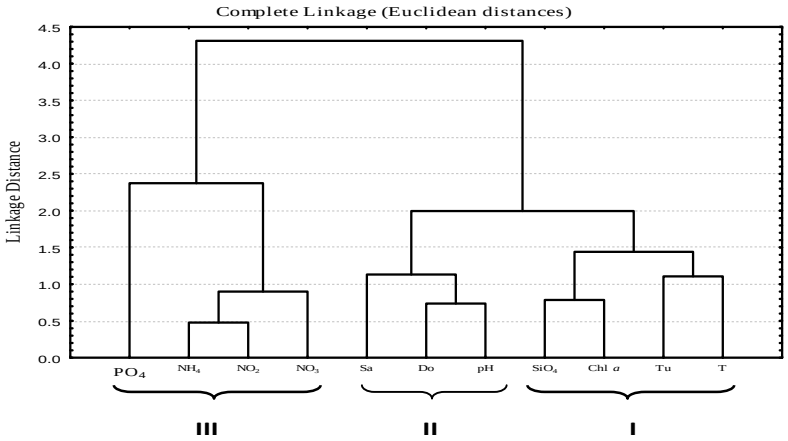

Fig. 12: Tree diagram for environmental parameters versus different stations (complete linkage Euclidean distance) in the study area. Sa = salinity, Tu = turbidity, T = Temperature, and Chl *a* = chlorophyll *a*.

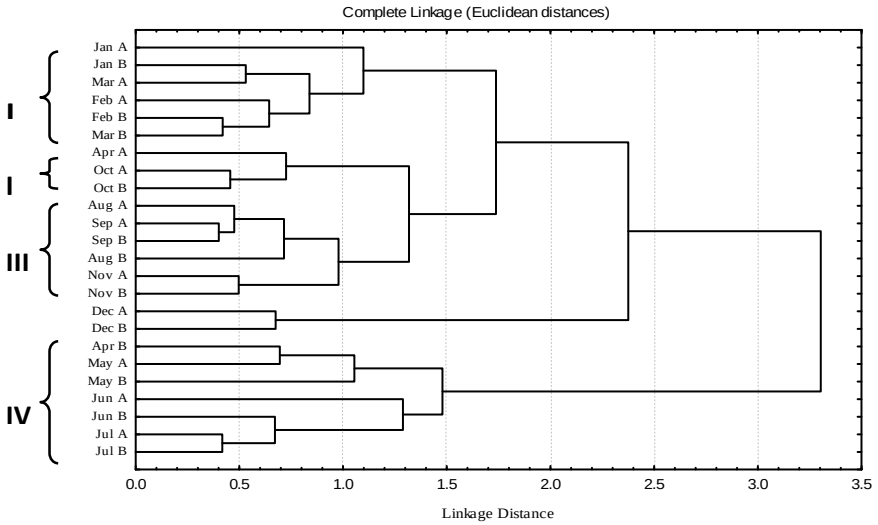

Fig. 13: Tree diagram for biweekly variations versus environmental variables (complete linkage Euclidean distance) in the study area.

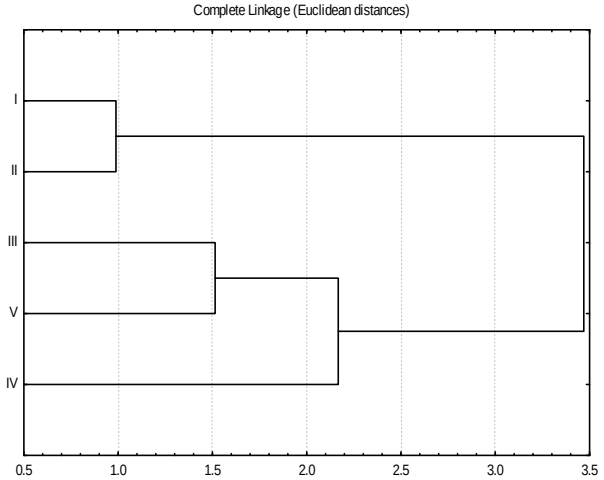

Fig. 14: Tree diagram for stations versus environmental variables (complete linkage Euclidean distance) in the study area.

DISCUSSION

The anthropogenic discharges caused drastic stress on the water quality along the Nile Delta coast, resulted in pronounced changes in its physical chemical characteristics. The salinity variation could be considered as key factor of such changes in the area of study, as it showed negative significant correlation with the majority of measured parameters. The water turbidity is usually used to indicate the amount of suspended living and nonliving particles in the water that are driven by mixing processes. High turbidity is characteristic to estuarine waters that are usually suffered from strong mixing (e.g. **Blaber *et al.* 1995; Westrich and Förstner, 2007**). The turbidity in the present study displayed pronounced variations due to the different mixing processes resulting from the variable amounts of discharged waste waters along the Nile Delta coast **(Zyadah, 1997)**. This is in agreement with the different turbidity levels recorded earlier in the region (1.6 to 15 NTU, **El-Gammal *et al.* 2015**; 10.28 – 12.05 NTU, **El-Sontabi, 2012**; 7.5 - 65.4 NTU, **Abou El-Magd and El-Zeiny, 2014**; 14.35-44.5 NTU, **El-Ghobashy, 2009**).

The dissolved oxygen is an important factor that indicates the suitability of environmental condition for marine organisms (**Best *et al.* 2007**), as it negatively impacts the sensitive marine organisms below 5 mg/l (**Grundy, 1971; Arin, 1974**), and reflects hypoxia condition below 2 mg/l (**Stachowitsch and Avcin, 1988**). Chlorophyll *a* is often used as criteria for assessing eutrophication (**Zhou *et al.* 2004**), showing strong correlation with the pH and DO in eutrophic waters (**Wang *et al.* 2004; Zang *et al.* 2011**). These observations support the findings of **Howland *et al.* (2000)** who stated that the pH could be used as a key chemical water indicator. The pH is pronouncedly affected by the algal abundance (**You *et al.* 2007**), particularly the DO produced by these algae (**Scholz, 2006).** During the present study, DO showed weak significant positive correlation with chlorophyll *a* and strong significant positive correlation with pH, while no correlation was recorded between pH and chlorophyll *a*. Such disturbance in the relationship between the three parameters could be attributed to the strong mixing in the coastal waters of the Nile Delta and the different volumes of the discharged waste waters to the sea.

Temperature and salinity are the main physical factors affecting the concentration of DO in the marine environment (**Balkis *et al.* 2012**) because its solubility decreases with increasing temperature and salinity (**Best *et al.* 2007**). In our area DO displayed negative significant correlation with temperature and positive significant correlation with salinity, indicating that DO in the area of study is affected by other factors rather than salinity. It seems that nitrification and denitrification processes play a role in production and consumption of DO and also its utilization in oxidizing the high organic matter in the area as indicated from the high negative significant correlation between the DO and inorganic nitrogen forms. This agrees with (**Karydis, 2009**) who stated that excessive bacterial and animal activity due to increased phytoplankton biomass and high organic loads in eutrophic systems can lead to oxygen depletion.

Based on the criteria adopted for eutrophication (**Vucak and Stirn, 1982; Franco, 1983; Marchetti, 1984**) the levels of nitrate and ammonium during the present study reflect eutrophic conditions at sites IV and V, and variable trophic conditions (oligotrophic, mesotrophic, eutrophic) at sites I, II and III. Furthermore, the variation range of the measured nutrients in the study area appeared to be more or less close to those found in other eutrophic regions of the Egyptian Mediterranean coast, but with different averages (Table 4)

Sakamoto (1966) proposed that the phytoplankton biomass was dependent on total phosphorus (TP) when TN:TP by weight was >17, on total nitrogen (TN) when TN:TP was <10 and both on TN and TP when the ratio of TN to TP was in the range of 10–17. However, the N:P rule was not suitable for highly eutrophic systems when the loadings of N and P exceed the assimilative capacity of phytoplankton (**Paerl *et al.* 2001**) and at much higher TP values there was no relation between Chl *a* and TN (**Guildford and Hecky, 2000**), probably due to the excessive concentrations of nutrients (**Jin. Lv *et al.* 2011**). These observations may support our findings, whereas the phytoplankton biomass (chlorophyll *a*) showed no correlation with nitrogen and phosphorus due to their high concentrations, but it was positively correlated with silicate, indicating the dominance of diatoms in the area of study. The silicate in the study area were pronouncedly higher than those recorded in other eutrophic waters (Table 4), and this reflected the great silicate load in the terrestrial discharges to the study area as indicated from the significant negative correlation between silicate and salinity ($p < 0.05$) .

Table 4: The range and average of nutrient concentrations (µM/L) in different eutrophic areas of the Egyptian Mediterranean Coast (Western Harbour, **Dorgham *et al.* 2004**; Abu Qir Bay, **Shams El Din and Dorgham, 2007**; Dekhaila Harbour, **Fahmy *et al.* 2004**; Mex bay, **Shreadah *et al.* 2014**).

	phosphate	Nitrate	nitrite	ammonia	Silicate	Chl. *a*
Western Harbour						
Range	0.12–5.7	0.21–20.46	0.29–3.3	0.56–57.46	0.30–36.3	1.89 –219.41
Average	1.17	5.73		14.53	9.03	33.82
Abu Qir Bay						
Range	0.00 –14.64	0.06-51.11	0.00-14.43	0.00 –338.5	0.10 –99.8	0.90 –90.73
Average	1.5	7.15	2.03	14.19	16.4	15.7
Dekhaila Harbour						
Range	0.54-56.46	0.30–45.29	0.21–14.98	2.15-166.25	3.90-148.2	1.63-1322.7
Average	6.48	19.21	4.13	38.89	49.52	106.66
Mex Bay						
Range	0.7 –30.45	0.2 –56.22	0.3–22.85	0.15 –233.3	0.48–99.86	1.49-241.91
Average	4.51	9.89	4.74	74.29	24.53	59.09
Present Study						
Range		0.05–27.12	0.01-24.04	0.00–91.25	0.43 –443	0.40–197.4
Average		3.09	2.34	8.16	120.67	23.4

Regarding chlorophyll a concentration as criteria for the water quality, **Pagou (2009)** considered >2.21 µg/l as indicator of eutrophic conditions, while **Wasmund *et al.* (2001)** considered 4–10 µg/l for eutrophic conditions and >10 µg/l for poly-trophication. In our area, both eutrophic and poly-trophic waters were commonly found at all the sampling sites, with the dominance of poly-trophic condition at sites IV and V. The present records of chlorophyll *a* appeared to be pronouncedly higher than those (up to 28.7 µg/l) observed in Tagus estuary (**Brito *et al.* 2015**) and in Zmiinyi Island Area, Black sea (**Kovalova and Medinets, 2012**), but they are still within the ranges recorded in hot spot areas along the Egyptian Mediterranean Coast (Table 4).

Based on the scales of the trophic state for the European waters (Table 5), the TRIX values along the area of study reflected degraded and very high trophic waters most of the year. However, TRIX values showed a gradual increase from site I towards site V, and attained the highest value in summer. The highest TRIX value at site V could be attributed to the abnormal high chlorophyll a and total phosphorus, particularly during summer. Such explanation is indicated from the positive correlation ($p<0.05$) of TRIX with both TP and chlorophyll *a*, and agrees with **Balkis *et al.* (2012)** who stated that TRIX values increased due to the increase in concentrations of phosphorus and chlorophyll *a*. The high summer value of the total phosphorus and chlorophyll *a* may be explained by the increase of discharged waste waters in summer due to intensive use of fresh water in irrigation of the cultivated lands and in daily human life, whereas these waters are usually loaded by high amount of phosphorus and fresh water phytoplankton.

Table 5: Water quality ranking according to TRIX values (After Balkis *et al*. 2012)

TRIX	Water quality
0-4	High quality and low trophic
4-5	Good quality and moderate trophic
5-6	Moderate quality and high trophic
6-10	Degraded and very high trophic

The decrease of trophicity index in summer period has been observed in the coastal waters of the Adriatic Sea (**Vollenveider *et al*. 1998**) and near Bulgarian coast (**Moncheva and Doncheva, 2000**).

The trophic condition of vast marine areas, like the Mediterranean and Black seas (Table 6), varies considerably from region to region and within regions (**Vollenweider *et al.* 1996**), that is considerably explained by the pronounced different water qualities resulting from the variability of the anthropogenic effects.

Table 6: TRIX range in different regions of Mediterranean and Black sea.

Area	TRIX range	Reference
Adriatic Sea	3.37-5.60	**Vollenweider *et al*. (1998)**
Thermaikos Gulf (Northern Aegean Sea)	5.0 - 6.0	**Moncheva *et al*. (2001)**
Kalamitsi (Central Ionian Sea)	1.9 - 4.7	**Nikolaidis *et al*. (2008)**
in southern Black Sea	6.90 -7.70	**Baytut *et al.* (2010)**
Edremit Bay of the Aegean Sea	0.86 - 2.98	**Balkıs and Balci (2010)**
Zmiinyi Island (Black Sea)	3.0 - 6.9	**Kovalova and Medinets (2012)**
Varna Bay (Black Sea)	5.3±1.16	**Moncheva *et al*. (2002)**
coastal area near the Danube River	5.8±1.0- 6.9±1.1	**Dyatlov *et al*. (2010)**
Samsun Bay (Black Sea)	6.9 - 7.7	**Baytut *et al*. (2010)**
Gulf of Erdek,	1.12 - 3.23	**Balkis *et al*. (2012)**
Gulf of Bandırma	1.68 - 4.46	**Balkis *et al.* (2012)**
Nile Delta Coast	3.61- 8.57	**Present study (2017)**

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