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Physicochemical Characteristics and Eutrophication Condition of Alexandria Beach Water Associated with Corniche Widening

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ABSTRACT

As a result of the constant increase of population and industrial expansion, the seawater in Alexandria, Egypt has become one of the most contaminated regions of the Mediterranean Sea. Thus, the recent implementation of safety measures and concrete bulkheads was set to protect the coastal line from sea level rise, resulting from climate change, causing poor water quality and an increased trend of eutrophication. Therefore, water quality evaluation and eutrophication status of Alexandria coastal water were addressed. The water samples were seasonally collected from July 2018 to April 2019 covering different coastal areas in Alexandria. The measured averages and ranges of these studied variables were as follows: temperature 23.6^{0}C (19-33.5 0C), salinity 38.0 (33.9-40.1), pH (7.0-8.5), DO 8.4 mg/l (5.2-13.6 mg/l), OOM 4.6 mg O2/l (0.6-14.7mg O2/l), BOD 4.0 mg O2/l (0.5-9.1 mg O2/l), and chlorophyll-a 2.010 mg/m3(0-16.354 mg/m3). For eutrophication studies, the dissolved nutrient salts sustained high values, with an annual average of 16.43 µM for nitrate, 0.84 µM for nitrite, 11.19 µM for ammonia, 1.37 µM for phosphate and 7.56 µM for silicate. Sidi-Gaber was the most suffering station from bad water quality and eutrophication conditions according to TRIX and Eutrophication Index (EI) due to the disposal of land-based and resort effluents created by ongoing construction and beach activities. Different types of eutrophication conditions were observed among studied beaches throughout the year. The water quality index (WQI) revealed that Sidi-Gaber, Stanly and Miami stations were more contaminated than the other stations. Moreover, principal component analysis (PCA) depicts the existence of oxygen-consuming contaminants, which might be attributed due to impacts from rural domestic wastewater and municipal point source of the discharge. Pre-treatment of the land-based effluents before their disposal into the sea, the renewal of the isolated parts of the beach with seawater, or the full closure of all outlets at the seacoast are recommended.

INTRODUCTION

The Mediterranean Sea, a semi-enclosed European sea, is surrounded by 21 countries in three continents, with a population of nearly 500 million as estimated in 2016. Additionally, more than 100 million tourists visit the cities and beaches of the Mediterranean each year.

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It is the most contaminated marine areas in the world. Urbanization, sewage and urban runoff, waste management, industrial effluents, maritime transport, sand erosion and eutrophication are the main environmental issues along the Mediterranean Sea's coastline. Moreover, the United Nations Environment Program (UNEP) estimated that 650 million tonnes of sewage are dumped into the Mediterranean each year (**Karadirek *et al.*, 2019**). The coasts of the Mediterranean, particularly the city of Alexandria, are the top tourist destination for their clear waters and diverse coastal habitats. They are also vital for fisheries and other maritime activities. The most serious coastal challenge affecting the city of Alexandria is global warming-induced sea level rise that leads to coastal deterioration and flooding. As a result, coastal-nourishment projects have been implemented at five Alexandria beaches (Asafra, El Mandara, Shatby, Miami and Stanly), using sand from the desert near Cairo (**Heger *et al.*, 2022**). Due to these ongoing construction activities, industrial development and the continuous increase in population on Alexandria's coast, its seawater becomes one of the polluted regions of the Eastern Mediterranean Sea. The coasts are under constant threat of pollution in the form of untreated domestic sewage from the different human and marine activities in addition to agricultural and industrial wastewater discharges. Water quality is a critical factor significantly affecting human and all oceanic organism health.

Monitoring the environmental quality is of great importance to determine the effectiveness of all the adopted governmental steps and assess if further steps are required to improve the quality of the environment. Although, the study of water quality in Alexandria coastal water has been investigated by numerous workers (**Nessim, 1989, 1991, 1995; Nessim *et al*., 2004**; **Hussein *et al.*, 2013; Dango *et al.*, 2015**), the present paper is one of the most important records to evaluate the water quality and eutrophication status of Alexandria coastal water from Abu-Qir to the Eastern Harbor from July 2018 to April 2019. This was achieved by measuring different parameters, such as temperature, salinity, pH-value, dissolved oxygen (DO), biological oxygen demands (BOD), oxidizable organic matter (OOM) and nutrients, as well as chlorophyll-a as an early biomarker for eutrophication in marine environment. In addition, an evaluation of the contamination levels was carried out by using ecological indices. Furthermore, the principal component analysis (PCA) was used to discuss the most significant parameters to develop water quality index.

MATERIALS AND METHODS

1. Area of study

The investigated area lies between longitudes 29.87 W, 30.12 E and latitudes 31.19 S to 31.33 N. Fig. (1) shows the locations of sampling stations covering the coastline of about 24 km between Abu-Qir in the east of Alexandria and the Eastern Harbor (EH) in the west. Water samples were seasonally collected from July 2018 to April 2019 at ten different beaches; namely, Abu-Qir Bay (Site 1), Montazah (Site 2), Asafra (Site 3), Miami (Site 4), Sidi-Bishr (Site 5), Gleem (Site 6), Stanly (Site 7), Sidi-Gaber (Site 8), Shatby (Site 9) and EH (Site 10). The beaches were selected to cover most of Alexandria's coastal area as well as the most densely populated beaches that are important to the tourist destinations (Fig. 1).

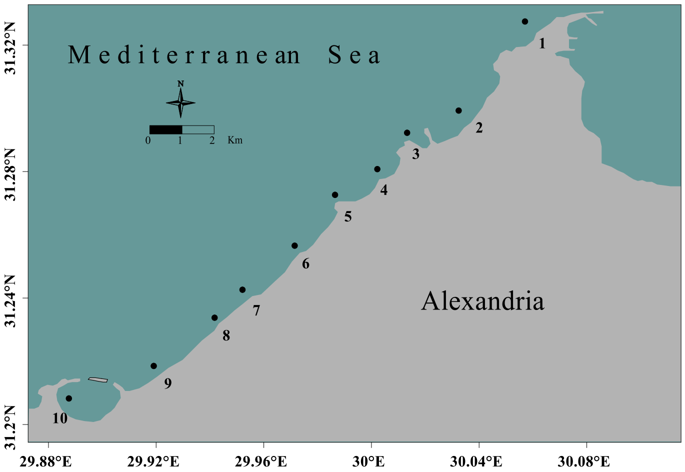

Fig. 1. Alexandria beaches, sampling locations: Abu-Qir Bay (Site 1), Montazah (Site 2), Asafra (Site 3), Miami (Site 4), Sidi-Bishr (Site 5), Gleem (Site 6), Stanly (Site 7), Sidi-Gaber (Site 8), Shatby (Site 9), and Eastern Harbour (EH, Site 10)

2. Methods of measurements

Coastal water samples were seasonally collected from July 2018 to April 2019, using Niskin bottles. Samples were preserved and stored at -20°C for subsequent analyses.

3. Hydrographical parameters

Surface water temperature, pH and salinity were measured directly *in situ* using CTD apparatus (Model: YSI 556). Fixation of DO was done using the common Winkler method, modified by **Carritt and Carpenter (1966)**. Samples for BOD were kept in the laboratory for five days at 20°C before fixation. OOM was determined according to the method described by FAO (**FAO, 1975**). Chlorophyll-a was measured after filtration of 2 liters of water samples on 0.45 mm membrane filter paper according to **Strickland and Parsons (1972)**. Chlorophyll-a was extracted using 90% acetone and spectrophotometrically quantified.

4. Nutrient salts

For the nutrient analysis, samples were immediately filtered after collection using GF/C Whattman filter paper. Filtered and unfiltered water samples were analyzed spectrophotometrically using UV/Visible double beam spectrophotometer (JENWAY model: 6800). Unfiltered water samples were fixed in the field for ammonia nitrogen determination using indophenol blue method. Dissolved inorganic nitrogen (DIN) was calculated by the summation of the different inorganic nitrogen forms (NO_3/N, NO_2/N, and NH_3/N) in filtered samples (**Strickland & Parsons, 1972**). Total nitrogen (TN) was analyzed on unfiltered spring samples according to **Koroleff (1977)** and **Valderrama (1981)**. Particulate nitrogen (PN) was calculated by subtracting TN from DIN. Dissolved inorganic phosphorus (DIP) was determined by molybdate methods on the filtrated sample (**Strickland & Parsons, 1972**), while total phosphorus (TP) was analyzed on unfiltered spring samples according to the method described by ICES (**ICES, 1972**). Particulate phosphorus (PP) was calculated by subtracting TP from DIP. Silicates were calorimetrically analyzed according to **Grasshoff (1976)**. The calibration curves for each nutrient salt were constructed using pure standards.

5. Ecological indices

TRIX index

The water quality of the sampling sites was evaluated using the TRIX index (**Vollenweider *et al.*, 1998**). This index was derived based on chlorophyll-a (µg/l), O_2 Sat.%, DIN (µg/l) and DIP (µg/l) concentrations according to the following equation:

$$TRIX = [log10(\text{chlorophyll a} \times \text{O2 Sat.\%phyll al}) + \text{K}]/m \qquad (1)$$

Where, K and m are constants measuring 1.5 and 1.2, respectively, as observed by **Giovanardi and Vollenweider (2014)**. The water quality index varies from high (TRIX < 4), to good (4 < TRIX < 5), moderate (5 < TRIX < 6) and poor (6 < TRIX < 10).

Eutrophication index (E.I.)

The E.I. was employed according to **Primpas *et al.* (2009)** as follows:

$$E.I. = (0.279\ \times DIP) + \ (0.261\ \times\ NO3/N) + (0.296\ \times\ NO2/N)\ + (0.275 \times NH3/N) + \ (0.214 \times \text{chlorophyll a}\ ) \qquad (2)$$

The concentration of dissolved inorganic nutrients was in µM/l, and chlorophyll-a was in µg/l. The water quality was divided into five classes according to E.I. as follows: high (<0.04), good (0.04-0.38), moderate (0.38-0.85), poor (0.85-1.51) and bad (>1.51).

6. Statistical analysis

The statistical analysis was performed using Microsoft Excel-2010 software and SPSS (IBM Statistics 19). The two-way ANOVA and Pearson's correlation analysis were carried out to better understand the link between variables and potential sources of pollution discharge. The principal component analysis (PCA) was used to offer information on the most significant parameters, which define the entire data set and allowed reduction of data without lost and assess water quality of each station in accordance with the following equation **(Akhtar *et al*., 2021; Morsy *et al*., 2022):**

$$\text{WQI} = \sum_{n=1}^{n} \frac{\lambda_\text{n}}{\sum \lambda_\text{s}} \times \text{PC}_\text{n} \qquad (3)$$

Where, n is the number of effective components; λ_n are the eigenvalues of the effective components; $\sum \lambda_s$ is the sum of the eigenvalues, and PC_n is the critical principal component scores.

RESULTS AND DISCUSSION

The absolute and average values of different physicochemical parameters are presented in Table (1) and Fig. (2, 3) during the year (2018-2019) at different locations along Alexandrian coastline. Table (A1) summarizes the results of two-way ANOVA study of physicochemical characteristics within seasons and stations.

Table 1. Water characteristics of Alexandria beach between Abu-Qir and EH during the year 2018-2019

Season	**Station**	**Temp.**	**S.**	**pH**	**DO**	**OOM**	**BOD**	**O_2 Sat.**	**BOD/ OOM**	**NH_3/N**	**NO_2/N**	**NO_3/N**	**DIN**	**TN**	**PN**	**PO_4/P**	**TP**	**PP**	**SiO_2/Si**	**N:P:Si**	**Chlorophyll -a**
		^{0}C	**‰**			**mg/l**		**%**						**µM**							**mg/m^3**
Summer (2018)	**1**	33.0	39.6	8.4	6.5	9.0	1.6	90.6	0.18	5.15	0.00^	7.48	12.63	-	-	0.29	-	-	0.00^	44 1 0	0.000^
	2	33.5*	39.6	8.2	9.1	2.3	6.0	126.8	2.59	16.85	1.17	6.28	24.30	-	-	0.14^	-	-	0.30	169 1 2	0.802
	3	32.5	40.1*	8.2	8.4	1.4	3.7	115.8	2.74	6.15	0.44	4.79	11.37	-	-	0.29	-	-	3.78	39 1 13	-
	4	31.5	39.5	8.3	8.1	2.6	2.1	109.4	0.80	5.00	1.35	3.45	9.80	-	-	0.38	-	-	0.60	26 1 2	-
	5	32.0	40.1*	8.5*	13.6*	1.4	9.1*	187.1*	6.68	3.60	0.14	2.76	6.49	-	-	0.29	-	-	0.66	23 1 2	0.454
	6	31.5	39.9	8.3	8.6	2.3	6.5	116.0	2.80	5.70	0.83	7.74	14.27	-	-	0.43	-	-	1.92	33 1 4	-
	7	31.0	39.8	8.3	8.3	1.7	4.1	111.6	2.41	3.75	0.45	4.04	8.24	-	-	0.38	-	-	0.18	21 1 0	-
	8	30.5	37.8	8.1	5.5	4.6	5.5	73.1	1.21	77.00	1.40	6.24	84.64	-	-	5.66	-	-	2.10	15 1 0	-
	9	30.0	39.4	8.3	9.1	3.1	5.2	120.4	1.66	9.20	0.54	6.31	16.05	-	-	0.53	-	-	2.52	30 1 5	-
	10	29.0	40.0	8.3	7.1	14.3	1.0	93.0	0.07^	5.60	0.60	3.13	9.34	-	-	0.43	-	-	6.72	22 1 16	1.255
	Seasonal average	**31.5**	**39.6**	**-**	**8.4**	**4.3**	**4.5**	**114.4**	**2.11**	**13.80**	**0.69**	**5.22**	**19.71**	**-**	**-**	**0.88**	**-**	**-**	**1.88**	**42 1 4**	**0.251**
	SD	**1.3**	**0.6**	**-**	**2.0**	**4.0**	**2.4**	**28.7**	**1.81**	**21.39**	**0.46**	**1.73**	**23.36**	**-**	**-**	**1.60**	**-**	**-**	**1.99**	**43 1 5**	**0.423**
Autumn (2018)	**1**	20.0	38.2	7.6	7.8	6.4	4.5	85.8	0.71	6.70	1.23	14.78	22.71	-	-	1.39	-	-	11.16	16 1 8	-
	2	20.0	37.9	7.4	7.9	9.6	5.4	87.6	0.56	5.75	1.25	13.08	20.08	-	-	1.25	-	-	13.98	16 1 11	1.695
	3	20.0	38.3	7.4	10.2	0.6	5.4	112.6	8.36*	4.95	1.05	8.31	14.31	-	-	0.96	-	-	48.00*	15 1 50	1.588
	4	20.5	38.4	7.4	8.3	12.2	6.3	89.3	0.52	5.05	1.48	9.28	15.81	-	-	1.30	-	-	7.26	12 1 6	2.180
	5	20.0	37.7	7.5	8.9	2.6	5.7	98.3	2.22	4.85	0.90	8.24	13.99	-	-	0.96	-	-	10.08	15 1 11	2.762
	6	20.0	38.2	7.3	7.5	9.0	3.6	82.2	0.40	4.35	0.13	12.57	17.05	-	-	1.30	-	-	7.08	13 1 5	1.509
	7	20.0	38.4	7.3	7.6	10.9	4.1	84.0	0.37	4.40	2.55*	8.42	15.37	-	-	1.73	-	-	21.96	9 1 13	1.404
	8	20.0	35.7	7.2	5.2^	2.6	5.2	57.2^	2.03	7.20	1.23	12.25	20.68	-	-	4.22	-	-	9.48	5 1 2	1.423
	9	20.0	38.4	7.3	6.0	1.3	4.1	66.2	3.17	10.25	1.23	10.11	21.59	-	-	2.35	-	-	40.26	9 1 17	1.335
	10	19.0^	38.2	7.3	6.5	14.7*	4.5	70.0	0.31	7.05	1.15	12.27	20.47	-	-	1.97	-	-	9.72	10 1 5	1.601

Season	Station	Temp.	S.	pH	DO	OOM	BOD	O_2 Sat.	BOD/ OOM	NH_3/N	NO_2/N	NO_3/N	DIN	TN	PN	PO_4/P	TP	PP	SiO_2/Si	N:P:Si	Chlorophyll -a
		^{0}C	‰		mg/l			%		µM											mg/m^3
	Seasonal average	**20.0**	**37.9**	**-**	**7.6**	**7.0**	**4.9**	**83.3**	**1.86**	**6.06**	**1.22**	**10.93**	**18.21**	**-**	**-**	**1.74**	**-**	**-**	**17.90**	**12 1 13**	**1.722**
	SD	**0.4**	**0.8**	**-**	**1.4**	**4.7**	**0.8**	**15.2**	**2.36**	**1.72**	**0.56**	**2.22**	**3.24**	**-**	**-**	**0.93**	**-**	**-**	**13.83**	**3 1 13**	**0.436**
Winter (2019)	**1**	21.5	37.7	7.1	8.8	10.2	4.9	98.4	0.48	3.75	0.08	68.82*	72.65	-	-	1.49	-	-	4.08	49 1 3	1.655
	2	21.2	36.9	7.0^	12.6	4.5	0.6	141.7	0.14	5.45	0.43	19.41	25.29	-	-	1.15	-	-	4.14	22 1 4	1.508
	3	21.5	37.9	7.1	9.4	1.3	5.5	105.7	4.31	4.45	0.28	6.64	11.37	-	-	1.25	-	-	4.26	9 1 3	1.590
	4	21.0	37.7	7.1	8.6	2.6	4.5	96.6	1.77	5.90	1.43	66.19	73.52	-	-	1.30	-	-	6.66	57 1 5	1.299
	5	21.0	38.1	7.2	9.2	1.3	4.7	103.9	3.67	9.30	1.30	10.03	20.63	-	-	0.91	-	-	6.48	23 1 7	1.951
	6	20.9	37.3	7.1	9.1	8.3	5.2	102.0	0.62	12.85	0.93	60.66	74.44	-	-	1.25	-	-	5.34	60 1 4	1.870
	7	20.5	37.1	7.1	8.8	1.9	4.5	96.5	2.36	13.70	0.68	67.08	81.46	-	-	0.48	-	-	6.30	170 1 13	1.531
	8	-	-	-	-	-	-			-	-	-	-	-	-	-	-	-	-	- - -	-
	9	19.5	36.2	7.0^	9.7	3.2	5.8	105.1	1.82	27.60	1.95	66.06	95.61	-	-	2.93	-	-	6.24	33 1 2	2.492
	10	19.0^	35.8	7.2	6.0	3.2	0.8	64.8	0.25	12.80	0.73	67.39	80.92	-	-	1.78	-	-	7.14	45 1 4	2.150
	Seasonal average	**20.7**	**37.2**	**-**	**9.1**	**4.1**	**4.1**	**101.6**	**1.72**	**10.64**	**0.86**	**48.03**	**59.54**	**-**	**-**	**1.39**	**-**	**-**	**5.63**	**52 1 5**	**1.783**
	SD	**0.8**	**0.7**	**-**	**1.6**	**3.0**	**1.8**	**18.4**	**1.43**	**7.02**	**0.57**	**25.73**	**31.30**	**-**	**-**	**0.64**	**-**	**-**	**1.13**	**45 1 3**	**0.332**
Spring (2019)	**1**	22.0	37.9	7.7	9.1	1.9	3.1	104.1	1.60	0.80^	0.08	3.43	4.31^	89.64	85.33	0.29^	1.15	0.86	6.84	15 1 24	1.496
	2	22.0	36.9	7.6	8.8	4.5	5.5	100.4	1.23	4.35	0.15	2.41^	6.91	107.79	100.88	0.29^	1.79	1.50*	4.56	24 1 16	2.287
	3	22.0	37.7	7.5	8.9	0.6^	2.1	102.3	3.29	2.35	0.15	4.52	7.02	61.12	54.10	0.91	1.15	0.24^	4.02	8 1 4	0.790
	4	22.0	37.7	7.6	8.4	4.5	2.0	96.7	0.43	3.55	0.10	3.79	7.44	50.74^	43.30^	1.06	1.92	0.86	3.54	7 1 3	1.602
	5	22.0	37.9	7.6	8.4	1.3	1.6	96.7	1.27	1.85	0.18	4.10	6.13	56.30	50.17	0.58	1.09^	0.51	4.74	11 1 8	0.789
	6	22.0	37.6	7.5	8.6	1.9	2.1	98.6	1.10	4.35	0.75	5.64	10.74	57.78	47.04	0.91	1.28	0.37	3.24	12 1 4	0.789
	7	22.0	37.5	7.7	8.4	1.9	2.0	96.7	1.01	3.85	1.03	5.20	10.08	69.26	59.18	0.72	1.22	0.50	3.66	14 1 5	1.962
	8	22.0	33.9^	7.5	6.2	9.6	6.2	70.7	0.64	111.05*	2.20	7.97	121.22*	253.35*	132.13*	8.93*	9.34*	0.41	10.08	14 1 1	2.741
	9	22.0	37.0	7.6	8.0	0.6^	0.5^	91.1	0.76	6.75	0.75	7.47	14.97	95.19	80.22	0.77	1.66	0.89	3.66	19 1 5	3.761

Season	Station	Temp.	S.	pH	DO	OOM	BOD	O_2 Sat.	BOD/ OOM	NH_3/N	NO_2/N	NO_3/N	DIN	TN	PN	PO_4/P	TP	PP	SiO_2/Si	N:P:Si	Chlorophyll -a
		^{0}C	‰		mg/l			%		µM											mg/m^3
	10	22.0	37.0	7.7	10.7	2.6	1.6	122.7	0.63	3.25	0.43	2.55	6.23	71.86	65.63	0.34	1.15	0.81	2.16	18 1 6	16.354*
	Seasonal average	**22.0**	**37.1**	**-**	**8.6**	**2.9**	**2.7**	**98.0**	**1.20**	**14.22**	**0.58**	**4.71**	**19.51**	**91.30**	**71.80**	**1.48**	**2.18**	**0.68**	**4.65**	**14 1 8**	**3.257**
	SD	**0.0**	**1.2**	**-**	**1.1**	**2.6**	**1.7**	**12.1**	**0.78**	**32.31**	**0.63**	**1.80**	**35.87**	**56.85**	**26.73**	**2.50**	**2.53**	**0.36**	**2.15**	**5 1 7**	**4.459**
Annual average	**1**	24.1	38.4	-	8.1	6.9	3.5	94.7	0.74	4.10	0.35	23.63	28.08	-	-	0.87	-	-	5.52	31 1 9	1.051
	2	24.2	37.8	-	9.6	5.2	4.4	114.1	1.13	8.10	0.75	10.30	19.15	-	-	0.71	-	-	5.75	58 1 8	1.573
	3	24.0	38.5	-	9.2	1.0	4.2	109.1	4.68	4.48	0.48	6.07	11.02	-	-	0.85	-	-	15.02	18 1 18	1.323
	4	23.8	38.3	-	8.4	5.5	3.7	98.0	0.88	4.88	1.09	20.68	26.64	-	-	1.01	-	-	4.52	25 1 4	1.694
	5	23.8	38.5	-	10.0	1.7	5.3	121.5	3.46	4.90	0.63	6.28	11.81	-	-	0.69	-	-	5.49	18 1 7	1.489
	6	23.6	38.3	-	8.5	5.4	4.4	99.7	1.23	6.81	0.66	21.65	29.13	-	-	0.97	-	-	4.40	29 1 4	1.389
	7	23.4	38.2	-	8.3	4.1	3.7	97.2	1.54	6.43	1.18	21.19	28.79	-	-	0.83	-	-	8.03	54 1 8	1.632
	8	24.2	35.8	-	5.6	5.6	5.6	67.0	1.29	65.08	1.61	8.82	75.51	-	-	6.27	-	-	7.22	11 1 1	2.082
	9	22.9	37.8	-	8.2	2.1	3.9	95.7	1.85	13.45	1.12	22.49	37.06	-	-	1.65	-	-	13.17	23 1 7	2.529
	10	22.3	37.8	-	7.6	8.7	2.0	87.6	0.32	7.18	0.73	21.34	29.24	-	-	1.13	-	-	6.44	24 1 8	5.340
	Total Average	**23.6**	**38.0**	**-**	**8.4**	**4.6**	**4.0**	**99.3**	**1.72**	**11.19**	**0.84**	**16.43**	**28.46**	**-**	**-**	**1.37**	**-**	**-**	**7.56**	**29 1 30**	**2.010**
	SD	**0.6**	**0.8**	**-**	**1.2**	**2.3**	**1.0**	**14.2**	**1.27**	**20.20**	**0.61**	**21.48**	**30.27**	**-**	**-**	**1.63**	**-**	**-**	**9.50**	**14 1 28**	**1.177**

1. Abu-Qir; 2. Montaza; 3. Asafra; 4. Miami; 5. Sidi-Bishr; 6. Gleem; 7. Stanly; 8. Sidi-Gaber; 9. Shatby, and 10. EH

*Maximum

^Minimum

Table A1. Two-way ANOVA analysis of physicochemical parameters between seasons and stations

Variable	**Class**	**SS**	**Df**	**MS**	**F**	**P**	**Variable**	**Class**	**SS**	**df**	**MS**	**F**	**P**
Temp.	Stations	12.9	9	1.4	3.3	***0.01****	**NH$_3$/N**	Stations	7480.5	9	831.2	2.8	***0.02****
	Seasons	860.1	3	286.7	666.0	***0.00****		Seasons	426.3	3	142.1	0.5	0.70
S.	Stations	17.4	9	1.9	5.0	***0.00****	**NO$_2$/N**	Stations	4.2	9	0.5	1.6	0.16
	Seasons	39.4	3	13.1	34.3	***0.00****		Seasons	2.3	3	0.8	2.7	0.07
Ph	Stations	0.2	9	0.0	4.7	***0.00****	**NO$_3$/N**	Stations	1708.2	9	189.8	1.2	0.35
	Seasons	7.9	3	2.6	534.6	***0.00****		Seasons	12893.7	3	4297.9	26.6	***0.00****
DO	Stations	36.9	9	4.1	1.9	0.09	**DIN**	Stations	10379.1	9	1153.2	2.2	***0.05****
	Seasons	12.1	3	4.0	1.9	0.15		Seasons	12255.5	3	4085.2	7.9	***0.00****
OOM	Stations	210.9	9	23.4	2.0	0.08	**PO$_4$/P**	Stations	62.8	9	7.0	5.0	***0.00****
	Seasons	88.6	3	29.5	2.5	0.08		Seasons	3.9	3	1.3	0.9	0.43
BOD	Stations	32.0	9	3.6	1.1	0.42	**SiO$_2$/Si**	Stations	480.3	9	53.4	0.9	0.51
	Seasons	27.8	3	9.3	2.8	0.06		Seasons	1513.6	3	504.5	8.9	***0.00****
O$_2$ Sat.	Stations	6177.7	9	686.4	2.1	0.07	**Chl.-a**	Stations	69.0	9	7.7	1.0	0.45
	Seasons	4898.8	3	1632.9	5.0	***0.01****		Seasons	15.1	2	7.6	1.0	0.38

*****significance level at $P < 0.05$

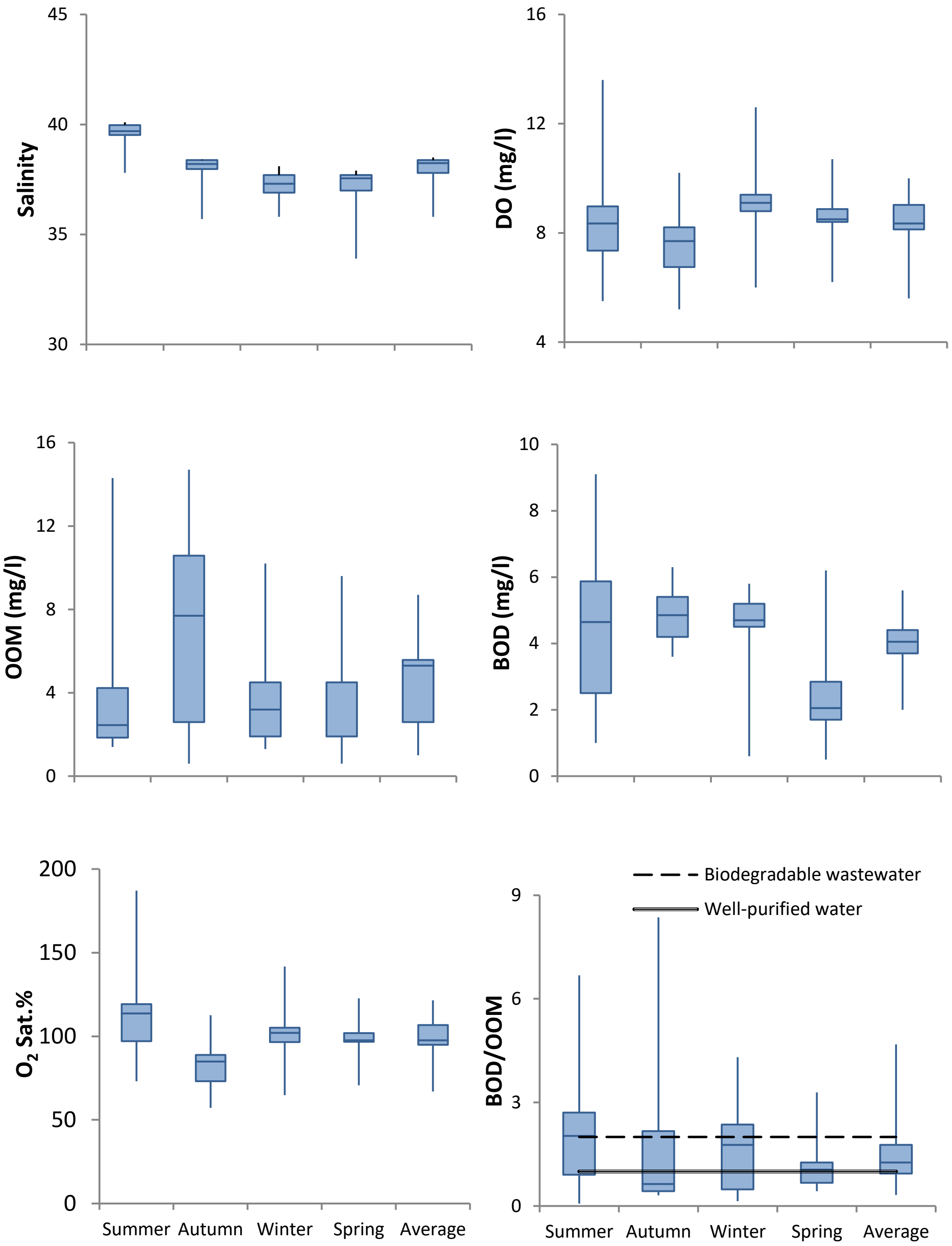

Fig. 2. Different hydrographical parameters during the year (summer, 2018-spring, 2019) at different locations along Alexandria coastal line (EH -Abu-Qir). n = 10, median values presented, whiskers indicate minimum and maximum values.

1. Temperature

The highest value of water temperature (33.5°C) was recorded at Montaza during the summer season, while the EH area showed the lowest value of 19.0°C during the autumn and winter seasons. A normal trend of seasonal variations was observed for water temperature during the period of study. The swimming season runs from May to December. During those months, the beaches' water temperature does not drop below 20ºC, and therefore it is suitable for comfortable swimming. **Nessim (1989)** recorded temperature range of 14.3-31.3ºC along the same beaches-during the period from July 1986 to August 1988, while a narrower range of temperatures (18.2-27.5°C) was observed during the period from June 2013 to June 2014 at the same beaches (**Dango *et al.*, 2015)**. Based on two-way ANOVA, temporal, and to a lesser extent, spatial changes in water temperature (Table A.1) were the result of various factors including seasons, sunlight intensity, wind force, water depth, tide, current and turbidity.

2. Salinity

Salinity as temperature affects the biological distribution of marine organisms. The results showed that the salinity values varied temporally and spatially during the year of study, based on the two-way ANOVA analysis (Fig. 2 & Table A.1). Seasonal variations fluctuated from 37.8 to 40.1, 35.7 to 38.4, 35.8 to 38.1, and 33.9 to 37.9 during summer, autumn, winter, and spring, respectively. Sidi-Gaber area gave the lowest salinity values most of the year, with the lowest annual average of 35.8, while EH water showed the lowest value (35.8) during winter, with an annual average of 37.8. Sidi-Bishr and Asafra beaches, recording the highest annual salinity level average of 38.5. The low annual average (35.8) in Sidi-Gaber area reflects the dilution impact of land-based effluents and construction work currently occurring in the location. For the other areas under study, the annual averages showed a narrow range of salinity (37.8-38.4), which is in good agreement with those estimated previously two decades ago by **Abou-Taleb (2004)** and **Dango *et al.* (2015)** during the period (2013-2014) in the same region. The seasonal salinity averages decreased, in general, from summer (39.6) to autumn (37.9), reaching minimal levels during winter (37.2) and spring (37.1) (Fig. 2). The relatively high evaporation of surface water may have led to the highest summer salinity average level recorded during the period of study, but it has not exceeded 40. **Hussein *et al.* (2013)** gave an increment in salinity caused by Corniche expansion; the values recorded before and after the expansion were as follows; Sidi-Bishr (38.9-41.8), Stanly (38.8-39.5), Cleopatra (38.0-42.7) and Shatby (38.5-40.7), respectively.

3. Hydrogen ion concentration

The pH of seawater is mainly related to the concentration of ionic compounds and chemical and biological processes that occur in the marine environment. The pH values presented strong spatial and seasonal variations based on the two-way ANOVA analysis (Table A.1). The highest pH values (8.1-8.5) were recorded during the summer season, while the lowest pH-values were observed in the range of 7.0-7.2 during the winter period. Most of the data lie on the alkaline side. Accordingly, it could be an indication that the highest values recorded during summer may be due to the increased temperature value which stimulates photosynthetic activity, hence that development resulted in the utilization of carbon dioxide, and consequently increased the pH-value. The relative decrease of the pH during winter period may be associated with high solubility of carbon dioxide in water that leads to the formation of HCO_3^-, and consequently resulted in the decrease of both CO_3^- content and pH values (**Emam *et al.,* 2013**). The lowest levels of pH estimated in Sidi-Gaber water during autumn (7.2) and summer (8.1) were associated with the minimal corresponding salinity values explaining the dilution effect at this area. **Nessim *et al.* (2005)** and **Shreadah *et al.* (2014**) indicated that changes in the pH-value coincide with the variation in oxygen content, and this is demonstrated in the current study by a significant positive correlation with O_2 Sat.% (r=0.40; *P*<0.01).

4. Dissolved oxygen (DO)

Dissolved oxygen is vital to aquatic life since it is needed to keep organisms alive. Seasonally, DO mean was fluctuating between a minimum of 7.6 mg/l (Sat.83.3%) during the autumn period and a maximum of 9.1 mg/l (Sat.101.6%) during the wintertime, with an annual concentration average of 8.4 mg/l (Fig. 2). The lowest level of DO coincided with high OOM (7.0 mg/l) and BOD (4.9 mg/l). The high winter value with oxygen oversaturation may be associated with a decrease in air temperature leading to an increase in the solubility of atmospheric oxygen, as well as mixing water by strong winds (**Nessim *et al.,* 2005**). On the contrary, spatial variations were recorded in DO levels where the minimum annual average of 5.6 mg/l (Sat.67.0%) was measured in Sidi-Gaber water and a maximum of 10.0 mg/l (Sat.121.5%) was at Sidi-Bishr beach. DO levels of surface waters collected from the same beaches were found in the range of 5.1-11.1 mg O_2/l by **Dango *et al.* (2015**). Regionally, the lowest DO and O_2 Sat.% averages at the Sidi-Gaber area compared to other locations are accompanied by low salinity, high levels of BOD, ammonia, nitrite and phosphate, which can be attributed to the disposal of polluted wastewater resulted from the continuous construction activities at this area. Moreover, the relatively low DO detected in the EH water resulted from the intensive consumption in the oxidation of high load of organic matter (up to 14-15 mgO_2/l) during summer to autumn period. **Shreadah *et al.* (2014**) recorded the same feature in El-Mex bay water. According to the annual average, <50% of samples were found at oversaturated condition, while the other locations were found at moderately oxygenated level. Anoxic or poorly oxygenated condition could not be detected among the beach areas during the study period. The Asafra area is the only region that showed its water O_2 oversaturation during the year of study (>100-<116%). According to the annual average of O_2 Sat.%, the beach water followed this order: Sidi-Bishr>>Montaza>Asafra, Gleem>Miami>Stanly>Shatby>Abu-Qir>EH>Sidi-Gaber. Seasonal variations in O_2 Sat. % were determined during the study period based on the two-way ANOVA analysis. Accordingly, the beaches water followed the following order: summer>winter>spring>autumn (Fig. 2).

5. Oxidizable organic matter (OOM)

OOM is used to assess organic pollution, adversely affecting aquatic life, principally through oxygen depletion. The maximum and minimum means of OOM being 7.0 and 2.9 mg O_2/l were estimated for autumn and spring, respectively, with an annual average of 4.6 mg/l (Fig. 2). Wide variations of OOM content could be detected where the values fluctuated between a minimum of < 1 mg O_2/lat each of Asafra and Shatby (spring) and a maximum level (14-15 mg O_2/l) in EH water during the summer and autumn periods, with an annual average of 4.6 mg O_2/l. According to the annual averages, the beaches can be divided into three distinct regions; the highest values for EH and Abu-Qir beaches (>7-<9 mg O_2/l), moderate levels for each of Sidi-Gaber, Miami, Stanly, Gleem, and Montazh waters (>4-<6 mg O_2/l), and low levels (1-2 mg O_2/l) recorded in Shatby, Sidi-Bishr, and Asafra beaches. The highest OOM content detected at each of EH and Abu-Qir beaches was expected and confirmed by many authors (**Abou-Taleb, 2004; Hemaida, 2007**). The arrival of domestic and other land-based effluents to EH and Abu-Qir beaches in addition to the autochthonous decomposition of planktonic and dead organisms, particularly during the warm seasons are responsible for the high level of OOM at both areas. In addition, the increased supply of organic matter into restricted area under relative slow rate of self-purification leads to an increase in OOM content. Shatby, Sidi-Bishr, and Asafra beaches could be considered the best beaches from the point of view of OOM content. This study refers to the rising OOM level in Alexandria beach water during the last few decades; about 3 times greater than that recorded by **Nessim (1989)** addressing the same area or 6 folds more than that of the open water (**Emara, 1969)** Statistically, no significant correlation was found between OOM and DO (r=0.1454, $P<0.01$), and this indicates that DO is not the only factor affecting the decomposition of OOM.

6. Biological oxygen demand (BOD)

The wide fluctuation in BOD content along the beach was detected where the values varied between a minimum of 0.5 mg O_2/l (Shatby, spring) and a maximum of 9.1 mg O_2/l (Sidi-Bishr, summer), with an annual average of 4.0 mg O_2/l. The increase in bacterial activity led to DO consumption in organic matters oxidation that resulted in the elevated level of BOD (**Emam *et al.*, 2013**). The water of the Eastern Harbor exhibited low BOD values, with an annual average of 2.0 mg/l, while Sidi-Gaber station had the highest annual average of 5.6mg/ l. **ECPH (1975)** pointed out that 1 ppm BOD is a characteristic of nearly pure water. The water is considered pure with a BOD of 3 ppm and of doubtful purity when the BOD value reaches 5 ppm. The BOD values for the entire area did not exceed 6.5 mg O_2/l during the period of study, except for Sidi-Bishr water (9.1 mg/l) during the summer season. Similar results were obtained by **Dango *et al.* (2015)**. To determine the type of wastewater discharge and knowing if it is biodegradable or not, BOD/OOM ratio was calculated. The BOD/OOM ratio of 1:1 is characteristic of well-purified water. The biodegradable compounds have a ratio of < 2:1 while that of 2:1- 4:1 is specific for crude domestic sewage. According to **ECPH (1975)**, the BOD/OOM ratio averages computed for most studied areas showed a narrow range (0.32-1.85). This indicates the presence of well-purified water at EH (0.32), Abu-Qir (0.74), and Miami (0.88), while biodegradable wastewater was a feature of the waste being discharged at Montaza (1.13), Gleem (1.23), Stanly (1.54), Sidi-Gaber (1.29), and Shatby (1.85) (Fig. 2). The ratio values at Asafra and Sidi-Bishr averaged 4.68 and 3.46, respectively, indicate the disposal of crude domestic sewage in both areas. According to the annual mean of BOD/OOM ratio (1.72:1), most of the domestic effluents reaching the studied area had a biodegradable feature (Fig. 2).

7. Nutrient salts

The main nutrients causing eutrophication are nitrogen (in the form of nitrate, nitrites, ammonia) and phosphorus (orthophosphate). Silicate is essential for diatoms growth, but it is assumed that its input is not significantly influenced by human activity. The absolute values of the measured nutrients demonstrated exceedingly wide variations according to time and space (Fig. 3).

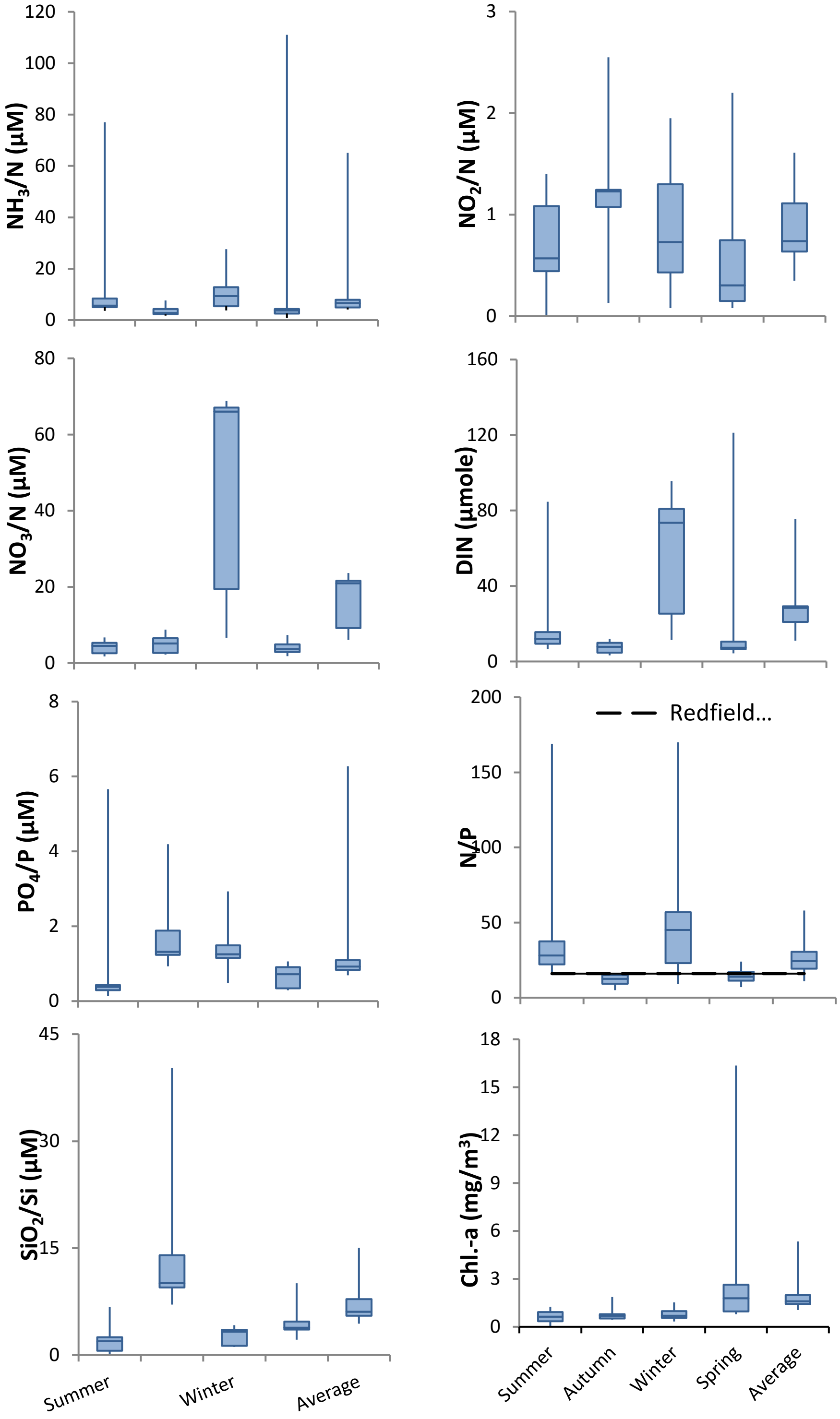

Fig. 3. Nutrient salts and chlorophyll-a content during the year (summer, 2018- spring, 2019) at different beaches locations along Alexandria coastal line (EH -Abu-Qir), based on all locations (n= 10), median values presented, whiskers indicate minimum and maximum values.

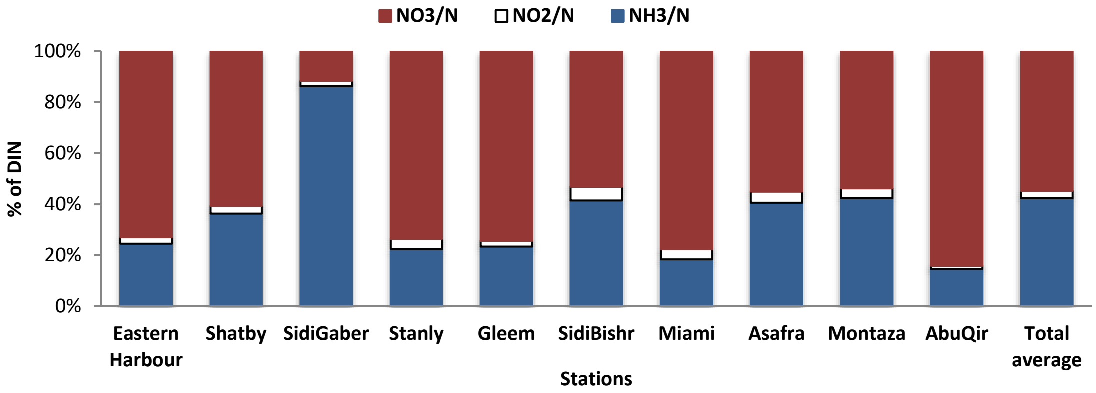

Fig. A.1: Percentage contribution of ammonia, nitrite, and nitrate to total DIN of Alexandria beach water samples during the year 2018-2019.

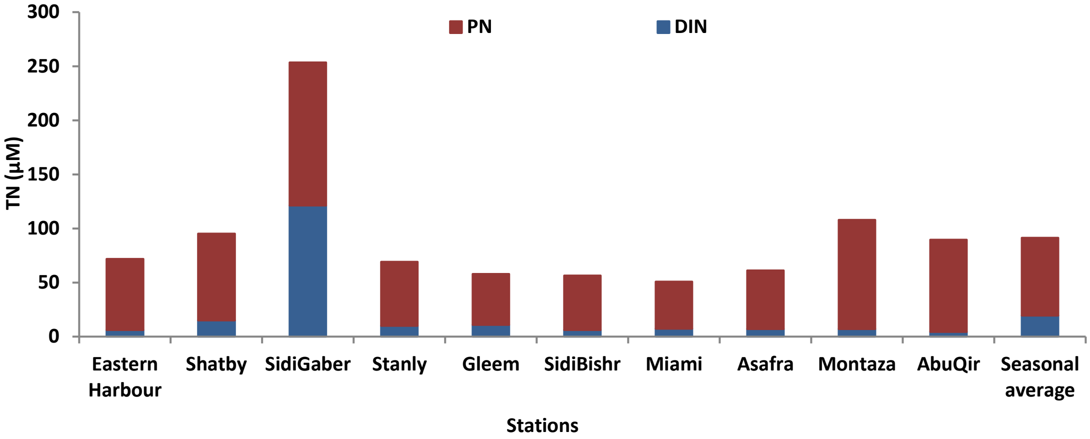

Fig. A.2: Spatial averages of TN, DIN, and PN along Alexandria beaches water during spring 2019.

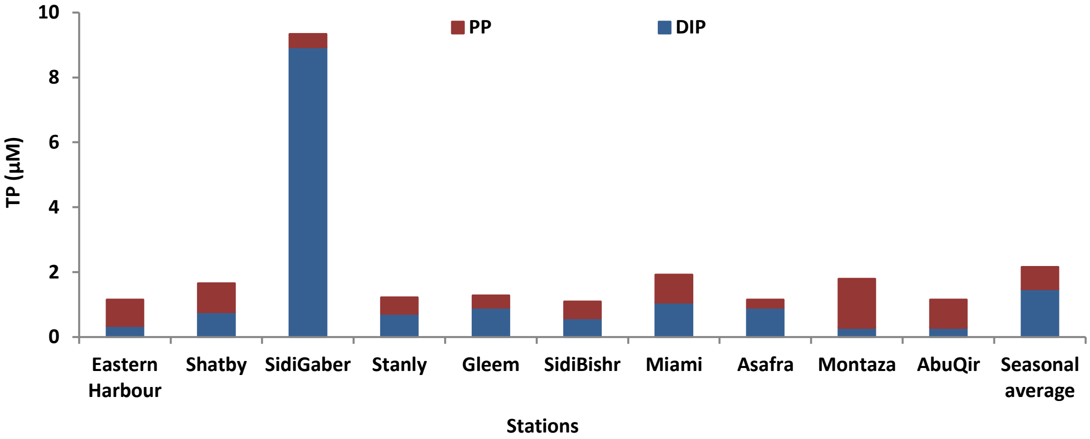

Fig. A.3. Total phosphorus, DIP and PP in water of Alexandria beaches during spring 2019

7.1 *Dissolved inorganic nitrogen (DIN)*

The samples showed very wide fluctuation either seasonally or regionally based on ANOVA analysis. The values vibrated from the lowest level of 4.31 µM in Abu-Qir water (spring) to the highest value of 121.22 µM in Sidi-Gaber (spring), with an annual average of 28.46 µM. Regionally, Sidi-Gaber area, which is subjected to continuous business construction, exhibited the highest annual average of ~75 µM. Shatby water is the second enriched area with DIN ~37 µM, while Abu-Qir, Montaza, Asafra, Miami, Sidi-Bishr, Gleem, Stanly and EH waters are slightly lower (<30 µM). Seasonally, the summer, autumn, and spring seasons averages are relatively low and closely nearer (18-20 µM). The winter samples, on the other hand, produced a higher average which has almost 3 times greater than the other three seasons' averages (Fig. 3).

7.1.1 Ammonia

During spring season, ammonia is the most abundant form of DIN and TN comprising about 72% and 15%, respectively, on average. It has been observed that the percentage contribution percentage of ammonia showed about 5% to 91% of DIN content in Abu-Qir and Sidi-Gaber areas during winter and spring seasons, respectively. Seasonally, autumn samples exhibit the lowest average with ~ 6 µM, while the summer and spring samples were much enriched with ammonia (more than twice the amount), and the winter gave intermediate content (10.64 µM) in its samples. Regionally, a significant increase in ammonia content was observed in Sidi-Gaber area during summer and spring seasons, with 77.00 and 111.05 µM, respectively, when compared to autumn season (7.20 µM), with an annual average of 65.08 µM. Concerning Shatby area, winter showed the highest ammonia values (27.60 µM), with an annual average of 13.45 µM. The remaining water samples were remarkably less in ammonia content (0.80 -16.85 µM). Accordingly, there were significant spatial variations in ammonia concentrations at a significance level of 0.05. The striking increase in ammonia content (111.05 µM) observed in Sidi-Gaber area during the spring season was accompanied with low levels of salinity and DO content and high levels of each of BOD, phosphate, TP and OOM. This condition may result from the degradation of an increasing amount of organic content due to land-based effluents, various construction work, and the algal blooms. The high ammonia concentration reported in the winter season at Shatby can be attributed to wastewater discharge. The concentration of ammonia at the sites where the research was conducted totaled an average of 11.19 µM, is too high if compared with a total average of the western harbor (**Nessim, 1995**) Alexandria beach waters (**Hussein *et al.*, 2013; Dango *et al.*, 2015**) and EH (**Nessim *et al.*, 2014**). Ammonia in Alexandria coastal water is mainly produced from allochthonous origin, derived from the discharge of drainage water.

7.1.2 Nitrite

Minor seasonal differences in nitrite concentration were ranged from 0.58 µM during the spring season to 1.22 µM during the autumn season, with an annual average of 0.84 µM which comprises 2.95% of DIN. Though the total annual average is nearly identical to the value recorded for the western harbor (**Nessim, 1995**), it is higher than that recorded for Alexandria beach waters (**Nessim, 1991; Nessim *et al.*, 2014; Dango *et al.*, 2015**). The lowest mean value of nitrite in spring resulted from either an increase in phytoplankton uptake or its reduction by denitrifying bacteria (**Emam *et al.*, 2013**). Abu-Qir water indicated an absence of nitrite content during summer and low levels during winter and spring (0.08 µM), with an annual average of 0.35 µM.

7.1.3 Nitrate

The two-way ANOVA analysis showed seasonal variations in nitrate concentrations. Summer and spring recorded relatively low levels around 5 µM, while autumn and winter exhibited high averages; two and 10 times greater than the other two seasons, respectively, which is in good agreement with the finding of **Nessim and Tadros (1986)**. The decrease of nitrate during summer and spring seasons and the noticeable increase in ammonia content (13.80 and 14.22 µM, respectively) may be attributed to two factors: the first is the assimilation by plants, and the second is denitrification (i.e. nitrate reduction to nitrite before releasing N_2O or N_2 molecules) (**Hutchinson, 1957**). Regionally, the annual averages were found to attain its maximum value in Abu-Qir area (23.63 µM) and minimum values at Asafra and Sidi-Bishr locations (about 6 µM), with a total annual average of 16.43 µM. High value (68.82 µM) during winter at Abu-Qir location may contribute to allochthonous inputs in addition to autochthonous source, resulting from the decaying organic matter.

7.1.4 Total and particulate nitrogen (TN and PN)

The TN along Alexandria beaches water was studied through 10 samples taken during the spring season of 2019 (Fig. A.2). The concentration fluctuated between 50.74 µM at Miami and 253.35 µM at Sidi-Gaber, with an average of 91.30 µM. The total dissolved inorganic nitrogen is the minor fraction of TN, comprising about 21% on average, and it is in a good agreement with that recorded for Alexandria western harbor (**Nessim, 1995**). For Sidi-Gaber area, all the other locations exhibited their water total DIN/TN ratios (5-19%) below the seasonal average (~21%); at Sidi-Gaber water, the ratio raised more double (48%). This refers to the amount of soluble nitrogen compounds brought by domestic effluents to the area of Sidi-Gaber higher than that of land-based effluents or drainage water received at the other locations. Particulate nitrogen in the ocean may be organic (bacteria, plant, and animal) or inorganic. This form of N was widely varied between 43.30 µM (85% of TN) at Miami and 132.13 µM (52% of TN) at Sidi-Gaber, with an average of 71.80 µM.

7.2 Phosphate

The amount of DIP in most of the beach water showed spatial variations based on two-way ANOVA analysis, where a minimum level of 0.14 µM was recorded in Montaza water during summer, and a maximum of 8.93 µM was in Sidi-Gaber sample (spring), with an annual average of 1.37 µM. The high enrichment of shore water in the Sidi-Gaber area with phosphate may be due to the huge amount of domestic effluents, resulting from continuous reconstruction processes carried out in this area. This was confirmed from the significant positive correlation reported with each of ammonia ($r=0.89$; $P<0.001$), nitrite ($r=0.56$; $P<0.001$), and PN ($r=0.70$; $P<0.001$) and negative correlation with each of salinity ($r= -0.64$; $P<0.001$) and DO ($r=-0.48$; $P<0.01$). The significant inverse correlation found with DO indicates the oxidation process of organic matter brought in domestic water. Complete depletion of DIP was not recorded in coastal water. For eutrophic seawater, it is above 0.15

μM and for highly eutrophic system much higher than 0.3 μM (**UNEP, 1988**). Alexandria coastal water, accordingly could be considered as eutrophic to a highly eutrophic system, and Sidi-Gaber water reflected hyper-eutrophication condition (**UNEP, 1988**). The relatively low levels estimated during the summer and spring seasons (Fig. 3) can be attributed to the uptake of phosphorus by algae, bacterial and phytoplankton (**Emam *et al.*, 2013**).

7.2.1 Total and particulate phosphorus (TP and PP)

The TP and PP along Alexandria-beach water were measured through 10 water samples taken during the spring period of 2019 (Fig. A.3). Except for Sidi-Gaber area, the beaches water exhibited a narrow range of TP where the values vibrated between 1.09 μM (Sidi-Bishr) and 1.92 μM in Miami area, with a seasonal average of 1.38 μM. The area of Sidi-Gaber, on the other hand, sustained a very high TP content that reached up to a value of 9.34 μM, which was more than six times greater than the seasonal average. The supply of organic matter and detergents present in land-based effluents reaching Sidi-Gaber area is probably the source of phosphorus compounds. The insoluble and adsorbed phosphorus in suspension (PP) was not widely varied among the different locations. It fluctuated between 0.24 μM (Asafra) and 1.5 μM (Montaza), with a total average of 0.68 μM.

7.2.2 N/P ratio

The ratio of N/P is an essential indicator for assessing eutrophication. It varied from 5:1 (Sidi-Gaber) during autumn to ~170:1 at Montaza (summer) or Stanly (winter). The annual averages of N/P ratios for the present work ranged from 11:1 to 58:1 for Sidi-Gaber and Montaza waters, respectively, with a total average of 29:1. The N/P ratios showed wide seasonal variations; 15:1-169:1, 5:1-16:1, 9:1-170:1, and7:1-24:1 for summer, autumn, winter, and spring, with seasonal averages of 42:1, 12:1, 52:1, and 14:1, respectively. The seasonal average ratios during the autumn and spring seasons were lower than that of Redfield ratio (16:1) (**Redfield, 1958; Richards, 1958)**, hence indicating that nitrogen was the limiting factor for phytoplankton growth during these two seasons (Fig. 3). On the contrary, N/P ratios were higher than that of Redfield ratio during summer and winter seasons, indicating that phosphorus was a limiting factor (Fig. 3). In the present work, about 54% of the data have higher N/P ratios than the oceanic ratio, while 31% of the data have N/P ratios below, and only 15% of N/P ratios are almost identical to the oceanic value. The N/P ratios show that P, in general, is the most limiting factor. **Zaghloul and Nessim (1991)** observed a pronounced increase in P relative to N in Alexandria Western Harbor water as an indication of the domestic and land-based effluents into the inshore area.

7.3 Silicate

The beaches water exhibited different and irregular concentrations of silicate during the year the study was conducted. The values varied from a maximum of 48 μM during autumn in Asafra water sample to an undetectable amount or just traces at Abu-Qir area (summer), with an annual average of 7.56 μM. According to this annual average, there are only two enriched areas with silicate (13-15 μM) namely Shatby and Asafra. The rest the studied beaches indicated that their water moderate amounts of silicate (4-8 μM). Significant seasonal changes in silicate content were demonstrated based on the ANOVA analysis ranging from 1.88 µM during summer to 17.9 µM during autumn (Fig. 3). According to **Zaghloul and Nessim, (1991)**, the diatom bloom which occurred in June, consumed a great amount of silicate and lowered its concentration in the present study to be < 2 µM during summer (on average) or only traces < 0.2 µM at some locations. The highest spring level of silicate at Sidi-Gaber (~10 µM) met with the lowest salinity level (33.9%), and maximal levels of each of ammonia (111 µM) and phosphate (8.93 µM) estimated during this season. The annual average of silicate (~7.5 µM) is in good agreement with the finding of **Zaghloul and Nessim (1991)** in Qait-bay region.

8. Chlorophyll-a

Chlorophyll-a contents can act as an indicator of phytoplankton abundance and biomass in the coastal water (**Carlson, 1977)**. The investigation of variations of chlorophyll-a is very important to the study of water quality and marine pollution in Alexandria beaches water. Chlorophyll-a content fluctuated between undetectable amounts in Abu-Qir water during summer, with the maximum occurring in the EH water during spring (up to 16.354 mg/m^3), while it recorded an annual average of about 2.010 mg/m^3. A gradual increase in chlorophyll-a content during spring was observed starting from the lowest (0.79 mg/m^3) recorded in Sidi-Bishr-Gleem area towards west reaching values of 1.96, 2.74 and 3.76 mg/m^3 in Stanly, Sidi-Gaber and Shatby, respectively. An abrupt rise in the chlorophyll-a content (16.35 mg/m^3) was measured in EH water (reaching its maximum value during the year of study). The annual average in the EH of 5.34 mg/m^3 is slightly greater than that recorded in the study of **Aboul-Kassim (1987**).

9. Ecological index

The TRIX index incorporated DIN, phosphate, chlorophyll-a and O_2 Sat. % was used to classify water quality (**Vollenweider *et al.*, 1998**), while E.I., an efficient five-level water quality classification scheme used nitrate, ammonia, nitrite, phosphate and chlorophyll-a to measure the trophic status. The TRIX values ranged from 6.06 to 7.46, indicating poor water quality meanwhile E.I. values varied from 3.48 to 22.87, suggesting eutrophic condition (Table 2). Sidi-Gaber is the most suffering station from bad water quality and eutrophication condition, with TRIX and E.I. indices being 7.46 and 22.87, respectively. This condition may be due to an increase in organic input as a result of construction activities and land-based effluents. **Shabaka and Moawad (2021)** reported poor water quality and eutrophic condition in EH water as indicated by the TRIX value of 7.03 and E.I. value of 6.1. Nutrient enrichment can be natural, but it is often greatly augmented by human activities, with the primary sources of anthropogenic nutrient input being runoff, erosion, and leaching from fertilized agricultural regions, as well as sewage from cities and industrial effluent **(Morsy *et al.*, 2022)**.

10. Principal component analysis

The principal component analysis (PCA) was performed to determine the individual significance of each water quality indicator, excluding those with little impact on the spatial variation (Table 3 & Fig. 4). Only three clusters were computed which explained 87.55% of total variance in this study (Table 3). Then, the variables having a correlation coefficient ≥0.7 in the factor loadings were selected for each component. The first principal component

(PC1), which described 48.11% of the total variation had significant negative loadings on salinity (0.963), DO (0.920) and O_2 Sat.% and significant positive loadings on ammonia (0.960), nitrite (0.811), DIN (0.976) and phosphate (0.970). The factor loadings of PC1 revealed the existence of oxygen-consuming contaminants, which might be attributed to impacts from rural domestic wastewater and municipal point source discharge **(Yang *et al.*, 2020)** On the other hand, ammonia nitrogen is produced during the organic matter decomposition process. Organic nitrogenous compounds decompose to nitrite and nitrate after passing through ammonia resulting in oxygen consumption, and hence their presence suggests recent pollution **(Garcia *et al.*, 2017)**. The second principal component (PC2), explaining 24.93% of the total variance, is strongly correlated with temperature (0.930), BOD (0.884), and chlorophyll-a (-0.842). The correlation between temperature and BOD was indicated by positive loading of these parameters, which mostly elevated during the hot season **(Morsy *et al*., 2022)**. The third principal component (PC3), which accounts for 14.51% of the overall variance is substantially associated with seawater OOM (-0.815) and silicate (0.901). On the other hand, the principal component data revealed that Sidi-Gaber, Stanly, and Miami stations were more contaminated than the other stations, based on WQI (Table A.2). As shown in Table (A.2), two stations were related to Cluster 1, five stations related to Cluster 2, and three stations related to Cluster 3. PC1variables have a strong impact on Sidi-Gaber and EH stations, whereas PC2 has a significant influence on Abu-Qir, Montaza, Miami, Sidi-Bishr, and Gleem, and PC3 influences Asafra, Stanly and Shatby.

Table 2. Values of TRIX and E.I. indices of the study sites along Alexandria beaches

Stations	**TRIX index**	**E.I. index**
1	6.27	7.87
2	6.27	5.67
3	6.06	3.48
4	6.49	7.71
5	6.09	3.68
6	6.44	8.29
7	6.43	8.23
8	7.46	22.87
9	6.92	10.90
10	6.94	9.22

Table 3. Rotated component matrix of water quality variables

Variable	Component*		
	1	2	3
Temp.	0.037	**0.930****	-0.136
S.	**-0.963****	-0.089	-0.003
DO	**-0.920****	0.236	0.191
OOM	0.259	-0.435	**-0.815****
BOD	0.295	**0.884****	0.219
O2 Sat.	**-0.887****	0.308	0.213
NH3/N	**0.960****	0.248	0.051
NO2/N	**0.811****	0.002	0.111
NO3/N	-0.078	-0.643	-0.475
DIN	**0.976****	-0.006	-0.138
PO4/P	**0.970****	0.203	0.047
SiO2/Si	0.028	-0.150	**0.901****
Chlorophyll-a	0.240	**-0.842****	0.017
Eigenvalues	6.25	3.24	1.89
Variance %	48.11	24.93	14.51
Accumulated variance %	48.11	73.04	87.55

*Rotation Method: Varimax with Kaiser Normalization
**Significant correlations > 0.7

Table A.2. WQI based on PCA of the study sites along Alexandria beaches.

Stations	PC1	PC2	PC3	WQI**
1	-0.45	**0.16**	-1.35	-0.81
2	-0.51	**0.82**	-0.35	0.04
3	-0.66	0.39	**1.80**	0.63
4	-0.20	**0.03**	-0.80	0.75
5	-0.87	**1.06**	0.45	0.36
6	-0.33	**0.22**	-0.87	-0.42
7	-0.08	-0.33	**0.09**	0.76
8	**2.66**	0.87	-0.01	0.85
9	0.30	-0.93	**1.43**	-0.36
10	**0.14**	-2.29	-0.39	0.46

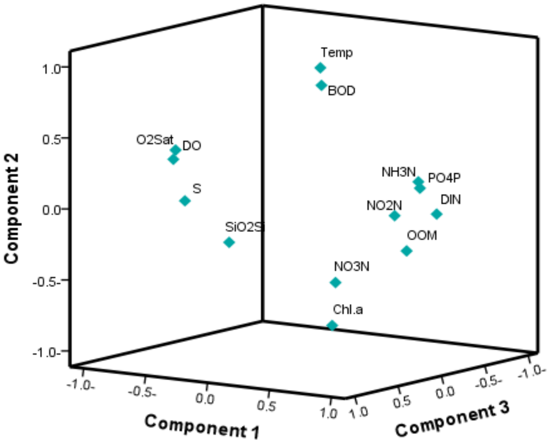

Fig. 4. Component plot in rotated space of water quality variables

CONCLUSION

Monitoring the environmental quality is of great importance to evaluate water quality and eutrophication status of Alexandria coastal water. The results indicated higher nutrient concentrations along Sidi-Gaber coast, compared to the other beaches. The nutrient levels are negatively correlated to salinity, pH and oxygen saturation. These could be resulted from the disposal of land-based and resort effluents created by the ongoing construction and beach activities. Sidi-Gaber is the most suffering station from bad water quality and eutrophication condition, with TRIX and E.I. indices being 7.46 and 22.87, respectively. More frequent events of hyper-eutrophication condition in Sidi-Gaber area as well as different types of eutrophication among EH and other isolated parts of beach could occur throughout the year. Moreover, PCA indicated the existence of oxygen-consuming contaminants, which might be attributed to impacts from rural domestic wastewater and municipal point source discharge. The water quality index (WQI) established by principle component analysis (PCA) revealed that Sidi-Gaber, Stanly and Miami stations were more contaminated than the other stations. Future studies should be conducted and concentrated on beach water quality. Pretreatment of the land-based effluents before their disposal into the sea, the renewal of the isolated parts of the beach with seawater, or the full closure of all outlets at the seacoast are also recommended.

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