

An Assessment on the Coastal Seawater Quality of the Gulf of Suez, Egypt

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Abstract

The present study focused on water quality assessment of 14 hotspot locations in the Gulf of Suez by measuring the physicochemical parameters seasonally during 2016. The results of investigated area revealed that, the annual mean range of water was: temperature (21.91°C - 29.22°C), pH (7.64 - 7.78), salinity (38.71‰ - 42.74‰), dissolved oxygen (6.09 - 8.78 mgO₂/l), oxidizable organic matter (1.4 - 5.4 mg/l), biological oxygen demand (1.14 - 3.94 mgO₂/l), total suspended solids (18.56 - 37.69 mg/l), ammonia (13.51 - 494.41 µg/l), nitrite (1.261 - 151.76 µg/l), nitrate (7.11 - 487.85), dissolved inorganic phosphate (2.22 - 53.26) and silicate (19.83 - 347.61 µg/l). The N:P ratio fluctuated between 4.21 and 1214.61 with the main value of 81.16 indicating that the different sites in the northern part of the Gulf of Suez are P-limited. Based on the Principal Component Analysis Data, the stations locating in the Northern and Southern side of the Gulf of Suez are relatively good water quality; meanwhile, water quality of the other stations locating in the northern side of the Gulf of Suez is found slightly polluted to a different degree coincided with an increase in the human activities in each of these locations.

Keywords

The Gulf of Suez, Seawater, Hydro-Chemical Parameter, Nutrients, Water Quality Index (WQI)

1. Introduction

Marine water quality is very important and critical due to its impact on human health and aquatic, including marine life [1] [2]. The water quality study is the strategy of deciding the chemical, physical, and biological distinctive of the possible contamination sources that degrade the quality of water determined by

both natural and anthropogenic processes. Generally, water quality information is very important in supporting the planning and management of coastal and marine areas under the influence of massive human activities. The Gulf of Suez extends around 280 km toward the north, ending at the City of Suez, which is the entrance to the Suez Canal. It is relatively shallow, with a maximum depth of around 64 m. It has a relatively flat base with a depth extending somewhere in the range of 55 and 73 m [3]. The coastal region of the Gulf of Suez is one of the most densely industrialized zones in Egypt. The sources and reasons of water contamination in the Gulf of Suez are exposed to different wellsprings of contamination that can be classified into sewage, organic solids, heavy metals, oils, nutrients, sediment mobilization, and litter. The mid-western side is situated under the immediate impact of sewage wastes and petrochemical effluents of the Ras-Gharib city. Whereas, the eastern (Sinai Peninsula) and southern (El Tour city) sides are affected by the human activities. Indeed, the water quality of the Gulf of Suez was monitored in previous studies [4] [5] [6] [7] [8]. The main objectives of the present study were set to study the water quality of the Gulf of Suez by measuring of physical and chemical characteristics; water temperature, dissolved oxygen (DO), oxidizable organic matter (OOM), pH, salinity, ammonia, nitrite, nitrate, reactive phosphate and reactive silicate in surface water. Principal component analysis (PCA) was used to assess water quality in the Gulf of Suez as the main requirement for environmental and technical management of the Gulf of Suez, and consequently to minimize or mitigate the adverse environmental effects of human, industrial and maritime activities to allow sustainable use of the marine water resources.

2. Materials and Methods

2.1. Study Area and Sampling

Fourteen coastal sampling stations were selected to represent the different locations situated under the direct effect of human activities, public resort beaches and some protected area (**Figure 1**). Duplicate water samples from each station were collected seasonally during 2016 at 25 cm depth below the water surface to avoid the floating materials using a high quality and Purified PVC Niskin's bottle to estimate hydrochemical parameters (*i.e.*, water temperature, salinity, pH, dissolved oxygen) and eutrophication parameter (chlorophyll-a, nutrient salts).

2.2. Sample Analysis

The water sample was immediately sub-sampled for the following determinations in sequence as follows:

- i) Water temperature, pH and salinity were measured using the Conductivity, Temperature, and Depth (CTD) (YSI 6000) after earlier calibration.
- ii) Fixation of the Dissolved oxygen is commenced immediately in the field; samples for biochemical oxygen demand (BOD_5) were incubated in the laboratory for five days at 20°C and then determined by Winkler's method [9] [10].

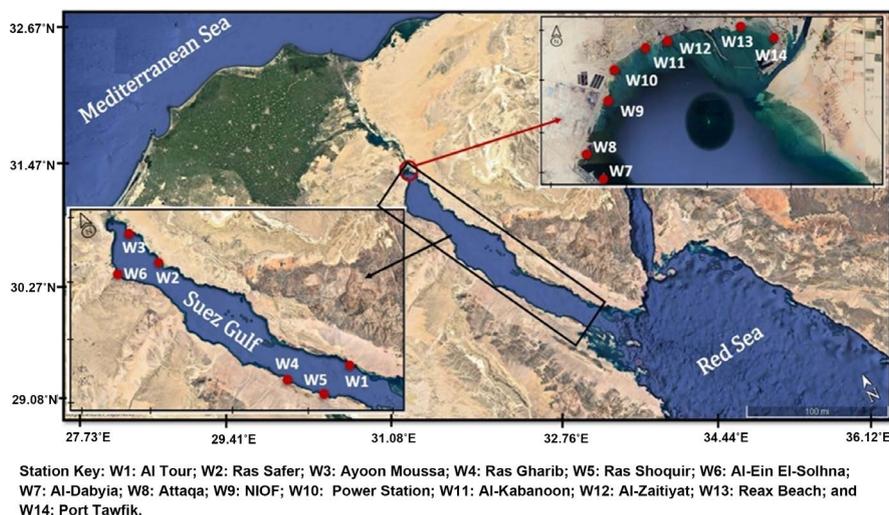


Figure 1. Sampling locations along Gulf of Suez, Egypt.

iii) Oxidizable organic matter (OOM) was determined according to the method described by FAO (Food and Agriculture Organization) [11].

iv) Chlorophyll-a (Chl-a) was analyzed according to method given by Strickland and Parson's [9].

v) TSM was determined according to APHA (American Public Health Association) [12].

vi) Water samples for total ammonia nitrogen determination were fixed in the field and determined, using the indophenol blue technique [13].

vii) Dissolved inorganic-N (DIN) ($\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$), reactive phosphate ($\text{PO}_4^{3-}\text{-P}$) and silicate ($\text{SiO}_4\text{-Si}$) were determined in filtered Seawater samples according to the methods described by Grasshoff *et al.* [11]

viii) DIN was calculated by summation of the inorganic-N forms:

$$[\text{DIN}] = [\text{NO}_3 - \text{N}] + [\text{NO}_2 - \text{N}] + [\text{NH}_4^+ - \text{N}]. \quad (1)$$

vi) TN and total phosphorus (TP) were determined according to the technique described by Koroleff [14] and modified by Valderrama [15].

The developed color was measured at different wavelengths using a spectrophotometer (JANEWAY6800 double-beam spectrophotometer). Synthetic samples and/or reference materials of different nutrient salts were used during analysis to get the calibration curve and for the precision and the accuracy as quality control tools.

2.3. Statistical Analysis

Principal component analysis (PCA), as a varimax rotated was performed with IBM-SPSS program (version 22) applying Kaiser Normalization.

3. Results and Discussions

The obtained data of hydrochemical characteristics of the present study are shown in (Figure 2) and illustrated in (Table 1) where these data demonstrating

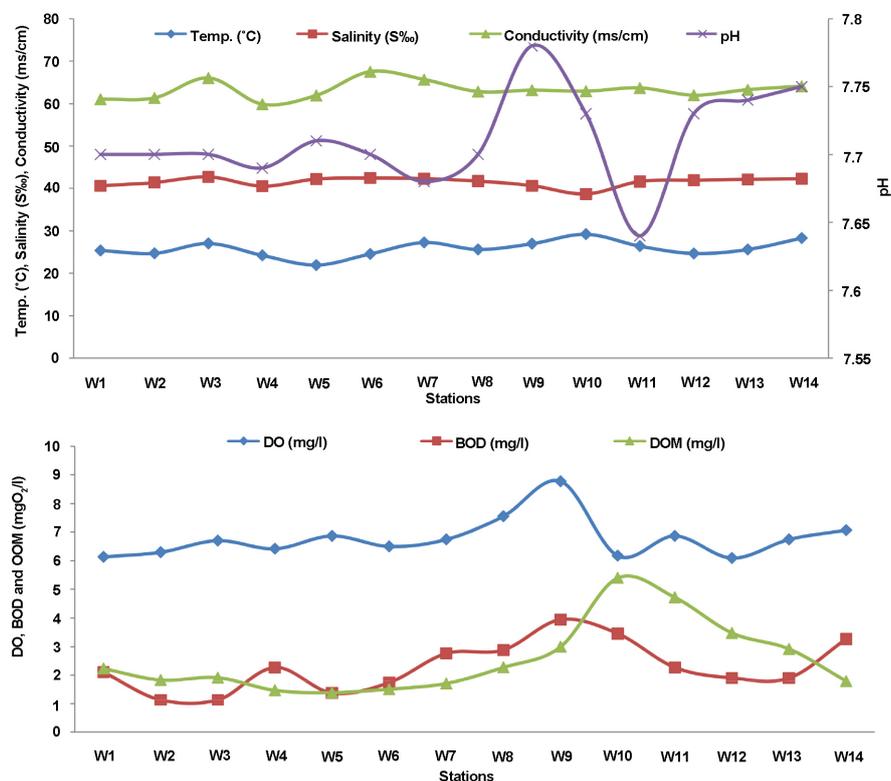


Figure 2. The distribution of regional variations averages of some hydrochemical characteristics of the Gulf of Suez surface coastal waters during 2016.

that water temperature fluctuated between 21.91 °C - 29.22 °C, 38.71‰ - 42.74‰ for salinity, 7.64 - 7.78 for pH, 6.09 - 8.78 mg/l for DO, 1.14 - 3.94 mgO₂/l for BOD, 1.4 - 5.4 mgO₂/l for OOM. The annually averages for temperature, salinity, pH, dissolved oxygen, biological oxygen demand, and oxidizable organic matter respectively, were found in agreement with UNEP and PERSGA [16]. Variations and fluctuation of salinity may be attributed to temperature and wastewater discharge. The seawater of the study area was found well-oxygenated; the relative increase in BOD at a station (W₉) could be the result of the relative increase of human impact at this location. Meanwhile, the presence of anthropogenic sources near to stations (W₈-W₁₃) is responsible principally for the relative increase in the OOM. The data of the present study when compared with those of coastal water quality standards suited to marine ecosystem [17], revealed that the present status of the Gulf of Suez seawater is locating within these standards of the acceptable levels since it should be taken into account that permissible deviation is up to >22 from the normal temperature, >0.2 in pH unit, and >5% over-age seasonal salinity.

3.1. Chlorophyll-a and Total Suspended Matter

The regional values of chlorophyll-a, total suspended matter, and nutrient salts are presented graphically in (Figure 3) and illustrated in (Table 2). The absolute values varied between 0.11 - 3.66 µg/l for Chl-a and 18.56 - 37.69 mg/l for TSM

Table 1. The absolute and average values of some hydrochemical parameters of surface coastal waters of the Gulf of Suez during 2016.

Code	Temp. (°C)		Salinity (S‰)		Conductivity (ms/cm)		pH		DO (mgO ₂ /l)		BOD (mgO ₂ /l)		OOM (mgO ₂ /l)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
W ₁	21.41	27.77	40.29	40.93	55.98	64.25	7.38	8.02	5.53	6.83	1.14	3.58	1.44	3.20
		25.36		40.61		60.99		7.7		6.13		2.11		2.24
W ₂	20.53	31.09	39.98	42.27	56.32	69.78	7.41	8.00	5.69	7.15	0.98	1.30	1.44	2.88
		24.7		41.4		61.31		7.7		6.3		1.14		1.84
W ₃	18.41	35.67	42.38	42.94	54.93	77.27	7.46	7.98	4.71	7.80	0.65	1.95	1.28	2.72
		27.03		42.74		66.02		7.7		6.7		1.14		1.92
W ₄	18.95	28.57	40.08	41.62	52.87	66.21	7.41	7.91	5.69	7.64	0.98	4.06	0.48	2.88
		24.2		40.55		59.82		7.69		6.42		2.28		1.48
W ₅	18.59	27.81	40.24	42.01	53.23	72.21	7.45	8.02	6.01	7.80	0.98	1.95	0.96	2.24
		21.91		42.24		61.9		7.71		6.87		1.38		1.4
W ₆	19.64	29.54	39.30	45.60	52.72	89.54	7.44	7.97	5.85	7.31	1.46	2.11	0.64	2.24
		24.55		42.45		67.52		7.7		6.5		1.75		1.52
W ₇	19.63	31.21	42.14	42.54	56.05	70.67	7.48	7.85	5.85	7.80	1.95	3.58	0.80	2.72
		27.26		42.34		65.66		7.68		6.74		2.76		1.72
W ₈	18.85	29.47	41.23	42.10	54.95	68.04	7.49	7.87	6.18	8.78	2.28	3.74	1.28	3.04
		25.61		41.73		62.81		7.7		7.56		2.88		2.28
W ₉	19.39	31.26	38.28	41.81	55.37	69.73	7.31	8.26	7.64	10.08	2.44	7.31	1.60	4.32
		26.97		40.67		63.15		7.78		8.78		3.94		3
W ₁₀	21.04	35.86	33.21	42.13	46.73	76.13	7.54	8.10	5.36	6.50	2.11	6.18	2.56	8.00
		29.22		38.71		62.91		7.73		6.18		3.45		5.4
W ₁₁	19.36	31.35	41.33	41.95	54.97	70.16	7.53	7.81	5.69	8.45	1.14	3.25	1.92	10.40
		26.4		41.65		63.66		7.64		6.87		2.28		4.72
W ₁₂	19.51	28.08	41.86	42.09	55.76	66.27	7.56	7.85	5.53	6.83	1.30	2.28	1.76	7.20
		24.66		41.97		61.96		7.73		6.09		1.91		3.48
W ₁₃	19.73	29.27	41.89	42.60	56.16	68.33	7.57	7.89	6.18	7.48	1.46	2.28	0.80	6.40
		25.6		42.14		63.26		7.74		6.74		1.91		2.92
W ₁₄	19.18	31.16	41.80	42.62	55.74	70.89	7.57	7.91	5.69	8.45	1.14	6.74	0.48	2.88
		28.3		42.3		64.07		7.75		7.07		3.27		1.8
Min.	21.91		38.71		59.82		7.64		6.09		1.14		1.4	
Max.	29.22		42.74		67.52		7.78		8.78		3.94		5.4	
Average	25.84		41.54		63.22		7.71		6.78		2.3		2.55	

giving the overall averages 0.98 and 26.15 for Chl-a and TSM respectively. An enrichment of DIN was correlated positively to the amounts with Chl-a, meanwhile, the present results clearly showed peaks in Chl-a with increasing temperature. The relative increase in TSM at a station (W₁₀) since it was subjected to

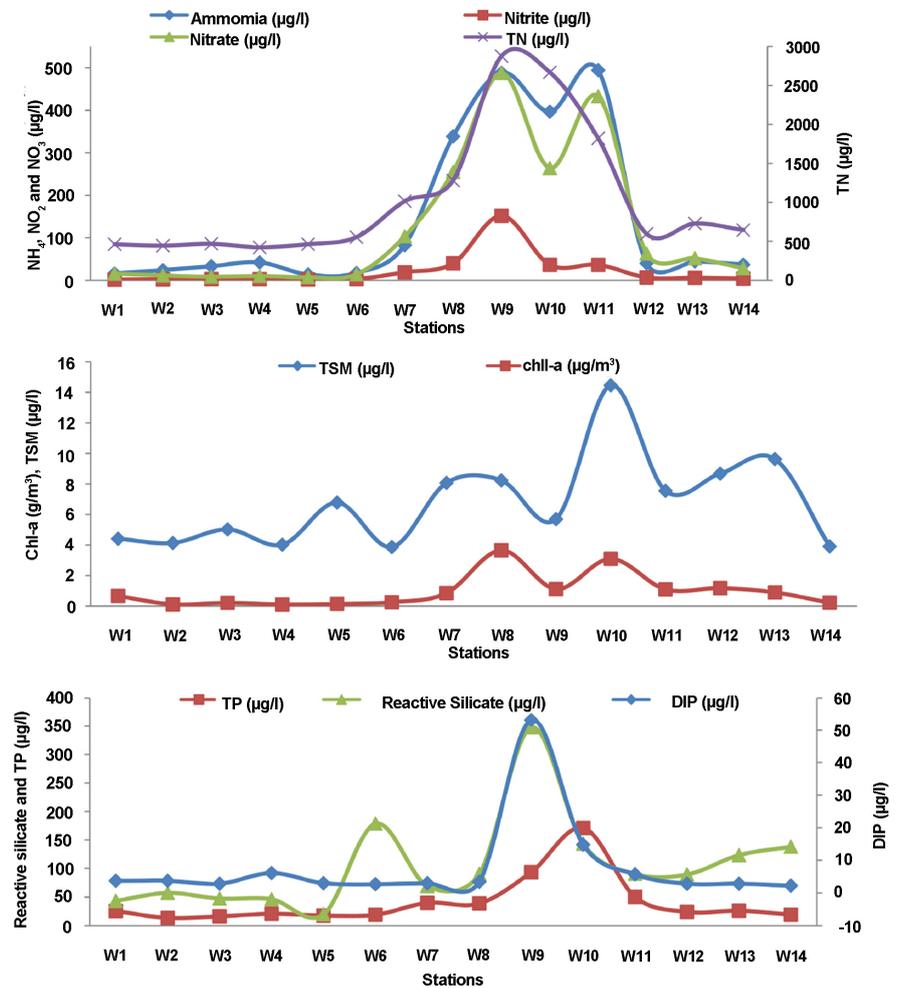


Figure 3. The distribution of regional variations averages of nutrient salts, Chl-a, and TSM of the Gulf of Suez surface coastal waters during 2016.

high amounts of effluents. The seasonal variations in TSM values pointed out that an increase in water temperature has coincided with an increase of TSM where suspended particulate matter contributed to a big extent in relating the heat.

3.2. Nutrient Salts

The obtained levels of nitrogen and phosphorus forms are given in (Table 2) and demonstrating graphically at (Figure 3). The results deduced that the absolute values varied between 13.51 - 494.41 µg/l for ammonium, 1.61 - 151.76 µg/l NO₂-N for nitrite and 7.11 - 487.85 µg/l NO₃-N for nitrate giving the overall means 147.72 µg/l NH₄-N, 22.47 µg/l NO₂-N and 125.22 µg/l NO₃-N. The result demonstrated that 50%, 7.60% and 42.4% for NH₄-N, NO₂-N, and NO₃-N of the DIN in the Gulf of Suez surface coastal waters, respectively. Variations in the amounts of different DIN forms could be accompanied by the relative increase or decrease in human activity and/or discharged effluents, up to taking rate by phytoplankton and nitrification or denitrification processes in the study area.

Table 2. The values of chlorophyll-a, total suspended matters and nutrient salts of coastal waters of the Gulf of Suez during 2016.

Code	Chl-a ($\mu\text{g}/\text{m}^3$)		TSM (mg/l)		NH_4 ($\mu\text{g}/\text{l}$)		NO_2 ($\mu\text{g}/\text{l}$)		NO_3 ($\mu\text{g}/\text{l}$)		TN ($\mu\text{g}/\text{l}$)		PO_4 ($\mu\text{g}/\text{l}$)		TP ($\mu\text{g}/\text{l}$)		SiO_4 ($\mu\text{g}/\text{l}$)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
W ₁	0.22	1.11	0.01	17.60	10.64	28.56	1.12	2.10	2.88	32.71	48.13	1424.53	2.38	4.76	14.28	34.03	23.39	59.76
		0.67		24.21		16.31		1.61		15.72		463.37		3.71		25.65		43.32
W ₂	0.00	0.25	0.01	16.50	4.20	65.24	1.68	3.08	7.42	14.06	64.94	1327.20	1.18	6.55	7.50	25.00	36.38	96.79
		0.12		22.88		23.94		2.24		11.26		444.08		3.72		13.68		57.16
W ₃	0.10	0.44	0.01	20.04	10.36	83.44	2.66	3.50	5.23	11.33	67.95	1362.59	2.36	3.57	11.90	18.75	29.23	87.70
		0.22		25.26		32.97		2.94		8.3		469.03		2.82		16.43		47.31
W ₄	0.00	0.21	0.01	16.06	8.40	108.36	1.96	4.48	8.24	13.66	72.02	1128.12	2.38	11.90	15.48	30.55	36.54	51.97
		0.11		18.56		42		2.8		10.17		422.05		6.08		20.81		46.16
W ₅	0.00	0.24	0.01	27.08	6.16	22.12	0.98	2.66	3.49	10.81	52.91	1216.60	1.79	4.71	12.96	23.21	11.04	29.88
		0.1		22.9		13.51		2.03		7.11		464.12		2.96		17.9		19.83
W ₆	0.12	0.44	0.01	15.43	6.16	26.04	1.12	4.20	3.50	18.69	50.61	1632.46	1.79	3.53	10.91	26.39	142.38	225.41
		0.26		27.21		17.01		3.05		14.05		554.15		2.67		19.2		178.51
W ₇	0.23	1.43	0.01	32.23	28.84	140.56	5.74	44.80	46.47	197.26	80.87	3167.58	1.79	3.57	26.78	60.70	41.57	113.68
		0.86		24.22		82.67		18.9		103.58		1016.06		2.97		39.93		69.19
W ₈	0.61	9.67	0.01	32.85	253.96	538.72	24.78	52.08	123.37	509.29	117.86	3809.06	1.79	4.17	30.55	63.09	51.97	135.12
		3.66		30.53		338.45		39.83		254.98		1280.93		3.41		38.9		90.24
W ₉	0.45	1.57	0.01	22.74	210.00	899.64	34.86	424.34	223.37	919.81	151.12	5791.02	2.38	202.3 7	41.66	241.65	62.36	1015.9 7
		1.12		21.62		488.67		151.76		487.85		2877.64		53.26		93.35		347.61
W ₁₀	0.87	5.96	0.01	57.74	89.60	883.12	16.24	57.12	95.10	397.66	119.45	8976.30	2.38	41.23	63.19	458.30	58.46	263.97
		3.1		37.69		396.83		36.4		263.77		2669.44		14.77		170.82		143.13
W ₁₁	0.00	2.66	0.02	30.14	51.52	897.40	5.74	64.12	16.28	1252.3 7	79.28	3609.98	1.79	14.28	19.10	122.91	64.96	116.28
		1.1		28.16		494.41		36.3		432.77		1823.13		5.66		50.23		90.38
W ₁₂	0.87	1.75	0.01	34.63	20.44	64.96	3.78	12.74	17.33	102.51	62.64	1667.85	2.38	3.53	14.32	32.64	55.22	120.18
		1.18		27.97		40.04		6.62		62.93		596.4		2.82		24.17		89.36
W ₁₃	0.46	1.32	0.01	38.43	12.60	78.68	3.92	11.48	9.48	139.05	63.00	2234.12	2.38	2.98	20.46	40.28	55.87	203.49
		0.9		33.34		44.31		5.99		52.02		727.57		2.82		26.25		123.14
W ₁₄	0.10	0.46	0.01	15.62	13.44	47.60	2.38	6.72	18.27	46.28	39.99	1849.23	1.19	2.98	13.89	27.78	55.22	237.10
		0.23		21.55		36.89		4.06		28.51		645.24		2.22		19.21		137.96
Min.	0.1		18.56		13.51		1.61		7.11		422.05		2.22		13.68		19.83	
Max.	3.66		37.69		494.41		151.76		487.85		2877.64		53.26		170.82		347.61	
Average	0.98		26.15		147.72		22.47		125.22		1032.37		7.85		41.18		105.95	

Total nitrogen showed a fluctuation between 422.05 - 2877.64 $\mu\text{g}/\text{l}$ -N giving an overall mean value nutrient salts 1032.37 $\mu\text{g}/\text{l}$ -N. The absolute values of DIP and TP varied between 2.22 - 53.26 $\mu\text{g}/\text{l}$ for PO_4 -P and 13.68 - 170.82 $\mu\text{g}/\text{l}$ for TP

giving the overall means 7.85 µg/l and 41.18 µg/l for dissolved inorganic phosphorus and total phosphorus in the Gulf of Suez surface coastal waters, respectively. Variations in DIP values could be controlled by the interplay of physical (upwelling, relaxation events) and biological action (DIP uptake) (agreed with the value determined by Ruttenberg and Dyhrman [18] [19]). The current study represented that an increase in the amounts of total nitrogen and total phosphorus was accompanied by a decrease in salinity values. This illustrates the role of industrial and sewage effluents in providing the coastal seawater with nitrogen and phosphorus forms. The DIN/DIP ratios showed very wide fluctuations ranging from 4.21 - 1214 giving the overall mean nutrient salts. They deviate from that of the normal case of the Red field (N/P is 16:1) coincided with the relative increase of anthropogenic activity. The results determined by Chraudani and Vighi [20], indicated that the marine algae are P-limited at P:N ratio < 6 and N-Limited at ratio > 4.5; in the range of 4.5 - 6; the two nutrients are close to their optimum assimilative proportion. Extremely variability of the N/P ratio is omitted to a land-based runoff as mentioned by Dorgham *et al.* [21]. Based on the measurement of TN (1.3 mg/l), TP (41.18 µg/l) and Chl-a (0.97 µg/l), classification of eutrophication status of Suez Gulf seawaters was done according to Håkanson, L. [22] they signified that Suez Gulf is locating within hypertrophic state based on TN and TP and oligotrophic state based on Chl-a (>1.0 µg/l) (<0.40 mg/l). The levels of reactive silicate varied between 19.83 - 347.61 µg/l SiO₄-Si giving an overall value silicate 105.95 µg/l SiO₄-Si for the Gulf of Suez surface coastal water. High fluctuation in the values could be associated with the physical mixing of seawater with freshwater, adsorption auto-sedimentary particles, chemical interaction with clay minerals, co-precipitation with humic constituents in addition to the biological removed by phytoplankton especially diatoms and silicoflagellates.

An assessment of the eutrophication status of waters of the Gulf of Suez has been based on the principal component analysis. The Eutrophication Index is calculated according to the following formula [23],

$$\text{E.I.} = aC_{\text{PO}_4} + bC_{\text{NO}_3} + cC_{\text{NO}_2} + dC_{\text{NH}_3} + eC_{\text{Chl-a}} \quad (2)$$

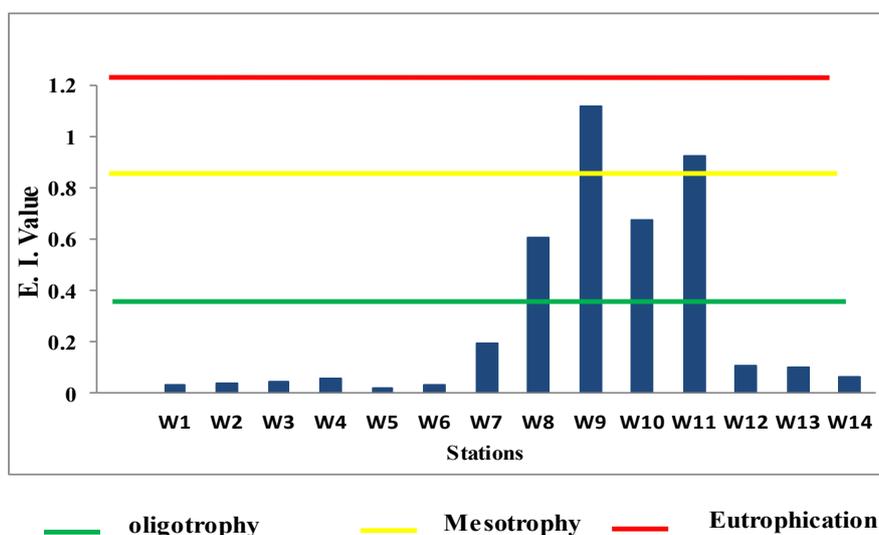
where, C is the concentrations and a, b, c, d and e are the coefficients derived from PCA analysis for the first component analysis. The coefficients of the five variables in the first principal component are displayed in (Table 3). The application of frequency distribution analysis represents the ranges of the eutrophication index as oligotrophic, mesotrophy and eutrophication as mentioned by Ignatiades *et al.* [24] (Table 4). The Enrichment index values for the fourteen stations of the Gulf of Suez seawaters are given in (Figure 4). The results demonstrate that the coastal seawaters of the Gulf of Suez varied from oligotrophy (0.02) at station W₅ to eutrophication (1.117) at station W₉, the average value of enrichment index (0.26) indicates that the coastal water of the Gulf of Suez is oligotrophy. Stations W₉ and W₁₁ are grouped as Eutrophication, stations, while stations W₈ and W₁₀ are grouped as mesotrophy and the rest of stations are

Table 3. The coefficients of the first principal component for five variables concentrations from the coastal waters of the Gulf of Suez.

Variables	Coefficients
Nitrate	0.962
Ammonia	0.943
Nitrite	0.934
Phosphate	0.828
Chl-a	0.584

Table 4. Ranges of the Eutrophication index “Oligotrophy, Mesotrophy and Eutrophication” resulting from the application of frequency distribution analysis.

Trophic status	Lower limit	Upper limit
Oligotrophy	0.04	0.38
Mesotrophy	0.37	0.87
Eutrophication	0.83	1.51

**Figure 4.** The Enrichment index values for the fourteen stations of the coastal seawaters of the Gulf of Suez.

oligotrophy. The Enrichment index values of W₈, W₉, W₁₀, and W₁₁ indicate an increase of the drainage effluents at these locations.

3.3. Statistical Analysis

A correlation matrix was displayed for surface coastal waters of the Gulf of Suez (Table 5) at N = 14, r is significant when it will be higher than 0.51. Correlation coefficient signified positive relationship between water temperature with each of BOD (0.58), DOM (0.60), NH₄-N (0.55), TN (0.67) and TP (0.71). An increase in temperature leads to an increase in the respiration of aquatic organisms and

Table 5. Pearson correlation matrix for all investigated environmental parameters.

	Temp. (°C)	Salinity (S‰)	Conductivity (ms/cm)	pH	Do (mg/l)	BOD (mg/l)	DOM (mg/l)	chl-a (µg/m ³)	TSM (µg/l)	NH ₄ (µg/l)	NO ₂ (µg/l)	NO ₃ (µg/l)	TN (µg/l)	PO ₄ (µg/l)	TP (µg/l)	SiO ₄ (µg/l)
Temp. (°C)	1															
Salinity (S‰)	-0.269	1														
Conductivity (ms/cm)	0.34	0.56	1													
pH	0.10	-0.17	-0.08	1												
Do (mg/l)	0.14	0.06	0.14	0.39	1											
BOD (mg/l)	0.58	-0.43	-	0.42	0.56	1										
DOM (mg/l)	0.60	-0.51	-0.08	0.01	-0.046	0.39	1									
chl-a (µg/m ₃)	0.48	-0.41	-0.06	0.04	0.18	0.52	0.58	1								
TSM (µg/l)	0.49	-0.44	-0.02	0.07	-0.115	0.33	0.75	0.72	1							
NH ₄ (µg/l)	0.55	-0.43	0.01	-0.022	0.56	0.65	0.71	0.64	0.45	1						
NO ₂ (µg/l)	0.40	-0.31	0.02	0.40	0.84	0.69	0.33	0.34	0.14	0.77	1					
NO ₃ (µg/l)	0.50	-0.34	0.03	0.02	0.64	0.66	0.65	0.54	0.37	0.97	0.84	1				
TN (µg/l)	0.67	-0.56	0.06	0.24	0.54	0.76	0.71	0.60	0.55	0.92	0.83	0.90	1			
PO ₄ (µg/l)	0.31	-0.41	-0.06	0.54	0.74	0.62	0.27	0.16	0.06	0.62	0.95	0.70	0.76	1		
TP (µg/l)	0.71	-0.76	-0.01	0.25	0.17	0.67	0.75	0.64	0.72	0.71	0.55	0.63	0.88	0.55	1	
SiO ₄ (µg/l)	0.38	-0.15	0.28	0.61	0.70	0.66	0.27	0.18	0.06	0.54	0.83	0.62	0.69	0.84	0.481	1

consequently decomposition of organic matter. Salinity was correlated negatively with each of TN (-0.56) and TP (-0.763) which gives an indication to the rule of effluents in increasing the levels for each of TN + TP. DOM was correlated positively with each of Chl-a (0.58), TSM (0.75), NH₄ (0.71), NO₃ (0.65), TN (0.71) and TP (0.75). An elevation of organic matter with an increase in TSM contents may give an indication of the importance of the adsorption process of organic matter onto TSM. A positive correlation between nutrients with each other and oxidizable organic matter revealed that they have the same source.

Analyzing the data was performed according to the principal component analysis using the statistical package for the social sciences SPSS [25]. The output data showed four factors with eigenvalues higher than one, which affected water parameters distribution, association and sources with cumulative covariance of 87.51% (Table 6, Figure 5).

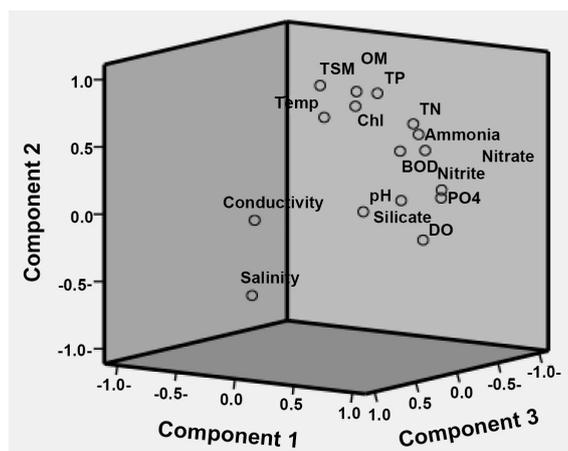
Principle component analysis was applied to evaluate Water Quality Index (*WQI*) at each station and to determine the hot spot stations. *WQI* was calculated according to the following formula [26],

$$WQI = \sum_{n=1}^n \left(\frac{\lambda_n}{\sum \lambda} \right) \times PC_n \quad (3)$$

where: *n* is the number of effective components, λ_n : are the Eigenvalues of the effective components, $\sum \lambda$: the sum of the Eigenvalues and *PC_n*: the *n* critical principal component scores. High values of the principal component factor

Table 6. Varimax rotated component matrix for coastal seawater of the Gulf of Suez.

Parameters	Component			
	PC ₁	PC ₂	PC ₃	PC ₄
Temp		0.74		
Salinity		-0.563	0.71	
Conductivity			0.95	
pH				0.91
DO	0.91			
BOD	0.61			
OM		0.86		
Chl-a		0.76		
TSM		0.891		
Ammonia	0.73	0.61		
Nitrite	0.94			
Nitrate	0.82	0.505		
TN	0.71	0.68		
PO ₄	0.86			
TP		0.86		
Silicate	0.77			
Eigen Values	0.59	0.21	0.12	0.08
Variance	51.94	17.98	10.21	7.39
CV %	51.94	69.92	80.13	87.51

**Figure 5.** Component plot of factors 1, 2, 3 in rotated space for the seasonal averages of studied parameters in Seawater of the Gulf of Suez during 2016.

scores mean that this station is situated under hot spot conditions. Data on water quality of the Gulf of Suez are shown in (Table 7); a positive value of *WQI* indicates pollution. They demonstrated that stations locating in the Northern and Southern side of the Gulf of Suez are relatively good and varied between (-0.07), (-0.55), meanwhile, water quality of the other stations locating in the northern side of Suez Gulf (W_7 , W_8 , W_9 , W_{10} , W_{11} , W_{14}) are found slightly

Table 7. Principal component factor scores and water quality index (WQI) of the Gulf of Suez Seawater.

Code	PC1	PC2	PC3	PC4	WQI
W ₁	-0.61	-0.3	-1.06	0.05	-0.55
W ₂	-0.45	-0.76	-0.77	-0.32	-0.54
W ₃	-0.51	-0.36	1.45	-0.15	-0.22
W ₄	-0.29	-0.81	-1.59	-0.13	-0.53
W ₅	-0.35	-0.97	-1.09	-0.23	-0.55
W ₆	-0.22	-0.68	1.57	0.21	-0.07
W ₇	-0.23	0.25	1.31	-0.35	0.04
W ₈	0.61	0.4	0	-1.05	0.36
W ₉	3.1	-0.21	-0.27	1.23	1.87
W ₁₀	-0.48	2.99	-0.59	0.94	0.34
W ₁₁	0.85	0.74	0.21	-2.61	0.46
W ₁₂	-0.76	0.17	-0.3	0.38	-0.42
W ₁₃	-0.58	0.13	0.38	0.76	-0.2
W ₁₄	-0.1	-0.59	0.74	1.27	0.01

polluted to a different degrees (0.04) - (1.87) coincided with an increase in the human activities in each of these locations. W₇ is located in Al Adabbia Harbour and W₈ in Attaqa, which are subjected to ships activities, whereas station (W₉) was found more polluted station ($WQI = 1.87$) as a result of sewage flow at W₉ station. The quality of waters of W₁₀ was affected with many industrial effluents coming from Attaqa Company for Electricity and Miratex for Textile. W₁₁ and W₁₃ are subjected to domestic effluents of the Suez Government. Station W₁₄ is located in port Tewfik Harbour that is affected with the activities of ships.

4. Conclusion

The present investigation gives some significant information about the ecological nature of the Gulf of Suez. The obtained results feature that, there is a pronounced variation in most of the water quality parameters with variation in season and geographic location. The water quality in the Gulf of Suez is influenced by the released from point wellsprings of contamination. The redesign spatial strategy of monitoring stations is required to assess the effect of hydro-advancement extends and assesses its impact on the studied area.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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