Journal of Environmental Protection, 2016, 7, 1810-1834
http://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

Evaluation of the Quality for the Egyptian Red Sea Coastal Waters during 2011-2013

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How to cite this paper: Fahmy, M.A., Fattah, L.M.A., Abdel-Halim, A.M., Aly-Eldeen, M.A., Abo-El-Khair, E.M., Ahdy, H.H., Hemeilly, A., El-Soud, A.A. and Shreadah, M.A. (2016) Evaluation of the Quality for the Egyptian Red Sea Coastal Waters during 2011-2013. *Journal of Environmental Protection*, **7**, 1810-1834.
http://dx.doi.org/10.4236/jep.2016.712145

Received: July 4, 2016
Accepted: November 20, 2016
Published: November 23, 2016

Abstract

To assess the quality of the Egyptian Red Sea coastal waters for the sustainable use and development, due to its importance for the national income, four field campaigns were annually carried out during the period from 2011-2013 to investigate the hydrography, nutrient salts, heavy metals and petroleum hydrocarbons. Except for the area of Bir Shalatein, the results of beach litter cleared out that the shoreline of the studied area is not affected by man-made litter. No sewage could be observed. The results of the present study showed that water temperature followed seasonal changes in air temperature. Red Sea water is more saline than adjacent Arabian Sea. DO revealed high values and presence of well oxygenated waters. Minor changes in the distribution of pH, BOD, DOM and COD, revealed that limited effects of human impacts and depend mainly on the dynamics of its water as well as on the geographical location. Low Chl-*a* and TSM concentrations and high transparency revealed that also the effect of human impacts is almost negligible. Significantly higher sea water temperatures, TSM, pH, DO, BOD, DOM, and COD were observed in summer season compared to their corresponding values in winter season. Dissolved inorganic nitrogen concentrations were quite low because there is little nutrient input from soil, agriculture and pollution on land. Based on the annual mean values, the pattern concentrations of dissolved inorganic nitrogen forms followed the order: NO_3 > NH_4 > NO_2. The Red Sea coastal waters are classified as oligotrophic to mesotrophic state. A remarkable increase of PO_4 concentration was observed in the middle Red Sea stations due to huge amounts of effluents enriched with phosphate from the main shipping and industry of Phosphate Companies. SiO_4 displayed a large variability due to the supply of SiO_4, which flows in the Red Sea through the strait of Bab El-Mandab, biological consumption, organic matter decomposition and the partial dissolution of quartz particle transported to the sea from the surrounding desert during sand storms. Concentrations of ammonia, phosphorus, total nitrogen, and total phosphorus were significantly higher in summer compared to their corresponding values in winter. In general, the majority of TN and TP in winter were in the form of organic-N (91.3%) and organic P (96.8%). The mean DIN/DIP ratio revealed high nitrogen concentrations in comparison with that of phosphorous and the surface coastal waters of the Red Sea are principally, P-limited for phytoplankton growth with higher values in winter season compared to summer season. Concentrations of heavy metals were quite low most probably due the absence of major local impacts of any land-based sources and/or any major negative impacts of coastal tourism. Regional variations were almost negligible and except for Mn, Cd, and Hg insignificant seasonal variations were observed. The present study revealed concentrations for metals in the acceptable levels. Furthermore, concentrations of petroleum hydrocarbons were significantly higher in winter than in summer which is mainly attributed to the increase in the rate of evaporation for petroleum hydrocarbons in summer. In general, the maximum concentration was much lower than the harmful concentrations reported for seawater. Correlation coefficients as well as principle component analysis (PCA) were applied.

Keywords

Hydrography, Nutrient Salts, Heavy Metals, Petroleum Hydrocarbons, Coastal Water, Red Sea

1. Introduction

The Northern Red Sea is an important sea area, not just as a unique environment, but as one of the most diverse marine ecosystems, great scientific and ecological sensitivity, and of great beauty and tourist-value. Hence, their natural resources provide a substantial economic support for the region. Furthermore, the regional resources contribute substantially to Egypt's economy, particularly in the areas of oil production, navigation, tourism and fisheries [1]-[11].

The Red Sea is 1930 km length and average 280 km in width. It is a gulf or basin of the Indian Ocean between Africa and Asia. It is a semi-enclosed, narrow water body with no river inputs. The surface area of the Red Sea is about 437,970 km^2 and its mean depth is 491 m, but it also has extensive shallow shelves, noted for their marine life and corals. The sea is the habitat of over 1000 invertebrate species, and 200 soft and hard corals [12] [13] [14] [15]. In the north, the width is only 175 km but southward it increases to a maximum of 370 km near Jizan, then decreases to 30 to 40 km at Bab El-Mandab [5] [7] [16]-[23].

The Red Sea, due to the low population density along the coast, is a considered relatively pristine area. Contamination of the Red Sea is one of the environmental crises that accompany with the rapid economic development and has become a subject of great deal of research in recent years [6] [9] [10] [18] [24]-[31]. The major threats to the marine environment of the Red Sea are related to land-based activities. These include urbanization and coastal development (for example, dredge and fill operations), industries including power and desalination plants and refineries, recreation and tourism, waste water treatment facilities, power plants, coastal mining and quarrying activities, oil bunkering and habitat modification such as the filling and conversion of wetlands [6] [9] [10] [18] [19] [20] [25]-[34].

The economic repercussions on the fishing and tourist trades depend, mainly on the degree of deterioration of environmental conditions. On the other hand, the rapid tourism development may lead to a serious threat to both the marine environment and the tourism industry itself, if not planned and developed on a sound environmental basis with the effective enforcement of environmental regulations combined with strong backing by scientific research and monitoring programs to control and follow up changes in the different habitats. It has been reported that areas such as Hurghada has been developed and exploited beyond their ecological and social carrying capacities and are already showing signs of environmental degradation [2] [5] [7] [8] [17] [18] [19] [20] [22] [32] [34]. Due to the importance of the area for tourism, fisheries, oil and other industries and because the economic repercussions on the fishing and tourist trades depend, to a great extent, on the degree of deterioration of environmental conditions, a proper environmental management with respect to the establishment of tourist facilities is highly desired.

The main objective of the present paper is to assess the environmental conditions including the hydrography, nutrient salts, heavy metals and petroleum hydrocarbons of the coastal waters along the Egyptian coast of the Red Sea for the management and sustainable development of the Red Sea environments.

2. Material and Methods

2.1. Study Area

The coastal zone in the Egyptian Red Sea Side, particularly in the distance between Hurghada and Bir Salatein, along a distance of 600 km is interesting from several points of view. In addition to the development of urban areas, ports, oil industry and may be other installations, the major asset of coastal zone is potential for development of tourism. The development of the coastal area with hotels, resorts, villages' beaches, pools, diving centers and other tourist facilities has taken place within the coastline, but in many sites as Hurghada the development has included the littoral zone and even part of the reef flat, which has been land filled. The coastal zone in between Abu Shar (El-Guona) and Bir Shalatein has attracted many investors for establishing their touristic projects along its coast. Some of these plants have been built on the course of wadies, on areas of loose sediments drifted to the wadi mouths by flash floods and torrents from the Red Sea Mountains. The Red Sea is a natural laboratory for investigating relatively rapid changes of short duration in a restricted marine environment. It covers a wide range of conditions, from normal marine, highly productive to external hypersaline and oligotrophic [21].

2.2. Sampling

Recently, an Environmental Information and Monitoring Program (EIMP) is initiated to assess the degree of deterioration of environmental conditions for a proper environmental management. Within the framework of this programm, 12 field campaigns were carried out in 3 years (2011-2013). A total of 108 coastal water samples were seasonally collected, in duplicate, during March, May, August and October of 2011-2013. Eight coastal sampling stations were selected to represent the different locations situated under the direct effect of human activities, public resort beaches, some protected and reference sites (Figure 1). The latitude and longitude of each station is given in Table 1.

2.3. Methods

2.3.1. Hydrographic Parameters

The hydrographic parameters (water temperature, salinity, pH, Transparency, dissolved oxygen (DO) were measured *in situ* at each station using CTD (YSI-6000) Transparency was measured by Secchi Disk. Dissolved oxygen was also measured using modified

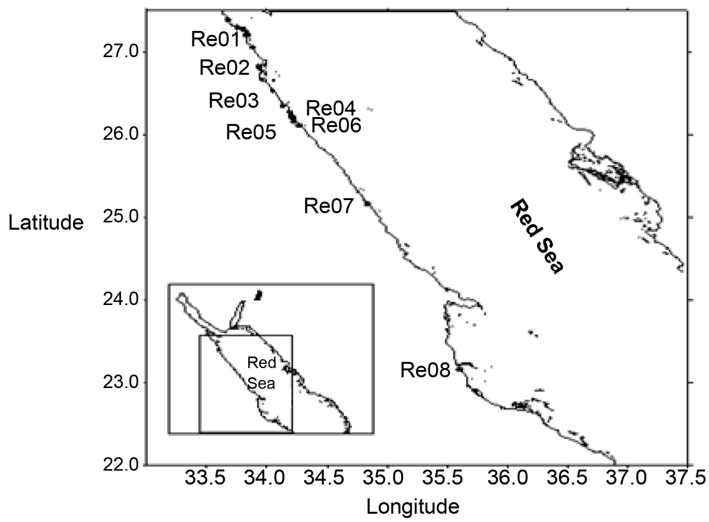


Figure 1. Locations of sampling sites along the coast of the Egyptian Red Sea.

Table 1. Locations of different sampling sites in the study area.

St.No	Area	Latitude	Longitude	Distance from (Km) Hurghada (km)
Re 01	Hurghada-Hotel Sheraton	27˚11'37.5"	33˚56'12.6"	10
Re 02	Safaga north	26˚47'34.9"	34˚00'20.0"	65
Re 03	Safaga middle	26˚30'20.0"	34˚04'15.0"	70
Re 04	El Hamarawein	26˚15'09.0"	34˚12'05.0"	120
Re 05	Quseir north	26˚12'15.0"	34˚13'15.0"	140
Re 06	Quseir middle	26˚08'30.0"	34˚14'30.0"	150
Re 07	Marsa Alam	25˚04'0 6.1"	34˚45'0 0.4"	275
Re 08	Bir Shalatein	23˚09'0 9.9"	35˚36'48.3"	550

Winkler method [35]. Biological oxygen demand (BOD) samples were kept in incubator and fixed after 5 days and their DO contents were determined. Dissolved organic matter (DOM) was carried out using potassium permanganate according to the method described by [36], and chemical oxygen demand (COD) was determined by the dichromate closed reflux titrimetric method [35].

2.3.2. Chlorophyll-*a*, TSM, Transparency, and Nutrient Salts

Chlorophyll-*a* (Chl-*a*) was measured in 3 L water samples after collection and filtration by using 0.45 µm filters. Chl-*a* was extracted using 90% acetone and measured spectrophotometerically according to [36]. Ammonium ion concentrations were determined according to [37]. Nitrite, Nitrate, reactive phosphate and reactive silicate concentrations were determined on pre-filtered seawater samples (Whatman GF/C) following the sepectrophotometric techniques described by [37] and [38] by using HACH DR-2000 direct reading spectrophotometer. Total P and total N were estimated in unfiltered water samples following the procedure described by [39]. Total suspended matter (TSM) was collected from 3 L seawater samples by filtration through washed, dried and pre-weighed 0.45 µm membrane filter. The filters with the retained particles were washed then air dried in the oven at 60˚C for 24 - 48 hours until constant weight. The difference between the dry weight of membrane filters before and after filtration was expressed in mg/l [37]. Transparency was measured by Secchi Disk. Transparency was measured by Secchi Disk. The concentration of dissolved inorganic nitrogen (DIN as the sum of NH_4-N + NO_2-N + NO_3-N) was calculated.

2.3.3. Heavy Metals

Dissolved heavy metals, *i.e*. Fe, Mn, Cu, Zn, Cd, … etc. were determined after pre-concentration from seawater by using chelex-100 cation-exchange resins according to [40] and [41]. Measurements were done by using the atomic absorption spectrophotometer (AAS)/flame mode (Shimadzu AA-6800).

2.3.4. Petroleum Hydrocarbons

Petroleum hydrocarbons were extracted from seawater samples by using dichloromethane. Sample extracts were concentrated by rotary evaporation to 5 ml. Finally, samples were concentrated under a gentle stream of pure nitrogen to a final volume of 1 ml, then measured using UV-spectrophotometer at 410 nm emission after excitation at 360 nm and chrysene as standard [42].

2.4. Quality Control

Calibration curves for each variable of nutrient salts and heavy metals were constructed of a blank and four or more standards (Merck Germany). Accuracy and precision were confirmed using synthetic samples and/or reference materials of different nutrient salts and metals and measured every five samples as quality control tools.

2.5. Statistical Analysis

A stepwise multiple linear regression to give insight about the relationships between the independent variables and the dependent variables were calculated (n = 106 $p \le 0.05$) to test the relationship between variables. The correlation coefficient is significant at $r \ge 0.195$. Analysis of variance (ANOVA) was applied to test significant differences in the measured variables and correlation matrices were constructed from the resulting coefficients with the aid of STATISTICA 10 program. Principle component analysis (PCA) and factor analysis as Varimax normalization rotated were applied with SPSS program version 15.0 for Windows. The number of factors was determined by the total variance explained, *i.e.* communality, usually more than 85% was necessary.

3. Results and Discussion

3.1. Visual Observations

Beach litter of lumps of new and old tar, oil, feces, sewage disposal, general and harmful liters as well as seaweeds of coastal beach zones especially those used for recreational purposes including pollution index and the magnitudes of pollution for respective items are assessed by eyes according to: none, light, moderate and heavy, allocating respective scores ranging from "0" to "3" (Table 2). Besides affecting the fishing industry and scuba diving tourism, beach litter cause a destruction of living resources and reduces the recreational utility of coastal waters, especially the beaches through shore damage [43]-[51].

Except for the area of Bir Shalatein, the results of Table 3 of respective years and

Table 2. The total scores of seven items stand for the pollution index.

Item	None	Light	Moderate	Heavy
Lumps of new and old tar	0	1	2	3
Oil	0	1	2	3
Faces	0	1	2	3
Seaweeds	0	1	2	3
General Litter	0	1	2	3
Harmful Litter	0	1	2	3
Sewage	0	1	2	3

Table 3. Magnitudes of pollution of respective years and annual average monitoring stations.

Stations		Respective years			Av.
No.	Area	2011	2012	2013	
Re 01	Hurghada-Hotel	0.18	0.18	0.07	0.14
Re 02	Safaga north	0.00	0.04	0.07	0.04
Re 03	Safaga middle El	0.93	0.54	0.28	0.58
Re 04	Hamarawein	0.25	0.46	0.36	0.36
Re 05	Quseir north	0.32	0.46	0.36	0.38
Re 06	Quseir middle	0.43	0.46	0.21	0.37
Re 07	Marsa Alam	0.39	0.21	0.21	0.27
Re 08	Bir Shalatein	0.96.	0.89	0.89	0.91

annual average monitoring for the density, composition, and distributions at different stations cleared out that the shoreline of the Egyptian Red Sea can be considered relatively not affected by man-made litter. The area of Bir Shalatein (Re 08) was subjected to many factors which undoubtedly affected the rate of man-made litter accumulation including general litter, harmful litter, seaweeds, sewage, faces, … etc. [45]-[50], yet it is not affected by oil contamination (oil and old or new tar) which is a good estimator of levels of oil contamination and an effective means of evaluating the potential threat of oil on coastal resources [45]-[51].

In general, the most abundant visible items were general litter as they represented 42.5% of the total items encountered. Seaweeds, on the other hand, represented 24.6% followed by faces and Oil which constituted 11.5% and 10.7%; respectively. On contrast, harmful litter and tar balls represented 8.3%, 2.4%, respectively. No sewage could be observed during the three respective years (2011-2013).

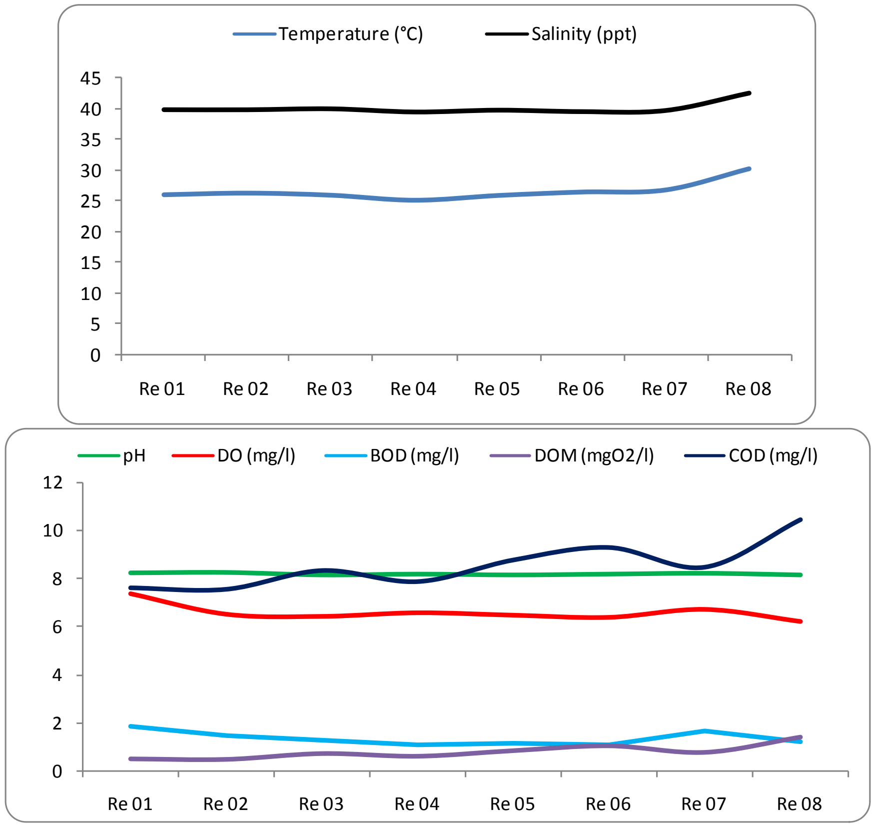
3.2. Physicochemical Characteristics

The ranges as well as average values of temperature, salinity pH, DO, BOD, DOM, COD of the Red Sea surface coastal waters are listed in **Table 4**. It has been reported that the Red Sea has a number of unique features. It is the warmest of the world's seas. The climate is equatorial 35˚C - 41˚C. The average water temperature is 18˚C - 21˚C in

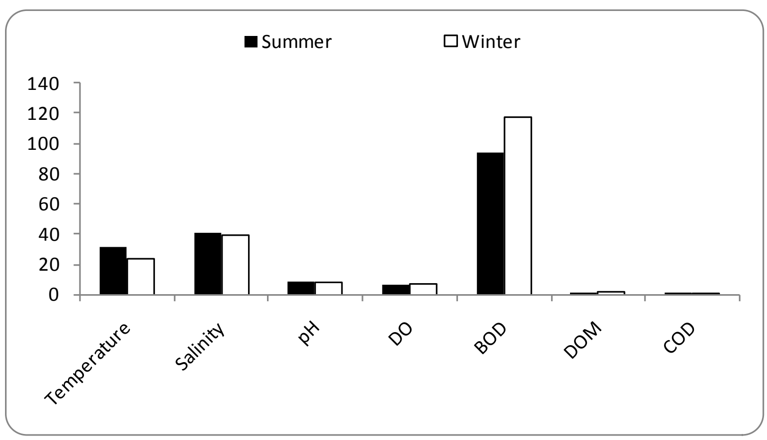
Table 4. Ranges and average values of physicochemical parameters of coastal surface waters of Red Sea during 2011-2013.

Stations	Code	Temp. (˚C)	Salinity (S‰)	pH	Do (mg/l)	Do %	BOD (mg/l)	DOM (mg/l)	COD (mg/l)
Hurghada-Hotel Sheraton	Re1	23.01 28.98	39.35 40.21	8.14 8.29	5.84 9.24	95.61 151.39	0.28 5.42	0.08 0.88	2.51 9.40
		25.99	39.79	8.22	7.34	114.11	1.85	0.48	7.59
Safaga North	Re2	22.93 29.51	39.34 40.12	8.14 8.29	5.35 8.41	87.65 137.73	0.28 4.36	0.16 0.88	2.51 9.64
		26.26	39.78	8.23	6.49	101.07	1.43	0.46	7.54
Safaga Middle	Re3	22.33 29.32	39.46 40.36	8.10 8.21	4.80 8.13	78.54 133.18	0.42 3.06	0.08 1.32	2.51 11.20
		25.91	39.95	8.17	6.40	99.22	1.23	0.70	8.32
El Hamarawein	Re4	19.41 28.74	38.40 40.10	8.13 8.22	5.00 8.69	81.95 142.28	0.56 1.53	0.16 1.04	2.97 10.00
		25.08	39.40	8.19	6.55	100.82	1.06	0.59	7.86
Quseir North	Re5	22.98 29.46	38.95 41.03	8.10 8.22	4.87 9.38	79.68 153.66	0.28 1.76	0.08 2.16	6.17 11.08
		25.87	39.72	8.18	6.45	100.19	1.09	0.82	8.75
Quseir Middle	Re6	22.78 29.60	38.20 40.18	8.12 8.23	5.00 8.13	81.95 133.18	0.28 1.74	0.08 3.12	7.49 12.03
		26.44	39.45	8.19	6.36	99.32	1.09	1.02	9.28
Marsa Alam	Re7	23.72 30.65	39.06 40.19	8.13 8.25	5.07 11.75	83.09 192.36	0.70 4.45	0.08 2.16	6.17 10.12
		26.79	39.65	8.21	6.69	104.89	1.65	0.75	8.47
Bir Shalatin	Re8	24.44 38.05	40.59 44.36	8.03 8.26	4.87 7.09	79.68 123.70	0.76 1.60	0.32 3.12	8.21 12.51
		30.31	42.62	8.17	5.86	95.31	1.15	1.39	10.44
	Min	19.41	38.20	8.03	4.80	78.54	0.28	0.08	2.51
	Max	38.05	44.36	8.29	11.75	192.36	5.42	3.12	12.51
	Average	26.61	40.01	8.18	6.82	110.44	1.58	0.91	8.03

winter and 21˚C - 26˚C in summer. Surface water temperatures remain relatively constant at 21˚C - 25˚C [52]. The results of the present study cleared out that water temperature followed seasonal changes in air temperature at different stations. Temperature varied between 19.41˚C at Re 04 during winter to 38.05˚C at Re 08 during summer. A slight increase in water temperature was observed in southward direction (Figure 2(a)).



(a)



(b)

Figure 2. (a) Regional variations of different physicochemical properties of the Red Sea coastal waters; (b) Seasonal variations of different physicochemical properties of the Red Sea coastal waters.

It is well known that the Red Sea is a concentration basin where extensive evaporation and winter cooling transform the surface waters to form one of the most saline water masses of the world Ocean [53]. Due to the high temperatures and no rivers flow into the Red Sea, the salinity in the investigated area fluctuated between 38.20 ppt at Re 6 to 44.36 ppt at Re 8 with a spatial average 40.01 ppt. In the Red Sea, evaporation exceeds the freshwater supply; therefore the outflow of Red Sea water is warmer and more saline than adjacent Arabian Sea [54]. pH values displayed no clear regional variations (**Figure 2(a)**). It fluctuated between 8.03 at Re 08 and 8.29 at Re 02 with an average value of 8.18. The general distribution of DO revealed high values and presence of well oxygenated waters in the investigated area (**Table 4** & **Figure 2(a)**). It ranged from 4.80 mg/l (78.54%) at Re 03 and 11.75 mg/l (192.36%) at Re 07 with a spatial average 6.82 mg/l (110.44%). The distribution patterns of BOD, DOM and COD, on the other hand, showed no regular distribution (**Figure 2(a)**). They fluctuated between 0.28 - 5.42; 0.08 - 3.12 and 2.51 - 12.51 mg/l, with spatial averages of 1.58; 0.91 and 8.03 mg/l for BOD, DOM and COD, respectively. Minor changes in these variables revealed that the effects of human impacts on the distribution pattern of different hydrographical conditions of the Red Sea coastal waters are still limited [29] [30] [31] [55]. The low population in the region, the absence of fresh water sources and the limitation of land-based sources, *i.e.*, sewage, agriculture and/or industrial effluents are the main reasons for such minor changes [6] [25] [30]. In fact, the environmental conditions are principally controlled by the circulation pattern of seawater in the Red Sea Regions. The hydrochemical characteristics of the Red Sea depend on the dynamics of its water as well as on the geographical location [20] [29] [31] [56] [57] [58] [59]. Seasonal variations of temperature showed significantly higher values (29.36˚C) in summer season compared to 23.56˚C in winter season. On contrast, higher values of pH (8.23), DO (7.74 mg/l, 118.48%), BOD (2.18 mg/l), DOM (1.43 mg/l), and COD (10.48 mg/l) were observed in winter season compared to their corresponding values (8.15, 5.61 mg/l, 90.24%, 0.70, 0.20, 6.36 mg/l; respectively) in winter season (**Figure 2(b)**).

3.3. Chlorophyll-*a*, Total Suspended Matter and Secchi Disk Depth

Ranges and regional average values of Chl-*a*, TSM and Secchi Disk depth are reported in **Table 5**. Low Chl-*a* and TSM concentrations and high transparency were generally encountered at most stations revealing that the effect of human impacts on the Red Sea coastal waters is still not significant [6] [20] [25] [29] [30] [31]. This can be highlighted by ranges and annual average values, at which chlorophyll-*a* ranged from 0.01 µg/l at Re 03 and Re 08 to 3.72 µg/l at Re 04 with a spatial average of 0.94 µg/l (**Figure 3(a)**). Total suspended matter ranged from 1.08 mg/l at Re 02 to 38.11 mg/l at Re 6 with a spatial average of 19.74 mg/l (**Figure 3(a)**). Secchi Disk transparency, on the other hand, reached bottom depth at most stations confirming the absence and/or the very limited impacts of human impacts due to the low population in the region, the absence of fresh water sources and the limitation of land-based sources, *i.e.*, sewage, agriculture and/or industrial effluents [6] [25] [30]. Seasonal variations cleared higher total suspended

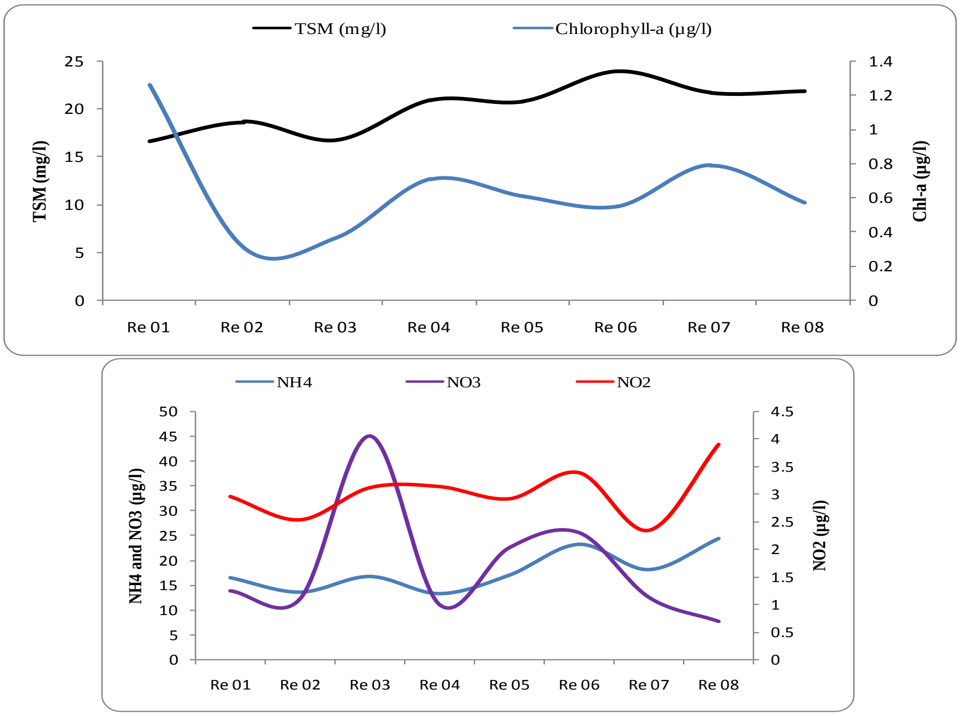
Table 5. Ranges and average values of chlorophyll-*a* (μg/l), total suspended maters (mg/l) nutrient salts (μg/l) of coastal surface waters of Red Sea during 2011-2013.

Station Name	Code	chll-*a*	TSM	NH_4	NO_2	NO_3	TN	PO4	TP	SiO_4
		Min Max								
Hurghada-Hotel Sheraton	Re1	0.02 1.46	1.50 27.40	4.12 25.70	0.78 8.50	4.12 38.31	20.16 2244.48	0.46 15.07	5.41 67.92	31.23 81.47
		0.50	16.64	9.70	4.28	14.08	880.36	2.91	26.44	54.08
Safaga North	Re 2	0.02 0.98	1.08 32.09	3.86 30.16	0.36 6.00	3.73 31.06	114.24 2878.40	0.00 6.03	5.26 1748.95	27.26 67.24
		0.45	18.65	10.86	3.91	12.65	952.63	1.92	213.49	48.22
Safaga Middle	Re 3	0.01 1.02	1.18 32.22	4.52 36.71	0.36 7.00	4.52 93.44	80.64 2443.84	0.60 11.30	5.18 114.59	37.14 284.21
		0.37	16.73	12.27	4.05	28.04	1006.56	3.09	39.33	106.34
El Hamarawein	Re 4	0.10 3.72	12.29 31.10	3.46 27.62	1.42 8.00	2.49 23.96	87.36 2495.36	0.60 13.56	3.53 197.90	18.01 161.36
		0.66	20.92	10.41	4.47	11.95	934.77	3.65	59.63	68.76
Quseir North	Re 5	0.02 1.72	9.68 33.14	3.24 34.96	1.05 10.00	7.05 87.92	87.36 1922.13	0.60 11.30	5.37 102.83	27.01 112.32
		0.62	20.80	13.68	5.35	21.85	876.56	3.13	45.41	60.17
Quseir Middle	Re 6	0.02 2.12	11.13 38.11	3.78 30.55	0.78 6.80	3.80 97.67	123.20 2598.40	0.46 18.83	3.88 69.09	18.01 112.32
		0.55	23.90	13.08	4.50	22.82	960.40	4.21	33.04	57.62
Marsa Alam	Re 7	0.05 2.32	10.96 31.42	5.67 56.47	1.35 8.50	6.79 24.52	105.28 2013.76	0.00 19.59	5.54 1782.55	28.14 128.93
		0.80	21.35	14.87	4.77	13.13	843.48	4.42	224.62	66.79
Bir Shalatin	Re 8	0.01 2.70	9.82 30.23	9.04 46.47	1.58 8.01	5.34 28.07	201.60 2197.44	0.46 22.60	6.10 44.40	25.89 105.20
		0.58	21.84	19.20	4.39	14.72	971.54	4.22	25.74	58.61
	Min	0.01	1.08	3.24	0.36	2.49	20.16	0.00	3.53	18.01
	Max	3.72	38.11	56.47	10.00	97.67	2878.40	22.60	1782.55	284.21
	Average	0.94	19.74	18.85	4.48	27.01	1151.48	6.60	254.70	80.33

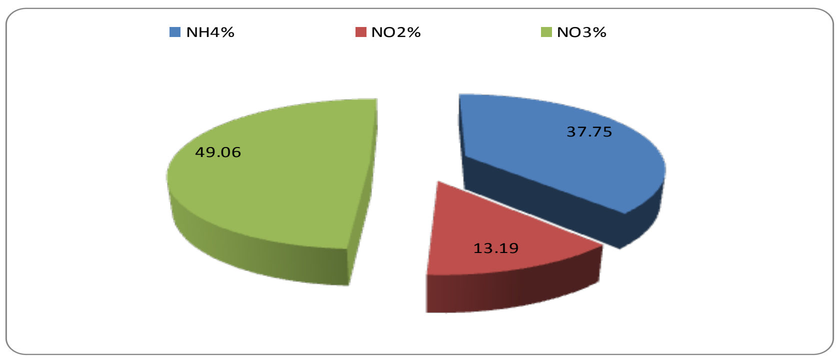
matter (24.80 mg/l) in summer than in winter (15.71 mg/l). On contrast, higher values of chlorophyll-*a* (0.51 μg·g/l) were observed in winter season compared to their corresponding values (0.39 μg·g/l) in winter season showing a different seasonal pattern compared to dissolved oxygen (**Figure 3(b)**).

3.4. Nutrient Salts

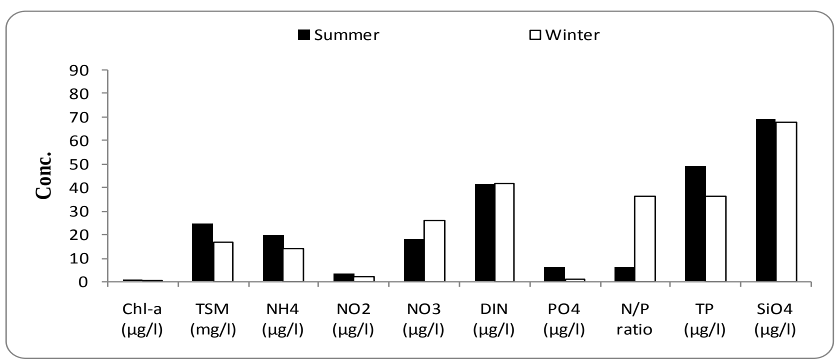
Lack of riverine input and negligible precipitation mean that the nutrient-depleted ecosystem of the Red Sea relies principally on the horizontal intrusion of nutrient-rich waters from the Indian Ocean through Bab El Mandab, (12.5×10^3 $K^3 \cdot Y^{-1}$), whereas in the northern end of the basin, nutrient enrichment is related to deep vertical mixing, *i.e.* winter convection and presence of a permanent cyclonic feature [56] [57] [60] [61]. Ranges as well as regional average values of different nutrients are listed in **Table 5**. The results indicated that dissolved inorganic nitrogen concentrations were quite low. There is strong evidence that the production potential of the Red Sea is low. Over most of the basin, thermoclines and haloclines prevent the cycling of nutrients from deeper water to the euphotic zone. There is little nutrient input to the pelagic system from land surface runoff to compensate for the steady loss by sinking of nutrients out of the



(a)



(b)



(c)

Figure 3. (a) Regional variations of Chlorophyll-*a*, TSM, and Nutrient Salts of the Red Sea coastal waters; (b) Nitrogen forms % of dissolved inorganic nitrogen (DIN) based on the mean annual values of the Red Sea coastal waters; (c) Seasonal Variations of Chlorophyll-*a*, TSM, and nutrient salts of the Red Sea coastal waters.

productive zone. On this basis, productivity can be expected to be low over most of the central Red Sea. Production increases somewhat to the north and south where mixing processes are known to occur [62]. The Red Sea surface waters are exceptionally clear and low in nutrients because the hot, arid climate means that population density is low and there is little nutrient input from soil, agriculture and pollution on land. It also creates a permanent surface layer of warm, nutrient-poor water, which does not mix with nutrient-rich deeper water in a process called stratification [30] [31] [57] [58] [59] [63]. They ranged from 3.24 - 56.47 µg/l NH_4-N at Re 05 and Re 07, respectively for ammonium; 0.36 µg/l/l NO_2-N at Re 02 and Re 03 to 10.0 µg/l/l NO_2-N at Re 05 for nitrite; from 2.49 µg/l/l NO_3-N at Re 4 to 97.67 µg/l NO_3-N at Re 6 for nitrate and from 20.16 to 2878.40 µg/l N at Re 1 and Re 2, respectively for total nitrogen (**Table 5** & **Figure 3(a)**). In general, dissolved inorganic nitrogen constituted of the TN in the investigated area revealing that the majority of TN content were in the form of organic-N which constituted more than 80% of TN. Based on the mean annual values, the concentrations of dissolved inorganic nitrogen forms followed the following order: NO_3 NH_4 > NO_2 (**Table 6**, **Figure 3(b)**). [64] and [65] reported that seawater with concentrations of 7.0 µg/l for each NH_4 and NO_3 is classified as oligotrophic. Whereas, in eutrophic waters the concentration of these nutrients are usually in order of 28.0 µg/l for NH_4 and 56.0 µg/l for NO_3. According to their classification, the Red Sea coastal waters are classified as oligotrophic to mesotrophic state. On the meantime, PO_4, ranged from ND to 22.6 µg/l PO_4-P at Re 02 and Re 08, respectively with an average value of 6.60 µg/l. TP ranged from 3.53 to 1782.55 µg/l P at Re 04 and Re 07, respectively with an average value of 254.70 µg/l. A remarkable increase of PO_4 concentration was observed in the middle Red Sea stations compared to the southern and northern stations (**Figure 3(a)**). The quite high phosphorus concentrations were attributed to allochthonous huge amounts of effluents enriched with phosphate from the main shipping and industry of Phosphate Company and El Hamrawein main phosphate shipping Harbour. In the other stations PO_4 concentrations were very low. Low phosphate contents could be

Table 6. Nitrogen forms percentages of dissolved inorganic nitrogen (DIN) in the Red Sea coastal waters during 2011-2013.

Station	code	NH_4 %	NO_2 %	NO_3 %
Hurghada-Hotel Sheraton	Re 01	34.57	15.25	50.18
Safaga North	Re 02	39.61	14.26	46.13
Safaga Middle	Re 03	27.66	9.13	63.21
El Hamarawein	Re 04	38.80	16.66	44.54
Quseir North	Re 05	33.46	13.09	53.45
Quseir Middle	Re 06	32.38	11.14	56.48
Marsa Alam	Re 07	45.38	14.56	40.06
Bir Shalatin	Re 08	50.12	11.46	38.42
Annual mean		37.75	13.19	49.06

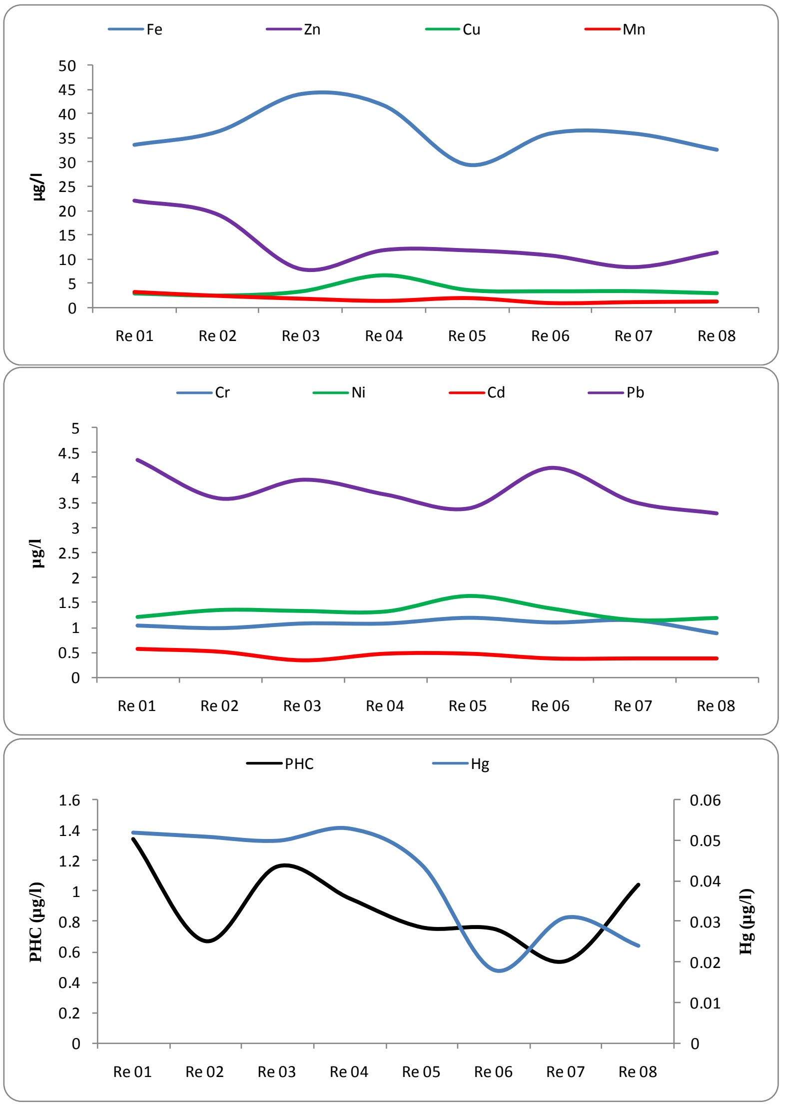
mostly related to their short life cycle, sorption and deposition on iron born dust conveyed to the basin from the surrounding deserts. [66] reported the effect of composition and physicochemical characteristics of natural particles on phosphate adsorption-desorption processes under various aquatic environment. The typical concentrations for eutrophic coastal waters are above 4.65 µg/l and for highly eutrophic system will be beyond 9.3 µg/l [65]. Accordingly the obtained results are consistent with the oligotrophic characteristics of the Red Sea coastal waters [21]. The geographic and temporal distribution pattern of SiO_4 displayed a large variability during the investigation period (**Figure 3(a)**). They fluctuated between 18.01 to 284.21 µg/l SiO_4 at stations Re 04 and Re 03, respectively with an average value of 80.33 µg/l SiO_4. A slight increase in SiO_4 concentration was observed in the northern side of Red Sea coastal water. [52] pointed out the main factors controlling SiO_4 distribution in the Egyptian Red Sea coastal waters are mainly: 1) the supply of SiO_4, which flows in the Red Sea through the strait of Bab El Mandab, 2) biological consumption, 3) organic matter decomposition and 4) the partial dissolution of quartz particle transported to the sea from the surrounding desert during sand storms. The cycles of the key nutrient elements nitrogen (N) and phosphorus (P) have been massively altered by anthropogenic activities [67]. In coastal marine systems, nitrogen has historically been considered to be the predominant limiting nutrient [68]. However, sequestration of P in calcareous sediments is thought to drive P limitation in the tropics [69], while constraints on planktonic N-fixation caused by insufficient light [70] or trace metal supply [71] [72] are thought to influence the predominance of N or P limitation offshore. In order to understand weather the phytoplankton growth in the coastal waters of the Red Sea is, or is not, limited by N or P, The DIN/P ratio has been calculated. In the present study, DIN/P ratio amounted between (0.01:1) and (76.67:1) with a regional average value of (18.85:1) for Red Sea coastal waters. Moreover, the mean DIN/DIP ratio during the three successive years was ranging from 11.44:1 to 27.51:1 with an average value of 18.85:1. The relatively higher ratios than that reported by Redfield's ratio with value of (16:1) revealed high nitrogen concentrations in comparison with that of phosphorous and the surface coastal waters of the Red Sea are principally, P-limited for phytoplankton growth in most investigated regions. Ammonia, phosphorus, total nitrogen, and total phosphorus had similar seasonal patterns (**Figure 3(c)**). Seasonal variations showed average concentrations of ammonia (17.2 g/l), phosphorus (6.42 g/l), total nitrogen (710.0 g/l), total phosphorus (49.74 g/l) which were significantly higher in summer compared to their corresponding values (14.09, 1.16, 560, 36.28 g/l; respectively) in winter. On contrast, seasonal distributions of nitrate (25.79 g/l) exhibited significantly higher values in winter compared to their corresponding values (18.20 g/l) in summer (**Figure 3(b)**). Nitrite and silicate exhibited more or less comparable values in winter (8.76 & 68.74; respectively) compared to their corresponding value in summer (8.66 & 69.50; respectively). In general, the majority of TN and TP in winter were in the form of organic-N (91.3%) and organic P (96.8%). These percentages were 96.2% and 87.1%, respectively in summer. Moreover, the DIN/DIP ratio was ranging from 15.19 to 44.85 with an average of 45.6:1 showing higher values in winter season compared to summer season. This indicates high nitrogen concentrations in comparison with that of phosphorous in winter, yet it reflects the generally lower nutrient levels present in the coastal waters of the Red Sea due to the lack of significant riverine nutrient input or oceanic upwelling [52].

3.5. Heavy Metals

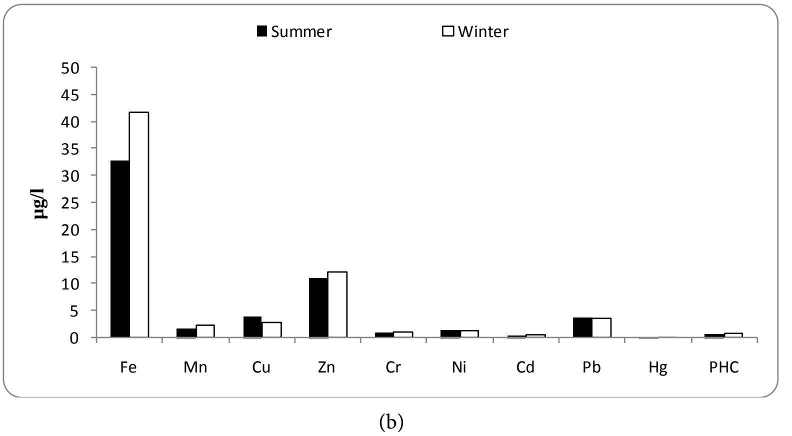
With the growth of industry, there has been a considerable increase in the discharge of industrial waste to the aquatic systems, which has led to the accumulation of heavy metals resulting in a major health concern worldwide, as they cannot be broken down to non-toxic forms and therefore have long-lasting effects on the ecosystem [73]-[78]. The increasing concentration of heavy metals in the marine environment due to industrial revolution has created an alarming situation for human life and aquatic biota [78] [79] [80] [81] [82]. The ranges and mean concentrations of the studied heavy metals, namely, Fe, Zn, Mn, Ni, Cu, Cr, Cd, Pb, and Hg revealed quite low concentrations (**Table 7**). The results of the present study (**Table 7** & **Figure 4(a)**) indicated that concentrations of dissolved metals in the investigated area followed the following order: Fe (36.12 µg/l) ≫ Zn (12.91 µg/l) ≫ Cu (3.74 µg/l) > Pb (3.49 µg/l) > Mn (1.98 µg/l) > Ni (1.33 µg/l) > Cr (1.08 µg/l) > Cd (0.44 µg/l) ≫ Hg (0.0385 µg/l). Regional variations were almost negligible (**Figure 4(a)**) which is most probably due to the lack of

Table 7. Ranges and regional average values of heavy metals (µg/l) in the Red Sea coastal waters during 2011-2013.

Station Name	Code	Fe	Mn	Cu	Zn	Cr	Ni	Cd	Pb	Hg
Hurghada-Hotel Sheraton	Re1	12.89 64.62	0.60 8.98	0.96 6.05	4.41 75.91	0.63 1.43	0.51 1.76	0.25 0.97	3.39 6.63	0.00 0.10
		33.66	3.29	3.04	22.09	1.06	1.22	0.58	4.35	0.05
Safaga North	Re2	25.63 57.16	0.49 12.73	1.35 4.87	7.28 41.22	0.46 1.46	0.95 2.06	0.16 1.18	2.06 5.40	0.02 0.08
		36.36	3.73	2.60	19.26	1.00	1.36	0.52	3.59	0.05
Safaga Middle	Re3	19.75 65.62	0.59 4.41	1.50 7.17	2.68 11.16	0.39 1.40	0.39 3.07	0.13 0.70	1.80 6.13	0.04 0.07
		44.02	1.90	3.43	7.91	1.09	1.35	0.35	3.96	0.05
El Hamarawein	Re4	23.50 56.31	0.52 2.34	1.61 14.12	9.40 15.39	0.73 1.36	0.98 1.79	0.24 0.81	1.32 6.11	0.01 0.10
		41.68	1.44	6.83	11.85	1.09	1.33	0.49	3.66	0.06
Quseir North	Re5	15.04 40.45	1.22 4.81	1.21 8.28	8.15 14.80	0.76 1.88	0.68 3.35	0.23 0.87	2.62 3.96	0.03 0.06
		29.61	2.02	3.78	11.79	1.20	1.64	0.48	3.38	0.04
Quseir Middle	Re6	21.45 47.10	0.19 1.55	1.27 8.43	5.52 15.79	0.69 1.54	0.83 2.27	0.20 0.61	2.31 8.90	0.01 0.03
		35.99	0.98	3.50	10.73	1.11	1.39	0.38	4.20	0.02
Marsa Alam	Re7	19.78 50.39	0.55 1.72	1.23 8.95	4.17 14.29	0.80 1.60	0.65 2.03	0.14 0.60	3.13 3.96	0.01 0.05
		35.99	1.18	3.51	8.32	1.15	1.16	0.39	3.56	0.03
Bir Shalatin	Re8	27.62 40.82	0.26 2.92	0.64 6.72	5.94 24.01	0.72 1.47	0.56 1.69	0.15 0.63	2.44 4.24	0.01 0.06
		32.66	1.30	3.09	11.34	0.91	1.19	0.37	3.28	0.02
	Min	12.89	0.19	0.64	2.68	0.39	0.39	0.13	1.32	0.00
	Max	65.62	12.73	14.12	75.91	1.88	3.35	1.18	8.90	0.10
	Average	36.59	2.49	4.34	15.14	1.08	1.42	0.48	3.93	0.04



(a)



(b)

Figure 4. (a) Regional variations of heavy metals and petroleum hydrocarbons of the Red Sea coastal waters; (b) Seasonal variations of heavy metals and petroleum hydrocarbons of the Red Sea coastal waters.

riverine input, the absence of major local impacts of any land-based sources and/or any major negative impacts of coastal tourism in the investigated area [6] [25] [29] [30] [73]. Except for Mn, Cd, and Hg, seasonal variations, on the other hand, showed insignificant variations for most dissolved metals. Concentrations of Mn (2.36 g/l), Cd (0.50 g/l), and Hg (0.043 g/l) were significantly higher in winter compared to their corresponding values (1.64, 0.35, 0.032 g/l; respectively) in summer (**Figure 4(b)**). The present study revealed that all water samples had acceptable metals concentrations.

3.6. Petroleum Hydrocarbons

Total petroleum hydrocarbons in the investigated area ranged from 0.20 μg/l at Re 07 in October, 2013 and 6.86 μg/l at Re 01 in May, 2012, with an average of 0.91 μg/l (**Table 7**). Among all studied locations, Re 01 at Hurghada area exhibited the maximum average concentration (1.34 μg/l) of petroleum hydrocarbons (**Figure 4(a)**). Re 07 at Marsa Alam area showed the minimum average one (054 μg/l). The coastal waters at Hurghada area are more suffered from oil pollution compared to the other areas (**Figure 4(a)**) which is mainly due to accidental, deliberate or operational discharges and spills of oil from ships, especially tankers. Offshore platforms and pipelines are additional reasons for the increase of total petroleum hydrocarbons in this area [45] [46] [47] [49]. Furthermore, seasonal variations showed concentrations of petroleum hydrocarbons ranging from 0.21 to 2.5, with an average value of 0.82 g/l which were significantly higher in winter compared to their corresponding values (**Figure 4(b)**) (0.22 - 1.48, av. 0.74 g/l) in summer (**Figure 4(b)**). The lower concentrations of petroleum hydrocarbons in summer are mainly attributed to the increase in the rate of evaporation for petroleum hydrocarbons in summer season due to the increase in water temperature and water salinity [45] [46] [47] [48] [49]. In general, the maximum concentration was much lower than the harmful concentrations reported for seawater. On the other hand, the reported concentrations are very far below the accepted level given by EEAA of Egypt and that recorded by the International level of 500 μg/l.

3.7. Statistical Analysis

3.7.1. Correlation Analysis

Statistically, correlation coefficient technique was applied between different measured variables to evaluate the relationships between them (**Table 8**). It was showed that, water temperature represents a positive significant correlation with each of salinity (0.49), COD (0.33), TSM (0.43), NH_4 (0.49) and PO_4 (0.22) and a negative significant correlation with each of DO (−0.51), Fe (−0.22), Cd (−0.36) and Hg (−0.35). The present study found a link among the nutrient salts, which illustrated that there was a positive significant correlation between NO_3 and each of NO_2 (0.52 0.32), NH_4 (0.22) and SiO_4 (0.54). Also, a positive significant correlation between NH_4 and PO_4^{---} (0.36), NO_2 and each of TN (0.43) and SiO_4 (0.41) were deduced. The positive correlations among the nutrients may mean that, there are all have the same source. It was observed that, there are strong relationships among the metals in the coastal water of Red Sea during the

Table 8. Pearson correlation matrix for all investigated environmental parameters (26 parameters) during the study period (n = 96, p ≤ 0.05).

	Temp	*Sal*	*pH*	*DO*	*BOD*	*DOM*	*COD*	*chll-a*	*TSM*	*NH_4*	*NO_2*	*NO_3*	*TN*	*PO_4*	*TP*	*SiO_4*	*Fe*	*Mn*	*Cu*	*Zn*	*Cr*	*Ni*	*Cd*	*Pb*	*Hg*	PHC
Temp	1																									
Sal	**0.49**	1.00																								
pH	−0.03	**−0.26**	1.00																							
DO	**−0.51**	−0.15	0.12	1.00																						
BOD	−0.18	0.02	**0.23**	**0.64**	1.00																					
DOM	−0.16	0.06	−0.01	**0.27**	−0.05	1.00																				
COD	**0.33**	**0.26**	−0.02	−0.01	0.19	**0.24**	1.00																			
chll-*a*	0.09	0.00	−0.16	−0.14	0.12	**−0.23**	−0.01	1.00																		
TSM	**0.43**	−0.02	0.00	**−0.30**	−0.02	**−0.23**	0.01	**0.23**	1.00																	
NH_4	**0.49**	**0.30**	−0.15	**−0.34**	0.03	**−0.32**	0.17	**0.27**	**0.32**	1.00																
NO_2	0.13	0.11	0.00	0.20	**0.35**	0.19	**0.29**	**0.34**	**0.35**	0.13	1.00															
NO_3	−0.11	−0.07	**−0.22**	0.18	0.14	0.03	0.05	0.14	0.00	**0.22**	**0.32**	1.00														
TN	0.06	−0.08	0.15	−0.11	−0.06	0.12	**0.24**	0.15	0.16	0.06	**0.43**	0.09	1.00													
PO_4	**0.22**	0.03	−0.08	**−0.39**	−0.15	**−0.31**	−0.10	**0.58**	**0.28**	**0.36**	0.22	0.02	0.17	1.00												
TP	0.04	−0.10	−0.11	−0.12	−0.06	−0.05	0.05	**0.43**	0.05	0.03	0.10	0.01	−0.05	0.18	1.00											
SiO_4	−0.05	0.04	**−0.25**	0.10	**0.22**	−0.03	0.19	**0.28**	0.15	0.13	**0.41**	**0.54**	0.10	0.20	0.19	1.00										
Fe	**−0.22**	−0.09	0.07	**0.34**	**0.34**	0.14	−0.03	**−0.23**	0.02	−0.11	0.21	**0.24**	0.18	−0.18	−0.07	0.13	1.00									
Mn	−0.20	−0.02	**0.21**	**0.22**	−0.09	−0.06	**−0.28**	−0.03	−0.08	**−0.22**	0.18	0.14	**0.44**	−0.02	−0.08	−0.06	0.07	1.00								
Cu	−0.05	−0.07	−0.02	−0.07	−0.16	0.00	0.10	**0.28**	0.12	−0.11	**0.40**	−0.01	**0.68**	**0.35**	0.37	0.18	0.15	0.15	1.00							
Zn	−0.11	−0.04	0.18	0.03	−0.06	−0.03	−0.12	0.03	**−0.30**	−0.19	0.09	0.10	**0.32**	−0.06	−0.04	−0.08	0.01	**0.36**	0.14	1.00						
Cr	−0.11	−0.17	0.05	**0.34**	**0.33**	0.06	0.08	−0.20	**0.22**	0.02	0.05	**0.35**	−0.03	−0.20	−0.05	0.11	**0.47**	0.06	−0.10	−0.02	1.00					
Ni	0.00	0.02	−0.10	0.21	0.19	−0.03	0.21	0.10	−0.05	0.14	0.15	**0.24**	0.01	0.08	0.13	0.07	**0.22**	0.14	0.04	0.05	**0.26**	1.00				
Cd	**−0.36**	−0.16	0.20	**0.22**	0.07	0.13	−0.14	0.10	−0.07	**−0.27**	**0.33**	0.15	**0.38**	0.07	−0.06	0.12	0.17	**0.42**	**0.35**	**0.37**	0.17	0.18	1.00			
Pb	0.07	−0.03	0.13	0.09	0.14	−0.15	−0.17	−0.13	−0.04	**0.21**	−0.16	−0.02	−0.03	−0.04	−0.08	−0.12	**0.34**	0.09	0.07	0.02	0.10	**0.33**	0.08	1.00		
Hg	**−0.35**	−0.20	−0.01	0.20	−0.09	−0.11	**−0.43**	−0.06	−0.03	**−0.40**	−0.05	0.07	0.11	−0.16	−0.08	0.12	0.10	**0.34**	0.15	0.17	0.02	−0.02	**0.29**	0.07	1.00	
PHC	0.00	0.08	−0.07	0.07	0.14	0.03	**0.21**	0.04	0.05	0.00	0.15	0.18	0.01	−0.12	0.03	0.30	0.07	−0.07	−0.03	−0.09	0.01	0.17	−0.07	−0.06	0.09	1.0

present study. There is a positive significant correlation between Cd and each of Mn (0.42) and Cu (0.35), Zn (0.37) and Hg (0.29). Also there are positive significant correlations between Ni and each of Fe (0.22), Cr (0.26) and Pb (0.33). It was found a strong positive significant correlation between Fe with each of Cr and Pb (0.47 and 0.34, respectively) and between Mn and each of Hg and Zn (0.34 and 0.36, respectively). PHC was showed a positive significant correlation with each of SiO_4 (0.30) and COD (0.21). It was observed that, there are relationships between heavy metals and nutrient salts in the coastal water of the Red Sea. A negative significant correlation between NH_4 and each of Mn (−0.22), Cd (−0.27) and Hg (−0.40), whereas positive significant correlations between NO_2 with each of Cu and Cd (0.40 and 0.33, respectively), NO_3 with each of Fe, Cr and Ni (0.24, 0.35 and 0.24, respectively), PO_4 was positive correlated with Cu (0.35). A strong positive significant correlation between TN and each of Mn (0.44), Cu (0.68) and Zn (0.32) were computed. TP was positively correlated with Cu (0.37). DO showed a strong positive significant correlation with each of BOD (0.64), DOM (0.27), Fe (0.34), Mn (0.22) Cr (0.34) and Cd (0.22), whereas, It showed a strong negative significant correlation with each of TSM (−0.30), NH_4 (−0.34) and PO_4 (−0.39). The relations between PHC and metals were weak.

3.7.2. Principal Component Analysis (PCA)

PCA is an application for assessment of water pollution. PCA is a multivariate statistical technique employed to reduce the dimensionality of dataset while attempting to preserve the relationships present in the original data. The Eigen values were computed for the standardized data using specialized statistical software package (SPSS version 16). PCA is an application for assessment of water pollution. PCA is a multivariate statistical technique employed to reduce the dimensionality of dataset while attempting to preserve the relationships present in the original data. The Eigen values were computed for the standardized data using specialized statistical software package (SPSS version 16). PCA is applied for multivariate data derived from the water analysis of 96 coastal water samples of Suez Gulf using 26 variables: water temperature, salinity, pH, DO, BOD, OM, COD, Chl-*a*, TSM, NH_4^+, NO_2^-, NO_3^-, TN, PO_4^{---}, TP, SiO_4, Fe, Mn, Ni, Zn, Cd, Cr, Pb, Cu, Hg and PHC. The component loadings are the linear combinations for each principal component, and the express the correlation between the original variables and the newly formed components. The component loadings are used to determine the relative importance of a variable compared to other variables in a principal component. The output data revealed that ten factors (PC1 - PC9) affected parameters distributions, association and sources, with cumulative covariance of 73.58%. Varimax rotation components matrix is given in **Table 9** to give an overview on the nature of loading among the parameters. PC1 explained 11.12% of the total variance, and represented positive high loading for water temperature 0.80, salinity 0.78, COD 0.47 and NH_4 0.73 while negative high loading for DO −0.44 and Hg −0.53. PC2 explained 10.50% of the total variance and represented positive loading for DO 0.39, TSM 0.37, NO_2 0.64, NO_3 0.80, SiO_4 0.69 and Cr 0.37 and negative loading for pH −0.48. PC3 explained 8.89% of the total variance and represented high positive loading for Mn 0.72, Zn 0.72 and Cd 0.54 and a negative loading for TSM −0.44. PC4 explained 8.89% of the total variance and represented high positive loading for NO_2 0.45, PO_4 0.82, Cu 0.84 and Cd 0.35. PC5 explained 8.41% of the total variance and represented high positive loading for Chll-*a* 0.80, PO4 0.59 and Cu 0.35. PC6 explained 7.55% of the total variance and represented high positive loading for Fe 0.61, Cr 0.46, Ni 0.71 and Pb 0.77. PC7 explained 7.25% of the total variance and represented positive loading for TSM 0.65, PO4 0.44 and negative loading for DO −0.35, DOM −0.80 and COD −0.41. PC8 explained 6.66% of the total variance and represented positive loading for pH 0.63, DO 0.44 and BOD 0.79 and a negative loading for Hg −0.37. PC9 explained 4.76% of the

Table 9. Varimax rotated component matrix for coastal water of Red Sea during 2011-2013.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
Temp. (˚C)	0.80								
Salinity (S‰)	0.78								
pH		−0.48						0.63	
DO	−0.44	0.39					−0.35	0.44	
BOD								0.79	
DOM							−0.80		
COD	0.47						−0.41		
Chll-*a*					0.80				
TSM		0.37	−0.44				0.56		
NH_4^+	0.73								
NO_2		0.64		0.45					
NO_3		0.80							
TN			0.38	0.82					
PO_4					0.59		0.44		
TP					0.75				
SiO_4		0.69							
Fe						0.61			
Mn			0.72						
Cu				0.84	0.35				
Zn			0.72						
Cr		0.37				0.46			
Ni						0.71			
Cd			0.54	0.35					
Pb						0.77			
Hg	−0.53							−0.37	
THC									0.87
Variance %	11.12	10.50	8.89	8.44	8.41	7.55	7.25	6.66	4.76
Cumulative %	11.12	21.62	30.51	38.95	47.36	54.91	62.16	68.82	73.58

total variance and represented high positive loading for PHC 0.87.

Statistical analysis of the results for different investigated parameters revealed that there are several commutative and correlative relations between several physicochemical parameters, nutrient salts, heavy metals and petroleum hydrocarbons.

4. Conclusion

It is reasonable to conclude that, the impact of the human coastal zone uses of the investigated locations of the Egyptian Red Sea coastal water is still limited and not noticeable on the basis of the studied parameters as well as heavy metals and total petroleum hydrocarbons, except for Bir Shalatein (station 8) in the south, which is subjected to the most intense shipping activity beside the middle region, which is located between Safaga and Quseir. This area is subjected to the most intense shipping activity and industrial discharge of phosphate in Egypt. Finally, it is safe to conclude that, the marine body of the Egyptian Red Sea coastal region is not seriously threatened in spite of recently rapid recreational human development taken place on its coast.

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