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Original research

Evaluation of Physicochemical Characteristics of Aquatic Environment for Mangrove Communities on the Red Sea Coast, Egypt

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Abstract:

Mangroves play an important role in reducing global warming and improving coastal and marine ecosystems. This research assessed the aquatic environment quality in some mangrove communities along Egyptian Red Sea coast compared to no-mangrove areas. In autumn 2021,the study was conducted in four regions: Safaga, Kalwaye, El-Quih, and Wadi El-Quih. The physicochemical parameters of the collected water samples were measured. The results showed that the levels of pH, temperature, turbidity, electric conductivity, salinity, NO_2, and PO_4 were all within the permissible limits of natural environment and mariculture according to CCME and MMWQS guidelines. They ranged between (7.57 – 8.60) ,(26.32 – 26.63 ^oC),(0.31 – 3.20 NTU), (54.98 – 62.54 ms/cm),(36.41 – 42.09 ppt) , (0.90 – 3.65 µg/L), and (0.12 – 14. 33 µg/L), respectively. Nitrate levels in all locations' water samples were above the permissible limits, which ranged from 67.17 to 83 µg/L. Dissolved oxygen levels were above 5 mg/L in most areas, while in the El-Quih region, it decreased to a value between 2 and 4.35mg/L. Generally, the results indicated that the aquatic environment of mangrove communities in the El-Quih area possesses the lowest water quality compared to other study areas. This is attributed to the low levels of dissolved oxygen and high concentrations of nitrates, salinity, turbidity, and nitrites. The present study highlights the necessity of applying integrated environmental management (IEM) to mangrove communities in El-Quih area and other areas to support the achievement of sustainable development goals in the Red Sea area.

Keywords: Mangroves, Red Sea, Physicochemical, Aquatic Environment.

1- Introduction

The Red Sea is regarded as one of the unique natural resources that contribute to sustainable development goals (SDGs) regarding climate action, zero hunger, affordable and clean energy, and a sustainable community (RSG, 2023). The Red Sea is a unique semi-closed basin due to its seclusion from the world's oceans and location (Halim, 1984).

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It is the warmest and saltiest body of water among the open seas and has a distinctive ecosystem (Alraddadi, 2013). The Red Sea's coastal and marine environment is a very diverse ecosystem. Mangrove Communities are important wetlands found along the intertidal zone of the coastal line in the Egyptian Red Sea. Mangroves are estimated in Egypt to cover about 525 hectares (Kairo and Hegazy, 2003). Mangrove forests play a crucial role in fighting global warming by absorbing and storing carbon in both their vegetation and underlying soil. (Alongi, 2022; Bartoli et al., 2020; IUCN, 2017). Mangroves are estimated to store 1023 Mg C ha^{-1} y^{-1} (Song et al., 2023). Additionally, mangroves help in preventing storms, hurricanes, coastal erosion, and tidal waves(Blankespoor et al., 2017, Hespen et al.,2023) Recently, mangroves have been threatened by natural and anthropogenic activities such as urbanization, pollution, aquaculture, and tourism. with 20% to 33% of their habitat lost (Marchio et al.,2016). Mangroves are contributing to water quality improvement through the maintenance of the health of marine waters. In consideration of their enormous role in filtering pollutants, protecting sediment erosion, and preserving biodiversity (Jitthaisong et al., 2012). Muttaqin et al. (2024) provided information on how water quality has impacted growth factors in the case of mangroves, where the optimal dissolved oxygen in mangrove ecosystems lies in the range of 3–7 mg/L, and the ideal range of salinity is 10–30 ppt. Samsudin and Azid (2018) emphasized the importance of continuous water quality monitoring in mangrove estuaries for ecosystem health. Sari and Soeprobowati (2021) identified the water quality within the coastal area of Tambakredjo by physical and chemical measurements and reported that the expected loss of the mangrove occurs due to natural processes or human activities that seriously affect biodiversity and water quality.

The current research focuses on studying the physicochemical characteristics of coastal waters surrounding mangrove communities on some Egyptian Red Sea coasts compared to coastal areas devoid of mangrove communities, in addition to estimating pollution levels, where periodic monitoring of water quality around mangrove communities is one of the main measures to preserve and develop them.

2. Materials and Methods

2.1. Study Area

This study was conducted on Egyptian Red Sea coast, the study was conducted in four regions: (a) El-Quih, (b) Wadi El-Quih, (c) Safaga, and (d) Kalwaye. Mangrove communities characterize the coasts of the Safaga and El-Quih regions, while Kalwaye and Wadi El-Quih areas are devoid of mangrove communities. (Fig 1). The study areas of Safaga, El-Quih, Wadi El-Quih, and Kalwaye cover 2 km, 1 km, 0.70 km, and 0.60 km of the coastal line of the Red Sea, respectively. A study of the characteristics of monitoring sites confirmed no point-source pollution was detected near any study areas.

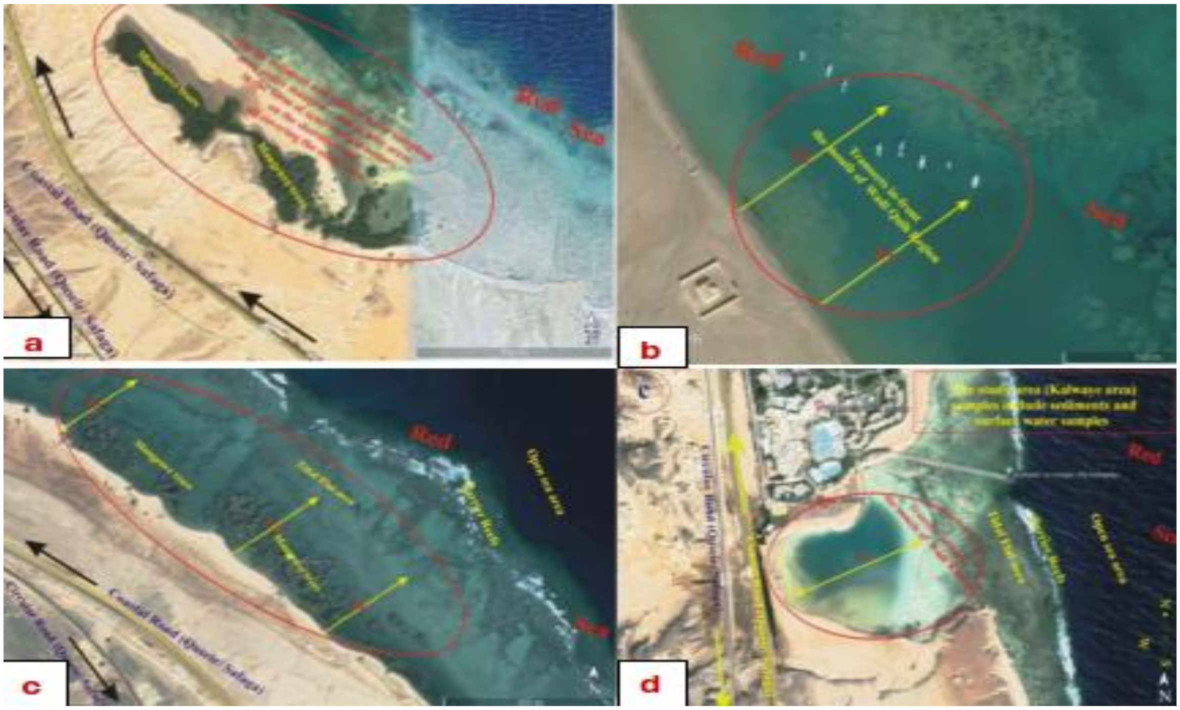

Fig 1. Study areas: (a) El-Quih, (b) Wadi El-Quih, (c) Safaga, and (d) Kalwaye regions

2.2. Water Sampling

Each of the study areas was divided into a number of transects, starting from the shoreline to the end of the tidal zone (Table 1). In autumn 2021, Triplicates and homogenized surface water samples (3L for each sample) were collected from ten sites using a water sampler (PVC tube 3 L). All water samples were assembled in previously acid-washed high-density polyethylene (HDPE) bottles and transferred immediately to the laboratory using ice boxes at a temperature < 4 °C.

Table 1: Locations of Water Sampling Stations

Region	Sites	symbol	Latitude	Longitude
Safaga	Transect 1	ST1	26° 36' 56.00"	34° 00' 49.00"
	Transect 2	ST2	26° 36' 59.00"	34° 00' 45.00"
	Transect 3	ST3	26° 37' 08.00"	34° 00' 32.00"
Kalwaye	Transect 1	KT1	26° 30' 30.30"	34° 04' 03.30"
El-Quih	Transect 1	QT1	26° 23' 53.90"	34° 07' 14.00"
	Transect 2	QT2	26° 23' 54.50"	34° 07' 10.00"
	Transect 3	QT3	26° 24' 00.90"	34° 06' 59.20"
	Transect 4	QT4	26° 24' 06.20"	34° 06' 50.70"
Wadi El-Quih	Transect 1	WT1	26° 21’ 10.45"	34° 09' 13.00"
	Transect 2	WT2	26° 21’ 12.03"	34° 09' 11.66"

2.3. Physicochemical Parameters Analysis

Surface water temperature (Temp), dissolved oxygen (DO), pH, salinity, electric conductivity (EC), and turbidity (Turb) were measured directly on site by using a multi-parameters probe

Hydrolab Instrument (HANNA HI 9028). In the laboratory, Phosphate (PO_4^{3-}), Nitrate as nitrogen (NO_3^- - N), and Nitrite as nitrogen (NO_2^- - N) have been determined according to standard methods (APHA 2017). All the used reagents were of analytical grade (BDH, England and Merck, Germany).

Table 2: Marine water quality guidelines for selected Physicochemical parameters

Parameters	Guideline levels		Reference
	Natural Environment	Mariculture	
Salinity	≤10% of the natural concentration	-	CCME 1999
Temp.	±1°C at any site and time	-	CCME 1999
	≤ 2 °C over maximum ambient	-	MMWQS 2017
pH	7.0-8.7	-	CCME 1999
	6.5-8.5	-	USEPA 1986
	6.5 - 9	6.5 - 9	MMWQS 2017
Turbidity	≤ 2 NTU from background concentration	-	CCME 2002
DO	>5 mg/l for sensitive marine habitats.	>6 mg/L	MMWQS 2017
	3 – 7 mg/l for mangrove ecosystem	-	Muttaqin et al., 2024
Nitrate	10 µg/L.	60 µg/L	MMWQS 2017
Phosphate	5 µg/L.	75 µg/L.	MMWQS 2017
Nitrite	-	-	-

CCME: Canadian Council of Ministers of the Environment.
USEPA: U.S. Environmental Protection Agency.
MMWQS: Malaysian Marine Water Quality Standards.

2.4. Statistical Analysis:

Statistical Analysis System (SAS) version 9.4 and Pearson's correlation coefficients were applied to verify the relationships among variables.

3. Results and Discussions

Marine water temperature is an important factor affecting water chemistry, sea currents, marine habitats, and the general global climate system. (Cordy, 2001; Kroeker et al., 2014) Surface marine water temperature values displayed no clear regional variations (Fig 3) . It ranged from 26.32 to 26.63 °C with an average value of 26.52 °C. The statistical analysis of Pearson's correlation coefficient indicates a moderate negative correlation between temperature and dissolved oxygen (r = -0.60, P < 0.05) and pH (r = -0.51, P < 0.05). However, a moderate positive association was observed between temperature and electric conductivity (r = 0.57, P < 0.05), turbidity (r = 0.55, P < 0.05), and salinity (r = 0.53, P < 0.05) (Table 4).

Table 3: Mean value ± SD of physicochemical parameters of water samples for the main study regions(n=3)

	Safaga	Kalwaye	El-Quih	Wadi El-Quih
Temp. (°C)	26.4 ±0.1	26.4 ±0.0	26.6 ±0.0	26.5 ±0.0
DO (mg/L)	5.48 ±0.16	6.8 ±0.10	**3.89 ±0.85**	6.6 ±0.23
pH	8.4 ±0.20	8.55 ±0.38	8.01 ±0.27	8.57 ±0.06
Salinity (ppt)	37.31 ±0.65	37.69 ±0.06	39.17 ±1.84	36.71 ±1.68
EC (ms/cm)	55.97 ±1.18	56.71 ±0.09	58.69 ±2.41	55.33 ±2.21
Turbidity (NTU)	0.52 ±0.31	0.3 ±0.07	**1.81 ±1.64**	0.54 ±0.15
NO_3 (µg/L)	80.01 ±4.5	71.3 ±2.1	75.0 ±5.0	70.1 ±3.6
NO_2 (µg/L)	1.24 ±0.48	1.47 ±0.15	**2.64 ±1.06**	1.82 ±0.30
PO_4 (µg/L)	9.11 ±7.47	6.33 ±2.52	**2.72 ±3.94**	7.5 ±2.74

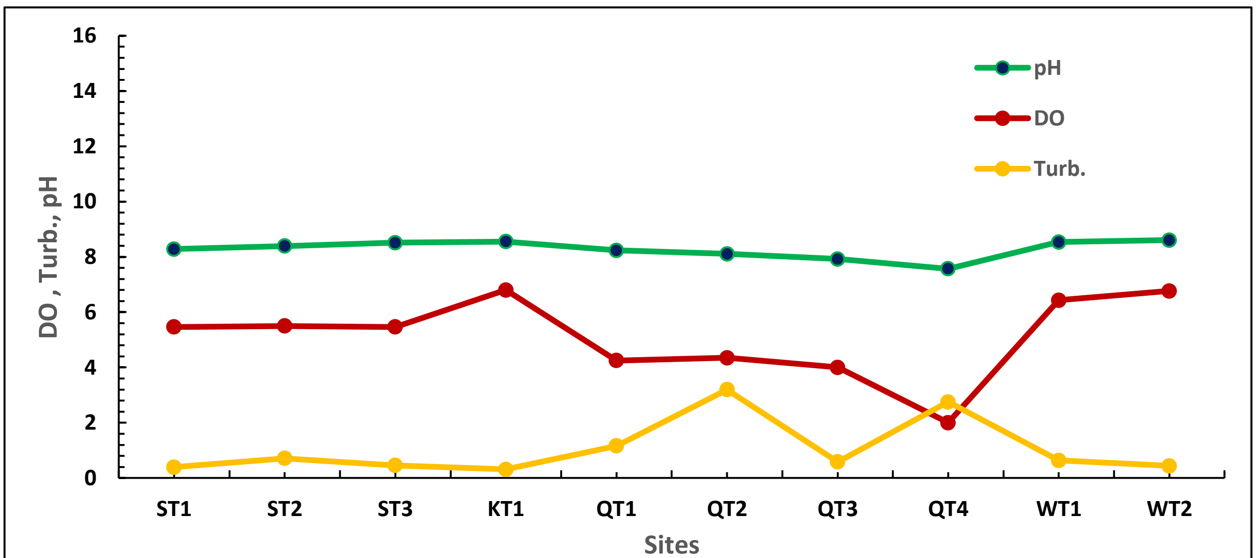

Fig 2. Turbidity (NTU), DO (mg/L), and pH values of water samples at study sites.

Nearshore marine organisms inhabit a highly variable pH environment, with daily fluctuations due to biological activity (photosynthesis and respiration) pH values often exceeding 1 unit (Hofmann et al., 2011; Cornwall et al., 2013; Hurd et al., 2011). Figure 2 shows that pH levels in research areas ranged from 7.57 to 8.60, with an average of 8.27. The highest pH of 8.60 was recorded at the WT2 site in the Wadi El-Quih region, while the lowest pH of 7.57 was observed at the QT4 site in the El-Quih region. The pH range of all water samples was within the permissible limits (6.5 to 9) of natural environment and mariculture (MMWQS,2017; USEPA,1986). Muttaqin et al.,2024 reported that the temperature and pH values of the marine aquatic environment are considered good for mangrove communities if they range between 28-32 ^{o}C and 5.9-9.4, respectively. This confirms that all of the current study sites' pH and temperature levels are appropriate for mangrove ecosystem. The statistical analysis of Pearson's correlation coefficient indicates that pH value has a strong negative correlation with salinity ($r = -0.91$, $P < 0.05$), and EC ($r = -0.90$, $P < 0.05$), while pH value has a strong positive correlation with DO ($r = 0.96$, $P < 0.05$).

Dissolved oxygen (DO) is an important water quality indicator in marine water, dissolved oxygen levels in marine environments are influenced by physical factors like currents, upwelling, warm water, and air-sea exchange, as well as biological factors including productivity, respiration, and decomposition. (e.g., Breitburg et al.,2018; Somero et al., 2016). Previous research indicates that low-dissolved oxygen waters can upwell to nearshore coastal habitats, potentially impacting them. (Chan et al., 2019).

The levels of dissolved oxygen in this study ranged from 2 to 5.50 mg/L in the Safaga and El-Quih regions (characterized by abundance of mangroves),while in the Kalwaye and Wadi El-Quih regions, which lack mangrove communities, DO ranged from 6.43 to 6.80 mg/L (Fig 1).For sensitive marine habitats and fisheries, dissolved oxygen levels should be higher than 5 mg/L (MMWQS,2017; USEPA,2003). In a mangrove ecosystem, the ideal dissolved oxygen concentration ranges between 3 –7 mg/L (Muttaqin et al., 2024). According to the above, dissolved oxygen levels (2- 4.35 mg/L) in El-Quih region (mangrove-rich area) are unsuitable for habitats and fisheries environment, it might also have an impact on species and growth rates of mangroves.

Salinity, a crucial physicochemical influenced by climate change, significantly impacts marine ecosystem structure and function, leading to extensive changes in biogeochemical cycles. (Kirst, 1990; Herbert et al., 2015; Villarino et al., 2018). Surface marine water salinity primarily depends on several factors including evaporation, precipitation, and freshwater added by rivers and rain. (Baumgartner and Reichel, 1975 ; Antonov et al., 2002). The salinity in the studied areas had a spatial average of 38.12 ppt and ranged from 36.41 ppt to 42.09 ppt. These salinity readings correspond to those of Red Sea water in various areas (36 ppt in the southern part and 41 ppt in the northern part), where high salinity is attributed to high evaporation rate and low precipitation, and no significant rivers or streams drain into the sea (Naidu et al., 2003; Mezger et al., 2016). Many studies confirmed that the ideal salinity level for mangrove growth ranges between 10-30 ppt, mangrove species typically show increased growth at low to moderate salinity, followed by a decline as salinity rises further (Mendez-Alonzo et al., 2016; Kodikara et al., 2018; Basyuni et al.,2019). The results of this study indicate that the El-Quih area recorded the highest salinity value, with an average of 39.17 ppt, and this may affect the growth rates of mangrove trees (table 3). The statistical analysis of Pearson's correlation coefficient (Table 4) indicates that salinity has a strong negative relationship with DO ($r = -0.86$, $P < 0.05$). In contrast, salinity has a strong positive correlation with EC ($r=0.99$, $P < 0.05$), and turbidity ($r = 0.77$, $P < 0.05$).

The values of electric conductivity ranged from the lowest averages (55.33 ms/cm) which are found in Wadi El-Quih Region and the highest averages (58.69 ms/cm) were found in El-Quih Region. (Table.3; Fig.3).

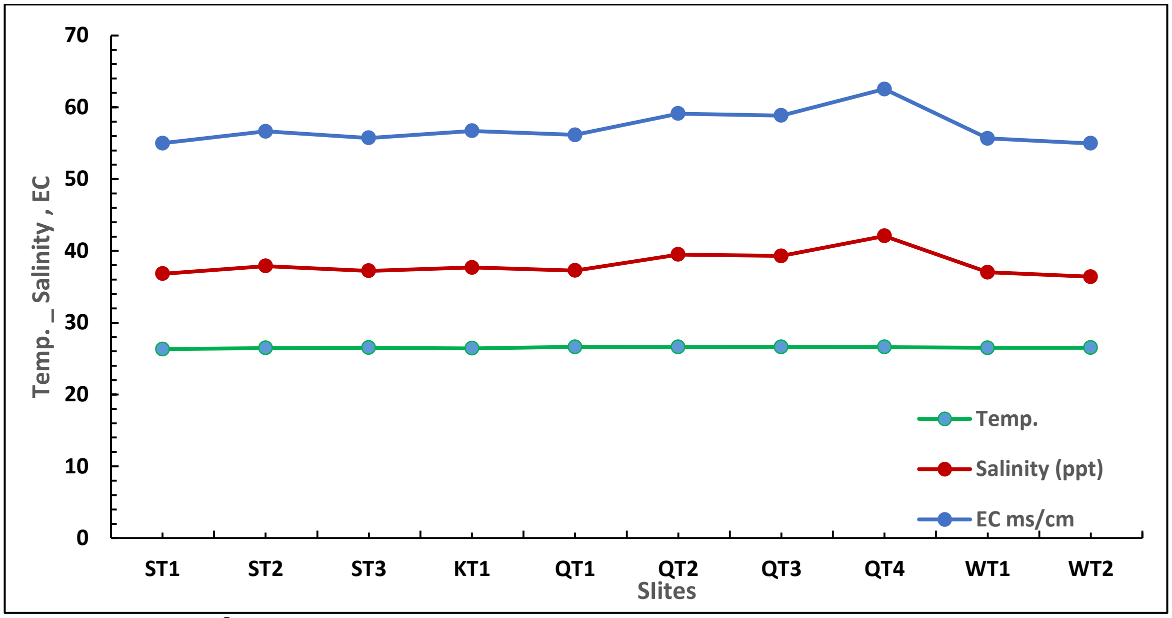

Fig 3. Temperature(^oC), Salinity(ppt) , and Electric conductivity(ms/cm) values of water samples at study sites.

The turbidity of marine water is mainly related to parameters such as total suspended matter, dissolved organic matter, phytoplankton, and algae concentration (Lee et al.,2015). Water turbidity is one of the most important quality indicators of an aquatic environment in general. Therefore, high turbidities cause lowered oxygen levels within water bodies directly impacting survival, growth, and reproduction in most aquatic organisms. (USEPA,2003; Shen et al., 2020). Figure 2 shows the turbidity in all the monitored areas, except in El-Quih region, was less than 0.72 NTU in El-Quih region average of turbidity was 1.9 NTU and contributed to reducing the dissolved oxygen to limits between 2 to 4.35 mg/L. Where the turbidity level at Site QT2 recorded 3.2 NTU.

Coastal marine environments are exposed to anthropogenic eutrophication due to nitrogen and phosphorus leaching from land-based sources and marine activities (Andersen et al.,2019; Phan and Stive, 2022). Excessive nutrient levels cause algal blooms that lower water oxygen levels (hypoxic conditions) causing loss of marine life, which has a catastrophic impact on coastal marine, significant socioeconomic impacts (e.g. Smith,1998; Schindler et al., 2008; Ho et al., 2019).

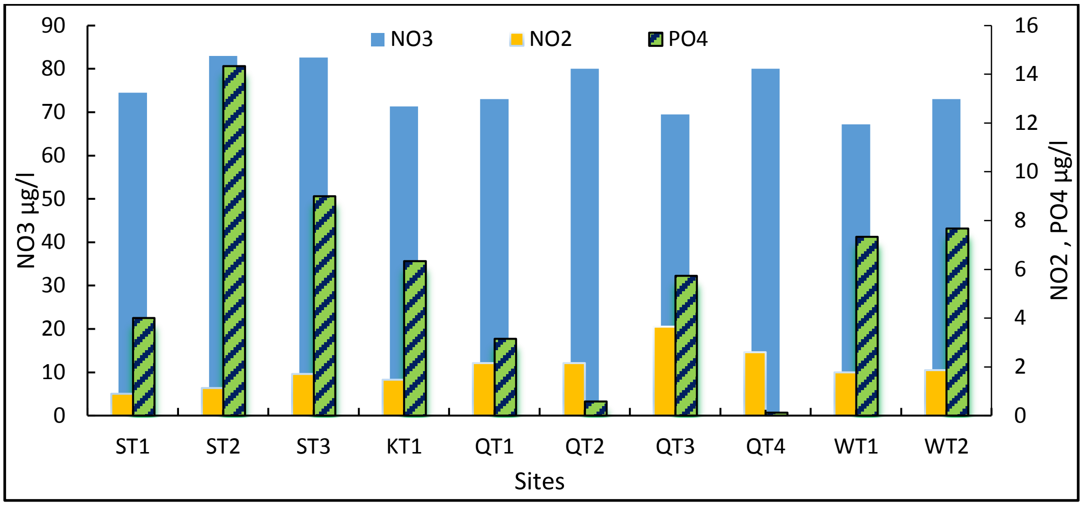

Fig 4. NO_3, NO_2, and PO_4 concentrations of water samples at study sites

Figure 4 shows that nitrate concentrations in study sites ranged between 67.17 to 83 µg/L which is higher than water quality standards for coastal marine areas (60 µg/L) according to (MMWQS,2017). When eutrophication is absent, surface waters have adequate oxygenation and consequentially, nitrate is the most common form of reactive nitrogen. Nitrite is a crucial element of the nitrogen cycle. Under higher oxygen conditions, nitrite is nitrified to NO_3. Commonly the natural concentration of NO_2 in marine water is very low, and minimum levels of dissolved oxygen support nitrite formation (Nelson and Hutchings ,1983; CCME,2012). The present study's findings indicate that in transect sites with dissolved oxygen higher than 5 mg/L, nitrite levels were less than 1.87 µg/L, while nitrite concentrations ranged between 2.15-3.65 µg/L in the El-Quih area, where oxygen levels were below 5 mg/L(Fig.4).The data in Pearson correlation matrix shows that nitrite has a strong positive correlation with surface water temperature ($r = 0.82$, $P < 0.05$)(Table 4). Phosphate concentrations varied from 0.12 µg/L at the QT4 site to 14.33 µg/L at the ST2 site, with a minimum average of 2.72 µg/L in the El-Quih Region and a maximum average of 9.11 µg/L in the Safaga Region. Based on guidelines of marine water quality (MMWQS,2017), the average of these concentrations falls within the acceptable ranges for the marine aquatic environment (5-75 µg/L). Dissolved phosphate was negatively correlated with NO_2 ($r = -0.40$, $P < 0.05$), and positively associated with dissolved oxygen ($r= 0.60$, $P < 0.05$) and NO_3 ($r = 0.12$, $P < 0.05$), (Table 4).

Table 4: Pearson correlation matrix for all investigated parameters.

	Temp.	DO	pH	Salinity	EC	Turb.	NO_3	NO_2	PO_4
Temp.	**1**								
DO	-0.60	**1.00**							
pH	-0.51	**0.96**	**1.00**						
Salinity	**0.53**	-0.86	-0.91	**1.00**					
EC	**0.57**	-0.85	-0.90	**0.99**	**1.00**				
Turb.	**0.55**	-0.71	-0.68	**0.77**	**0.77**	**1.00**			
NO_3	0.05	-0.34	-0.20	**0.32**	**0.28**	**0.42**	**1.00**		
NO_2	**0.82**	-0.59	-0.64	**0.58**	**0.62**	**0.32**	-0.25	**1.00**	
PO_4	-0.35	**0.60**	**0.64**	-0.54	-0.56	-0.68	**0.13**	-0.40	**1.00**

The El-Quih region's poor water quality could be caused by geological processes (erosive, sedimentary, etc.) or biological activities or natural wildlife. To improve the quality of the aquatic environment of the mangrove communities in the El-Quih area, good environmental management and ongoing monitoring are required.

Conclusion

The Red Sea coast is characterized by mangrove communities in many areas that can confront climate change. This study was conducted on Egyptian Red Sea coast; it has focused mainly on assessment of the aquatic environment quality of mangrove plants in Safaga and El-Quih regions compared to water quality in Wadi El-Quih and Kalwaye regions (devoid of mangroves). The levels of physiochemical parameters (temperature - DO - pH - turbidity - electric conductivity - salinity – NO_2 - PO_4) were within the limits of CCME and MMWQS guidelines except for relatively low values of dissolved oxygen in the El-Quih area that ranged from 2-4.25 mg/L. Nitrate levels were high in all monitoring sites, which ranged between 67.17-75.47 µg/l. The El-Quih region (mangrove-rich area) recorded maximum values in salinity, Turbidity, electric conductivity, and nitrites, while a minimum value in dissolved oxygen and phosphate. Low water quality in El-Quih area may be render to biological activity or natural wildlife, or geological processes (erosion, sedimentation,..). The aquatic environment of the mangrove communities in El-Quih area needs continuous monitoring and many measures to improve its quality. This helps conserve and develop mangrove forests, which contribute directly to reducing climate change through the absorption of greenhouse gases.

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