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Environmental Characterization of Summer and Winter Distribution of Mangrove Patches Along the Red Sea, Egypt

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ABSTRACT
The mangrove ecosystem is a unique and precious habitat. This ecosystem is scattered along the Red Sea coast. It is considered one of the most distinguished ecosystem**s** worldwidesince it works as an ecosystem stabilizer. It provides the ecosystem with countless benefits, such as shoreline protection, climate enhancement, and nutrient enrichment. Hence, studying the mangrove ecosystem is critically important to understand the habitats around the mangrove, the factors affecting their growth, and the threats they face, in addition to building a baseline of informationto reduce and mitigate them. In the current study, water samples were collected adjacent to the patches of mangroves from different five locations along the Egyptian Red Sea coast (during the summer and winter of 2023). Samples were analyzed for physicochemical characterization, including temperature, TDS, pH, salinity, turbidity, electrical conductivity, and nutrients (NH_4, NO_2, NO_3, PO_4 andSIO_4) for winter-to-summer variation evaluation. Chlorophyll a and b concentrations and total chlorophyll were also assessed. The results showed variations by season and site; the highest temperature was recorded in summer at the Hamata site, reaching 36.20°C. Mostly, the Hamata site showed an increase in nutrient concentrations (NH_4, PO_4, NO_2, NO_3 and SIO_4), reaching 2.42, 2.45, 1.76, 3.75 and 2.94mg/l, respectively. Chlorophyll a and b concentrations, and total chlorophyll in the summer season reached 3.80, 8.23 and 12.03µg/l, respectively.

INTRODUCTION

The Red Sea is a semi-closed basin that connects the Mediterranean Sea to the north with the Indian Ocean to the south and divides the African Continent from the Arabian Peninsula **(Saad, 2010)**. The Egyptian Red Sea coastal region extends for about 1200km from the Suez Governorate in the north to the Egypt/Sudan borders in the south, with an average width of about 200km in Egypt **(Hereher, 2015)**. The ecosystems of the Red Sea (including habitats and species) are very productive, producing a variety of marine and coastal renewable resources **(Hariri *et al*., 2002)**. It is notable because the majority of the Egyptian Red Sea's output is concentrated over a short coastal region. However, this coastal strip is connected with the most human activity, causing several environmental stresses **(Madkour, 2015)**.

The Red Sea coastal vegetation is an essential biological component, comprising date palms, reed swamps, and other freshwater-dependent plants, as do salt-tolerant flora (halophytes) and mangroves **(Zahran *et al*., 2009)**. These ecosystems assist in stabilizing shorelines and keep them from erosion. Several plant species present in the coastal plain of the Red Sea are also of cultural and therapeutic value **(Shaltout*et al*., 2018)**.

Mangrove swamps are one of the most special and mysterious ecosystems along the Egyptian Red Sea coast. Mangrove regions are generally found on brackish and salty coasts in the intertidal zone **(Abdel-Hamid *et al.*, 2018)**. Mangrove of the Red Sea represents the Indo-Pacific region's northernmost limit of mangroves (28°N) **(Shaltout*et al*., 2018)**. The growth of the vegetation, like seagrasses, rises toward the southern Red Sea. The *Avicennia marina*, by far is the most frequent of the four mangrove species identified for the Red Sea **(Abbas *et al*., 2019)**. Mangroves are represented by two species around the Egyptian Red Sea; *Avicennia marina* (*A. marina*) (black mangrove) and *Rhizophoramucronata* (the red mangrove) **(Khalifa, 2015)**. *A. marina* is mostly distributed along the coast, whereas *R. mucronata* is only found along the Egyptian-Sudanese border **(Gab-alla*et al*.,2010)**.

Mangroves play a critical role in ecosystems by serving as essential habitats for a wide variety of marine and terrestrial species, while simultaneously offering invaluable advantages to both the environment and human communities **(Alongi, 2015)**. Due to their exceptional capacity to flourish in saline environments, mangroves provide refuge and breeding areas for a multitude of species, including those of commercial significance among fish populations**(Nagelkerken *et al*., 2008)**. Additionally, they play a crucial role in coastal protection by stabilizing shorelines and reducing the impact of erosion and storms **(Gilman *et al*., 2008)**. Furthermore, mangroves are key players in carbon sequestration, helping to mitigate climate change by storing significant amounts of carbon dioxide **(Donato *et al*., 2011)**. Their economic importance cannot be understatedsince they provide resources and ecosystem services that support local economies and livelihoods **(Cintrón-Molero *et al*., 2018)**. Protecting and conserving the mangroves is essential for maintaining biodiversity, safeguarding coastal communities, and combating climate change on a global scale **(McLeod &Salm, 2009)**.

Mangroves are sensitive habitats, and they face anthropogenic stresses, such as coastal developments, overfishing, pollution (especially solid wastes and oil spills), wood cutting, plant diseases, habitat destruction, and irresponsible tourism practices **(Abdelwahab, 2021).** This research seeked to assess the status of the mangroves in the designated areas by examining the environmental characteristics of the adjacent waters during two opposite climatic seasons. This involved conducting physicochemical and biological measurements, followed by the interpretation of the findings to better understand this ecosystem and propose some mitigation measures for its existence and sustainability.

MATERIALS AND METHODS

1. Description of the study area

The study area extends on the Red Sea coast for a distance of up to approximately 350km; starting from Abu Monkar Island in the north at latitude 27°12'55.41" N and longitude 33°52'38.90" E to the city of Hamata in the south at latitude 24°19'20.43" N and longitude 35°20'34.71"E. The study area was divided into 5 stations: Abu Monkar Island, Safaga Protectorate, Al-Quwaih area (north of the city of Al-Qusier), Wadi Mastoura area in Wadi El-Gemal Protectorate, and finally the Hamata area, respectively, from north to south. It can be noted that all stations are stations where mangrove trees grow in different densities along the coast in the form of separate patches. The study stations can be divided and described as follows:

Site (1) Abu Monkar Island (27°13'2.48"N, 33°52'47.98"E): The mangroves at this site are dense stands of the *Avicenna marina* species covering $0.4km^2$ at the center of the Island. A shallow channel passes through the trees. Oil pollution affects the island along its coast and within the channel due to oil strikes on the island that were not treated or controlled promptly, and solid wastes, particularly plastics, accumulate in the mangroves. The area where the mangrove is located has no direct human activities or influences although there are some tourist activities on the island, including swimming, skiing, etc.

Site (2) Safaga protectorate (26°36'59.98"N , 34° 0'43.61"E): The mangrove stands are located about 19km south of Safaga City, with a dense and healthy *Avicenna marina* covering about $0.1km^2$. There is a nursery in the reserve to replant seedlings to restore mangroves. There have also been successful attempts to cultivate the *Rhizophora mucronata* species, with some five-year-old trees having been planted.

Site (3) Al-Quwaih (26°24'3.68"N , 34° 6'56.83"E): This area is located 35km north of Qusier City, with an area of approximately $0.1km^2$. Its mangroves are dense and interwoven in the form of patches. Most trees are not submerged in water all the time, as they are in a shallow area connected to the sandy beach.

Site (4) Wadi Mastoura (24°22'48.00"N , 35°15'46.80"E): This mangrove patch is located within the boundaries of the “Wadi El Gemal” protectorate. Separate stands of mangrove trees of the *Avicenna marina* species exist with no dense patches directly exposed to the sea and are almost submerged all the time.

Site (5) Hamata (24°19'20.43"N , 35°20'34.71"E): Both types of mangroves exist in the Hamata area: The *A. marina* and *R.mucronata* mangrove trees are present in separate, with dense patches parallel to the coast and separate areas in front of the coast from the seaside. The area shows some efforts to replant mangrove trees in this area with seedling nurseries for both species.

Those five stations targeted for the study were visited twice a year during the summer and winter of 2023. Twenty water samples were collected from the stations (4 samples/site) during the study periods for later laboratory analyses. In addition, *in-situ* measurements for water quality were conducted during the field visits at five determined points at each site. All measurements were conducted using a transect starting from and running perpendicular to the seaward edge. Measurements were taken to measure water quality in areas where mangroves are present, as well as in front of the mangrove areas on the seaside, where measurements and samples were taken perpendicular to the shoreline.

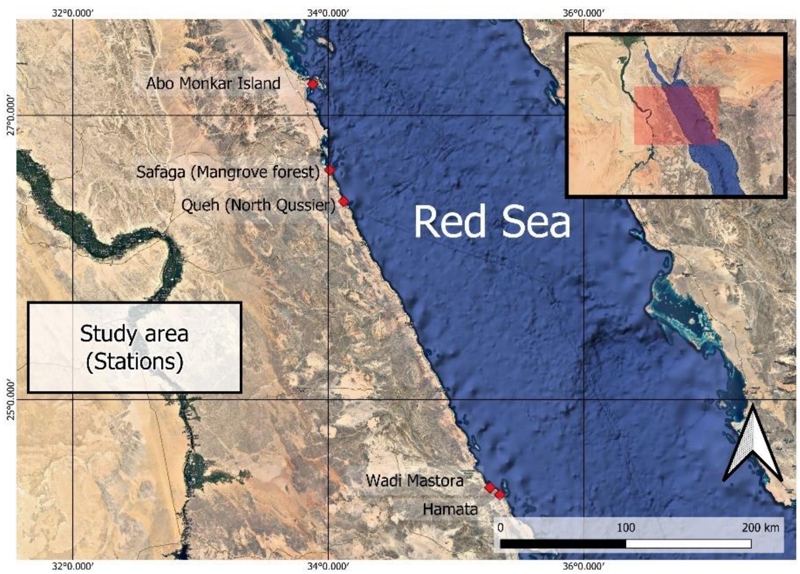

Fig. 1. Locations of sampling sites (1): Abo Monkar Island, (2) Safaga, (3) Al-Quwaih "North Qussier", (4) WadiMastora, (5) Hamata (Source: Google Earth Pro)

2. Sampling procedures

Two liters of subsurface water (10cm below the surface of the water) were collected in a tightly sealed polyethylene bottle from eachsite. Each site was sampled with onshore and offshore samples. Water bottle samples were wrapped with aluminum foil paper to prevent light effects and kept in an icebox under freezing conditions until they were returned to the laboratory for further treatments and analyses.

Fig.2. Photos taken during the sampling process for different sites during the study period

3. Sampling procedures and analysis

Several parameters were measured on-site during the sampling process: salinity, total dissolved solids, electrical conductivity, turbidity, pH, and temperature using a portable multi-water parameter model: Lutron YK-2001PHA, while turbidity was measured using a portable turbidity meter model: Lutron TU-2016.

For nutrient samples, the water samples were stored in polyethylene bottles and analyzed for nitrates, nitrites, phosphates, and silicates using a Shimadzu double beam spectrophotometer model UV-150-02 at the relevant parameter wavelength, according to the protocol of **Strickland and Parsons(1965)**.

For chlorophyll samples present in water, the water samples were collected in polyethylene bottles placed in a dark cooler and packed in ice at the time of collection, then they were filtered upon return from the trip within 3- 4 hours.

Subsequently, 500ml of water sample was passed through a membrane filter (47mm diameter, 5.0µm pore size). The pigments from the concentrated seawater sample were then extracted using an aqueous solution of acetone. The concentration of chlorophyll a was assessed through spectrophotometric measurement of the extract's absorbance at different wavelengths **(Environmental Sciences Section, 1991)**. Subsequently, the absorbance readings were utilized in a standard equation for analysis **(Pérez-Patricio *et al.*, 2018)**.

The concentrations of each pigment fraction (Chlorophyll-a, chlorophyll-b, and total chlorophyll) were determined as µg/l using the following equations:

$$\textbf{Chl-a} = (12.7 * A_{664}) - (2.69 * A_{630})$$

$$\textbf{Chl-b} = (21.5 * A_{630}) - (5.20 * A_{664})$$

$$Chl_{total} = \text{Chl-a} + \text{Chl-b}$$

Fig.3. Sampling process example for all sites showing that the starting point (A) is the nearest point to the shoreline and the last point (F) is the farthest point from the shoreline

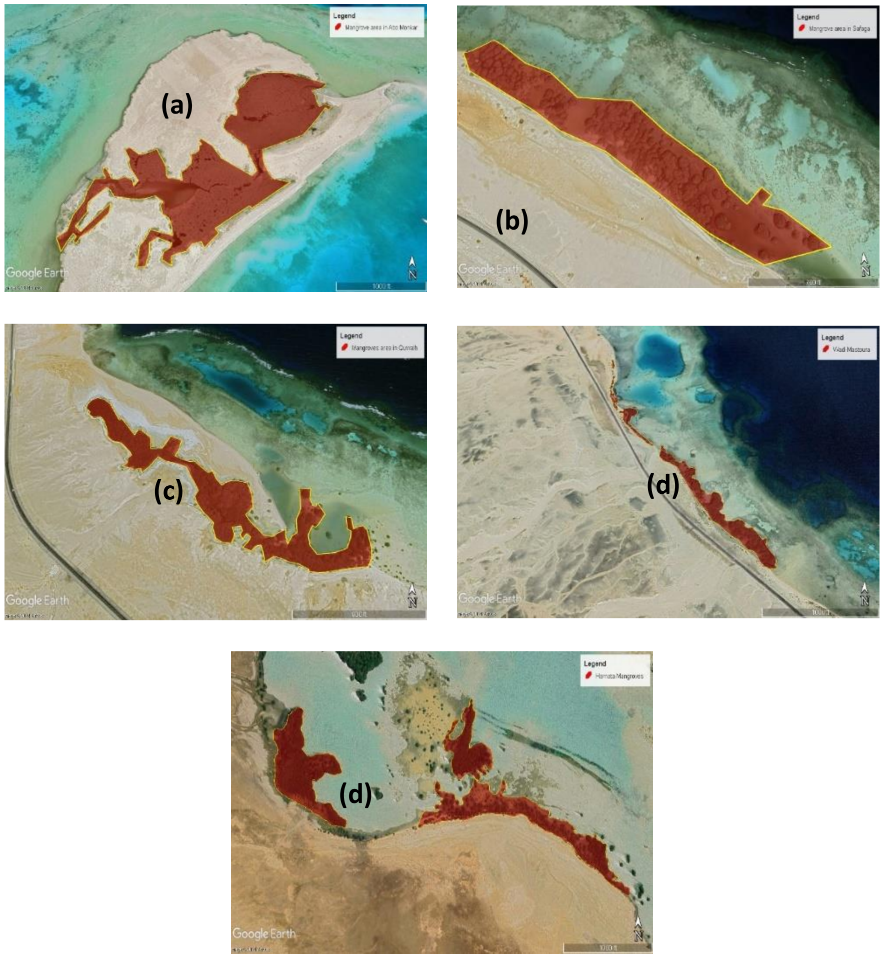

Fig.4. Aerial view of the study area sourced from Google Earth Pro **(Google Earth Pro, 2024)** Sampling sites: the red color illustrates mangrove distribution:**(a)** Abo Monkar Mangroves, **(b)** Safaga Protectorate Mangroves, **(c)** Al-Quwaih Mangroves, **(d)** Wadi Mastora Mangroves, **(e)** Hamata Mangroves

RESULTS

1. Physico-chemical parameters along the investigated seasons

1.1. Salinity and temperature

1.1.1. Winter data

The detailed temperature and salinity data shown in Fig. (5) across various points (A, B, C, D, E, F) and stations offered a nuanced understanding of environmental conditions. In terms of temperature, Abo Monkar and Safaga presented relatively moderate conditions, with average temperatures of 18.53 and 22.08°C, respectively. Al-Quwaih station showcased a consistent temperature pattern with an average of 26.12°C, while Wadi Mastoura and Hamata stood out with higher averages of 26.85 and 26.72°C, respectively. The maximum temperatures further emphasized the distinctiveness of Wadi Mastoura and Hamata, reaching 27.30 and 27.00°C, respectively. In contrast, Safaga recorded the lowest minimum temperature at 21.40°C. Turning to salinity, Abo Monkar and Safaga exhibited moderate levels between sites, while Al-Quwaih showed higher salinity, contributing to the diversity in environmental conditions. Wadi Mastoura emerged with the highest average salinity at 43.65ppt, underlining its unique characteristics.

1.1.2. Summer data

The provided data encompasse temperature and salinity measurements at various points (A, B, C, D, E, F) for the five stations, as shown in Fig. (5). In terms of temperature, Abo Monkar recorded the highest maximum at 32.10°C, while Safaga exhibited the maximum average temperature of 31.08°C. The lowest temperature values were observed at point F in Abo Monkar (30.60°C). Generally, the average temperatures ranged from 26.65°C in Al-Quwaih to 34.40°C in Hamata. The salinity measurements indicated that Abo Monkar had the highest salinity values, with a maximum of 50.1ppt and an average of 47.98ppt. Safaga consistently showed high salinity levels as well. Al-Quwaih exhibited the lowest average salinity (46.07ppt), while point F in Abo Monkar had the lowest recorded salinity at 45.1ppt.

1.2. Total dissolved solids (TDS) and electrical conductivity

1.2.1. Winter data

During the winter sampling period, as shown in Fig. (5), water quality parameters were assessed at five different points: Abo Monkar, Safaga, Al-Quwaih, Wadi Mastoura, and Hamata. The total dissolved solids (TDS) in parts per million (ppm) varied across the locations, with the average TDS ranging from 44183ppm at Safaga to 45383ppm at Al-Quwaih. The maximum TDS was recorded at Al-Quwaih with 46700ppm, while the minimum was at Safaga with 43300ppm. A similar trend was observed in conductivity measurements in milliSiemens (mS), where average values ranged from 66.82mS at Safaga to 67.80mS at Al-Quwaih. The maximum conductivity was observed at Al-Quwaihat 69.1mS, while the minimum was at WadiMastouraat 66.08mS. Overall, the water quality parameters fluctuated slightly across the locations, with Al-Quwaih consistently exhibiting higher TDS and conductivity compared to the other points.

1.2.2. Summer data:

During the summer sampling period, as shown in Fig. (5), water quality parameters were assessed at five different points: Abo Monkar, Safaga, Al-Quwaih, Wadi Mastoura, and Hamata. TDS (ppm) varied across the locations, with an average TDS ranging from 45650ppm at WadiMastoura to 48883ppm at Abo Monkar. The maximum TDS was recorded at Abo Monkar with 51200ppm, while the minimum was at Al-Quwaih with 45300ppm. Conductivity measurements in milliSiemens (mS) also showed variability across the locations, with average values ranging from 68.72mS at Safaga to 73.58mS at Abo Monkar. The maximum conductivity was observed at Abo Monkar with 77.5mS, while the minimum was at Safaga with 69.4mS. Overall, the water quality parameters exhibited fluctuations across the sites during the summer period, with Abo Monkar consistently showing higher TDS and conductivity compared to the other points.

1.3. pH values

1.3.1. Winter data

The dataset provided pH measurements at various points (A, B, C, D, E, F) in five distinct locations (Abo Monkar, Safaga, Al-Quwaih, WadiMastoura, Hamata), as shown in Fig. (6). Abo Monkar maintained a relatively stable pH range, with values ranging from 8.24 to 8.35, suggesting a consistent acidity level. Safaga exhibited slight variations, with the pH fluctuating between 8.25 and 8.35. Al-Quwaih showed a narrow pH range, with values between 8.22 and 8.31, indicating relatively stable acidity levels. Wadi Mastoura demonstrated a consistent pH level ranging from 8.24 to 8.36, while Hamata showed a slightly wider range, with pH values ranging from 8.42 to 8.9.

The average pH across all points in the respective locations was 8.29, emphasizing an overall acidity stability. The maximum pH values were observed at different points across locations, with Hamata recording the highest value of 8.9. The minimum pH values were relatively consistent, ranging from 8.22 to 8.42.

1.3.2. Summer data

The pH measurements at the sampling points (A, B, C, D, E, F) in the specified locations revealed that Abo Monkar recorded the highest maximum pH value at 7.48, while Safaga exhibited the maximum average pH of 7.33. The lowest pH values were observed at point D (7.04) and point A (7.01) in Abo Monkar. On average, pH levels ranged from 7.03 in Al-Quwaih to 7.67 in Wadi Mastoura. The data indicated spatial variability in pH levels, with Abo Monkar and Safaga showing distinct pH patterns. These variations may be influenced by local environmental factors, anthropogenic activities, and natural processes, as shown in Fig. (6).

1.4. Turbidity (ntu) values

1.4.1. Winter data

During the winter sampling period, turbidity levels were measured at five different points: Abo Monkar, Safaga, Al-Quwaih, Wadi Mastoura, and Hamata. as shown in Fig. (7). Turbidity, measured in nephelometric turbidity units (ntu), varied across the locations. The average turbidity levels ranged from 0.37NTU at Al-Quwaih to 1.31NTUat Abo Monkar. The maximum turbidity was observed at Abo Monkar with 3.55NTU, while the minimum was consistently recorded as 0NTU across all locations. Notably, Safaga exhibited the second-highest average turbidity at 0.76NTU. These findings suggest variations in water clarity across the studied sites during the winter season, with Abo Monkar showing the highest turbidity levels among the locations surveyed.

1.4.2. Summer data

During the summer sampling period, turbidity levels were measured at five different points: Abo Monkar, Safaga, Al-Quwaih, Wadi Mastoura, and Hamata, as shown in Fig. (7). Turbidity, representing water clarity, varied across the locations. The average turbidity levels ranged from 0.00NTU at Al-Quwaih to 1.16NTU at Abo Monkar. Notably, Safaga exhibited the lowest average turbidity at 0.27NTU. The maximum turbidity was observed at Abo Monkar with 3.22NTU, while Wadi Mastoura and Hamata both showed high turbidity values with 1.33 and 3.2 NTU, respectively. It's worth mentioning that Al-Quwaih exhibited no detectable turbidity during this period. These findings indicate fluctuations in water clarity across the surveyed sites during the summer season, with Abo Monkar and Hamata showing the highest turbidity levels.

1.5. Nutrients level

1.5.1. Winter data

During the winter sampling period, nutrient concentrations were measured for two locations, onshore and offshore, across five different points: Abo Monkar, Safaga, Al-Quwaih, Wadi Mastoura, and Hamata, as shown in Fig. (8). The average concentrations of various nutrients in milligrams per liter (mg/l) varied across the locations. For NH4 (ammonium), the onshore concentrations ranged from 1.83mg/l at WadiMastoura to 2.1mg/l at Abo Monkar, while offshore concentrations ranged from 1.93mg/l at Abo Monkar to 2.31mg/l at Safaga, respectively. For PO4 (phosphate), the onshore concentrations ranged from 1.53mg/l at Hamata to 1.99mg/l at WadiMastoura, andthe offshore concentrations ranged from 1.39mg/l at Abo Monkar to 3.54mg/l at Safaga, respectively. For NO2 (nitrite), the onshore concentrations ranged from 1.25mg/l at Hamata to 1.48mg/l at Abo Monkar, while offshore concentrations ranged from 1.39mg/l at Abo Monkar to 1.69mg/l at Safaga, respectively. For NO3 (nitrate), the onshore concentrations ranged from 2.33mg/l at Hamata to 2.93mg/l at Abo Monkar, while offshore concentrations ranged from 2.81mg/l at Abo Monkar to 3.54mg/l at Safaga, respectively. Lastly, for SIO4 (silicate), the onshore concentrations ranged from 1.91mg/l at Hamata to 2.34mg/l at Abo Monkar, while offshore concentrations ranged from 1.96mg/l at Al-Quwaih to 2.69mg/l at Safaga, respectively.

1.5.2. Summer data

During the summer sampling period, nutrient concentrations were measured in two locations, onshore and offshore, across five different points: Abo Monkar, Safaga, Al-Quwaih, Wadi Mastoura, and Hamata, as shown in Fig (8). The average concentrations of various nutrients (mg/l) varied across the locations. For NH4 (ammonium), the onshore concentrations ranged from 1.930mg/l at Al-Quwaih to 2.100mg/l at Abo Monkar, while offshore concentrations ranged from 1.930mg/l at WadiMastoura to 2.420mg/l at Hamata, respectively. For PO4 (phosphate), the onshore concentrations ranged from 1.580mg/l at Al-Quwaih to 2.160mg/l at Wadi Mastoura, and the offshore concentrations ranged from 1.600mg/l at Al-Quwaih to 3.750mg/l at Hamata, respectively. For NO2 (nitrite), the onshore concentrations ranged from 1.350mg/l at Al-Quwaih to 1.460mg/l at Abo Monkar, while offshore concentrations ranged from 1.660mg/l at Wadi Mastoura to 1.760mg/l at Hamata, respectively. For NO3 (nitrate), the onshore concentrations ranged from 2.550mg/l at Al-Quwaih to 3.060mg/l at Abo Monkar, while offshore concentrations ranged from 2.080mg/l at Wadi Mastoura to 3.750mg/l at Hamata, respectively. Lastly, for SIO4 (silicate), the onshore concentrations ranged from 2.020mg/l at Al-Quwaih to 2.650mg/l at Abo Monkar, while offshore concentrations ranged from 2.150mg/l at Abo Monkar to 2.940mg/l at Hamata, respectively.

2. Variations in chlorophyll content

2.1. Chlorophyll-a, chlorophyll-b and total chlorophyll along the investigated seasons

2.1.1. Winter data

The winter profile for chlorophyll data revealed variations in concentrations across different locations, as shown in Fig. (9), both onshore and offshore, along the studied coastal areas. Abo Monkar exhibited moderate levels of chlorophyll-a (3.33µg/l) and chlorophyll-b (6.73µg/l) onshore, with slightly lower values offshore (2.86µg/l for chlorophyll-a and 6.11µg/l for chlorophyll-b). However, the total chlorophyll concentration remained relatively higher onshore (10.07µg/l) compared to offshore (8.97µg/l). Safaga, on the other hand, demonstrated slightly elevated chlorophyll levels both onshore and offshore, with chlorophyll-a concentrations of 3.56 and 3.86µg/l, respectively, and chlorophyll-b concentrations of 6.92 and 9.37µg/l, respectively. The total chlorophyll content was also higher compared to Abo Monkar, reaching 10.49µg/l onshore and 13.23µg/l offshore. Al-Quwaih showcased similar patterns, with moderate chlorophyll levels onshore and slightly lower concentrations offshore, while Wadi Mastoura and Hamata exhibited comparable trends as well. Overall, the winter profile highlighted varying chlorophyll concentrations across different locations, suggesting localized dynamics in algal productivity and environmental conditions along the coastal regions during this season.

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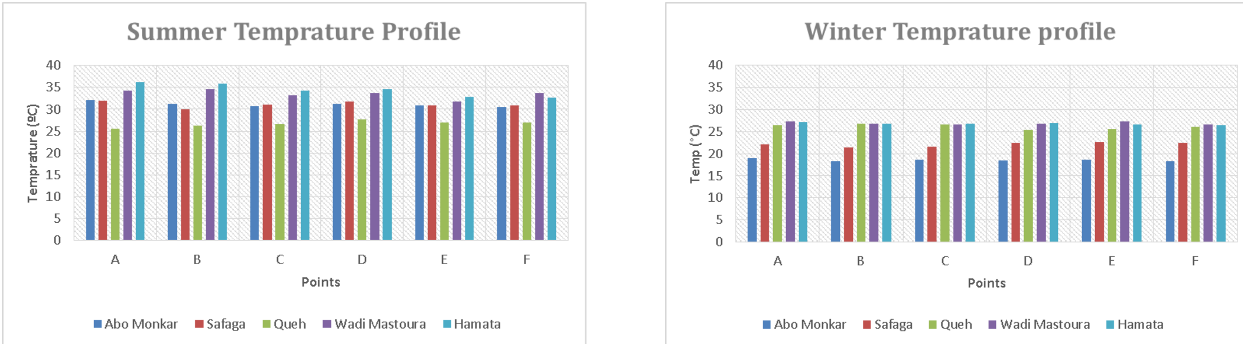
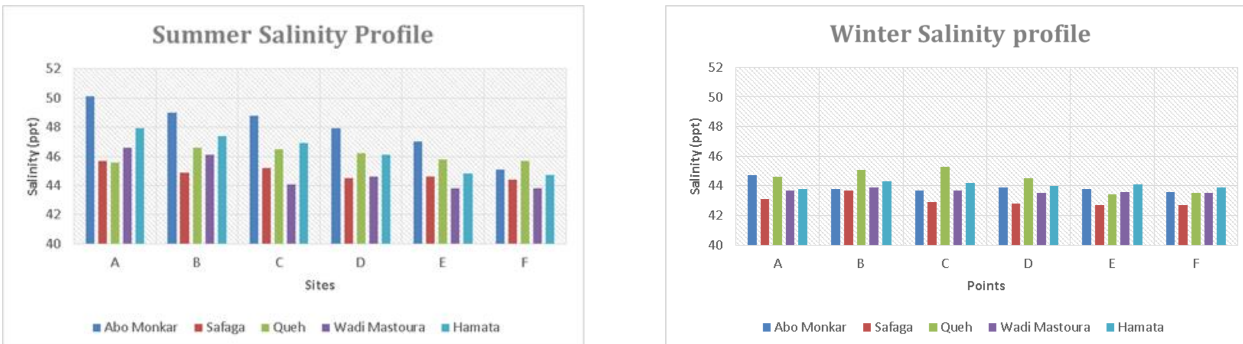
2.1.2. Summer data

In the summer profile of chlorophyll data presented in Fig. (9), notable variations in concentrations were observed across different coastal locations, both onshore and offshore. Abo Monkar showed moderate levels of chlorophyll-a (2.79µg/l) and chlorophyll-b (5.68µg/l) onshore, with slightly higher values offshore (2.90µg/l for chlorophyll-a and 5.76µg/l for chlorophyll-b). The total chlorophyll content remained relatively consistent between onshore (8.48µg/l) and offshore (8.67µg/l) sites. Safaga exhibited similar trends with slightly elevated chlorophyll concentrations onshore and offshore, with chlorophyll-a concentrations of 3.33 and 3.31µg/l, respectively, and chlorophyll-b concentrations of 6.20and 6.59µg/l, respectively. The total chlorophyll content at Safaga remained relatively stable, with values of 9.53µg/l onshore and 9.91µg/l offshore. Al-Quwaih displayed a different pattern, with lower chlorophyll levels onshore compared to offshore, suggesting potential offshore productivity. Wadi Mastoura and Hamata also showed variations in chlorophyll concentrations between onshore and offshore locations. Overall, the summer profile underscored dynamic fluctuations in chlorophyll concentrations across different coastal areas, indicative of seasonal changes in algal productivity and environmental conditions.

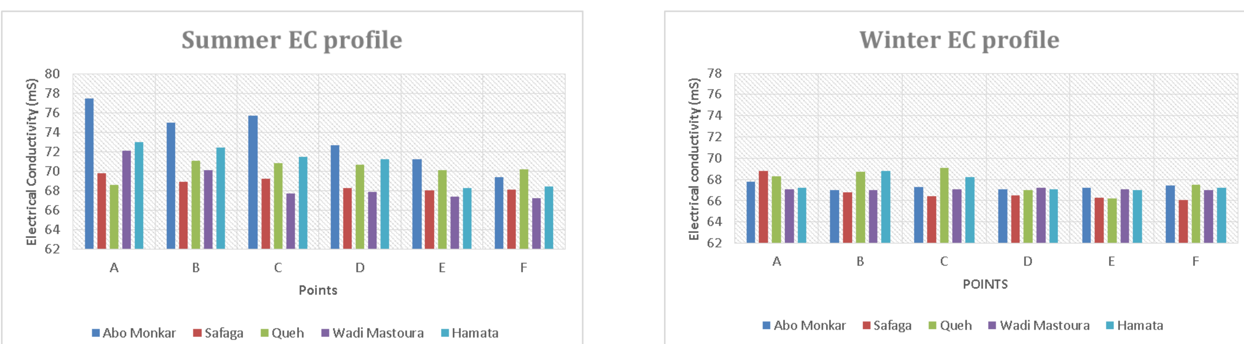


(a)



(b)

Fig. 5.(a) Summer to wintervariations in temperature profile between the two seasons in "ºC" during day time between 4:00 to 5:00 pm; **(b)** Summer to winter variations in salinity profile between the two seasons in "ppt"



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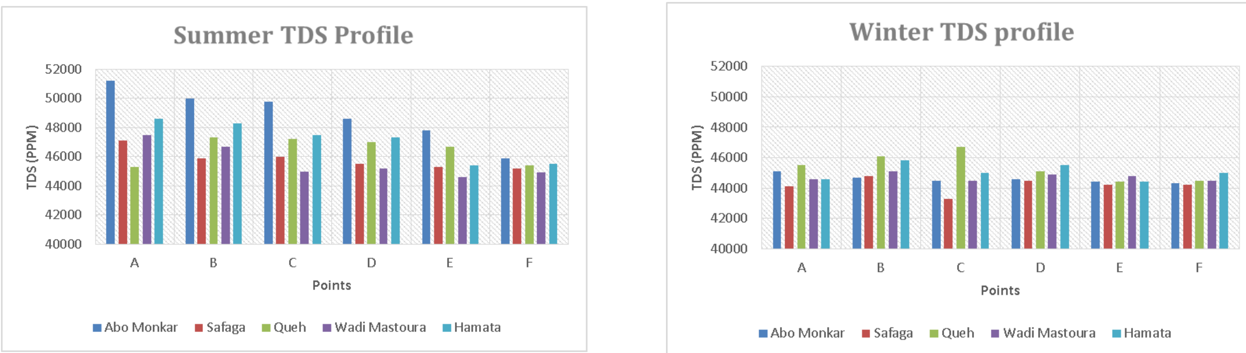
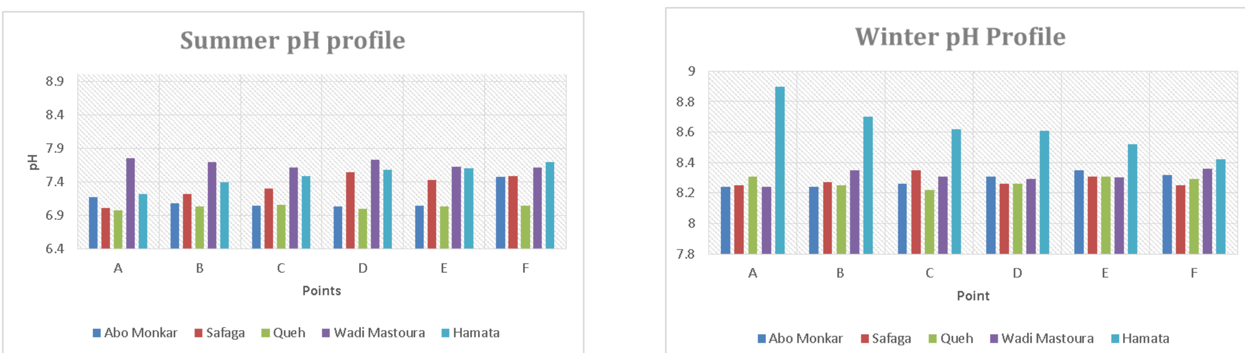
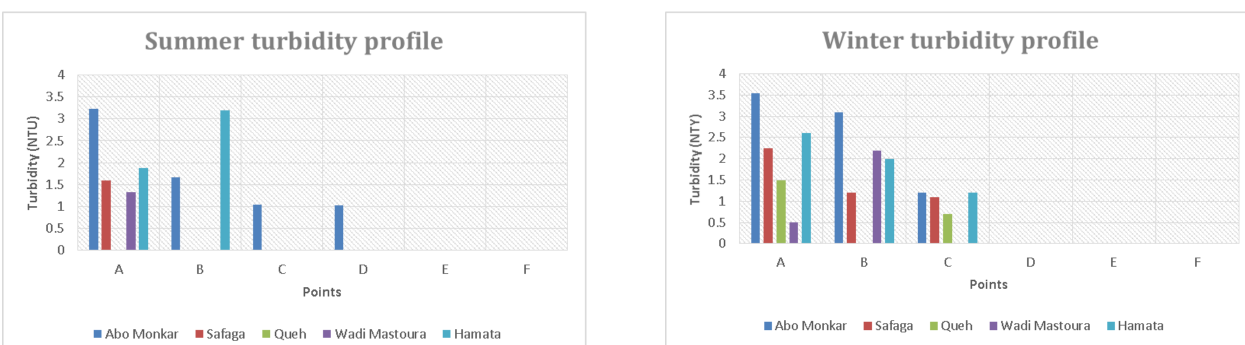


(d)

Fig.6.(c) Summer to winter variations in electric conductivity profile in "mS"; **(d)** Variation in TDS profile between two seasons in "ppm"

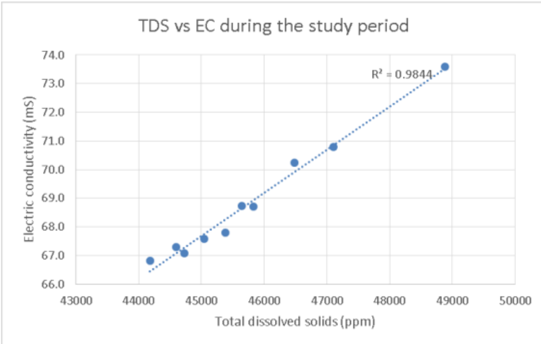


(e)

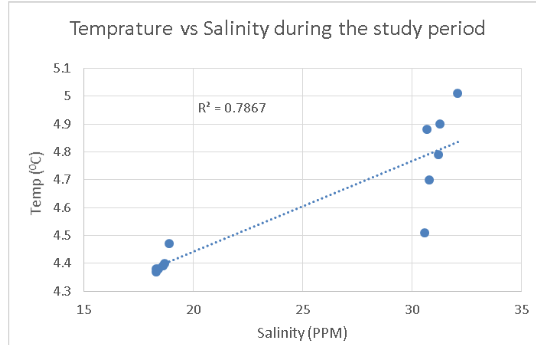


(f)

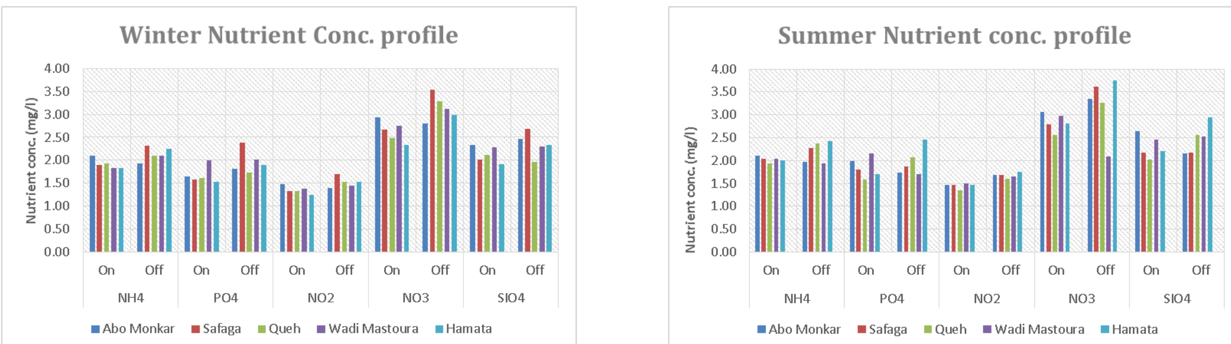
Fig.7.(e) Variation in pH profile between two seasons; **(f)** Variation in turbidity profile between the two seasons in "NTU"



(g)



(h)



(i)

Fig.8.(g) Regression plot for TDS against EC during the study period;**(h)** Regression plot for temperature against salinity during the study period; **(i)** Variations of nutrients profile "NH4 , PO4, NO2, NO3, SIO4" during the two seasons of study

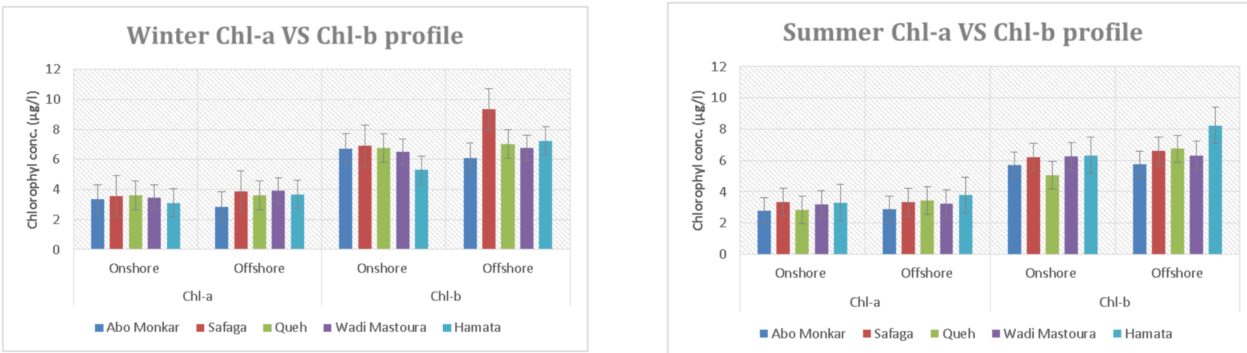


Fig (j)

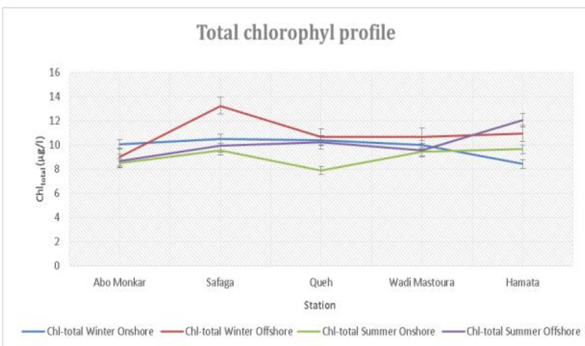


Fig (k)

Fig.9.(j) Summer to winter variations inchlorophyll-a& chlorophyll-b profile during the two seasons of study**;(k)** Summer to winter variations in total chlorophyll profile for winter and summer

3. Average variations between the two seasons

Table 1. Average water quality parameters during winter and summer seasons at the five study sites

Average results	Winter					Summer				
	Abo Monkar	Safaga	Al-Quwaih	WadiMastora	Hamata	Abo Monkar	Safaga	Al-Quwaih	Wadi Mastora	Hamata
Salinity	43.92	42.98	44.40	43.65	44.05	47.98	44.88	46.07	44.83	46.30
TDS	44600	44183	45383	44733	45050	48883	45833	46483	45650	47100
EC	67.30	66.82	67.80	67.08	67.58	73.58	68.72	70.25	68.73	70.80
Turbidity	1.31	0.76	0.37	0.45	0.97	1.16	0.27	0.00	0.22	0.85
Temp	18.53	22.08	26.12	26.85	26.72	31.12	31.08	26.65	33.57	34.40
pH	8.29	8.28	8.27	8.31	8.63	7.15	7.33	7.03	7.67	7.50

Table (1) provides a comprehensive comparison of average water quality parameters during both the winter and summer seasons in five different locations (Abo Monkar, Safaga, Al-Quwaih, WadiMastora, Hamata). In winter, salinity ranged from 42.98 to 46.30, with the highest value recorded at Hamata site. The total dissolved solids (TDS) varied between 44183 and 47100ppm, with the maximum at the site of Hamata. The electrical conductivity (EC) ranged from 66.82 to 73.58, peaking at Safaga site. Turbidity fluctuated from 0.00 to 1.31, with the highest observed at Abo Monkar site. The temperature ranged from 18.53 to 34.40°C, with the highest recorded at Wadi Masora site. While, the pH value varied from 7.03 to 8.63, reaching its peak at Hamata during winter.

In summer, salinity ranged from 44.05 to 46.07, with the highest at Hamata site. TDS varied between 45050and 48883ppm, peaking at Hamata. EC ranged from 67.08 to 73.58mS, with the highest recorded at Safaga site. Turbidity fluctuated from 0.00 to 1.16, with the highest observed at Abo Monkar. The temperature ranged from 26.12 to 34.40°C, with the highest recorded at the site of WadiMastora. The pH varied from 7.03 to 8.63, reaching its peak at Hamata site during the summer season.

3.1. Nutrient levels

By comparing the nutrient levels between winter and summer seasons in various on-shore and off-shore locations, the specific values highlight seasonal variations:

- **NH4 (Ammonium)**

In Abo Monkar, NH4 increased from 2.1(winter) to 2.1mg/l (summer) on-shore and from 1.93 to 1.97mg/l off-shore. Safaga experienced a slight decrease from 1.9 to 2.04mg/l on-shore and an increase from 2.31 to 2.28mg/l off-shore. Al-Quwaih showed a decrease from 1.93 to 1.93mg/l on-shore and an increase from 2.1 to 2.38mg/l off-shore. Wadi Mastoura displayed an increase from 1.83 to 2.04mg/l on-shore and a decrease from 2.1 to 1.93mg/l off-shore. Hamata exhibited a slight decrease from 1.83 to 2.0mg/l on-shore and an increase from 2.24 to 2.42mg/l off-shore.

- **PO4 (Phosphate)**

Abo Monkar and Safaga both showed a decrease in PO4 levels on-shore and off-shore. Al-Quwaih exhibited an increase from 1.64 to 1.99mg/l on-shore and a decrease from 1.81 to 1.73mg/l off-shore. Wadi Mastoura displayed a decrease from 1.99 to 1.93mg/l on-shore and an increase from 2.01 to 1.7mg/l off-shore. Hamata demonstrated a slight decrease from 1.53 to 1.7mg/l on-shore and an increase from 1.9 to 2.45mg/l off-shore.

- **NO2 (Nitrite)**

Abo Monkar and Safaga generally exhibited a decrease in NO2 levels on-shore and off-shore. Al-Quwaih displayed an increase from 1.48 to 1.46mg/l on-shore and a decrease from 1.39 to 1.69mg/l off-shore. Wadi Mastoura demonstrated a decrease from 1.37 to 1.5mg/l on-shore and an increase from 1.45 to 1.66mg/l off-shore. Hamata experienced a slight decrease from 1.25 to 1.46mg/l on-shore and an increase from 1.53 to 1.76mg/l off-shore.

- **NO3 (Nitrate)**

Abo Monkar, Safaga, and Al-Quwaih generally exhibited a decrease in NO3 levels on-shore and off-shore. Wadi Mastoura showed a decrease from 2.93 to 3.06mg/l on-shore and an increase from 2.81 to 3.35mg/l off-shore. Hamata demonstrated a slight decrease from 1.91 to 2.21mg/l on-shore and an increase from 2.34 to 2.94mg/l off-shore.

- **SIO4 (Silicate)**

Abo Monkar and Safaga generally exhibited a decrease in SIO4 levels on-shore and off-shore. Al-Quwaih showed a decrease from 2.34 to 2.65mg/l on-shore and an increase from 2.46 to 3.35mg/l off-shore. Wadi Mastoura decreased from 2.28 to 2.46mg/l on-shore and increased from 2.3 to 2.53mg/l off-shore. Hamata experienced a slight decrease from 1.91 to 2.21mg/l on-shore and an increase from 2.34 to 2.94mg/l off-shore.

3.2. Chlorophyll content

3.2.1. Chlorophyll dynamics

Comparing the two seasons, winter and summer, revealed distinct patterns in chlorophyll concentrations along the studied coastal areas. In the winter, chlorophyll levels tend to be higher overall compared to the summer. Across various locations, including Abo Monkar, Safaga, Al-Quwaih, Wadi Mastoura, and Hamata, chlorophyll-a and chlorophyll-b concentrations showed a general trend of being elevated during the winter months. This suggested potentially enhanced algal productivity during the colder season. Additionally, the total chlorophyll content, which combined chlorophyll-a and chlorophyll-b, also demonstrated higher values during winter across most sites, indicating a more robust presence of phytoplankton during this time. In contrast, summer chlorophyll levels exhibited slightly lower concentrations overall, indicating potential seasonal fluctuations in algal growth and productivity. However, variations in chlorophyll concentrations between seasons were also observed across different locations, highlighting the complexity of seasonal dynamics in coastal ecosystems. Overall, the comparison underscored the influence of seasonal changes on chlorophyll concentrations, reflecting the intricate interplay between environmental factors and biological processes in coastal regions throughout the year.

DISCUSSION AND CONCLUSION

Mangroves are the most productive ecosystems that share their resources with their surroundings, and the ecosystem needs to be healthy to allow the mangroves to survive and flourish **(Spalding & Leal, 2021)**. Mangrove forests exist in tropical and subtropical regions, serving as a transitional zone between terrestrial and near-shore marine ecosystems, with a connection to estuarine environments **(Dodd & Ong, 2008)**.

The variation in results between seasons for the factors measured at all study sites is evident, which explains the great diversity of living organisms in the region that was observed during field trips to the sites.

The resulting average water quality parameters for winter and summer seasons at the five locations (Abo Monkar, Safaga, Al-Quwaih, Wadi Mastoura, Hamata) offer insights into the environmental conditions of these coastal areas, in which salinity levels vary between winter and summer across all locations. There is a general increase in salinity observed in the summer, indicating potential evaporation and reduced freshwater input during the warmer season.

Higher salinity in summer, particularly at coastal sites like Hamata, may impact the distribution of marine organisms adapted to specific salinity ranges.Temperature variations between winter and summer are consistent with expectations, with a notable increase in summer temperatures. Elevated temperatures during this period can accelerate biological processes, affect species distribution, and influence the metabolic rates of aquatic organisms. Total dissolved solids (TDS) display a parallel trend with salinity, indicating a concentration of dissolved minerals and ions in the water during the warmer months. This has implications for water quality and may affect aquatic ecosystems.

Electrical conductivity (EC) values align with salinity and TDS trends reflect an increased ion content. Elevated EC can impact the nutrient availability and aquatic organism physiology, contributing to the overall dynamics of the aquatic ecosystem.

Turbidity levels, representing water clarity, show a reduction in summer. Clearer water during this season can influence light penetration and impact the growth of aquatic plants and algae, further shaping the ecological balance.

pH levels exhibit seasonal variations, which can have implications for nutrient availability and substance toxicity. The lower pH observed at Hamata in summer raises questions about potential influences on marine life, warranting further investigation.

In summary, the observed patterns in salinity, TDS, EC, turbidity, temperature, and pH provide a comprehensive overview of the seasonal dynamics in water quality. These variations have ecological implications for marine ecosystems, emphasizing the need for continued monitoring and research to understand and mitigate potential impacts on aquatic life.

The chlorophyll concentrations in the winter and summer seasons provide valuable insights into the primary productivity and phytoplankton abundance in the studied locations. During the winter season, chlorophyll levels at both onshore and offshore sites exhibit relatively higher values compared to the summer season.

In winter, Abo Monkar, Safaga, Al-Quwaih, Wadi Mastoura, and Hamata all show elevated chlorophyll concentrations in both onshore and offshore locations. This could be attributed to factors such as nutrient availability, lower water temperatures, and favorable conditions for phytoplankton growth during this period. The higher chlorophyll concentrations in winter suggest increased biological activity and potential nutrient upwelling, supporting phytoplankton productivity.

Conversely, during the summer season, chlorophyll concentrations decrease across the sites. Abo Monkar, Safaga, Al-Quwaih, Wadi Mastoura, and Hamata exhibit lower chlorophyll levels, both onshore and offshore, indicating a reduction in phytoplankton biomass. The decline in chlorophyll concentrations during the summer may be influenced by factors like increased water temperatures, potential nutrient limitations, and changes in light availability.

The observed seasonal variations in chlorophyll concentrations have ecological implications for the overall health of the marine ecosystem. Higher chlorophyll levels in winter suggest increased nutrient availability and biological activity, while lower levels in summer may indicate a shift in the environmental conditions affecting phytoplankton growth **(Suikkanen, *et al.*, 2007)**.Continued monitoring of chlorophyll concentrations is essential for understanding the dynamics of primary productivity and the overall health of the marine environment in the studied locations.

The nutrient levels in winter and summer play a crucial role in understanding the ecological dynamics of the marine environment **(Guo *et al.*, 2020)**. In winter, the onshore and offshore nutrient concentrations show variations across locations. Abo Monkar, Safaga, Al-Quwaih, Wadi Mastoura, and Hamata all exhibit distinct levels of ammonium (NH4), phosphate (PO4), nitrite (NO2), nitrate (NO3), and silicate (SiO4). These differences may be attributed to factors such as local hydrodynamics, nutrient sources, and water circulation patterns.

During the winter, elevated nutrient levels in Abo Monkar, Safaga, and Wadi Mastoura, particularly in offshore areas, indicate potential nutrient upwelling or external inputs. The presence of higher nutrients could stimulate the phytoplankton growth and support the increased biological activity during this season **(Severiano *et al.*, 2016)**

In contrast, the nutrient levels in summer show a different pattern. Generally, there is a decrease in nutrient concentrations compared to winter. Abo Monkar, Safaga, Al-Quwaih, Wadi Mastoura, and Hamata all experience a reduction in NH4, PO4, NO2, NO3, and SiO4 during the warmer season. This decline could be associated with increased biological uptake, warmer temperatures, and potential nutrient utilization by marine organisms. **(Reef *et al.*, 2010)**.

Similarly, the nutrient dynamics in the studied locations exhibit seasonal variations, with higher levels in the winter and lower levels in summer. These variations have implications for the overall productivity and health of the marine ecosystem. Continued monitoring of nutrient levels is essential for assessing long-term trends and understanding the factors influencing nutrient dynamics in the Red Sea **(Lundsor *et al.*, 2020)**.

In conclusion, the comprehensive analysis of seasonal variations in water quality parameters, chlorophyll concentrations, and nutrient levels in the studied locations highlights the dynamic nature of marine ecosystems in the Red Sea. The observed patterns underscore the complicated interaction between environmental factors and biological processes, shaping the health and productivity of coastal waters. These findings emphasize the importance of ongoing monitoring efforts to better understand and manage the impacts of changing environmental conditions on marine life. Addressing the seasonal fluctuations in water quality and nutrient dynamics is crucial for the sustainable management and conservation of coastal ecosystems in the region. Furthermore, continued research is essential to determine the underlying mechanisms driving these seasonal variations and their implications for marine biodiversity and ecosystem functioning.

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