Environmental Assessment on Water and Sediments of Bardawil Lagoon, North Sinai; Egypt

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ABSTRACT

Bardawil lagoon, a hypersaline coastal lagoon located along the northern Mediterranean coast of Sinai, Egypt, plays a vital ecological and economic role, especially through its fishery resources. This study assesses the lagoon's environmental status by analyzing water and sediment quality. Key water parameters—such as temperature, salinity, pH, dissolved oxygen (DO), and nutrient concentrations—were monitored across 12 stations during 2020. Salinity levels varied from 37.50 PSU to 57.21 PSU, with higher levels recorded in summer, driven by evaporation. Dissolved oxygen ranged from 4.31 mg/L to 8.21 mg/L, with lower values observed in warmer months, indicating seasonal oxygen stress. Sediment analysis revealed varying levels of the total organic matter (TOM) content ranged from 1.60% to 6.23%, reflecting different ecological conditions across the lagoon. Despite generally good water quality across most stations, increasing salinity, sediment accumulation, and pollution risks require continuous monitoring. The study highlights the importance of sustainable management practices to protect the biodiversity and fish productivity of this ecologically significant lagoon.

Keywords: Bardawil Lagoon, Water quality assessment, Egypt.

INTRODUCTION

Bardawil lagoon, a large hypersaline coastal lagoon located on the Mediterranean coast of Sinai, Egypt, plays a vital role in the region's ecology and economy. It is renowned for its rich biodiversity and fishery resources, including high-value species such as sea bream, sea bass, and Solea Solea. The lagoon's unique geochemical and physicochemical characteristics, shaped by both natural processes and human activities, distinguish it as one of Egypt's most important coastal lagoons(Samy-Kamal, 2015).

As one of the least polluted wetlands in the Mediterranean region, lagoon El-Bardawil serves as a critical spawning and nursery area for economically valuable fish species (El-Shabrawy and El Sayed, 2005). Despite its relatively pristine condition, the lagoon's ecosystem is highly sensitive to environmental fluctuations, including changes in temperature, salinity, and human-induced pressures such as pollution and habitat modification. These factors have led to increased interest in studying its environmental dynamics over the past two decades (Abd Ellah and Hussein, 2009).

The lagoon's hypersaline nature, with salinity levels ranging from 38.18 to 62.40 PSU, is influenced by its separation from the Mediterranean Sea by a narrow sandbar and its connection to the sea through artificial inlets. These inlets regulate water exchange and significantly impact water circulation, salinity, and, consequently, fish productivity. The lagoon's shallow depth and varied sediment composition further contribute to its ecological complexity(El-Shabrawy and El Sayed, 2005).

In recent years, Lagoon Bardawil has faced growing environmental challenges, including rising salinity levels, sediment accumulation, and the impacts of overfishing and tourism development(Elshinnawy and Almaliki, 2021). These changes have affected fish populations and water quality, underscoring the need for continuous assessment of the lagoon's physicochemical and geochemical parameters. Monitoring these factors is essential for understanding the lagoon's ecological status, ensuring the sustainability of its biodiversity, and supporting economic activities such as fisheries (El-Bana *et al.*, 2002).

Like other coastal lagoons, Lagoon Bardawil is impacted by various human activities, such as the large-scale land reclamation project in Northern Sinai and the El-Salam Canal. Seepage from irrigation and drainage waters through the loose sandy soil will influence the lagoon's water quality and eventually percolate into the aquifer beneath the lagoon and its surrounding area (Said, 2022). Additionally, domestic waste from new settlements near the project will combine with agricultural pollutants, further altering the environmental conditions of the region. The region's low rainfall and shifting shorelines also significantly affect the lagoon's geomorphology (Touliabah *et al.*, 2002).

A key concern for Lagoon Bardawil is heavy metal contamination. Metals such as iron (Fe), copper (Cu), zinc (Zn), cadmium (Cd), and manganese (Mn) accumulate in the lagoon's sediments and water,

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potentially entering the food chain and posing risks to both aquatic life and human health. Given the lagoon's importance as a source of high-quality fish, assessing and mitigating the effects of heavy metal pollution is crucial for maintaining its ecological balance and protecting public health (Shreadah et al., 2015).

This study focuses on assessing the water quality of Lagoon Bardawil, with particular attention to key parameters such as salinity and nutrient concentrations. The findings will provide valuable insights into the current environmental status of the lagoon and inform future management strategies aimed at preserving its ecological integrity and supporting its vital fishery resources.

MATERIALS AND METHODS

Study Area:

Lagoon Bardawil is a large coastal lagoon situated on the northern Mediterranean coast of the Sinai Peninsula in Egypt between 32° 40`and 33° 30 ` E and 31° 3` and 31° 14` N Fig (1). It stretches approximately 85 km in length and up to 22 km in width, with depths ranging from 0.3 to 3 meters(Khalil *et al.*, 2013). The lagoon is mostly separated from the Mediterranean Sea by a narrow sandbar, and four channels connect it to the sea, two of which are artificial (Figure 1).

The lagoon features several islands and peninsulas, particularly in the eastern section, and its surrounding dunes support diverse vegetation. Extensive mudflats are frequently exposed, especially in the eastern part of the lagoon (Azab and Noor, 2003).

Lagoon Bardawil is a crucial habitat for migratory birds, serving as an important wintering and staging area. During autumn, it hosts up to 500,000 birds. Due to its ecological significance, Lagoon Bardawil was added to the Record of Sites Likely to Undergo Changes in Ecological Character, following concerns raised in the 1990 Egyptian National Report (Pritchard, 2014). In October 1991, a preliminary application of the Ramsar Monitoring Procedure was conducted to assess and monitor the lagoon’s environmental status (McInnes *et al.*, 2017).

Sampling analysis:

Water samples were seasonally collected in 2020 from twelve stations representing different habitats within Bardawil Lagoon (Table 1). A 4-liter Ruttner water sampler was used for sample collection. Physico-chemical parameters such as temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), and nutrient salts were analyzed following standard methods (APHA, 2012) (Rice et al., 2012).

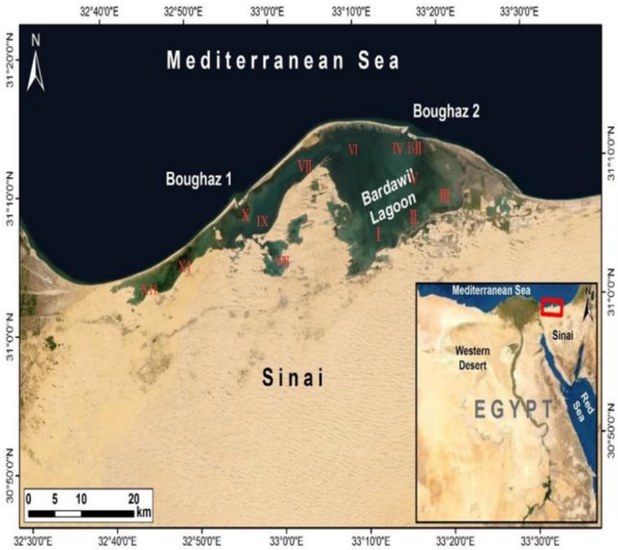

Fig. 1: study area Lagoon El-Bardawil, Egypt using Sufrer 21 (Golden Software).

Table 1. Location of sampling station in lagoon Bardawil

Station No.	Location	Latitude	Longitude
I.	Karn Hamda	31° 09` 18``	33° 19` 25``
II.	Boughaz ‖	31° 12` 27``	33° 15` 43``
III.	El- Kals	31° 11` 78``	33° 06` 24``
IV.	El-Aofra	31° 08` 96``	33° 07` 92``
V.	El-Telul	31° 04` 50``	33° 10` 13``
VI.	Mitzfag	31° 05` 81``	33° 13` 65``
VII.	El-Rooc	31° 05` 35``	32° 59` 18``
VIII.	Boughaz l	31° 05` 35``	32° 59` 18``
IX.	Romea	31° 06` 12``	32° 53` 30``
X.	El-Nasr	31° 05` 67``	32° 51` 18``
XI.	Nedjela	31° 04` 20``	32° 48` 36``
XII.	Raba´a	31° 03` 51``	32° 46` 75``

A Hydro-lab Multi Set 430i WTW was used to measure physical and chemical parameters at multiple locations throughout the day, following standard procedures (APHA, 2012) (Rice *et al.*, 2012), with prior calibration. Dissolved oxygen (DO) was measured using the modified Winkler method (Shriwastav *et al.*, 2017), Nitrite and ammonium were determined following the method proposed by (Strickland, 1972), while nitrate and phosphate were measured using the techniques as described by (Sa'id and Mahmud, 2013).

Also, twelve surface sediment samples were collected from various locations across Bardawil Lagoon. Approximately 2 kg of sediment was gathered using a Van Veen Grab sampler, stored in plastic bags within an icebox, and transported to the laboratory. Once in the lab, the samples were air-dried, sieved through a 2mm mesh to remove larger debris like pebbles and branches, and then ground in an agate mortar for further analysis.

Grain size analysis of the sediment followed (Folk, 1974) method. The total organic carbon (TOC%) was determined according to the procedure outlined by (Loring and Rantala, 1992), while Dissolved Organic Matter (DOM) was carried out using potassium permanganate method according to. (Yeomans and Bremner, 1988). Total phosphorus (TP) content in the sediment was analyzed through combustion at 550°C for two hours, followed by a 16-hour extraction with 1 N HCl, as described by (Aspila *et al.*, 1976). Phosphorus concentrations were then determined colorimetrically in the sediment extracts using the method of (Murphy and Riley, 1962). The total nitrogen (TN) content of the sediment was estimated through Kjeldahl digestion, following the procedure of (Mudroch and Azcue, 1995).

RESULTS AND DISCUSSION

Physico-Chemical Parameters

Physico-chemical parameters are critical for determining the nature, quality, and classification of water (fresh, brackish, or saline) in any aquatic ecosystem (Abdo, 2005). The key physical parameters measured in Bardawil Lagoon during 2020 include water temperature, salinity, pH, transparency, chemical oxygen demand (COD), biological oxygen demand (BOD), dissolved oxygen (DO), and dissolved organic matter.

Water Temperature:

Temperature plays a crucial and vital role in aquatic ecosystems, influencing metabolism, photosynthesis, and chlorophyll concentration in organisms. It also affects the chemical and physical properties of water (Mackey et al., 2013). Temperature controls the rate of chemical reactions and has significant effects on fish growth, reproduction, and immunity. Additionally, as water temperature rises, oxygen levels decrease.

In this study, water temperature in Bardawil Lagoon varied seasonally (Figure 2). The lowest temperature recorded was 11.92 °C at station III during winter, while the highest was 28.48°C at station XII during summer. The temperature in spring ranged from 23.23°C to 25.25°C, while in summer, it varied between 27.07°C and 28.48°C. During autumn, temperatures ranged from 18.69°C to 21.51°C, and in winter, they spanned from 11.92°C to 15.35°C. The average seasonal temperature was 24.22°C in spring, 27.72°C in summer, 20.65°C in autumn, and 14.02°C in winter. The minimal variation in water temperature may be attributed to the lagoon’s shallow nature.

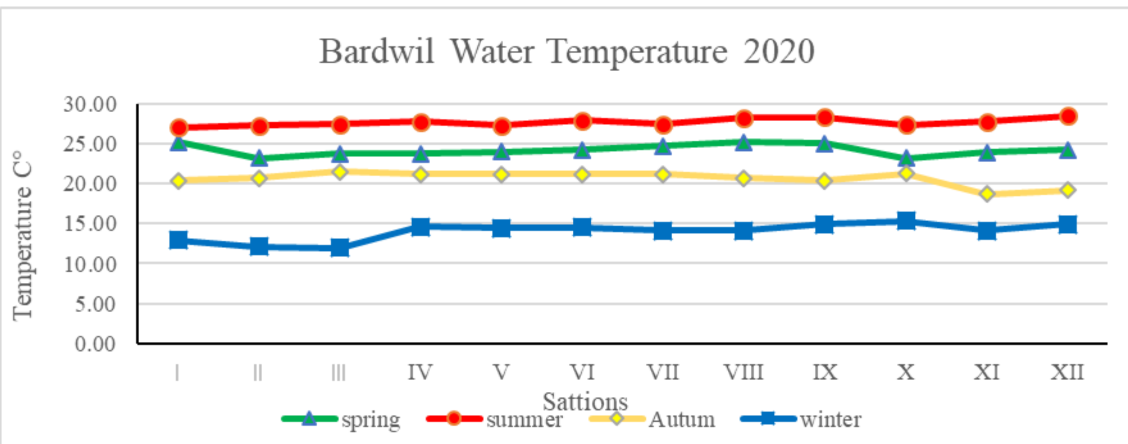

Fig. 2. Seasonal and regional distribution of water temperature (°C) in Bardawil Lagoon water during 2020

Salinity:

Salinity is a crucial factor that influences the health of marine organisms and serves as an indicator of seawater dilution caused by land-based discharges, which helps gauge contamination levels in aquatic environments (Zyadah *et al.*, 2004). The exchange of water between Bardawil Lagoon and the Mediterranean Sea plays a vital role in regulating both water circulation and salinity levels (Ali and Khairy, 2016). Climatic conditions are also a key driver of salinity fluctuations, with the highest levels typically recorded farther from the inlets. Historical data shows that Bardawil Lagoon reached a maximum salinity of 73.02 PSU in 1967, and the salinity rose even further to 100% in some parts of the lagoon when its inlets were blocked between 1969 and 1971 (Krumgalz, 1980).

In this study, salinity measurements demonstrated noticeable seasonal variations. The highest salinity was observed in Spring 2020 at station XII (Figure 3), where it reached 57.21 PSU, likely due to increased evaporation and climate conditions such as wind. The lowest salinity was recorded during Autumn 2020 at station X, measuring 37.50 PSU. On average, annual salinity levels were recorded at 45.53 PSU ±4.48. Winter 2020 had the lowest seasonal salinity average of 42.31 PSU ±3.76, likely due to reduced evaporation and increased rainfall, which diluted the lagoon's water with inflow from the Mediterranean. In contrast, the highest average salinity occurred in Summer 2020, at 47.49 PSU ±6.18, driven by increased evaporation during the hotter months (Ali and Khairy, 2016).

Hydrogen ion concentration (PH):

Hydrogen ion concentration (pH) refers to the amount of hydrogen ions in a solution, typically measured in pH units, which indicates the acidity or alkalinity of the solution. pH is calculated as the logarithm of the inverse of hydrogen ion activity. In natural waters, an optimal pH value range between 6.5 and 8.5. If the pH rises above 9.6 or drops below 4.5, aquatic life may not survive (El-Gamal, 2017). The pH of water can also influence the solubility and toxicity of chemicals and heavy metals (Wong, 2003).

In Bardawil Lagoon, the water has consistently shown alkaline pH levels (pH > 7). The lowest recorded pH was 7.0 in 1997 (Touliabah et al., 2002), while the highest was 9.01 in 2012 (Khaled et al., 2017). Several factors, including water temperature, dissolved oxygen, organic matter decomposition, and photosynthetic activity, can influence pH levels (El-Gamal, 2017).

In this study, the pH values remained on the alkaline side (Figure 4). The highest pH value of 8.89 was recorded in spring at station XII, likely due to increased photosynthetic activity, which consumes carbon dioxide and raises pH (Shakweer, 2006). The lowest pH, 8.20, was observed at station II during summer, possibly linked to higher bicarbonate levels and reduced carbon dioxide uptake by phytoplankton (Abdel-Satar, 2005). The lagoon's annual pH average was 8.49, with seasonal averages ranging from 8.38 ± 0.03 in autumn to 8.71 ± 0.10 in spring. These results indicate a slight increase compared to previous studies (Zaghloul et al., 2018) (Khalil et al., 2016, Saad et al., 2012) (Ali et al., 2006).

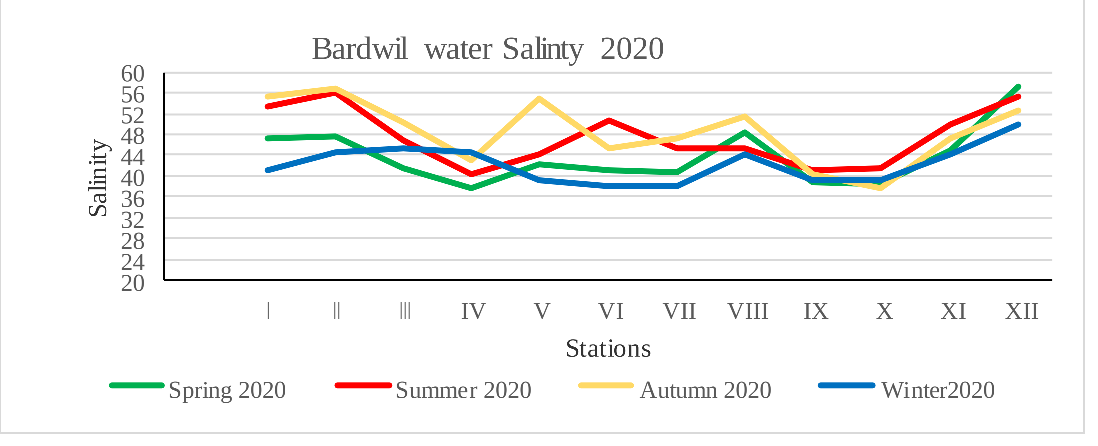

Fig. 3. Seasonal and regional distribution of water salinity (PSU) in Bardawil Lagoon during 2020

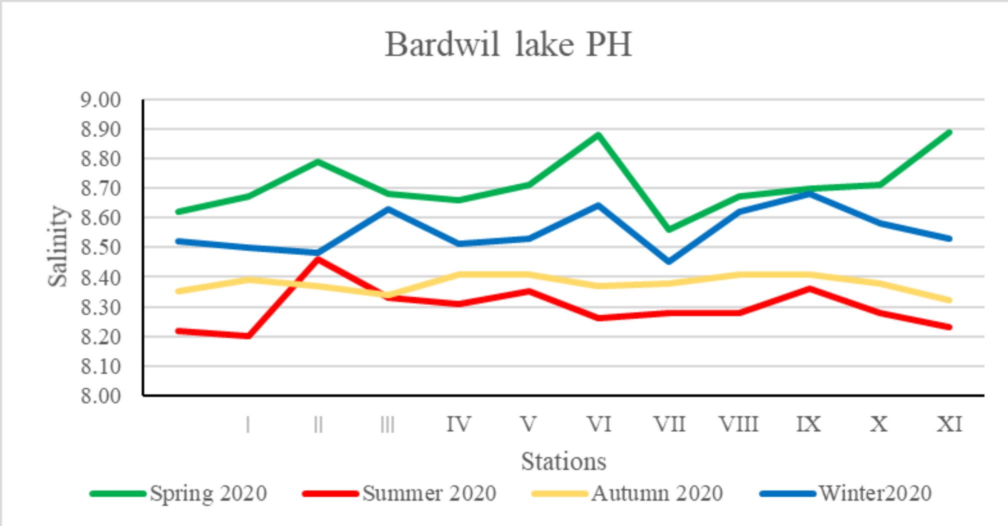

Fig. 4. Seasonal and regional distribution of water PH value in Bardawil lagoon during 2020

Table 2. Comparison between water pH values of Bardawil lagoon that obtained during the present study and those early records in the same lake

	Spring	Summer	Autumn	Winter	Year	References
Min	8.56	8.20	8.32	8.45	2020	Present study
Max	8.89	8.46	8.41	8.68		
Min	--	7.8	--	--	2015	(Zaghloul *et al.*, 2018)
Max	--	8.3	--	--		
Min	--	--	--	7.4	2014	(Khalil *et al.*, 2016)
Max	--	--	--	8.6		
Min	7.6	7.1	--	--	2006-2007	(Saad *et al.*, 2012)
Max	8.3	8.8	--	--		

Water transparency/turbidity:

Water transparency/turbidity refers to how easily light can pass through water, which is crucial for the growth of aquatic plants and algae. Transparency is directly related to the amount of light that can penetrate through the water column, affecting how deep sunlight can reach. This is important because plants and algae require sunlight for photosynthesis, a process that produces oxygen essential for fish and other aquatic organisms.

Turbidity, as defined by the American Public Health Association (APHA, 1998)(Rice *et al.*, 2012), is the optical property of water that causes light to scatter and be absorbed rather than transmitted in straight lines. The transparency of water depends on the quantity of suspended particles. More particles result in lower transparency, meaning murky or cloudy water prevents light from reaching deeper levels. Good water transparency is beneficial to aquatic life because it supports photosynthesis, which in turn produces oxygen needed by fish and other organisms.

To measure water transparency, a Secchi disk is commonly used. This simple device, about 20 cm in diameter, is lowered into the water until it is no longer visible, and the depth at which it disappears is recorded.

In the present study, Lagoon Bardawil showed high transparency levels. The values fluctuated between 100 cm in spring and winter, and 450 cm in summer at station X (Figure 5). The lowest transparency, 100 cm, was observed during spring and winter, while the highest, 450 cm, was recorded during summer. The seasonal averages were 162.50 ± 37.69 cm in spring, 204.17 ± 98.18 cm in summer, 168.75 ± 28.45 cm in autumn, and 145.83 ± 39.65 cm in winter. The annual average ranged from 112.50 cm to 262.50 ± 125 cm. The higher transparency observed in summer could be due to the stability of the lagoon water, while the higher turbidity in winter may be attributed to strong wind action and the resulting mixing of lagoon water, as well as phytoplankton blooms (Siliem, 1989). Turbidity in the lagoon is caused by suspended mineral or organic particles (Saad *et al.*, 2012).

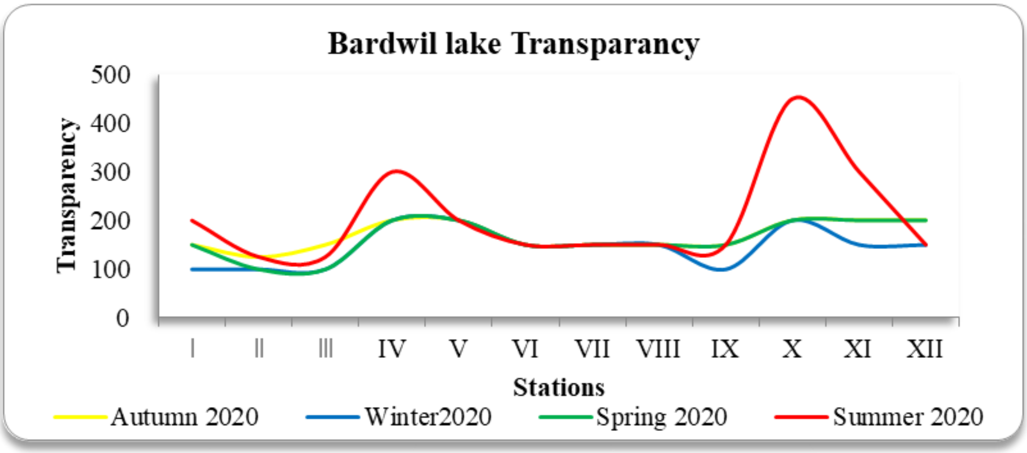

Fig. 5 .Seasonal and regional distribution of water transparency value in lagoon Bardawil during 2020

Chemical Analysis of water:

Dissolved Oxygen (DO):

Dissolved oxygen is a key parameter in aquatic ecosystems, vital for many physical and biological processes. It is essential for various forms of aquatic life, including fish, invertebrates, bacteria, and plants. In addition, oxygen is necessary for oxidation, nitrification, and decomposition processes. The factors that influence dissolved oxygen levels include respiration, photosynthesis, and the exchange of gases at the air-water interface (Saad *et al.*, 2012). Fish and crustaceans rely on oxygen for respiration through their gills, while plants and phytoplankton require dissolved oxygen for respiration, particularly when photosynthesis is not occurring due to the absence of light.

Dissolved oxygen refers to the amount of free, non-compound oxygen present in water and is crucial for both organisms and water quality (Wetzel, 2001). The actual concentration of DO (measured in mg/L) varies with temperature, pressure, and salinity. Low dissolved oxygen levels can lead to adverse health effects, including anorexia, respiratory issues, and tissue hypoxia in aquatic organisms (Wedemeyer and Wedemeyer, 1996).

In this study, the dissolved oxygen levels in Lagoon Bardawil fluctuated. The maximum value of 8.21 mg/L was recorded at stations VI and VII in winter, while the minimum value of 4.31 mg/L was observed at station I in summer. The lagoon's annual average DO levels ranged between 5.88 ± 0.80 mg/L and 6.79 ± 1.60 mg/L. Seasonal averages were 6.39 ± 0.52 mg/L in autumn, 7.42 ± 0.43 mg/L in winter, 5.84 ± 0.67 mg/L in spring, and 5.68 ± 0.81 mg/L in summer (Figure 6).

more oxygen during the decomposition of organic matter (Jadhav *et al.*, 2013). As the temperature increases, oxygen solubility decreases, meaning that warmer surface waters require less dissolved oxygen.

In comparison with previous studies, the present study shows a slight decrease in DO levels during winter (table 3). For instance, (El-Shabrawy and El Sayed, 2005) and (Ali *et al.*, 2006) reported different results for the same lagoon. (Khalil *et al.*, 2016) recorded dissolved oxygen concentrations ranging from 6.5 mg/L to 4.6 mg/L during winter.

Table3. comparison between dissolved oxygen in lagoon Bardawil water that obtained during the present study and those other records in the same lagoon

	Spring	Summer	Autumn	Winter	Year	References
Min	5.86	4.31	5.04	6.91	2020	Present study
Max	7.31	7.23	7.31	8.21		
Min	4.9	4.7	4.5	4.6	2014	(Khalil *et al.*, 2016)
Max	6.7	6.3	6.3	6.5		
Min	--	--	--	4.8	2004	(Ali *et al.*, 2006)
Max	--	--	--	10.2		
Min	--	--	--	5.8	2003	(El-Shabrawy and El Sayed, 2005)
Max	--	--	--	10		

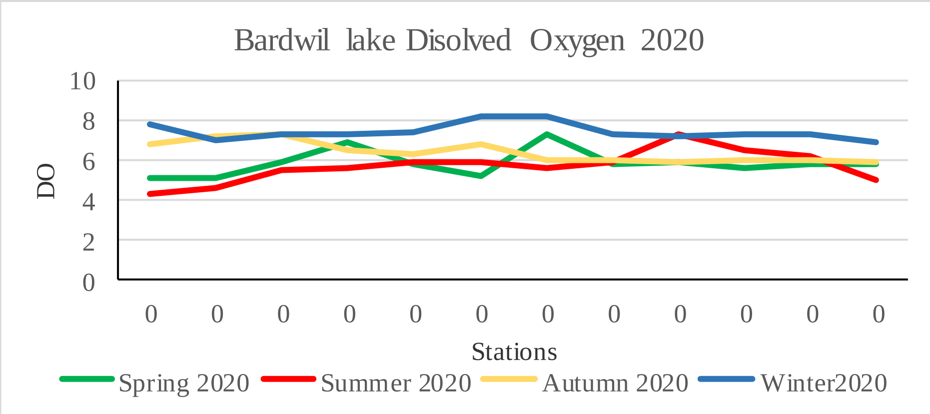

Fig. 6. Seasonal and regional distribution of dissolved oxygen concentration (mg/l) in lagoon Bardawil during 2020

In contrast, the current study observed levels of 8.21 mg/L and 6.91 mg/L. The higher levels of dissolved oxygen in winter may be due to wind-induced water mixing and lower temperatures, while lower levels in summer are likely caused by higher temperatures, increased biological activity, and respiration by organisms.

Dissolved Organic Matter (DOM):

Dissolved organic matter (DOM) refers to the fraction of organic material that remains in solution after passing through a 0.45 µm filter (Thurman and Thurman, 1985, Zsolnay, 2003). In aquatic systems, DOM originates from the partial decomposition of organic materials such as soil organic matter, plant residues, and organic matter released by living organisms, including bacteria, algae, and plants (Zhang *et al.*, 2019). DOM can support bacterial proliferation within water distribution systems (Volk *et al.*, 2002) and plays a significant role in ecosystems by influencing chemical and biological oxygen demand and affecting aquatic life (Jones, 1992).

In Lagoon Bardawil, DOM serves multiple purposes, including acting as a source of nutrients for aquatic fauna (Abdo, 2005). It can accumulate and release pollutants and plays a key role in ecosystem processes, as it is one of the largest reservoirs of organic carbon in aquatic environments (Hiriart-Baer *et al.*, 2013). DOM also functions as a food source, trace metal chelator, and photosensitizer in aquatic systems. It is produced both within aquatic ecosystems and from external sources like groundwater and terrestrial landscapes (Findlay and Parr, 2017).

During warmer seasons, DOM concentrations increase, likely due to higher organic productivity from flourishing phytoplankton and zooplankton (Tucker *et al.*, 1979). Conversely, lower DOM levels in cold seasons may result from high decomposition rates of organic matter in the presence of high dissolved oxygen levels (Wahby *et al.*, 1972).

In Lagoon Bardawil, the concentration of dissolved organic matter varied throughout the seasons. The highest DOM concentration was observed in summer at station II (8.48 ± 2.78 mg/L), while the lowest was recorded in winter at stations V, VI, and VII (0.96 ± 0.39 mg/L) (Figure 7). Seasonal averages for DOM were 2.23 ± 1.09 mg/L in winter, 2.83 ± 0.90 mg/L in autumn, 2.72 ± 0.92 mg/L in spring, and 4.20 ± 1.76 mg/L in summer. The annual average fluctuated between 1.9 mg/L and 4.50 ± 0.74 mg/L.

When compared to previous studies, the results showed little variation during the cold seasons, with previous studies recording DOM values of 9.33 and 9.25 mg/L (El-Shabrawy and El Sayed, 2005). The low DOM values in colder seasons can be attributed to increased decomposition rates in the presence of high dissolved oxygen content. The current study highlights a notable increase in DOM during the warmer months, likely due to higher temperatures (Table 4).

Table. 4. comparison between dissolved organic matter in lagoon Bardawil water that obtained during the present study and those other records in the same lake

	Spring	Summer	Autumn	Winter	Year	References
Min	1.28	2.24	1.6	0.96	2020	Present study
Max	4.4	8.48	4.32	4.32		
Min	4.9	4.7	9.25	8.04	2002-2003	(El-Shabrawy and El Sayed, 2005)
Max	6.7	6.3	9.33	8.1		

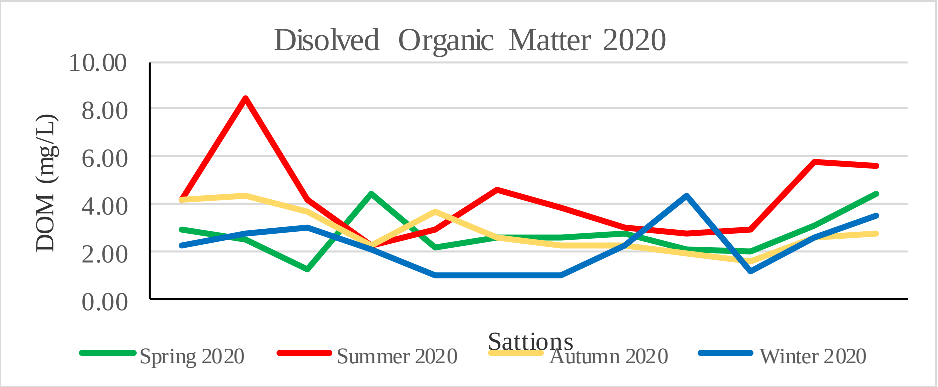

Fig .7. Dissolved organic matter concentration (mg/L) in lagoon Bardawil water during 2020

Water Quality Index (WQI):

The Water Quality Index (WQI) is a widely used tool for assessing the overall quality of water by aggregating various water quality parameters into a single number ((El-Hamid and Hegazy, 2017, Tokatli, 2019). The mathematical expression for calculating WQI is as follows:

$$WQI = \sum qi$$

Where *qi* the quality rating for each water quality parameter can be determined using the following equation:

$$qi = 100\left[\frac{Vi}{Si}\right]$$

Where Vi represents the measured value of a specific parameter at a particular sampling location, and Si is the water quality standard for that parameter. Therefore, a higher qi value indicates more polluted water.

The average water quality index AWQI is calculated using the following formula, which averages the n parameters:

In this study, WQI values have been calculated for 12 stations in the Bardawil lagoon. According to the WQI classification, water quality can be categorized into four broad categories: Excellent (0-25), Good (26-50), Poor (51-75), and Very Poor (76-100) (Rubio-Arias et al., 2012).

This classification provides a clear and structured way to assess and compare water quality across different sites. Stations I, II, III, V, X, and XI all have WQI values below 25, indicating excellent water quality. These values range from 3.56 at station V to 5.01 at station III. While, stations, such as IV, VI, VII, VIII, and XII, have WQI values ranging from 6.05 to 10.39, which classify them as having good water quality Figure 8.

The WQI values for Lagoon Bardawil indicate generally good to excellent water quality across the various sampling stations. Stations such as I, V, and II exhibit the best water quality, with WQI values below 5. On the other hand, stations like VII and VI, while still classified as "good," show slightly elevated WQI values that may require monitoring for future water quality management.

Overall, the data suggest that Lagoon Bardawil has relatively clean water, with no areas falling into the poor or very poor categories. However, areas with higher WQI values, such as stations VI and VII, may be more susceptible to future water quality degradation and should be monitored closely to maintain ecological balance (Wu et al., 2017).

Sediments Analysis:

Grain Size Composition

The grain size distribution of the sediments in Lagoon Bardawil varied significantly among the stations, with three distinct fractions: gravel, sand, and mud. Gravel content ranged from 0% at stations V, VII, X, and XII to a maximum of 32.07% at station IX. Sand dominated the sediment composition across most stations, with the highest percentage observed at station III (93.57%) and the lowest at station IV (59.63%). Mud content remained relatively low, with the highest value recorded at station X (26.18%) and the lowest at station IX (0.60%) (Table 5).

This variation in grain size can be attributed to differences in hydrodynamic conditions within the lagoon. Stations with higher sand percentages likely experience more energetic water movement, preventing finer particles such as mud from settling, whereas stations with higher gravel content may represent areas with a greater input of course materials from surrounding sources. The relatively low mud content indicates limited deposition of fine particles, which is consistent with the dynamic nature of the lagoon (Sondi and Pravdic, 2001, Tattersall *et al.*, 2003).

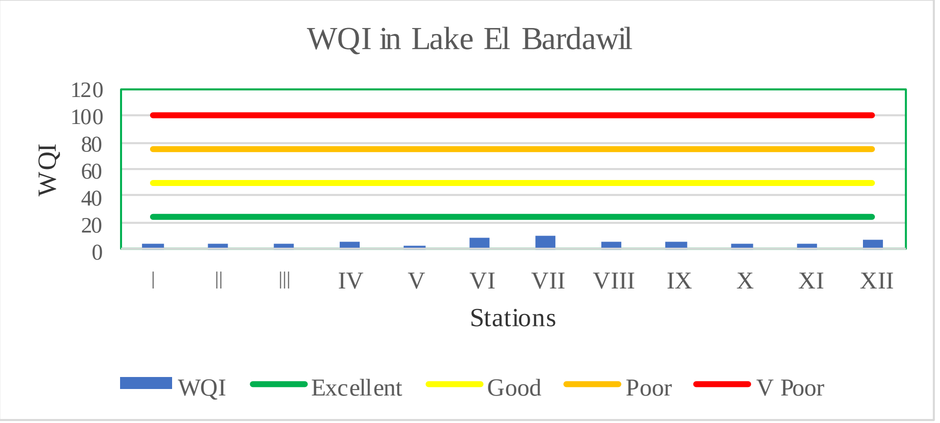

Fig. 8. Water Quality Index WQI in lagoon Bardawil during 2020

Table 5. The grain size analysis and the values of TOM%, water content%, TP, IP, OP and TN in surface sediments of Bardawil Lagoon

Sediments									
Stations	**Gravel %**	**sand %**	**mud %**	**TOM %**	**Water content %**	**TP (µg/g)**	**IP(µg/g)**	**OP(µg/g)**	**TN (µg/g)**
I	15.69	81.3	3.01	6.23	58.60	458.32	311.65	146.66	1104.6
II	26.74	71.06	2.2	2.14	29.53	151.76	110.97	40.79	706.3
III	4.78	93.57	1.65	4.89	44.94	319.71	231.83	87.88	726.25
IV	15.9	59.63	24.47	2.07	23.76	69.90	56.40	13.51	875.55
V	0	84.77	15.23	5.78	56.55	380.78	267.18	113.60	930.65
VI	16.37	61.52	22.11	3.52	41.73	293.02	291.80	1.22	876.1
VII	0	78.87	21.13	1.91	24.95	278.81	235.53	43.28	442.85
VIII	14.36	79.26	6.38	2.09	30.76	90.93	66.46	24.47	772.75
IX	32.07	67.33	0.6	2.68	35.08	113.82	74.04	39.78	761.55
X	0	73.82	26.18	1.60	23.69	194.91	176.45	18.46	740.1
XI	10.62	74.69	14.69	4.50	43.73	346.82	261.71	85.12	755.1
XII	0	76.5	23.5	4.67	37.84	277.09	217.58	59.51	681.15
Min	0.00	59.63	0.60	1.60	23.69	69.90	56.40	1.22	442.85
Max	32.07	93.57	26.18	6.23	58.60	458.32	311.65	146.66	1104.60
Average	11.38	75.19	13.43	3.51	37.60	247.99	191.80	56.19	781.08

Total Organic Matter (TOM%)

The total organic matter (TOM) content in the sediments also exhibited considerable variation among the stations (Table 5). TOM values ranged from a minimum of 1.60% at station X to a maximum of 6.23% at station I. The average TOM content across all stations was 3.51%.

The high TOM percentage at station I may indicate a significant input of organic matter, either from terrestrial sources or from in-lagoon biological productivity (Weston and Joye, 2005). This station's proximity to potential sources of organic input, such as vegetation or human activities, may contribute to the higher organic matter accumulation. Conversely, stations with lower TOM percentages, such as station X, likely experience more rapid decomposition of organic matter due to higher oxygen levels or less organic input (Burone *et al.*, 2003).

The variations in TOM content are consistent with the organic matter cycling and decomposition processes occurring within the lagoon. Stations with higher TOM levels may have slower decomposition rates or greater organic inputs, while those with lower TOM values might experience faster organic matter breakdown.

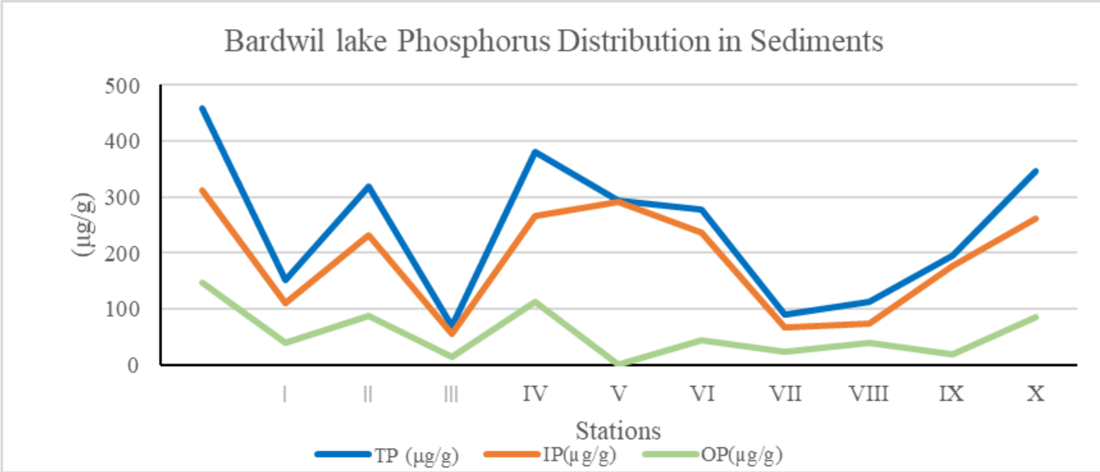

Fig. 9. Phosphorus Distribution (µg/g) in lagoon Bardawil sediments during 2020

Water Content (A%)

Water content (A%) in the sediments, which reflects the amount of water retained within the sediment matrix, ranged from 23.69% at station X to 58.60% at station I. The average water content across all stations was 37.60% (Table 5).

Stations with higher water content (e.g., station I) may have more porous or loosely packed sediments, allowing greater water retention. This could also be linked to the higher organic matter content at these stations, as organic-rich sediments tend to retain more water (Reza *et al.*, 2014). On the other hand, stations with lower water content (e.g., station X) likely consist of more compact sediments with lower porosity, which can reduce water retention.

Total Phosphorus (TP)

Total phosphorus (TP) concentrations exhibited substantial variability across the stations (Table 5), ranging from 69.90 µg/g at station IV to 458.32 µg/g at station I, with an average of 247.99 µg/g Figure 9. Station I had the highest TP concentration, likely due to high organic matter input or phosphorus-enriched runoff from nearby terrestrial sources. In contrast, station IV recorded the lowest TP levels, which may indicate limited nutrient input or more rapid phosphorus cycling and mineralization (Lukawska-Matuszewska and Bolałek, 2008).

The wide range in TP concentrations suggests that different stations experience varying degrees of phosphorus deposition and retention, influenced by factors such as hydrodynamic conditions, organic matter input, and sedimentation processes.

Inorganic Phosphorus (IP) and Organic Phosphorus (OP)

Inorganic phosphorus (IP) concentrations ranged from 74.60 µg/g at station IV to 296.12 µg/g at station X, with an average of 207.64 µg/g across the lagoon. Organic phosphorus (OP) concentrations exhibited similar variability, ranging from 16.11 µg/g at station VI to 229.40 µg/g at station I. The average OP concentration was 69.67 µg/g (Table 5).

The dominance of IP over OP at most stations suggests that a significant portion of phosphorus in the sediments is derived from mineral sources rather than from organic matter. However, the elevated OP concentrations at stations like I and X indicate that organic matter plays an important role in phosphorus dynamics at these locations (Anderson and Sarmiento, 1994). The higher OP levels at station I, in particular, align with the higher organic matter content and suggest a greater contribution of biological processes to phosphorus accumulation in the sediments (Bastami *et al.*, 2018).

Total Nitrogen (TN)

Total nitrogen (TN) concentrations in the sediments ranged from 442.85 µg/g at station VII to 1104.6 µg/g at station I. The average TN concentration was 781.08 µg/g across all stations (Table 5).

The highest TN values at station I suggest a strong connection between nitrogen content and organic matter input, as nitrogen is often associated with the breakdown of organic materials. Stations with lower TN values, such as station VII, may have less organic input or experience higher rates of nitrogen mineralization, where organic nitrogen is converted to inorganic forms and removed from the sediments (Voss *et al.*, 2011).

The observed variability in TN across the stations reflects the different ecological and biogeochemical processes influencing nitrogen cycling within the lagoon. Areas with higher TN content may support greater biological productivity, while stations with lower nitrogen levels may experience more limited nutrient availability.

Sediments Enrichment Factor:

The Enrichment Factor (EF) is used to assess the extent of element accumulation, such as carbon, nitrogen, and phosphorus, in sediments compared to natural background levels. This metric helps identify human-induced enrichment and its potential environmental impact. In Lagoon Bardawil, EF values were calculated for organic matter (OM), total phosphorus (TP), and total nitrogen (TN) across various stations. The study highlights key variations in EF, providing insights into nutrient dynamics and pollution risks (Mudroch and Azcue, 1995).

Organic Matter (OM) Enrichment:

Most stations exhibited minimal to moderate organic matter enrichment. Stations with higher EF values for OM indicate areas with significant organic input, likely from biological productivity or human activity. For instance, station I showed the highest TOM (6.23%), suggesting localized organic accumulation, possibly due to natural vegetation or nearby human activities (Zhang *et al.*, 2015) Figure 10.

Phosphorus Enrichment (TP and OP):

Total phosphorus (TP) levels ranged from 69.90 µg/g to 458.32 µg/g, with inorganic phosphorus (IP) dominating over organic phosphorus (OP) in most stations. The highest phosphorus enrichment was recorded at station I, reflecting organic-rich sediment input. Such enrichment indicates the potential influence of anthropogenic sources like agricultural runoff or nutrient loading, contributing to phosphorus accumulation (Li *et al.*, 2016)Figure 11.

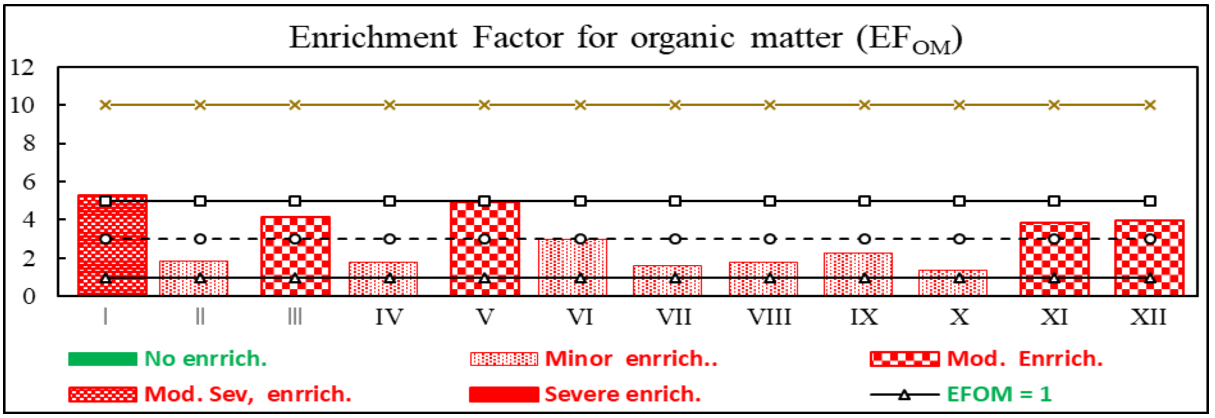

Fig. 10. Enrichment Factor for organic matter (EFOM) in sediments of Bardawil lagoon

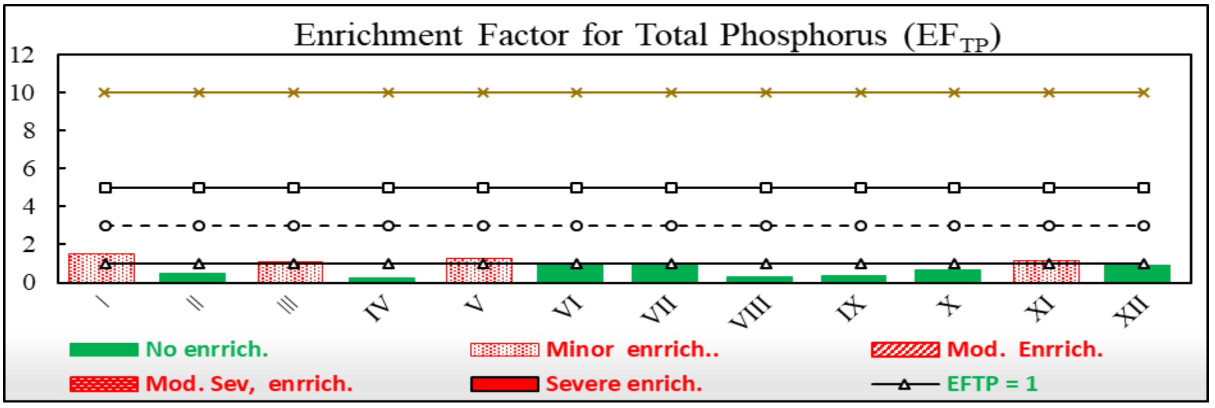

Fig. 11. Enrichment Factor for Total Phosphorus (EFTP) in sediments of Bardawil lagoon

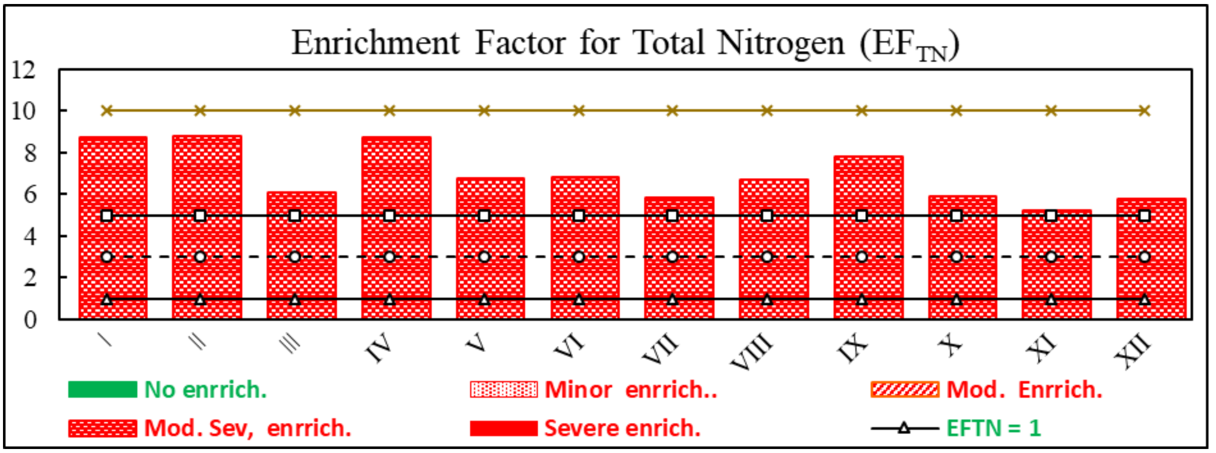

Fig. 12. Enrichment Factor for Total Nitrogen (EFTN) in sediments of Bardawil lagoon

Nitrogen Enrichment (TN):

Total nitrogen (TN) levels varied across the lagoon, with concentrations ranging from 8.73% to 5.22%. The highest nitrogen levels were found at station I, correlating with higher organic matter content. This suggests that organic decomposition and nutrient input are driving nitrogen enrichment in some areas. Elevated nitrogen can fuel eutrophication, leading to potential ecological imbalances if unmanaged Figure 12.

CONCLUSION

This study provides a comprehensive environmental assessment of Lagoon Bardawil by analyzing key water and sediment parameters across 12 stations during 2020. The findings reveal that the lagoon's ecosystem is highly influenced by seasonal variations in temperature, salinity, and dissolved oxygen, which play critical roles in shaping aquatic life and fish productivity. Salinity levels were found to fluctuate between 37.50 PSU and 57.21 PSU, with higher values during summer, potentially stressing aquatic organisms. Dissolved oxygen levels, ranging from 4.31 mg/L to 8.21 mg/L, indicated seasonal oxygen depletion in warmer months, which could impact fish health.

Sediment analysis identified the presence of potential environmental risks due to organic matter and nutrient content varied across stations, some areas showed higher accumulation, emphasizing the need for targeted monitoring. Despite the lagoon maintaining good overall water quality, environmental challenges such as rising salinity, sedimentation, and pollution from human activities pose risks to its ecological stability and fishery resources.

To address these challenges, several actions are recommended. A sustainable fishery management plan should be implemented to regulate fishing, protect nursery areas, and prevent overfishing. Strengthened pollution control measures are needed to limit agricultural runoff, industrial waste, and untreated sewage, coupled with strict enforcement and regular monitoring of water quality. Additionally, restoring natural water exchange through inlets could help stabilize salinity levels and improve the lagoon's ecological balance. Long-term monitoring of heavy metals and nutrient levels in sediments should be established to ensure safe levels for aquatic life. Engaging local communities in conservation efforts and raising awareness about the importance of the lagoon's ecosystem will also be critical. Furthermore, collaborating with international environmental organizations could provide the necessary technical expertise and financial support to address these ongoing challenges. Implementing these recommendations alongside continuous monitoring will be crucial in preserving Bardawil Lagoon's biodiversity, ensuring sustainable fish productivity, and supporting the local economy.

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الملخص العربي

التقييم البيئي للمياه والرواسب في بحيرة البردويل، شمال سيناء، مصر

احمد محمود عبد الحليم ، مني محمد صديق الباز ، شيماء محمد مجدي رجب عبد العظيم الجمل

بحيرة البردويل، بحيرة ساحلية مالحة تقع على طول الساحل الشمالي للبحر الأبيض المتوسط في سيناء بمصر، تلعب دورًا بيئيًا واقتصاديًا حيويًا، خاصةً من خلال مواردها السمكية. تقوم هذه الدراسة بتقييم الحالة البيئية للبحيرة من خلال تحليل جودة المياه والرواسب. تم مراقبة المعايير الأساسية للمياه، مثل درجة الحرارة، والملوحة، ودرجة الحموضة (pH)، والأكسجين الذائب(DO) ، وتركيزات المغذيات، في ١٢ محطة خلال عام ٢٠٢٠. تراوحت مستويات الملوحة بين ٣٧,٥٠ و٥٧,٢١ وحدةPSU ، مع تسجيل مستويات أعلى في الصيف بسبب التبخر. تراوح الأكسجين الذائب بين ٤,٣١ و٨,٢١ ملجم/لتر، مع ملاحظة قيم أقل في الأشهر الأكثر دفئًا، مما يشير إلى وجود ضغط موسمي على مستويات الأكسجين. أظهرت تحاليل الرواسب ان محتوى المادة العضوية الكلية (TOM)تراوح بين ١,٦٠٪ و٦,٢٣٪، مما يعكس الظروف البيئية المختلفة في أنحاء البحيرة. ورغم أن جودة المياه كانت جيدة بشكل عام في معظم المحطات، فإن زيادة الملوحة وتراكم الرواسب ومخاطر التلوث تتطلب مراقبة مستمرة. تسلط الدراسة الضوء على أهمية تبني ممارسات إدارة مستدامة لحماية التنوع البيولوجي وإنتاجية الأسماك في هذه البحيرة ذات الأهمية البيئية الكبيرة.