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Assessment the Physico-Chemical Characteristics of Sediment in Bardawil Lagoon, Egypt

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Abstract

In many coastal, estuarine, and freshwater settings across the world, contaminated sediment is a serious environmental issue. Bardawil Lagoon in North Sinai, Egypt, is a remarkable Mediterranean semi-enclosed coastal water feature that has been designated a Ramsar Wetland of International Importance. The current study aims to characterize the physical and chemical properties of the Bardawil Lagoon sediments. In surface sediments taken from the Bardawil Lagoon at 12 stations over the course of four seasons in 2021, chemical variables (pH, EC, $CaCO_3$, OM, cations, and anions), porosity, water holding-capacity and grain size analyses have all been measured. In the present result, the soil classes are loamy sand (sand > silt > clay). Autumn and winter have the greatest mean values of WHC and porosity, which are 40.42 and 33.57%, respectively. In this study, the soil was slightly alkaline to alkaline at all sites, and the greatest EC value of 10.78 mS/cm was recorded in the autumn season. Additionally, most chemical variables ($CaCO_3$, OM, HCO_3^-, Cl^-, SO_4^{-2}, Na^+, K^+, Ca^{+2}, Mg^{+2}) had their maximum values during the autumn season, while the summer season had their lowest values. The sediment variables follow the seasonal order: autumn > spring > winter > summer. The aquatic environment depends heavily on bottom sediments, which act as significant pollutant sinks. However, a yearly investigation of the physical and chemical characteristics is necessary to determine the best management strategy for bottom sediments.

***Keywords**:* Coastal Lakes, Bardawil Lagoon, hydrosoil, contamination, environmental impacts.

1. Introduction

Lakes are one of the most significant natural resources on Earth. Due to their enormous contribution to the ecological sustainability of any given region, these productive ecosystems are of the utmost priority. These ecosystems operate as reservoirs for nutrients and sediments from flood waters and surface runoff, reducing the risk of eutrophication or over-enrichment of other natural waterways like streams and rivers. These sediments build up over time and become an extremely significant part of the lake environment. They serve as records for monitoring alterations to a water body's environment and catchment area [1,2]. Additionally, sediment has an impact on water quality because of its highly dynamic character because of various biogeochemical interactions and transformations [3,4].

Lagoons that display salinities can go from being perfectly fresh to hypersaline, depending on the local climate. This is especially true for the type of coastal lagoon known as a choked lagoon, where the lagoon is occasionally connected to the coastal sea via a single channel and the tidal variability is mainly filtered out during tidal wave propagation into the lagoon [5]. Due to frequently limited water exchange with the nearby sea, coastal lagoon habitats are particularly susceptible to eutrophication [6].

Bardawil Lagoon and the nearby Zaranik protected area [7] provide a haven for migrating birds

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along the southern Mediterranean coast. It provides a wealth of habitat for a wide variety of animals [10], as well as fish and salt for human consumption [8, 9]. The lagoon is almost transparent since it has the lowest levels of pollution in all of the Mediterranean [11].

Numerous issues at the Bardawil Lagoon have the potential to degrade the environment, reduce fish catches, and significantly alter the ecosystem [8-10]. Due to the regular variations in inlet shape and size, some parts inside the lagoon are becoming drier and, as a result, losing their ecological and economic importance. A large-scale salt production system (built in the eastern section) causes significant ecological impacts. Around the lagoon, there have been several investments made in tourism-related projects [8]. The North Sinai lagoon is located near an extensive agricultural reclamation project, which threatens the water quality by diverting freshwater from newly reclaimed regions into the saltwater lagoon. Some unfavorable changes in the Bardawil Lagoon system are encouraged by engineering projects like artificial inlets and urbanization [9, 10].

Monitoring the sediment quality has become extremely important due to the growing anthropogenic demand on inland freshwater resources caused by sewage pollution, ground water pollution, soil erosion, agricultural and industrial waste disposal, etc. The goal of the current study was to assess the physico-chemical characteristics of sediment in Bardawil Lagoon by examining the physical properties of sediment at 12 sites in Bardawil Lagoon to represent their different habitats.

2. Materials and Methods

2.1. Description of the Study Site

Bardawil Lagoon is about 90 km long and 22 km broad (at its widest point) (Figure 1). It has an area of around 700 km^2. "Open sea, wet salt marshes, saline sand flats and hummocks (nebkas), stabilized sand dunes, interdune depressions, and mobile sand dunes" are among the six ecosystems present on the island [13].

A long, thin sand bar separates Bardawil Lagoon from the Mediterranean Sea for most of its length, serving as a transitional zone between land and sea (Figure 1). Three confined, man-made inlets connect it to the ocean. The western and eastern inlets are man-made, whereas the third has been closed naturally [14]. The lagoon has a microtidal regime because it stretches along the coast. The lagoon's water flow is regulated by the tides of the Mediterranean Sea, which have mean tidal excursions of roughly 35 cm during spring tides and 25 cm during neap tides, respectively [15].

Figure 1. Location map of Egypt, and Bardawil Lagoon showing sampling sites in North Sinai.

2.2. Sample Collection and Preparation

Samples of sediment were taken from the twelve geo-referenced stands that represented the Lagoon (Table 1). Soon after collection, all samples were transported in plastic bags to the lab. These samples were properly mixed, air dried, sieved through a 2 mm sieve to remove pebbles and other debris, and then kept in plastic bags for later physical and chemical examinations.

2.3. Laboratory Measurements

2.3.1. Physical analyses

The sieve technique was used to assess the texture of the soil samples, whereas the method described by Piper [16] was used to estimate porosity and water-holding capacity (WHC).

Table 1. Coordinates and description of sampling sites in Bardawil Lagoon.

Site No	N	E	Description
1	31.07694	33.22667	El- Telol
2	31.09944	33.25083	El-Rodh

3	31.11750	33.28083	El-Zarnik
4	31.20417	33.26139	Boughaz 2
5	31.14306	33.26111	M. El-Telol
6	31.19639	33.15556	Masqut-Eplis
7	31.19056	33.09833	El-Gals
8	31.06389	33.00056	El-Rewak
9	31.10778	32.94694	N. El-Rewak
10	31.13361	32.92972	Boughaz 1
11	31.08194	32.82139	El-Nasr
12	31.05667	32.74250	Raba'a

2.3.2. Chemical analyses

In 1:5 soil suspensions, the pH of the soil was measured with a pH-meter (Model Lutron YK-2001, pH meter), and the electrical conductivity of the soil was measured with an electrical conductivity meter (YSI Incorporated Model 33), both according to the method given by Jackson [17]. The titration technique was used to determine the levels of carbonates and bicarbonates in the sample, as reported by Pierce *et al*. [18]. According to Jackson [17], the amount of calcium carbonate that was present was measured. Piper's [16] protocol was followed in order to determine the levels of chlorides, sulfates, and organic carbon. Allen *et al*. [19] detailed the procedure for the extraction of a variety of elements, including sodium, potassium, calcium, and magnesium.

2.4. Data Treatments (Statistical analysis)

COSTAT 6.3 was used to analyze sediment analysis data using analysis of variance (ANOVA), and the mean values were separated using least significant difference (LSD) at a probability threshold of 0.05. To determine significant difference between the sediment parameters of the various study sites, the Pearson correlation bivariate two-tailed test was run on SPSS 16 for Windows. The principal component analysis was computed using the PAST software (multivariate statistical package, version 1.72).

3. Results and Discussion

3.1. Physical parameters

3.1.1. Soil texture

There are two types of soil particles-primary and secondary. Sand, silt, and clay are examples of primary particles that are grouped according to their effective diameter. These fractions' physical, chemical, and mineralogical characteristics differ significantly from one another. The term "soil texture" refers to their relative distribution in a soil [20,21]. One of the most crucial physical characteristics of soil that influences its fertility and production is its texture [22].

In the present study, the soil texture determined by the sieve method revealed generally that the soil is sandy with a very low content of silt and clay fractions. Sand, silt, and clay percentages in the springtime ranged from 50.59 to 100%, 0-31.8%, and 0-17.61%, respectively, with mean values of 82.03%, 12.34%, and 5.63%. The percentages of sand, silt, and clay in lake sediment ranged from 54.19 to 99.15%, 0.27 to 29.5%, and 0 to 16.13%, respectively, with mean values of 85.54%, 9.82%, and 4.64% over the summer (Table 2). While sand, silt, and clay percentages in the autumn season ranged from 51.38 to 98.21%, 0.39 to 30.22%, and 1.40 to 18.40%, respectively, with mean values of 82.17%, 11.22%, and 6.61%. The ratios of sand, silt, and clay did not significantly vary during the winter, ranging from 53.17 to 98.13%, 0.10 to 29.33%, and 0.50 to 17.50%, respectively, with average values of 84.15%, 10.29%, and 5.55% (Table 2, Figure 2). According to Shaltout *et al*. [23], the composition is 75% sand, 16.5% silt, and 8.5% clay. In addition to the author, sand concentrations in Egyptian coastal lakes and wetlands vary from 60.8% (Edku) to 79.6% (Mariut), while silt concentrations range from 12.9% (Mariut) to 21.9% (Burullus) and clay concentrations range from 7.4% (Manzala) to 17.8% (Edku).

Soil texture is not usually altered by management techniques. It develops through weathering and pedogenic processes such recrystallization, elevation, and illuviation and acquires properties from the parent materials. However, erosion, deposition, truncation, and other human actions might change it [22, 24].

Different classification systems have different upper limits for sand and silt, but all of them agree that 2 mm is the largest size for sand. Silt is between sand and clay in terms of particle size, while sand is the largest [25]. There are three types of loamy soil; each is determined by its composition. It is a combination of sand, silt, and clay such that the beneficial properties of each are included [26]. In the present result, the soil classes are loamy sand.

3.1.2. Water Holding Capacity (WHC)

The ability of soil to retain moisture and provide it to plants in between rainstorms or irrigations is one of its primary roles. Between water applications, the soil's moisture level decreases because of deep percolation, plant transpiration, and soil surface evaporation. Plant stress results from too-low water content [27]. A plant's ability to tolerate dry spells is determined by the soil's capability to store plant-available moisture. The ability of soil to retain water is largely dependent on its texture and the amount of organic matter present in it [28]. Soil organic matter (SOM) is another factor that plays an important role in water holding capacity [29].

Water-holding capacity of the sediment samples collected from Bardawil Lagoon during the summer varied from 30.12% to 47.29% with a mean value of 36.80%. In the sediment samples collected during spring, water-holding capacity varied from 31.87% to 41.74% with a mean value of 37.97%. In the sediment samples collected during autumn, water-holding capacity varied from 34.32% to 50.79%, with a mean value of 40.42%. In the sediment samples collected during winter, water-holding capacity varied from 32.62% to 49.09%, with a mean value of 38.72% (Table 2). The amount of accessible surface area affects the soil's capacity to retain water and interact with nutrients. There is more surface area accessible when soil contains a significant amount of material with very small particle sizes [30].

3.1.3. Porosity

The percentage of total soil volume occupied by pore space is referred to as soil porosity [31]. Pore spaces primarily aid in the flow and accessibility of air or water inside the soil environment. According to the current findings, the porosity of the sediment samples taken during the spring from various sites in Bardawil Lagoon ranged from 22.32 to 42.01%, with a mean value of 31.82%, and ranged from 20.48 to 40.15%, with a mean value of 30.30%, over the summer. Additionally, it fluctuated between 21.37 and 41.06% during the autumn season, with a mean value of 30.88%, and between 24.07 and 43.76% in the winter, with a mean value of 33.58% (Table 2). The interaction between biochar particles and soil aggregates may influence overall soil porosity [32].

3.2. Chemical parameters

3.2.1. pH

The hydrogen ion concentration in the soil is used to calculate the soil's pH, which indicates whether the soil is acidic, neutral, or alkaline (basic). The availability of nutrients, toxicity, microbial populations, and the activity of some pesticides are all influenced by the pH of the soil [33]. The soil in this study was found to be slightly alkaline to alkaline. During the spring, the pH of the lake sediment varied from 7.21 to 8.59, with a mean value of 7.79. During the summer, the pH was generally between 7.18 and 8.56, with a mean of 7.74. The autumn season had a pH range of 7.29-8.67, with a mean of 7.87. pH ranged between 7.37 and 8.75 with a mean value of 7.95 during the winter season (Table 3). According to Shaltout [23], the pH values are on the alkaline side, with a range of 7.3 (Burullus and Bardawil) and 7.6 (the other lakes). Nutrient availability is frequently constrained by alkaline soil's lower solubility compared to neutral or acidic soil [34].

3.2.2. EC

The test results provide an indication of the salinity of the soil since soil EC is a measurement of the concentration of ions from water-soluble salts in soils [35]. Although soil EC has been used as an indirect predictor of salinity levels and the quantity of nutrients available for plant absorption, it does not directly affect plant development. Salt content, organic matter, cation-exchange capacity, soil texture, soil thickness, nutrients (such as nitrate), water-holding capacity, and drainage conditions have all been substituted for using EC [36]. In the sediment, EC varied from 5.23 to 8.06 $mS.cm^{-1}$ with a mean value of 6.65 $mS.cm^{-1}$ during spring season. In the summer, it ranged from 3.63 to 6.04 $mS.cm^{-1}$, with a mean of 4.74 $mS.cm^{-1}$. Whereas it varied from 8.60 to 14.28 $mS.cm^{-1}$ and 5.95 to 11.63 $mS.cm^{-1}$ with an average of 10.78 and 8.13 $mS.cm^{-1}$ in autumn and winter seasons, respectively (Table 3). Salinity was lowest in Manzala (2.0 mS cm^{-1}) and highest in Bardawil (6.6 mS cm^{-1}), as reported by Shaltout *et al*. [23]. EC is used to divide up management areas, distinguish between different types of soil, and forecast crop yields and soil fertility [37].

Table 2: Physical properties of sediment samples (1-12) in Bardawil Lagoon. ns = not significant at P < 0.05.

Variable		Seasons				$LSD_{0.05}$
		Spring	Summer	Autumn	Winter	
Sand %	Min	50.59	54.19	51.38	53.17	44.68ns
	Max	100	99.15	98.21	98.13	
	Mean±SD	82.03±16.98	85.54±15.39	82.17±16.45	84.15±15.72	
Silt %	Min	0.00	0.27	0.39	0.10	28.69ns
	Max	31.80	29.5	30.22	29.33	
	Mean±SD	12.34±11.58	9.82±10.30	11.22±11.24	10.29±10.76	
Clay %	Min	0.00	0	1.40	0.50	16.40ns
	Max	17.61	16.31	18.40	17.50	
	Mean±SD	5.63±5.61	4.64±5.29	6.61±5.41	5.55±5.18	
Soil class		Loamy sand	Loamy sand	Loamy sand	Loamy sand	
WHC %	Min	31.87	30.12	34.32	32.62	15.84ns
	Max	48.34	47.29	50.79	49.09	
	Mean±SD	37.97±4.63	36.80±4.65	40.42±4.63	38.72±4.63	
Porosity %	Min	22.32	20.48	21.37	24.07	18.54ns
	Max	42.01	40.15	41.06	43.76	
	Mean±SD	31.82±6.82	30.3±6.69	30.87±6.82	33.57±6.82	

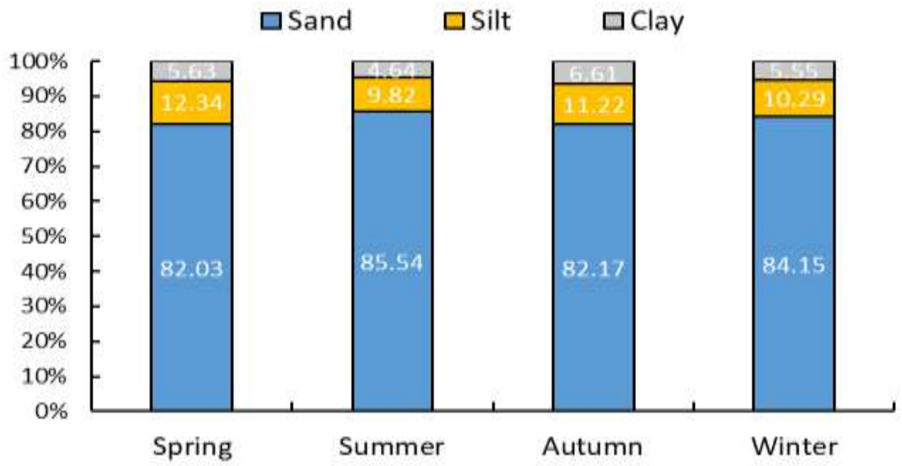

Figure 2. Percentage of Soil texture (sand, silt, and clay) in sediment samples in Bardawil Lagoons, Egypt.

Table 3. Chemical properties of sediment samples (1-12) in Bardawil Lagoon.

Variable		Seasons				$LSD_{0.05}$
		Spring	Summer	Autumn	Winter	
pH	Min	7.21	7.18	7.29	7.37	0.49***
	Max	8.59	8.56	8.67	8.75	

	Mean±SD	7.79±0.46	7.74±0.47	7.87±0.46	7.95±0.46	
EC (mS/cm)	Min	5.23	3.63	8.60	5.95	3.95ns
	Max	8.06	6.2	14.28	11.63	
	Mean±SD	6.65±0.89	4.75±0.90	10.78±1.79	8.13±1.79	
$CaCO_3$ %	Min	1.50	1.33	6.79	8.15	5.23ns
	Max	10.20	8.31	13.77	15.13	
	Mean±SD	5.47±2.39	3.82±2.10	9.53±2.05	10.89±2.05	
OM %	Min	2.80	2.46	3.75	5.11	3.71**
	Max	13.30	11.96	12.15	15.61	
	Mean±SD	7.06±3.15	5.695±3.05	7.60±2.41	9.29±3.02	
HCO_3^- %	Min	0.14	0.131	0.21	0.24	0.09ns
	Max	0.30	0.287	0.36	0.38	
	Mean±SD	0.23±0.05	0.22±0.05	0.29±0.05	0.32±0.05	
Cl^- %	Min	0.18	0.173	0.25	0.28	0.13**
	Max	0.50	0.491	0.57	0.60	
	Mean±SD	0.35±0.11	0.33±0.11	0.41±0.10	0.46±0.10	
SO_4^{-2} %	Min	0.11	0.097	0.17	0.19	0.07ns
	Max	0.23	0.216	0.29	0.31	
	Mean±SD	0.17±0.04	0.16±0.04	0.22±0.04	0.25±0.04	
Na^+ mg/100g dry soil	Min	1547.05	644.4	1647.70	2902.05	4351***
	Max	16958.26	15055.61	17058.91	18313.26	
	Mean±SD	5671.78±530.6	4602.46±492.9	7355.76±614.7	8610.11±629.4	
K^+ mg/100g dry soil	Min	163.71	33.21	174.39	228.73	204.46***
	Max	874.92	678.2	885.60	939.94	
	Mean±SD	389.12±94.62	221.43±69.98	339.80±90.62	454.14±89.62	
Ca^{+2} mg/100g dry soil	Min	654.61	531.17	665.29	1169.63	2838.32***
	Max	9648.88	9525.44	9659.56	10163.90	
	Mean±SD	2822.25±213.5	2698.81±305.1	2832.93±133.8	3337.27±933.4	
Mg^{+2} mg/100g dry soil	Min	156.18	19.56	166.37	199.71	303.35***
	Max	1350.07	1227.49	1360.66	1379.00	
	Mean±SD	587.83±352.2	437.81±378.6	597.97±352.2	630.06±349.3	
SAR	Min	67.28	17.72	67.28	98.16	92.40**
	Max	253.73	221.84	253.73	422.61	
	Mean±SD	129.71±57.49	114.49±64.024	129.71±57.49	196.27±116.00	
PAR	Min	4.97	1.98	4.97	6.22	4.03*
	Max	14.43	10.29	14.43	14.21	
	Mean±SD	10.28±2.70	5.72±2.14	10.28±2.70	10.85±2.39	

ns = not significant at $P < 0.05$. *: Values are significant at $P < 0.05$, **: Values are significant at $P < 0.01$, ***: Values are significant at $P < 0.001$.

3.3. *Statistical correlation*

The principal component analysis (PCA) approach is commonly used to minimize the number of variables by selecting those that are most important in the data. The PCA has been widely used to describe soil and has been shown to be useful in understanding numerous sources of soil contamination [56,57]. Table 4 summarizes the PCA results over four seasons. The first three Principal Components (PCs) had eigenvalues greater than one; hence, these PCs were employed according to Kaiser [58] technique, while the remaining PCs were discarded (Table 4).

Table 4. Summarization of Principal Component Analysis.

	Spring			**Summer**		
	PC 1	**PC 2**	**PC 3**	**PC 1**	**PC 2**	**PC 3**
Eigenvalue	5.40	2.91	1.33	4.38	3.41	1.58
Variability (%)	51.09	16.70	10.95	45.43	19.49	12.35
Cumulative %	51.09	67.79	78.74	45.43	64.92	77.27
pH	0.620	-0.021	-0.412	0.454	-0.198	0.581
EC	0.006	0.064	0.656	0.071	0.636	0.356
CaCO3	0.122	0.740	-0.194	-0.027	0.811	-0.484
OM	-0.477	0.005	0.375	-0.483	0.076	-0.449
HCO3	0.615	0.519	0.335	0.628	0.503	-0.533
Cl	0.648	0.393	0.306	0.652	0.502	-0.504
SO4	0.625	0.453	0.308	0.641	0.472	-0.468
Na	0.765	-0.176	-0.067	0.808	-0.193	0.285
K	0.713	0.233	-0.067	0.724	-0.089	0.433
Ca	0.711	-0.156	-0.020	0.772	0.089	0.284
Mg	0.576	0.343	-0.156	0.586	0.351	0.485
SAR	0.741	-0.271	-0.095	0.631	-0.328	-0.298
PAR	0.146	0.669	-0.190	0.355	-0.334	0.624
Sand	0.298	-0.990	0.191	0.305	-0.885	-0.481
Silt	-0.272	0.973	-0.230	-0.289	0.851	0.523
Clay	-0.341	0.988	-0.106	-0.325	0.917	0.391
WHC	-0.086	0.013	-0.417	0.253	0.374	0.636
Por	-0.487	0.099	0.573	-0.424	-0.351	0.502
	Autumn			**Winter**		
	PC 1	**PC 2**	**PC 3**	**PC 1**	**PC 2**	**PC 3**
Eigenvalue	4.19	2.14	1.48	3.30	3.73	1.29
Variability (%)	44.41	12.42	11.78	39.45	21.29	10.75
Cumulative %	44.41	56.83	68.6	39.45	60.73	71.48
pH	0.003	-0.022	0.440	0.415	0.238	-0.560
EC	-0.038	-0.210	0.531	0.520	-0.195	0.567
CaCO3	-0.071	0.680	0.172	-0.030	-0.096	0.655
OM	-0.399	-0.391	0.670	-0.753	0.113	0.451
HCO3	0.661	0.268	0.554	0.360	0.767	0.383
Cl	0.715	0.231	0.438	0.308	0.855	0.370
SO4	0.701	0.334	0.527	0.587	0.565	0.319
Na	0.729	-0.031	0.233	0.819	-0.069	0.349
K	0.686	0.363	-0.478	0.659	0.405	-0.454
Ca	0.719	0.441	0.026	0.817	0.245	0.194
Mg	0.475	0.297	-0.568	0.480	0.305	0.185
SAR	0.844	0.036	0.230	0.744	-0.203	0.490
PAR	-0.033	0.831	0.202	0.001	0.648	-0.583
Sand	0.466	-0.982	0.087	0.415	-0.844	0.116
Silt	-0.438	0.982	0.348	-0.361	0.876	0.269
Clay	-0.509	0.947	0.236	-0.510	0.742	0.311
WHC	-0.324	0.045	-0.533	-0.350	0.489	0.330
Por	-0.059	-0.089	0.319	0.134	0.180	0.024

The data demonstrate that the first three PCs account for 78.74% of the total variance throughout the spring season. According to the factor loadings, the first PC accounts for 51.09% of the total variance and is positively connected with pH, $CaCO_3$, OM, HCO_3, Cl, SO_4, Na, K, Ca, and SAR, whereas the second PC accounts for 16.70% of the variance and is highly correlated with $CaCO_3$, PAR, Silt, and Clay. The third PC explains 10.95% of the total variance and is correlated with the EC. In contrast, during the summer months, the first PC (explaining 45.43%) has stronger positive correlations with HCO_3, Cl, SO_4, Na, K, Ca, and SAR, while the second PC (19.49%) has significant connections with EC, $CaCO_3$, silt, and Clay. The third PC correlates with PAR and WHC, and accounts for 12.35% of the total variance (Table 4).

According to the results, the first three PCs explain 44.41% of the total variance throughout the autumn season. Factor loadings show that the first PC is responsible for 51.09% of the total variance and has strong positive correlations with HCO_3, Cl, SO_4, Na, K, Ca, and SAR, while the second PC is responsible for 12.42% and has strong positive correlations with $CaCO_3$, PAR, Silt, and Clay. The third PC correlates with the OM and accounts for 11.78% of the total variance. In the winter months, Na, K, Ca, and SAR have stronger positive correlations with the first principal component (PC; explains 39.45%), whereas HCO_3, Cl, PAR, Silt, and Clay have strong correlations with the second principal component (PC; explains 21.29%). $CaCO_3$-related variables account for 12.35% of the total variance of the third main component (Table 4).

The distribution of physicochemical parameters on the PCs axis (PC1-PC2) is shown in Figure 3.

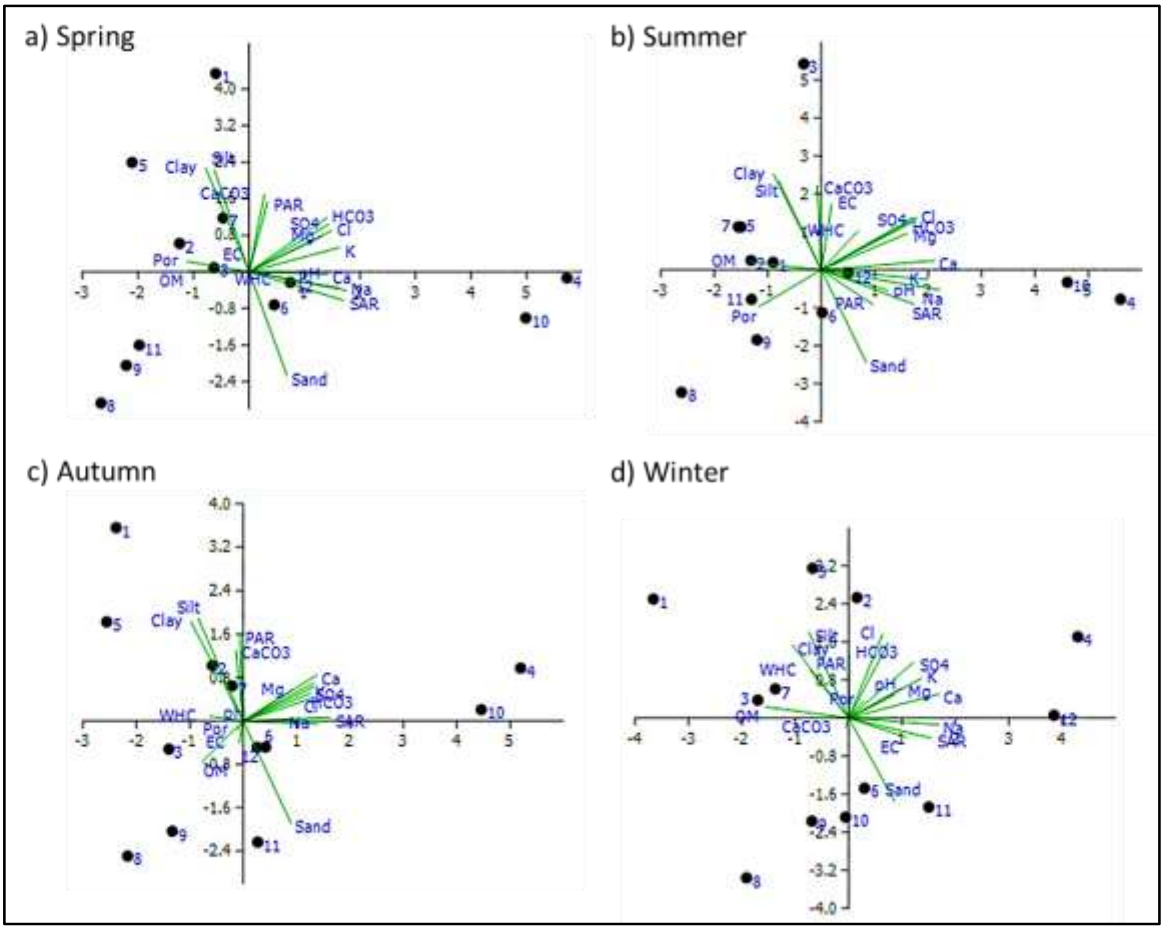

Figure 3. PCA biplot of physico-chemical properties of sediments during different seasons.

The examination of Pearson's correlation demonstrated significant correlations ($p \leq 0.05$) between most of the soil physicochemical parameters, and it also revealed that the correlation between soil physicochemical values remained stable across all four seasons (Table 5). The study revealed a greater number of positive correlations between the chemical parameters, such as those found between HCO_3, Cl, SO_4, Na, K, Ca, Mg, and SAR. The same kind of positive correlations were also found between OM and $CaCO_3$. In addition, the soil's porosity, water holding capacity, and soil texture all show substantial correlations with positive relationships among themselves. In most cases, the level of interaction changed according to the kind of soil, the seasons, and the property that was involved.

Table 5. Pearson Correlation matrices between various sediment parameters in Bardawil Lagoon during different seasons.

	Sand	Silt	Clay	WHC	Por	pH	EC	$CaCO_3$	OM	HCO_3	Cl	SO4	Na	K	Ca	Mg	SAR
Spring season																	
Silt	-0.994	1															
Clay	-0.975	0.945	1														
WHC	-0.127	0.172	0.029	1													
Por	-0.223	0.171	0.321	-0.057	1												
pH	0.241	-0.199	-0.318	-0.004	-0.874	1											
EC	0.027	-0.041	0.002	-0.15	0.718	-0.451	1										
$CaCO_3$	-0.506	0.491	0.516	-0.041	-0.167	0.345	-0.184	1									
OM	-0.157	0.08	0.31	-0.107	0.595	-0.505	0.171	0.052	1								
HCO_3	-0.037	0.014	0.082	-0.309	-0.192	0.429	0.239	0.415	-0.265	1							
Cl	0.078	-0.101	-0.028	-0.263	-0.278	0.512	0.173	0.407	-0.223	0.972	1						
SO_4	0.01	-0.026	0.024	-0.475	-0.312	0.508	0.185	0.371	-0.268	0.94	0.913	1					
Na	0.442	-0.403	-0.508	-0.068	-0.495	0.682	0.078	0.026	-0.519	0.606	0.653	0.612	1				
K	0.128	-0.091	-0.202	0.093	-0.399	0.484	0.158	0.095	-0.605	0.728	0.719	0.696	0.841	1			
Ca	0.415	-0.388	-0.455	-0.008	-0.362	0.569	0.11	0.091	-0.425	0.609	0.67	0.532	0.957	0.801	1		
Mg	-0.084	0.122	0.003	0.373	-0.374	0.548	0.102	0.143	-0.307	0.583	0.614	0.534	0.678	0.78	0.622	1	
SAR	0.502	-0.45	-0.592	-0.137	-0.553	0.71	0.074	-0.053	-0.576	0.52	0.557	0.592	0.954	0.763	0.846	0.612	1
PAR	-0.422	0.439	0.37	0.063	-0.122	-0.008	0.013	0.134	-0.546	0.381	0.224	0.372	-0.006	0.449	-0.093	0.209	-0.004
Summer season																	
Silt	-0.993	1															
Clay	-0.974	0.941	1														
WHC	-0.403	0.485	0.229	1													
Por	-0.106	0.133	0.049	-0.082	1												
pH	0.177	-0.133	-0.257	0.458	0.129	1											
EC	-0.519	0.465	0.604	0.073	-0.09	-0.009	1										
$CaCO_3$	-0.516	0.487	0.551	0.246	-0.44	-0.255	0.094	1									
OM	-0.153	0.107	0.235	-0.443	0.117	-0.765	0.004	0.137	1								
HCO_3	0.004	-0.039	0.064	0.087	-0.602	0.047	0.345	0.471	-0.254	1							
Cl	0.004	-0.038	0.062	0.094	-0.597	0.144	0.336	0.484	-0.33	0.972	1						
SO_4	0.000	-0.037	0.070	0.064	-0.611	0.181	0.306	0.38	-0.342	0.938	0.922	1					
Na	0.425	-0.39	-0.476	0.247	-0.201	0.513	-0.031	-0.185	-0.452	0.574	0.592	0.535	1				
K	0.253	-0.229	-0.291	0.263	-0.395	0.355	0.174	-0.313	-0.317	0.401	0.417	0.447	0.782	1			
Ca	0.238	-0.23	-0.244	0.291	-0.427	0.394	0.324	-0.041	-0.269	0.644	0.664	0.577	0.865	0.832	1		
Mg	-0.201	0.237	0.124	0.519	-0.403	0.400	0.068	0.175	-0.292	0.387	0.462	0.499	0.573	0.725	0.619	1	
SAR	0.470	-0.423	-0.542	0.165	0.013	0.398	-0.364	-0.121	-0.441	0.453	0.450	0.392	0.871	0.475	0.53	0.338	1
PAR	0.195	-0.168	-0.241	0.178	-0.041	0.360	0.083	-0.601	-0.234	-0.141	-0.139	-0.016	0.391	0.780	0.395	0.441	0.166
Autumn season																	
Silt	-0.994	1															
Clay	-0.975	0.946	1														
WHC	-0.155	0.167	0.124	1													
Por	-0.013	0.032	-0.028	-0.057	1												
pH	0.009	0.042	-0.115	-0.137	-0.22	1											
EC	-0.103	0.12	0.063	-0.129	-0.183	-0.079	1										
$CaCO_3$	-0.376	0.353	0.409	-0.011	-0.246	-0.313	-0.182	1									
OM	-0.138	0.17	0.066	0.078	0.042	0.139	0.357	-0.047	1								
HCO_3	0.142	-0.071	-0.284	-0.387	0.185	0.177	0.164	0.046	-0.022	1							
Cl	0.218	-0.159	-0.335	-0.304	0.197	0.068	0.024	0.029	-0.07	0.95	1						
SO_4	0.134	-0.078	-0.243	-0.53	-0.066	0.265	0.169	0.051	-0.133	0.938	0.894	1					
Na	0.373	-0.362	-0.383	-0.455	-0.353	-0.097	0.312	0.029	-0.329	0.53	0.525	0.637	1				
K	0.255	-0.254	-0.248	-0.013	-0.126	-0.041	-0.381	-0.067	-0.67	0.408	0.576	0.502	0.502	1			
Ca	0.174	-0.173	-0.169	-0.291	-0.014	-0.255	-0.32	0.227	-0.608	0.505	0.599	0.552	0.711	0.801	1		
Mg	0.089	-0.088	-0.088	0.365	-0.344	-0.224	-0.072	-0.025	-0.47	0.137	0.31	0.197	0.518	0.78	0.622	1	
SAR	0.453	-0.405	-0.538	-0.27	-0.031	-0.007	0.068	-0.097	-0.427	0.771	0.769	0.773	0.817	0.674	0.768	0.519	1
PAR	-0.415	0.424	0.382	0.042	0.007	0.369	-0.33	0.198	-0.44	0.154	0.05	0.209	-0.28	0.241	0.062	-0.093	-0.004
Winter season																	
Silt	-0.993	1															
Clay	-0.971	0.936	1														
WHC	-0.553	0.522	0.595	1													
Por	-0.174	0.185	0.144	-0.057	1												
pH	0.018	0.039	-0.135	-0.146	-0.08	1											
EC	0.262	-0.259	-0.256	-0.224	-0.284	0.176	1										
$CaCO_3$	0.033	-0.049	0.001	0.003	-0.055	-0.432	0.348	1									
OM	-0.435	0.404	0.483	0.486	-0.271	-0.515	-0.329	0.38	1								
HCO_3	-0.423	0.478	0.291	0.14	-0.001	0.134	0.147	0.007	-0.136	1							
Cl	-0.531	0.578	0.41	0.22	-0.039	0.223	0.183	0.079	-0.095	0.965	1						
SO_4	-0.113	0.183	-0.037	-0.119	-0.019	0.267	0.262	0.034	-0.37	0.934	0.881	1					
Na	0.368	-0.336	-0.417	-0.142	0.274	0.047	0.474	-0.023	-0.587	0.307	0.187	0.441	1				
K	0.06	0.003	-0.187	0.047	0.275	0.554	0.036	-0.154	-0.479	0.357	0.399	0.483	0.502	1			
Ca	0.112	-0.054	-0.23	-0.236	0.21	0.456	0.409	0.076	-0.52	0.365	0.383	0.518	0.711	0.801	1		
Mg	-0.041	0.061	-0.004	0.395	0.076	0.313	0.031	-0.013	-0.244	0.193	0.237	0.222	0.503	0.651	0.634	1	
SAR	0.351	-0.341	-0.357	-0.261	0.207	-0.013	0.711	0.203	-0.573	0.182	0.108	0.318	0.889	0.223	0.618	0.361	1
PAR	-0.401	0.421	0.342	0.051	0.3	0.353	-0.406	-0.244	-0.181	0.353	0.462	0.325	-0.263	0.521	0.151	0.024	-0.439

4. Conclusions

The Bardawil Lagoon, located on the northern coast of Sinai, is a small lagoon with two inlets that lead to the Mediterranean Sea. Sedimentation at the lake's inlets has reduced the flow of saltwater inland. Water salinity increases when there is insufficient incoming freshwater to dilute it. Chemical variables, porosity, water holding capacity, and particle size were examined in surface sediments from the Bardawil Lagoon at 12 locations across four seasons in 2021. It is evident that the degree of relationship between soil physicochemical factors varied according to soil type, seasons, and properties involved. Most chemical variables ($CaCO_3$, OM, HCO_3^-, Cl^-, SO_4^{-2}, Na^+, K^+, Ca^{+2}, Mg^{+2}) peaked in autumn and dropped in summer. Consequently, one of the primary goals of the state's strategy to develop the Sinai Peninsula is to enhance the natural environment of the lagoon by preventing the deterioration of its water quality and instead improving it.

5. Conflicts of interest

"There are no conflicts to declare".

6. Acknowledgments

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7. References

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