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Nature-Based Approach to Mitigate Climate Change Through Carbon Sequestration in Aquatic Habitats: A Case Study along The Egyptian Northern Lakes

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Abstract

Global warming and carbon emissions are becoming of worldwide concern and many studies and research have reported the consequences and impacts of these problems with different solutions aiming to control or reduce carbon in the atmosphere. This research has recently shifted focus towards natural methodologies aimed at curbing emissions and safeguarding the environment, resulting in the adoption of nature-based solutions, including the sequestration of carbon in water, sediment, and aquatic flora. The primary objective of this study is to evaluate and compare the rates at which carbon is sequestered in water and sediment samples extracted from the northern Egyptian lakes of Idku, Mariout, Manzalah, and Burullus. The assessment encompasses an examination of the carbon sequestration capacities exhibited by these aquatic habitats in both planted and unplanted areas. The study findings demonstrate that water has a significantly higher capacity for carbon sequestration compared to sediment. The data reveals that the carbon dioxide absorption potential of water is considerably greater than that of the underlying sediment within the studied aquatic ecosystems. Furthermore, the presence of the common wetland plant species Phragmites australis was found to be associated with diminished carbon sequestration rates in the locations where it is present. Compared to unplanted control areas, the areas dominated by Phragmites australis exhibited lower overall carbon sequestration capabilities. Based on the study findings, it is recommended to explore the replacement of Phragmites australis with alternative plant species that can enhance carbon sequestration without adversely affecting the ecological balance of the lake ecosystems. One promising alternative is the Azolla spp., which has demonstrated high carbon sequestration potential in previous studies. Azolla spp. offers additional advantages, such as rapid reproduction and growth rates, which could make it a more suitable candidate for optimizing carbon sequestration efforts in the Northern Lakes region.

Keywords: Carbon Sequestration, Egyptian Northern lakes, Sediment, vegetation, and Water

1. Introduction

According to the Fifth Assessment Report (AR5) (IPCC, 2014), the amount of carbon dioxide (CO2) in the atmosphere has been gradually rising and will reach worrisome levels of 410 parts per million (ppm) in 2019, This increase in atmospheric CO2 concentration is a primary driver of global warming and climate change, leading to a range of detrimental environmental and societal impacts . As a result, there is an increasing focus on creative methods to cut CO2 emissions and stop global warming. With a typical focus on terrestrial ecosys-

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tems like forests, carbon sequestration has drawn significant attention as a critical strategy to solve this problem [1]. Recent studies have, however, emphasized the potential of wetlands as natural reservoirs for sequestering carbon and reducing climate change.

The northern lakes of Egypt—Idku, Mariout, Manzalah, Burullus, and Bardawil—represent significant wetland ecosystems with unique physical and chemical characteristics [2].These lakes are made up of both natural and manmade basins, ranging from freshwater to hypersaline environments, and they are subject to a variety of ecological processes. Understanding these northern lakes' capacity to absorb carbon is crucial for determining how effective they will be at halting climate change and reducing carbon emissions. By assessing the rates of carbon sequestration in both water and sediment samples from these lakes, we may learn more about the effectiveness and efficiency of these ecosystems as carbon sinks.

This study aims to (1) evaluate carbon sequestration rate along Egypt's northern lakes (Idku, Mariout, Manzalah, Burullus, and Bardawil) and to present a thorough evaluation of their capability for carbon sequestration. Using water and sediment samples as the primary data sources, this project will (2) evaluate and compare the rates of carbon sequestration in planted and unplanted sections of the lakes. With the help of this evaluation, the study hopes to clarify the relative roles played by different wetland ecosystems in carbon sequestration and increase our knowledge of how effective they might be at reducing carbon emissions.

Our knowledge of the dynamics of carbon sequestration in wetlands and how to use it as a natural strategy for reducing carbon emissions and mitigating climate change will be improved by the study's findings. Additionally, the findings will direct sustainable management strategies for the preservation and restoration of these vital natural resources and inform environmental managers and policymakers about the significance of these ecosystems in carbon sequestration efforts.

2. Material and methods

2.1. Study area:

The stretch of Egypt's Mediterranean coast is roughly 970 km, running from Sallum in the west (Lat. 31° 39 26.26 N, long. 25° 08 57.44 E) to Rafah in the east (Lat. 31° 19 24.32 N, long. 34° 13 07.57 E). Along the northern coast there are five lakes (fig. 1): Mariout (western coast), Bardawil (Sinai coast) Idku, Burullus, and Manzalah (Deltaic coast). These lakes connect to the Mediterranean Sea as the water reaches lakes through gaps in sand bars or old branches of delta. Sea water is not the only water source for lakes. Lake Mariout receive its water from drainage water from agriculture lands of Beheira governorate that surrounding it, while lake Bardawil is merely nourished by seawater so it is the saltiest lake of northern lakes [3].

2.1.1. Lake Idku

The Northern Deltaic coast's third-largest coastal lake, Lake Idku, has 17.3% open water while the remaining area is covered by islands and aquatic vegetation, A small brackish coastal basin called Lake Idku is in El-Behira Governorate, which is about 40 kilometers (km) east of Alexandria and 18 kilometers (km) west of the Rosetta branch of the Nile River. The lake is typically 6 km wide and 16 km long. The lake's water depths range from 0.1 to 1.4 meters, reaching a maximum of 1 meter in its eastern and center regions, it is considered as main source of fish production, has three major drains that discharge their water into the lake's eastern shore: Bersik, Idku, and El-Bousily [4].

2.1.2. Lake Mariout

Lake Mariout is a Salt Lake, and it is considered a major coastal lagoon, is Located between longitude 29° 47.1′ and 29° 50.4′ E and latitude 31° 7.5′ to 31° 9′ N, it is one of Alexandria's primary fishing locations. The Lake is a shallow brackish water basin with a less than 65km2 surface area, the lake's original area was likely greater than 700 km2, but due to road and railway development isolating portions of the lake, its area is presently less than 65 km2.(Abu El-Magd et al., 2021) and Its bottom is approximately 3.25 meters below sea level,

Table 1: Morphometry of the four Egyptian northern lakes.

Lake	Coordinate		Dimension			Area (km^2)
	Latitude (N)	Longitude (E)	Depth (m)	Width (km)	Length (km)	
Mariout	31° 02′ – 31° 12′	29° 51′ – 29° 59′	1.2	7.7	8.8	63
Idku	31° 13′ – 31° 16′	30° 07′ – 30° 14′	1.0	6.0	21.0	126
Burullus	31° 25′ – 31° 35′	30° 30′ – 31° 10′	1.0	16.0	64.0	410
Manzalah	31° 00′ – 31° 30′	31° 16′ – 32° 20′	1.1	49.0	64.5	1200
Bardawil*	31° 09′ – 31° 03′	31° 19′ – 32° 46′	3	20	80	595

* Due to the inherent difficulties in getting to and visiting the site, Lake Bardawil was excluded from the study. It was impractical to include Lake Bardawil within the purview of the research project due to the logistical challenges and geographic limitations around it.

and a barrier known as Abuser separates it from the nearby Mediterranean Sea [5].

2.1.3. Lake Burullus

Lake Burullus, the second-largest natural lake in Egypt, shape is that of an extended ellipse. As shown in, it is situated in the middle of the two Nile River branches (Damietta and Rosetta). It is located between latitudes 31° 25′ and 31° 35′ N and longitudes 30° 31′ and 31° 05′ E in the Nile Delta. It is regarded as a rich source of fish production [6]. The lake, which covers 420 km^2. The lake's longitudinal axis, which runs along to the Mediterranean shore and is around 54 km long, varies in width from a minimum of 3 km in the western sector to a maximum of 12 km in the eastern one, The depth of the lake, which ranges from 0.4 to 2.0 meters, makes it a shallow body of water, with the exception of the inlet area, where the depth reaches a maximum of 4 meters.

2.1.4. Lake Manzalah

Lake Manzalah, with a maximum length of 50 km along the perilous Mediterranean shore, is situated in the northern quadrant of the Delta between 31° 00" and 31° 30" latitude and 31° 45" and 32° 20" longitude. It is connected to the East by the Suez Canal, the West by the Damietta Branch of the Nile River, the North is surrounded by the Mediterranean Sea, and the South by Sharkia, Dakahlia Provinces, and the El-Salam Canal [7]. Despite being the largest lake in the Nile Delta, the lake is steadily losing area. The 750,000 feddan lake area in 1900 has been decreased to less than 14% during the last century by extensive land reclamation. In addition, the lake is less than 100 cm deep in about 67% of its area [8]. The northern Egyptian lakes have been acknowledged as one of Egypt's most important natural-based solutions because they are not only important birding or fishing areas, although they are crucial for preserving biodiversity, but they are also important plant areas that contribute to global warming solutions [1]. Climate change and global warming are the crisis that the world try to control, while at the same time we damage our nature, through reclamation projects, and road construction along the north coast, as wetlands are natural based solutions for climate change and global warming, which considered as the solution for Egypt to get over this disaster, as Carbon Sequestration process through water and sediment of wetland beside plants that have the same process within lakes all this share in reducing carbon emission from atmosphere [9]. The main objective of this study is to evaluate carbon sequestration along Egypt's northern lakes (Idku, Mariout, Manzalah, Burullus, and Bardawil) and to present a thorough evaluation of their capability for carbon sequestration. Using water and sediment samples as the primary data sources, this project will evaluate and compare the rates of carbon sequestration in planted and unplanted sections of the lakes. With the help of this evaluation, the study hopes to clarify the relative roles played by different wetland ecosystems in carbon sequestration and increase our knowledge of how effective they might be at reducing carbon emissions.

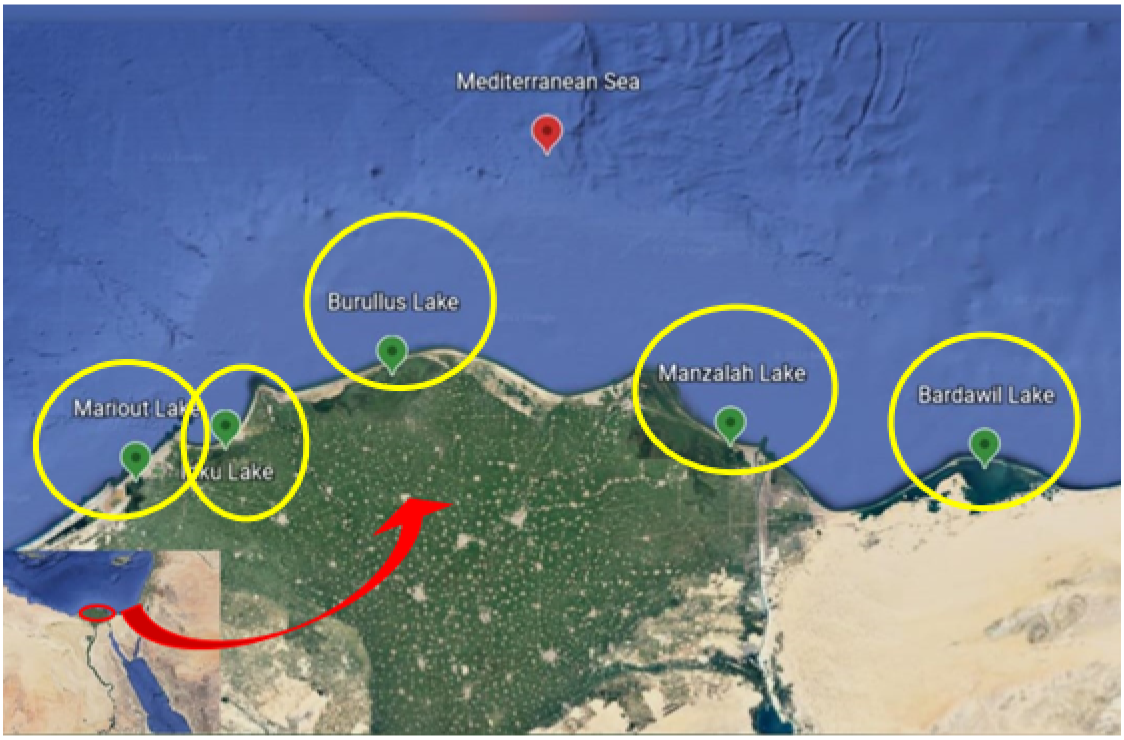

Figure 1: Map of the five northern lakes of Egypt.

2.2. Sampling strategy and location selection

samples entailed for this research include water and sediment samples from each selected site of the four lakes the study sites, paying close attention to the existence of flora, by employing the latitude and longitude coordinates specific to each lake (Idku, Mariout, Manzalah, and Burullus), a random sample strategy was utilized to determine the sampling locations. As part of the approach, water samples were taken at depth 20 cm from the surface. Following the site selection criteria, eight vegetative sites in total were chosen. Water samples were taken in glass bottles to guarantee the precision and integrity of the carbon sequestration rate measurements. Following a similar procedure as with the water samples, sediment was sampled. The same areas where the water samples were taken were used to gather the sediment samples, with an emphasis on a 400 cm2 area beneath the water column. Using the proper sample equipment, sediment cores were taken from each location at a depth of roughly 10 cm. A total of eight samples were carefully selected to cover each lake and capture the diverse ecosystem characteristics present within them. This sampling strategy aimed to provide a comprehensive understanding of the ecological dynamics across the study area. Prior to analysis, it is necessary to prepare the water and sediment samples to ensure accurate and reliable measurements of TOC.

Water samples preparation:

• Transfer 20 mL of the water sample into a pre-cleaned sample vial.

• Filter the water sample to remove any particulate matter using a glass fiber filter.

• Avoid air contact during sample transfer and handling to minimize the risk of contamination.

Sediment samples preparation:

• Homogenize the sediment sample by gently mixing or stirring to ensure a representative subsample is taken.

• Collect a representative subsample from the homogenized sediment.

• Remove any visible debris or large particles from the subsample using forceps or a clean spatula.

• Transfer the subsample into a pre-weighed, pre-cleaned crucible or sample vial, ensuring that the sample is evenly distributed within the container.

The samples can then be injected into the multi-N/C 3100 device for TOC analysis after being properly prepared, as long as you follow the manufacturer's instructions and use the correct settings for the high-temperature combustion procedure. Following the specified sample introduction method (such as liquid injection for water samples or solid sample combustion for sediment samples), inject the prepared water and sediment samples into the multi-N/C 3100 equipment. Permit the samples to undergo high-temperature catalytic oxidation (HTCO), and then let the NDIR detector detect the CO2 that results. The equipment will record the CO2 concentrations, and using the calibration curve, it will determine the TOC content of the samples (ASTM D7573-18 - Standard Test Method for Total Carbon and Organic Carbon).

3. RESULTS AND DISSCUSION

The study found that water samples obtained from non-planted sites had higher organic carbon content compared to those from planted sites. This suggests that the presence of the plant species selected for the study may have contributed to a decrease in organic carbon content in the water samples.

Specifically, the findings showed that:

1. Water samples from Lake Mariout, which is a non-planted site, exhibited the highest organic carbon content among the lakes studied.
2. Water samples from Lake Idku (a planted site) and Lake Burullus (a non-planted site) had the lowest organic carbon content.

These results highlight the potential influence of vegetation on carbon dynamics in aquatic ecosystems. The presence of the plant species in the planted sites appears to have led to a reduction in the organic carbon content of the water samples, suggesting that the plants may have played a role in the cycling and removal of organic carbon from the water. The findings underscore the importance of considering the impact of vegetation when studying the carbon dynamics in aquatic environments. The choice of plant species and their presence or absence can potentially affect the organic carbon content in the water, which is a crucial factor in understanding the overall carbon cycle and the functioning of these ecosystems.

3.1. Lake Idku

The results of the analysis comparing the percentage of total organic carbon in water and sediment samples of Lake Idku (Tab.2) indicate significant variations between these two types of samples. The TOC percentages of the water samples were substantially lower than those of the sediment samples. Additionally, the findings of the comparison of the percentages of total organic carbon in vegetated and non-vegetated sites in Lake Idku in both water and soil samples show that these two types of sites differ significantly from one another. Contrary to expectations, non-vegetation sites consistently had greater total organic carbon percentages than vegetation sites. This finding suggests that the vegetation in question does not significantly contribute to the lake's ecosystem's ability to accumulate organic carbon.

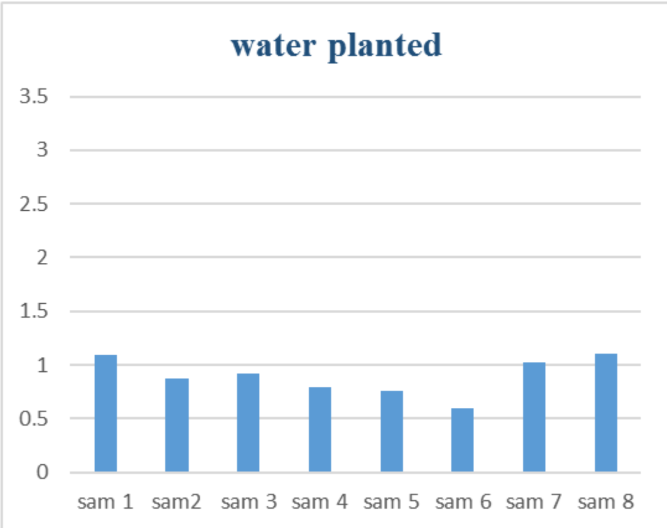

Figure 2: Planted Water organic Carbon content (%) in lake Idku.

3.2. Lake Mariout

The percentage of total organic carbon in samples of Lake Mariout's water and sediment (Tab.3)showed substantial differences in the analysis comparing the two types of samples. The water samples' TOC percentages were much lower than those of the sediment samples.

Table 2: Organic Carbon sequestration percentage (%) of planted and non-planted water and sediment in Lake Idku.

Lake Idku Organic Carbon sequestration percentage (%)				
Samples/station	water planted	water non-planted	sediment planted	sediment non-planted
sam 1	1.09	1.39	1.33	1.73
sam2	0.87	0.99	0.807	1.95
sam 3	0.92	1.43	1.53	1.84
sam 4	0.79	1.23	2.84	2.47
sam 5	0.76	1.54	1.62	2.62
sam 6	0.59	2.03	1.58	3.05
sam 7	1.02	1.15	2.25	3.13
sam 8	1.1	1.51	2.03	2.92

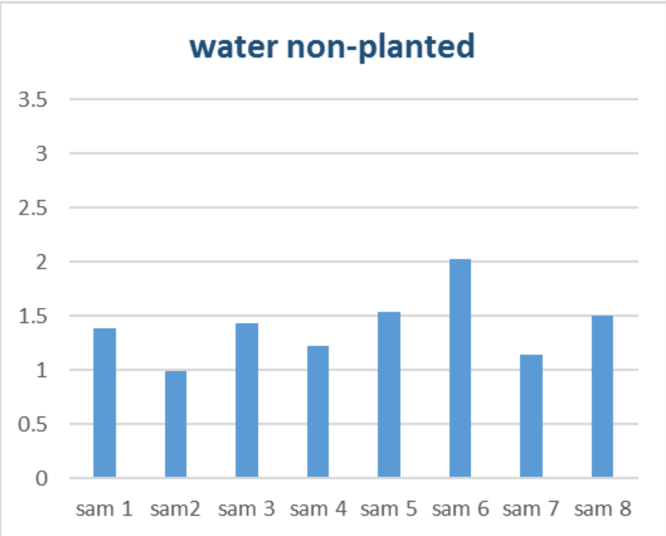

Figure 3: Non-planted Water organic Carbon content (%) in lake Idku.

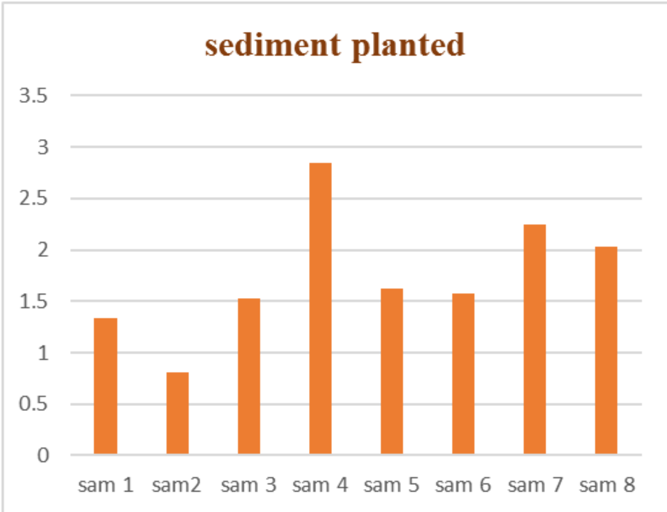

Figure 4: Planted sediment organic Carbon content (%) in lake Idku.

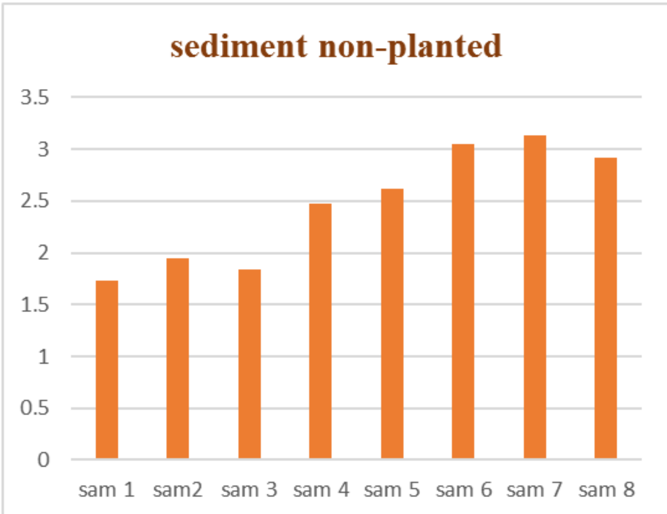

Figure 5: Non- planted sediment organic Carbon content (%) in lake Idku.

Furthermore, samples of both water and sediment were included in the experiment comparing the proportions of total organic carbon in vegetated and non-vegetated areas within Lake Mariout. The findings showed that the total organic carbon content of non-vegetated water samples was higher than that of vegetated ones, but a different trend was seen in sediment samples. It is possible to explain this discrepancy by pointing to recent reclamation works in Lake Mariout, which have had a substantial impact on the soil composition there. The adjustments brought about by these reclamation efforts may have an impact on the organic carbon content of the lake's sediments, causing them to exhibit different patterns from those of the water.

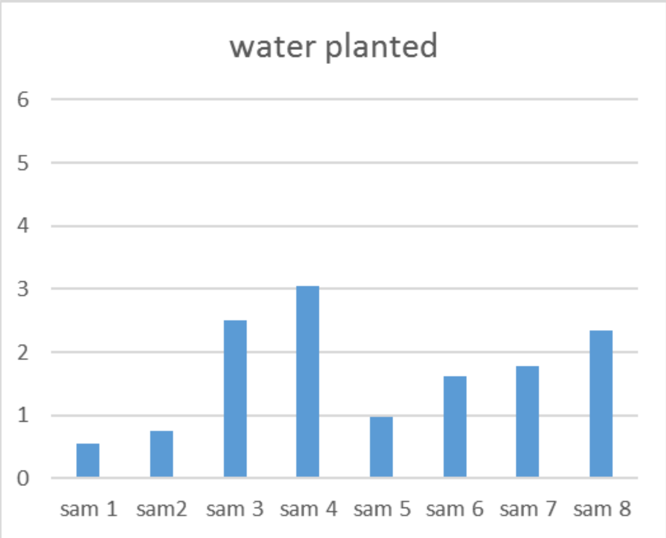

Figure 6: planted Water organic Carbon content (%) in lake Mariout.

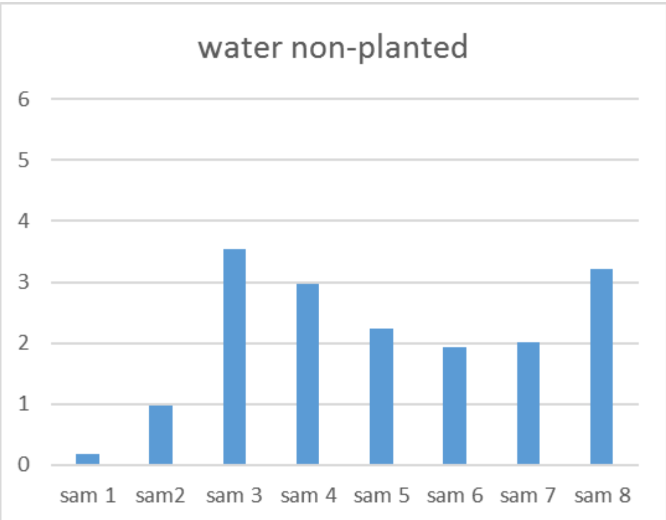

Figure 7: Non- planted Water organic Carbon content (%) in lake Mariout.

3.3. Lake Manzalah

The analysis comparing the two types of samples revealed significant variations in the amount of total organic carbon in the samples of Lake Manzalah's water and sediment (Tab. 4). The TOC percentages of the water samples were substantially lower than those of the sediment samples.

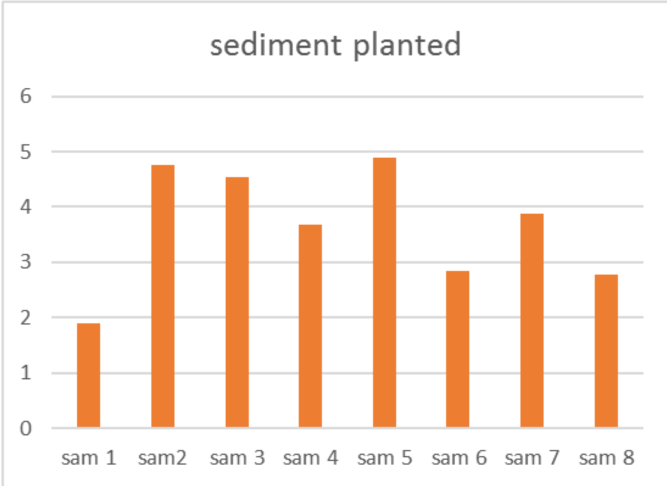

Figure 8: Planted sediment organic Carbon content (%) in lake Mariout.

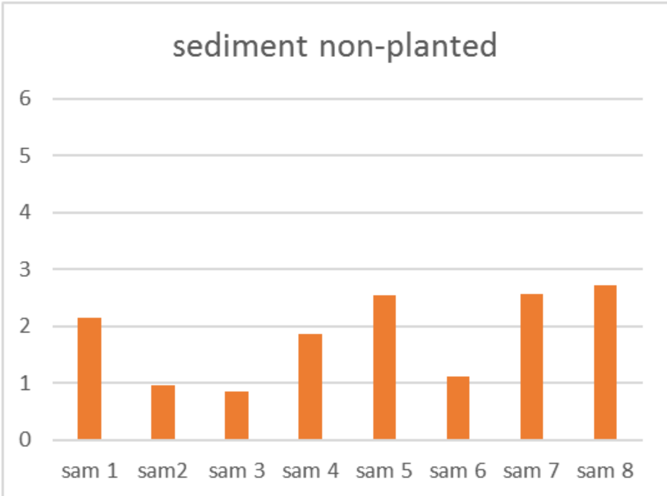

Figure 9: Non- planted sediment organic Carbon content (%) in lake Mariout.

Total organic carbon (TOC) percentages were compared between vegetated and non-vegetated sites inside Lake Manzalah, considering samples of the water and soil. This comparison found considerable disparities between these two site types. Unlike what was initially anticipated, vegetated locations consistently had lower TOC percentages than non-vegetated ones. This unexpected pattern indicates that the amount of vegetation in the lake environment has little to no impact on the buildup of organic carbon. According to these results, the influence of vegetation on the accumulation of organic carbon may be overshadowed by other factors, such as sedimentary processes, in regulating

Table 3: Organic Carbon sequestration percentage (%) ofplanted and non-planted water and sediment in lake Mariout

Lake Mariout Organic Carbon sequestration percentage (%)				
Samples/ station	water planted	water non-planted	sediment planted	sediment non-planted
sam 1	0.55	0.183	1.89	2.15
sam 2	0.75	0.98	4.76	0.956
sam 3	2.50	3.54	4.54	0.839
sam 4	3.04	2.98	3.68	1.87
sam 5	0.98	2.23	4.90	2.54
sam 6	1.61	1.93	2.84	1.11
sam 7	1.77	2.01	3.88	2.57
sam 8	2.34	3.21	2.77	2.73

the dynamics of organic carbon in Lake Manzalah.

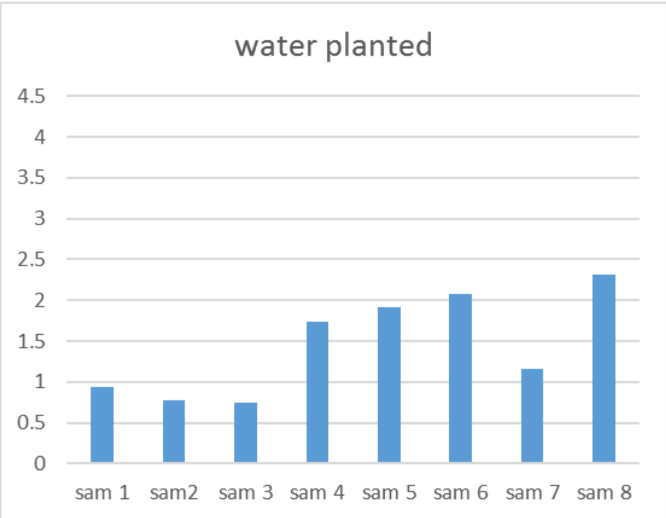

Figure 10: Planted Water organic Carbon content (%) in lake Manzalah.

3.4. *Lake Burullus*

The results of the analysis comparing the percentage of total organic carbon in water and sediment samples of Lake Burullus (Tab. 5) indicate significant variations between these two types of samples. The TOC percentages of the water samples were substantially lower than those of the sediment samples.

In addition, water and sediment samples were used in the experiment to compare the levels of total organic carbon in vegetated and non-vegetated areas of Lake Burullus. The current study focused

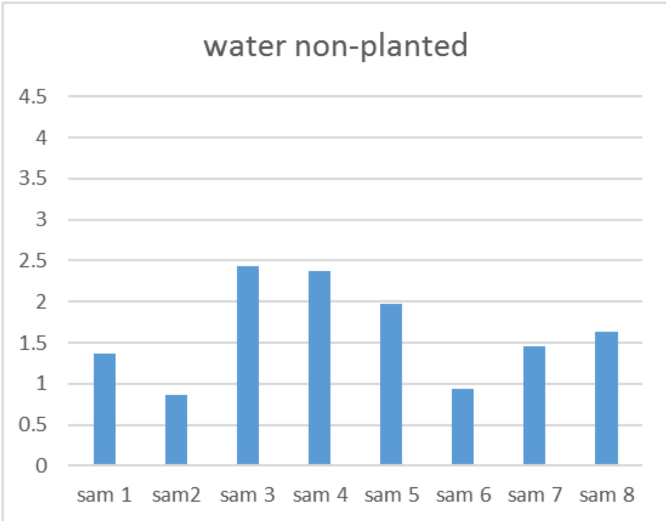

Figure 11: Non-planted Water organic Carbon content (%) in lake Manzalah.

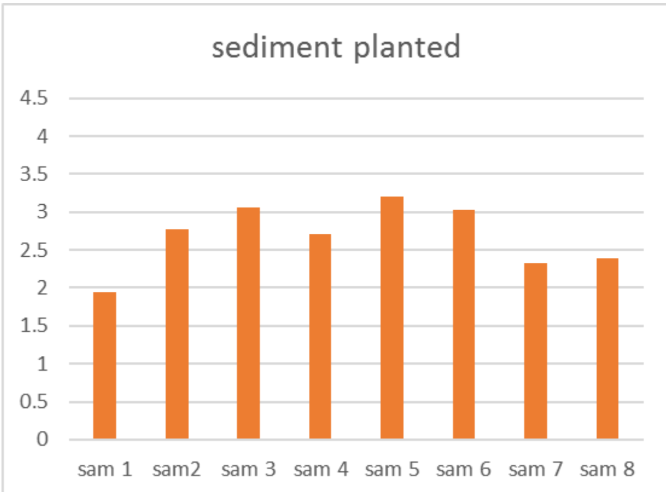

Figure 12: Planted Sediment organic Carbon content (%) in lake Manzalah.

Table 4: Organic Carbon sequestration percentage (%) of planted and non-planted water and sediment in lake Manzalah.

Lake Manzalah Organic Carbon sequestration percentage (%)				
Samples/ station	water planted	water non-planted	sediment planted	sediment non-planted
sam 1	0.93	1.37	1.95	2.51
sam 2	0.78	0.86	2.78	1.31
sam 3	0.75	2.43	3.06	2.94
sam 4	1.74	2.37	2.71	3.28
sam 5	1.91	1.97	3.21	3.59
sam 6	2.08	0.94	3.03	4.02
sam 7	1.16	1.46	2.33	3.86
sam 8	2.31	1.63	2.39	3.92

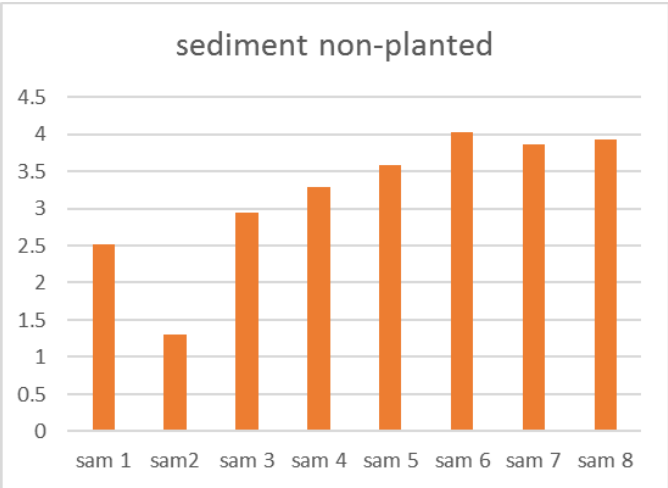

Figure 13: Non-planted Sediment organic Carbon content (%) in lake Manzalah.

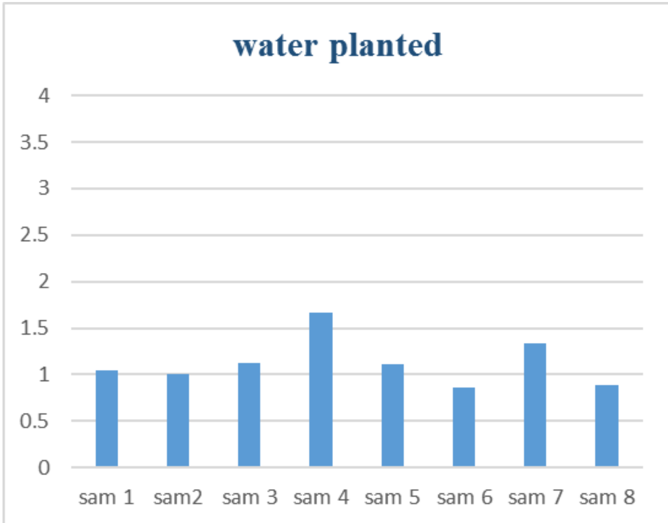

Figure 14: Planted Water organic Carbon content (%) in lake Burullus.

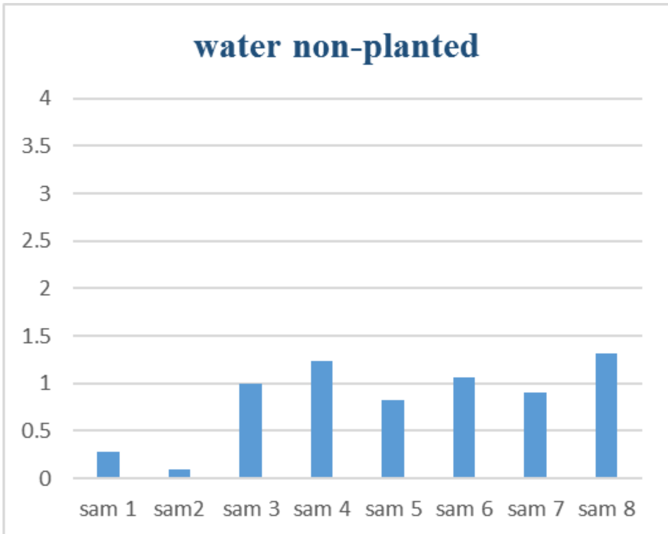

Figure 15: Non- planted Water organic Carbon content (%) in lake Burullus.

on the levels of total organic carbon (TOC) in water and sediment samples collected from both vegetated and non-vegetated regions of Lake Burullus. The conclusions demonstrated that the patterns in the water and sediment samples were distinct. Vegetation showed higher levels of total organic carbon than non-vegetation, according to the analysis of the water sample. The sediment sample analysis, on the other hand, showed an inverse relationship, with the highest concentrations of total organic carbon being discovered in arid regions.

The study's findings provide details on the amount of total organic carbon (TOC) in water samples taken from the northern lakes Idku, Mariout, Burullus, and Manzalah. The findings revealed that areas of these lakes that are devoid of vegetation typically had higher TOC readings Except

Table 5: Organic Carbon sequestration percentage (%) of planted and non-planted water and sediment in Lake Burullus.

Lake Burullus Organic Carbon sequestration percentage (%)				
Samples/ station	water planted	water non-planted	sediment planted	sediment non-planted
sam 1	1.04	0.286	1.312	3.45
sam 2	1.01	0.095	1.17	2.71
sam 3	1.12	1.002	2.36	2.64
sam 4	1.67	1.24	2.16	2.77
sam 5	1.11	0.83	1.86	2.51
sam 6	0.86	1.06	2.48	2.38
sam 7	1.34	0.91	2.06	3.31
sam 8	0.89	1.32	1.46	3.19

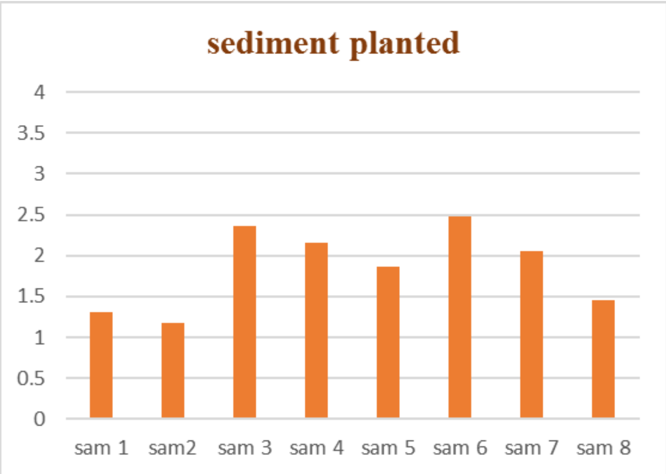

Figure 16: Planted sediment organic Carbon content (%) in lake Burullus.

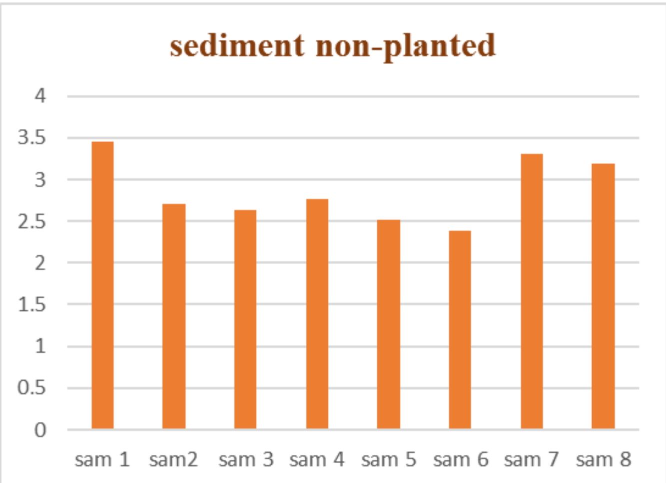

Figure 17: Non-planted sediment organic Carbon content (%) in lake Burullus.

for Burullus Lake, where the total organic carbon content of water samples from the vegetated sections was higher than that of samples from the non-vegetated areas (Tab. 6), the results showed that the vegetation-free areas of these lakes often have higher TOC readings (Fig. 2).

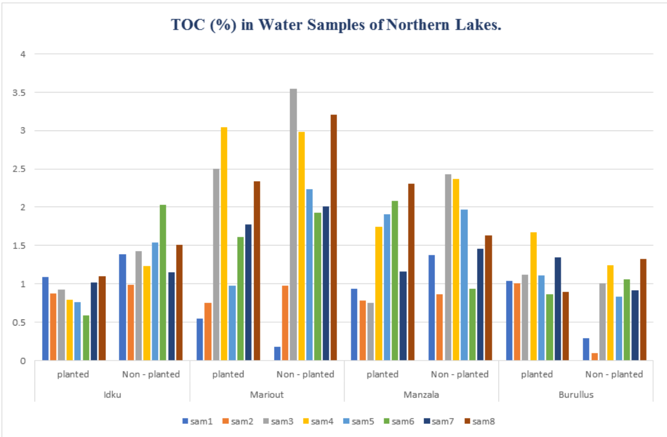

Figure 18: Total organic carbon percentage in water planted and non-planted samples.

The total organic carbon (TOC) in sediment samples taken from the northern lakes, including Idku, Mariout, Burullus, and Manzalah, was quantified in the present study(Tab. 7). The results show that non-vegetated areas within these lakes typically displayed greater TOC concentrations, with Mariout Lake being the exception. Surprisingly, in Mariout Lake, sediment samples taken from vegetated areas had greater TOC contents than samples from unvegetated areas(Fig. 3). These findings highlight the likelihood that vegetation may have an impact on the accumulation of organic carbon

Table 6: Organic Carbon sequestration percentage (%) of Water planted and non- planted samples of Northern lakes.

Lake/ water samples	Idku		Mariout		Manzalah		Burullus	
	planted	Non-planted	planted	Non-planted	planted	Non-planted	planted	Non-planted
sam 1	1.09	1.39	0.55	0.183	0.93	1.37	1.04	0.286
sam 2	0.87	0.99	0.75	0.98	0.78	0.86	1.01	0.095
sam 3	0.92	1.43	2.50	3.54	0.75	2.43	1.12	1.002
sam 4	0.79	1.23	3.04	2.98	1.74	2.37	1.67	1.24
sam 5	0.76	1.54	0.98	2.23	1.91	1.97	1.11	0.83
sam 6	0.59	2.03	1.61	1.93	2.08	0.94	0.86	1.06
sam 7	1.02	1.15	1.77	2.01	1.16	1.46	1.34	0.91
sam 8	1.10	1.51	2.34	3.21	2.31	1.63	0.89	1.32

in these aquatic ecosystems by emphasizing the trend for vegetation-free areas of northern lakes to have higher TOC levels.

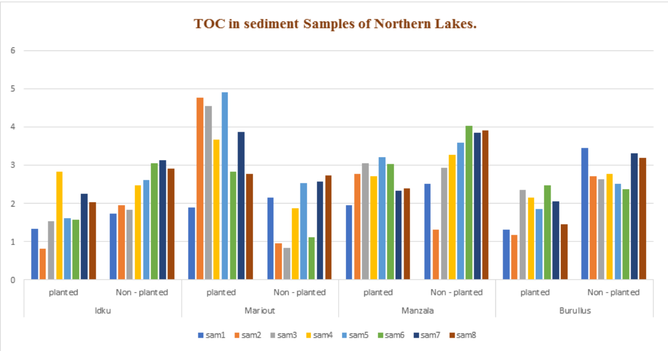

Figure 19: Total organic carbon percentage in Sediment planted and non-planted samples.

4. DISCUSSION

Climate change mitigation has become a global imperative as the world grapples with the far-reaching consequences of a warming climate. One promising strategy to address this challenge is the sequestration of carbon in wetland ecosystems [10]. Egypt Wetland environments play a vital role in the global carbon cycle, serving as significant carbon sinks that can actively remove and store atmospheric carbon dioxide. This process of carbon sequestration occurs through the accumulation of organic matter in wetland soils and sediments, as well as the sequestration of carbon within the water column and the biomass of aquatic plants and organisms [11]. Carbon sequestration in wetlands occurs not only in sediment with plants but also in water, contributing to a significant reduction in carbon emissions.

The depth of sediment within wetland ecosystems has been found to significantly influence the amount of carbon that can be sequestered within these environments This is due to the varying organic carbon content and biogeochemical processes that occur at different sediment depths [1]. Numerous studies have indicated that surface sediment, specifically within the top 10 centimeters of depth, exhibits a considerably higher concentration of carbon content when compared to the deeper sediment layers [8]. This is likely due to the increased deposition of organic matter and the enhanced microbial activity in the surface sediments [12]. Consequently, this particular study focused its investigation on the carbon sequestration potential of the surface sediment samples, which were collected from the top 10 centimeters of the wetland sediment profiles. The results of the study demonstrated that the sediment, in general, exhibits a significantly higher carbon sequestration potential compared to the overlying water column, regardless of the presence or absence of vegetation in the wetland ecosystem. For instance, the sediment samples collected from Lake Mariout, which contained abundant vegetation, had the highest recorded organic carbon content of 3.6575%. In contrast, the non-vegetated sediment samples from Lake Manzalah exhibited the second-highest

Table 7: Organic Carbon sequestration percentage (%) of sediment planted and non- planted samples of Northern lakes.

Lake/ water samples	Idku		Mariout		Manzalah		Burullus	
	planted	Non-planted	planted	Non-planted	planted	Non-planted	planted	Non-planted
sam1	1.33	1.73	1.89	2.15	1.95	2.51	1.312	3.45
sam2	0.807	1.95	4.76	0.956	2.78	1.31	1.17	2.71
sam3	1.53	1.84	4.54	0.839	3.06	2.94	2.36	2.64
sam4	2.84	2.47	3.68	1.87	2.71	3.28	2.16	2.77
sam5	1.62	2.62	4.9	2.54	3.21	3.59	1.86	2.51
sam6	1.58	3.05	2.84	1.11	3.03	4.02	2.48	2.38
sam7	2.25	3.13	3.88	2.57	2.33	3.86	2.06	3.31
sam8	1.33	1.73	1.89	2.15	1.95	2.51	1.312	3.45

organic carbon content of 3.17875%. These findings align closely with the carbon sequestration potential that was observed in a previous study conducted by Ebrahem M. Eid on the five Mediterranean lakes located within Egypt [13], According to the results reported in the previous study [9], the sediment in Egypt's Mediterranean lake ecosystems had a consistently better potential for storing and sequestering carbon than the overlying water column, regardless of whether the wetland areas were vegetated or non-vegetated (Tab. 8).

With a few rare exceptions (such as sample 4), the majority of water samples taken from Lakes Idku, Mariout, and Manzalah show that samples without plants sequester a higher Percentage of organic carbon than those that do. This is not the case, however, for water samples taken from Lake Burullus. Similar to sediment samples, most sediment samples from Lakes Idku, Manzalah, and Burullus without plants have larger percentages of organic carbon sequestration than those from Lakes with plants; however, this is not the case with water samples taken from Lake Mariout.

Interestingly, the carbon content of vegetated sites was found to be lower than that of non-vegetated sites, contrary to expectations based on the chosen plant species (Phragmites australis) [14], [13]. When comparing the four studied lakes, Lake Mariout exhibited a distinct pattern in all tracks, differing from the other lakes. Further investigation revealed that the presence of backfill operations in Lake Mariout was the only

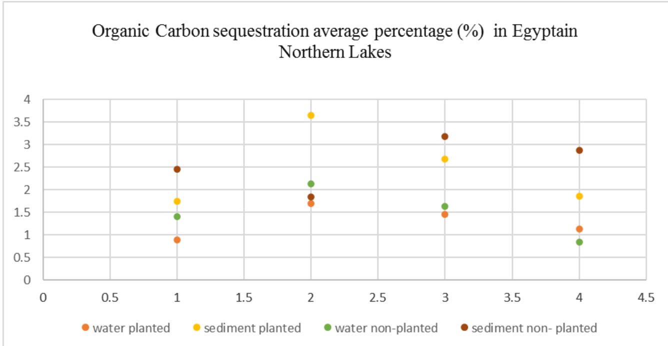

Figure 20: Organic carbon sequestration average in northern lakes.

discernible difference. Consequently, vegetated sediment samples from Lake Mariout displayed a higher carbon content (3.6575%) compared to non-vegetated samples. Conversely, non-vegetated sediment samples from Lake Manzalah exhibited the highest organic carbon content (3.17875%), while vegetated sediment samples from Lake Idku had the lowest organic carbon content (1.748375%).

5. CONCLUSION

In conclusion, this research provides an updated assessment of the potential mitigation opportunities for carbon sequestration in the Egyptian Northern Lakes. The results demonstrate that sediment has a higher capacity for carbon sequestration compared to water. However, the selected plant species, Phragmites australis, commonly found in the Northern Lakes, exhibits a relatively

Table 8: Organic Carbon sequestration percentage (%) in planted samples of northern lakes.

Organic Carbon sequestration percentage (%) in planted samples of northern lakes									
Lake/ planted samples		S1	S2	S3	S4	S5	S6	S7	S8
Idku	water	1.09	0.87	0.92	0.79	0.76	0.59	1.02	1.1
	sediment	1.33	0.81	1.53	2.84	1.62	1.58	2.25	2.03
Mariout	water	0.55	0.75	2.5	3.04	0.98	1.61	1.77	2.34
	sediment	1.89	4.76	4.54	3.68	4.9	2.84	3.88	2.77
Manzalah	water	0.93	0.78	0.75	1.74	1.91	2.08	1.16	2.31
	sediment	1.95	2.78	3.06	2.71	3.21	3.03	2.33	2.39
Burullus	water	1.04	1.01	1.12	1.67	1.11	0.86	1.34	0.89
	sediment	1.31	1.17	2.36	2.16	1.86	2.48	2.06	1.46

Table 9: Organic Carbon sequestration percentage (%) difference of sediment and water samples of Northern lakes.

Idku Difference (%)		Mariout Difference (%)		Manzalah Difference (%)		Burullus Difference (%)	
Water samples	Sediment samples	Water samples	Sediment samples	Water samples	Sediment samples	Water samples	Sediment samples
0.30	0.40	-0.37	0.26	0.44	0.56	-0.754	2.138
0.12	1.143	0.23	-3.81	0.08	-1.47	-0.915	1.54
0.51	0.31	1.04	-3.70	1.68	-0.12	-0.118	0.28
0.44	-0.37	-0.06	-1.81	0.63	0.57	-0.43	0.61
0.78	1	1.25	-2.36	0.06	0.38	-0.28	0.65
1.44	1.47	0.32	-1.73	-1.14	0.99	0.20	-0.10
0.13	0.88	0.24	-1.31	0.30	1.53	-0.43	1.25
0.41	0.89	0.87	-0.04	-0.68	1.53	0.43	1.73

-ve values mean that the % of the OCS in samples with plants are higher than that without plants.

Table 10: mean of total organic carbon percentage in the northern lakes.

Sample		Idku	Mariout	Manzalah	Burullus
water	Mean	1.15	1.91	1.54	0.98
	Mean min	0.74	1.09	1.03	0.74
	Mean max	1.56	2.73	2.06	1.24
Sediment	Mean	2.11	2.75	2.93	2.36
	Mean min	1.55	1.74	2.37	1.85
	Mean max	2.66	3.76	3.5	2.88

low carbon sequestration potential. Therefore, it is recommended to replace Phragmites australis with other species that can enhance carbon sequestration without adversely affecting the lake ecosystems. One promising alternative is Azolla spp., which has shown high carbon sequestration potential and has transitioned from an invasive species to an endemic plant. Azolla spp. offers additional advantages, such as its rapid reproduction and growth rates, as highlighted in previous studies [15].Exploring the benefits of Azolla spp. could prove valuable in optimizing carbon sequestration efforts in the Northern Lakes while considering the ecological balance of these ecosystems. To complement our ongoing investigation into the assessment of carbon sequestration rates in the water and sediment of Egyptian northern lakes, notably Idku, Mariout, Manzalah, and Burullus, additional research in other coastal and marine locations is crucial. We can better understand the dynamics of carbon sequestration and identify more plant species and habitats in addition to Phragmites australis by expanding our research to various coastal and marine areas. We may investigate the capacity for carbon sequestration of various plant species and the ecosystems that support them by investigating diverse habitats like mangroves, seagrass meadows, and salt marshes. With the help of this study, it will be possible to more fully comprehend the coastal regions' overall potential to store carbon and to determine how effective they are at reducing climate change. Additionally, by examining various habitats, we might spot plant species that might have higher rates of carbon sequestration or particular adaptations for effective carbon storage. The development of focused conservation and restoration strategies will be made easier as a result of this knowledge, promoting the maintenance and improvement of carbon sinks in coastal and marine settings. In the end, further study in these fields will help us understand how carbon sequestration works, promote good management techniques, and support international efforts to combat climate change.

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