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Aquatic Hydrophytes Biodiversity in Delta Wetlands, Egypt

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ABSTRACT

The main objective of this study was to shed light on the diversity of aquatic plants in the North Delta wetlands of Egypt—specifically Manzala, Burullus, and Idku—in alignment with Egypt's Sustainable Development Goals (SDGs). To achieve this, 45 sites were selected (15 sites in each wetland) to study the physico-chemical characteristics of water and sediment, as well as the composition of hydrophytic vegetation. Water depth averaged 82cm in Manzala, 99.4cm in Burullus, and 76.4cm in Idku. The pH values ranged from 7.3 to 9.2, electrical conductivity (EC) ranged from 0.6 to 29.6g/ L, and total dissolved solids (TDS) varied between 0.3 and 14.6mg/ L. Dissolved oxygen levels ranged from 2.6 to 9.6mg/ L, while biological oxygen demand (BOD) values were between 1.2 and 8.2mg/ L. The highest recorded silica concentration was 93 µg/L, and the maximum phosphorus content was 43 µg/L. Regarding sediment composition, total carbon ranged from 0.8 to 11.3%, total nitrogen reached a maximum of 95 µg/g dry weight, and total phosphorus peaked at 13µg/ g dry weight. The flora of the study area was found to comprise 26 species of hydrophytes, including 4 submerged, 8 floating, and 14 emergent species. These macrophytes play an essential role in monitoring water and sediment pollution and contribute to the sustainable management of these wetland ecosystems. Notably, *Pistia stratiotes* was found exclusively in the Manzala wetland.

INTRODUCTION

Rafah and Salum lie approximately 970 kilometers apart along Egypt's Mediterranean coast. This narrow, arid coastal belt consists of three distinct component **(Zahran *et al.*, 1985)**. Three shallow wetlands—Manzala, Burullus, and Idku—are identified in this region. These wetlands act as reservoirs, receiving the bulk of the drainage water from the Nile Delta **(Ahmed *et al.*, 2001)**.

According to **Zyadah *et al.* (2004)**, **Zyadah (2005)** and **Nafea (2020)**, the primary threats facing these wetlands are industrial activities, agricultural runoff, land use changes, sewage discharge, and illegal fishing. The distribution of macrophytes in Manzala was investigated by **Zahran *et al.* (1989)** and **Khedr (1997)**, who linked their presence to variables such as water depth, salinity, oxygen levels, pH, chloride, nitrate

(NO_3), and phosphate (PO_4). Through the classification of 100 stands, eleven dominant plant communities were identified. Eight main macrophyte groups were found: *Eichhornia crassipes*, *Potamogeton pectinatus*, *Najas armata*, *Ceratophyllum demersum*, *Ruppia maritima*, *Phragmites australis*, *Typha domingensis*, *Scirpus maritimus*, *Echinochloa stagnina*, and *Ludwigia stolonifera*, considered as emergent hydrophytes.

Samaan *et al.* (1988) studied the hydrophytes in Burullus and noted a higher abundance of these plants, especially in the southern areas. Submerged species were mainly represented by *Potamogeton pectinatus*, while *Ceratophyllum demersum* and *Potamogeton crispus* were less frequent. *Najas armata* was of limited distribution. Emergent hydrophytes like *Phragmites australis* and *Typha domingensis* occupied the margins and areas around the islets.

Saad (1976) stated that chlorinity correlates with the high volume of drainage water and the limited influx of seawater into the wetland. **Shriadah (1992)** concluded that drainage water significantly affects the hydrography and chemistry of the wetland water. Phosphorus was identified as the limiting factor for algal growth.

Abbas *et al.* (2001) reported that the Idku wetland is impacted by drainage water discharge, with low salinity levels supporting the proliferation of macrophytes. **Okbah and El-Gohary (2002)** evaluated the water quality at Idku and found that pollution sources—agricultural, industrial, and domestic—contributed to increased nutrient loading and water contamination. **El-Shenawy (1994)** noted that certain species are restricted to either high or low salinity environments, and that pH also plays a key role in determining species distribution.

Hydrophyte management has been explored by many researchers **(Gee *et al.*, 1997; Kasas *et al.*, 2002; Zahran & Willis, 2003)**. The management of the three Nile Delta wetlands—Manzala, Burullus, and Idku—should be prioritized in the context of achieving Sustainable Development Goals (SDGs).

The main objectives of this study were:

1. Monitoring the physico-chemical characteristics and pollution levels in both water and sediment.
2. Studying the types and floristic composition of aquatic vegetation in the wetlands, and their relationship with water and sediment quality.

Thus, the primary aim of this work was to assess the diversity of aquatic macrophytes in the three wetland stations in support of achieving the SDGs.

MATERIALS AND METHODS

Study area

Manzala is located between longitudes 31°05′00″ and 32°15′00″ E and latitudes 31°00′00″ and 31°30′00″ N. It is the largest of the northern deltaic wetlands in Egypt, covering an area of approximately 1,000km² **(Zahran & Willis, 2003)**. Manzala stretches about 47km in length and 30km in width. It is predominantly shallow and receives three types of water: freshwater, seawater, and drainage water **(Nafea, 2005)**.

Burullus lies between the Damietta and Rosetta branches of the River Nile, extending between longitudes 30°31′00″ and 31°10′00″ E and latitudes 31°21′00″ and 31°35′00″ N **(Ahmed *et al.*, 2001)**. It connects to the Mediterranean Sea through a narrow channel known as Boughaz El-Burullus. The southern boundary of Burullus is bordered by agricultural lands and fish farms **(Nafea, 2019)**. The lagoon receives a substantial volume of drainage water through multiple drains. Additionally, 26 islands are present in the lagoon **(El-Bayomi, 1999; Nafea, 2005)**.

Idku is located west of the Rosetta branch, between longitudes 30°08′00″ and 30°23′00″ E and latitudes 31°11′00″ and 31°18′00″ N. The lagoon covers approximately 12,000 feddans, or about 50km². It is a shallow, brackish water body measuring about 17 km in length and 6km in width **(Khadr *et al.*, 1992)**. Idku receives large volumes of drainage water—ranging from 83,000 to 280,000m³/day. The southern part is affected by inflow from Barsik Drain, while the western part is directly connected to Abu Qir Bay through Boughaz El-Maadiya. This bay receives approximately 1,850,000 m³/day of wastewater discharged from the El-Tabia Drain pumping station **(Shriadah & Tayel, 1992)**.

Table 1. The investigated sites selected within the three studied wetlands

Site No	Manzala wetland		Burullus wetland		Idku wetland	
1	El-Ghamil	N=31º 9´ E=32º 15´	El-Boughaz area	N=31º 34´ E=30º 59´	El-Maadiya	N: 31º 16´ E: 30º 10´
2	Tenis	N=31º 30´ E=32º 14´	Emade	N=31º 33´ E=30º 59´	El-Nakha	N: 31º 15´ E: 30º 10´
3	El-Bashtir	N=31º 12´ E=32º 10´	Mouth of drain El-Burullus	N=31º 33´ E=31º 04´	Western zone	N: 31º 15´ E: 30º 10´
4	Legan	N=31º 16 ´ E= 32º 20´	Mouth of El-Gharbia drain	N= 31º 31´ E=31º 04´	Near Qarn Diab	N: 31º 13´ E: 30º 11´
5	Dishdy	N=31º 13´ E=32º 5´	Mouth of Nasser Drain	N=31º 31´ E= 31º 31´	Western zone	N: 31º 12´ E: 30º 12´
6	El-Nassima	N=31º 13´ E= 32º 3´	Mishkhilah	N=31º 30´ E=30º 57´	Southern zone	N: 31º 9´ E: 30º 14´
7	El-Gamalyia	N=31º 13´ E=32º 18´	Mouth of Drain 7	N=31º 27´ E=30º 56´	Southern zone	N: 31º 10´ E: 30º 15´

8	Tolmpat fahim	N=31º 20´ E= 31º 51´	Mid. of eastern section	N=31º 32´ E=30º 58´	Middle zone	N: 31º 12´ E: 30º 15´
9	Abwat 1	N=31º 20´ E=31º 50´	El-Kom El-Akhder	N=31º 24´ E=30º 43´	Middle zone	N: 31º 15´ E: 30º 15´
10	Hemir	N=31º 20´ E=31º 15´	Kodaa	N=31º 36 ´ E=31º 01´	Northern zone	N: 30 º 16´ E: 30º 16´
11	El-Midah	N=31º 21´ E=31º 51´	El-Maksabah	N=31º 29´ E=30º 45´	Northern zone	N: 31º 15´ E: 30º 14´
12	El-Serew 1	N=31º 21´ E=31º 52´	Deshemi	N=31º 20´ E=30º 37 ´	Eastern zone	N: 31º 15´ E: 30º 20´
13	El-Rodah 2	N=31º 21´ E=31 25 29	El-Tawilla	N=31º 26´ E=30º 44´	Eastern zone	N: 31º 16´ E: 30º 19´
14	Shatta	N=31º 20´ E=31º 15´	Sakkarana	N=31º 24´ E=30º 37´	Eastern zone	N: 31º 15´ E: 30º 19´
15	El-Baghdadi	N=31º 80´ E=32º 5´	Brimbal canal	N=31º 24 ´ E=30º 35´	Eastern zone	N: 31º 16´ E: 30 º 21´

Field studies

Forty-five sites were selected to represent the three northern wetlands under study—15 sites for each station—during the summer of 2023 and winter of 2024. The physico-chemical parameters of water samples were analyzed according to the standard methods described in **Sawyer and McCarty (1978)**, **Walker (1982)**, **EPA (1983)**, **APHA (1985, 1989, 1992)**, **Adams (1990)** and **Standard Techniques (1992)**.

Macrophyte diversity was assessed at 45 stands (10 × 10m) located in open water zones at each site (15 per station), focusing on hydrophytic plant communities. Dominance, floristic composition, and abundance of various species were determined following the methods of **Cottam and Curtis (1956)** and **Kershaw (1973)**. Species presence-absence was estimated according to **Raunkiaer (1934)**, and species identification was conducted based on the taxonomic keys and references provided by **Bolus (1995, 2000, 2001, 2009)**.

Sediment water extract and analysis followed the methodologies outlined in **Walkley (1935)**, **Piper (1947)** and **Adams (1990)**.

All statistical analyses were performed on an IBM mainframe computer using the Statistical Package for the Social Sciences (SPSS). An analysis of variance (ANOVA) was conducted to test for group differences with respect to the concentrations of the studied elements. Mean ± standard error (MSE) values were calculated for all datasets.

Multivariate analysis

Cluster analysis

Cluster analysis was performed using the SYSTAT 7.0 software **(Wilkinson, 1997)**, applying Euclidean distances and the centroid linkage method to classify the biological data into distinct groups.

Canonical correspondence analysis (CCA)

Canonical correspondence analysis was applied to the matrix of biological parameters and environmental variables using the CANOCO (Canonical Community Ordination) software **(Ter Braak, 1987)**.

RESULTS

1- The Physico-chemical evaluation of the water of the 3 studied wetlands

Water quality

Water temperature in the northern deltaic wetlands ranged between 15–20°C in winter and 28–33°C in summer. Water transparency varied significantly between sites, with maximum recorded values of 100cm in Manzala, 39cm in Burullus, and 40cm in Idku. Transparency values were generally higher in summer than in winter.

The average pH values across the wetlands were within a narrow range: 8.1–8.3 in both seasons (Tables 2, 3). Electrical conductivity (EC) and total dissolved solids (TDS) showed correlated behavior. Manzala recorded the highest TDS value (14.6mg/ L) during summer, while Idku recorded the lowest TDS values during winter. TDS was generally higher in summer than in winter.

Dissolved oxygen (DO) concentrations ranged from 2.6–9.4mg/ L in summer and 3.9–9.6mg/ L in winter. Higher DO values were recorded during winter, while biological oxygen demand (BOD) values were higher in summer. Manzala recorded the lowest DO values among the three wetlands.

As shown in Tables (2, 3), concentrations of phosphate, ammonia, nitrate, nitrite, and silica were generally higher at Idku during both seasons compared to the other lakes. All these parameters exhibited higher values in winter except for silica, which showed a slight increase in summer.

2. Physico-chemical characteristics of sediments

The total organic matter (TOM) percentage in sediment ranged from 1.1–4.1% in Manzala, 0.61–2.9% in Burullus, and 0.6–11.6% in Idku (Tables 4 & 5). Idku displayed the highest values of total organic carbon (TOC) among all stations. Total nitrogen (TN) concentrations ranged widely between 3.1 and 100 µg/ g dry weight, with the lowest values in Manzala and the highest in Idku. Burullus and Idku exhibited the highest TN concentrations overall (Tables 4, 5).

Total phosphorus (TP) in sediments ranged from 40–113µg/ g dry weight, with Burullus recording the lowest values. The winter season showed elevated levels of TOC, TN, and TP compared to the summer.

Sediment texture at Manzala was predominantly sandy-silt, with mean compositions of 56.5% sand, 32.5% silt, and 9–11% clay. Burullus had a silt-clay texture, with 20.7–22% sand, 41–48.6% silt, and 30.8–37% clay. Idku exhibited a loamy texture, with 36–45% sand, 36–39.2% silt, and 19–24.8% clay (Tables 4, 5).

3. Vegetation

A total of 26 aquatic macrophyte species were recorded across the three wetlands: 4 submerged, 8 floating, and 14 emergent species. *Pistia stratiotes* was found exclusively in Manzala. *Najas armata* showed high presence at Burullus (65%) and low presence in Manzala (5%) and Idku (10%) (Table 6). *Marsilea aegyptiaca* was most common in Idku (65%) and less frequent in Manzala and Burullus (15 and 5%, respectively). *Potamogeton crispus* was abundant in Manzala (65%).

The dominant submerged macrophytes were *Ceratophyllum demersum* and *Potamogeton pectinatus*. Floating species were dominated by *Eichhornia crassipes* and *Lemna gibba*. Emergent species included *Phragmites australis*, *Typha domingensis*, *Saccharum spontaneum*, *Ludwigia stolonifera*, *Echinochloa stagnina*, and *Panicum repens*. *Nymphaea caerulea* was rare (Table 6).

Cluster analysis of the 45 sampling stands (Fig. 2) identified four vegetation groups, encompassing 18 plant communities:

- **Group A**: Dominated by *Juncus rigidus* and *Panicum repens*, with codominant *Lemna gibba* and indicator species *Spirodella polyrrhiza* (mainly in Idku).
- **Group B**: Dominated by *Phragmites australis* and *Echinochloa stagnina*, with codominant *Potamogeton crispus* and indicator *Ranunculus scleratus* (Manzala stands).

- **Group C**: Dominated by *Potamogeton pectinatus*, *Najas armata*, and *Ceratophyllum demersum*, with *Saccharum spontaneum* and *Pistia stratiotes* as codominants. *Ranunculus scleratus* also served as an indicator species. This group shows overlap between Manzala and Burullus.
- **Group D**: Dominated by *Saccharum spontaneum*, with codominant *Persicaria salicifolia* and indicators *Cynanchum acutum*, *Rumex dentatus*, and *Marsilea aegyptiaca*. This group shows overlap across all three wetlands.

4. Vegetation–Environment Relationships (CCA)

Canonical Correspondence Analysis (CCA) (Figs. 3, 4) revealed strong correlations between environmental parameters and vegetation distribution. Arrows in the biplot indicate the strength and direction of environmental gradients:

- The dominant species *Ceratophyllum demersum* and indicator *Persicaria salicifolia* (lower right of the biplot) were closely associated with high concentrations of NH_4, DO, SiO_2, and Cd.
- *Phragmites australis* (upper left) correlated with elevated EC, NO_2, and Cu levels.
- *Eichhornia crassipes* and *Azolla filiculoides* (upper right) were linked to high TDS.
- *Potamogeton pectinatus* and *Typha domingensis* (lower left) correlated with PO_4, NO_3, Zn, and BOD.

Sediment traits such as TN, TOC, TP, EC, pH, Cd, Cu, Zn, Pb, and soil texture (sand, silt, clay) were also significantly associated with the first and second axes.

- *Eichhornia crassipes* and *Persicaria salicifolia* (lower biplot) related strongly to EC, TOC, and sediment texture.
- *Phragmites australis* (upper biplot) was distinctly positioned.
- *Potamogeton pectinatus* and *Cyperus articulatus* (upper left) aligned with high TN and Pb.
- *Panicum repens* and *Lemna minor* (lower left) correlated with high Zn, Cd, TP, Cu, and pH.

DISCUSSION

Water temperature in the northern deltaic wetlands ranged between 15–20°C in winter and 28–33 °C in summer. This marked seasonal variation is attributed to solar radiation, which influences air temperature and, consequently, water temperature **(Aboul-Kassim & Dowidar, 1990)**. Water temperature affects both abiotic and biotic components of wetland ecosystems.

Transparency varied significantly across sites, with maximum depths of 100, 39, and 40cm in Manzala, Burullus, and Idku, respectively. Transparency values were higher in summer than in winter, with Manzala recording the highest values (Tables 3, 4). The high transparency in Manzala may be due to the dense growth of *Potamogeton pectinatus* and other hydrophytes, which trap and settle suspended particles. This finding is consistent with earlier studies in Mariut **(Samaan & Aleem, 1969)** and Burullus **(Radwan *et al.*, 2001)**. Additionally, the low percentage of clay in Manzala's sediments contributes to increased transparency and reduced turbidity **(Beltagy, 1985)**.

The low transparency at Burullus may be due to strong winds causing water turbulence and increased suspended matter from drainage inputs **(Sayed, 2003)**.

pH values ranged between 8.1 and 8.3 during both seasons, with extremes of 9.2 (winter) and 7.3 (summer) recorded in Manzala. Higher pH levels are linked to increased photosynthetic activity of phytoplankton and aquatic plants in summer **(Samaan, 1974; Sayed, 2003)**. Conversely, lower pH values, especially near drain outlets, are due to pollution and CO_2/H_2S release during organic matter decomposition **(Abbas *et al.*, 2001)**.

Manzala recorded the highest total dissolved solids (TDS) at 14.6mg/ L during summer, while Idku had the lowest in winter. TDS levels were generally higher in summer due to saline water intrusion from the Mediterranean. Salinity typically decreased with distance from the El-Boughaz areas, while wind played a significant role in its spatial distribution **(Nafea, 2019)**. In Burullus, salinity levels are affected by freshwater inflow from the Brenbal Canal. The high TDS in Manzala is linked to seawater inflow through the El-Gamil and El-Borg channels.

Dissolved oxygen (DO) levels ranged between 2.6–9.4mg/ L (summer) and 3.9–9.6mg/ L (winter). Winter values were higher due to lower temperatures and wind-induced mixing, increasing oxygen solubility **(Younis & Nafea, 2012)**. Lower DO in summer correlates with higher temperatures, which reduce oxygen solubility **(Sawyer & McCarty, 1978)**. Manzala had the lowest DO, likely due to eutrophication. Biological oxygen demand (BOD) was higher in summer, related to respiration by aquatic organisms and aerobic bacteria **(Ahmed *et al.*, 2001)**. BOD and DO were inversely related **(Younis & Nafea, 2012)**.

Concentrations of phosphate, ammonia, nitrate, nitrite, and silica were higher at Idku, influenced by heavy drainage inputs from sewage and agriculture **(Abbas *et al.*, 2001; Sayed, 2003)**. High phosphorus levels further confirmed the eutrophic state of Idku **(Zaghloul & Hussein, 2002)**.

High ammonia concentrations stem from drainage inflows, while low concentrations indicate phytoplankton uptake. Nitrate, the most stable form of inorganic nitrogen in oxygenated water, had its highest concentration (13.3µg/ L) at Idku, due to agricultural runoff. Nitrite levels peaked at 42 µg/L, consistent with previous findings **(Abbas *et al.*, 2001)**. Reactive silicate levels, important for diatom productivity, were highest at Burullus (91 µg/L), aligning with findings of 97.5 µg/L by **(Younis & Nafea, 2012)**.

Phosphorus is a key nutrient for plant and microbial life **(Vanloon & Duffy, 2000)**. The highest phosphate concentration recorded was 43µg/ L at Idku, compared to 32.9 µg/L in previous reports **(Abbas *et al.*, 2001)**. Phosphate sources include fertilizers, domestic and industrial waste, and decomposition of organic phosphorus compounds **(Foust & Aly, 1981)**. The increased pollution at Idku is linked to various drainage sources **(Okbah & El-Gohary, 2002)**.

Sediment characteristics

Total organic carbon (TOC) in sediments ranged from 1–1.4% in Manzala, 0.4–2.9% in Burullus, and 0.6–11.6% in Idku (Tables 5, 6). The highest TOC values in Idku are attributed to sewage discharge and decomposing aquatic plants **(Sayed, 2003)**. Total nitrogen (TN) varied from 3.1 to 100 µg/g dry weight, with the highest levels in Idku and the lowest in Manzala. This reflects the heavy wastewater loads entering Burullus and Idku **(Younis & Nafea, 2012)**.

Total phosphorus (TP) in sediments ranged between 40–113 µg/g. The highest TP values, observed in winter, are linked to runoff from phosphate fertilizers **(Sayed, 2003)**. A strong correlation exists between TP and TOC content in these wetlands **(Abbas *et al.*, 2001)**.

Sediment textures were as follows:

- **Manzala**: sandy-silty (56.5% sand, 32.5% silt, 9–11% clay)
- **Burullus**: silty-clayey (20.7–22% sand, 41–48.6% silt, 30.8–37% clay)
- **Idku**: loamy (36–45% sand, 36–39.2% silt, 19–24.8% clay)

Aquatic vegetation and ecological indicators

A total of 26 macrophyte species were identified: 4 submerged, 8 floating, and 14 emergent. *Pistia stratiotes* was exclusive to Manzala. *Najas armata* was dominant at Burullus (65%) but sparse at Manzala (5%) and Idku (10%) and is not found elsewhere in Egypt's aquatic systems **(Nafea, 2005, 2019; Khedr, 1999)**. *Ruppia maritima* was found in the northern wetland zones. **(Khedr, 1989)** reported 22 halophytes in Manzala—a figure that remains consistent.

Species like *Phragmites australis*, *Typha domingensis*, and *Juncus rigidus* are sources of fibrous materials for construction and paper production. Overgrowth of aquatic vegetation can impede fishing, navigation, and water resource management. Therefore, sustainable weed control, rather than eradication, is recommended **(Zahran & Willis, 2003; Nafea, 2020)**.

Potamogeton pectinatus is widely distributed in fresh and brackish waters and is considered a bioindicator for water salinity, while *Potamogeton crispus* has a more localized distribution.

Cluster analysis identified 18 plant communities categorized into four groups:

- **Floating**: *Eichhornia crassipes*, *Azolla filiculoides*, *Lemna gibba*, *Pistia stratiotes*
- **Submerged**: *Potamogeton pectinatus*, *P. crispus*, *Ceratophyllum demersum*, *Najas armata*
- **Emergent**: *Phragmites australis*, *Typha domingensis*, *Echinochloa stagnina*, *Ludwigia stolonifera*, *Saccharum spontaneum*, *Persicaria senegalensis*

Salinity (as EC) is the most critical factor influencing species distribution. Species like *Eichhornia crassipes* and *Azolla filiculoides* dominate floating mats, while generalists like *Phragmites australis* and *Potamogeton pectinatus* span all habitats. Drain inputs favor floating and emergent hydrophytes like *Ludwigia stolonifera* and *P. australis*.

Some communities were monospecific, likely reflecting extremes along environmental gradients. Floating and creeping species often occur in association **(Nafea, 2019a)**.

Aquatic macrophytes contribute to ecosystem diversity and can serve as habitat indicators. For example, *Potamogeton crispus* indicates oxygen-rich, mesotrophic habitats, while *Ceratophyllum demersum* thrives in nutrient-rich, polluted waters **(Younis & Nafea, 2015)**. These plants also act as bioindicators, accumulating inorganic pollutants **(Nafea & Zyada, 2015; Nafea, 2020)**.

Integrated aquatic weed management is crucial for sustainable water use and supports progress toward the Sustainable Development Goals (SDGs). Management approaches include mechanical, chemical, and biological methods, with mechanical and biological control showing the most promise, particularly for floating vegetation.

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Appendixes

Table 2. Physico-chemical characteristics of water in the Nile Delta-wetlands during summer 2023

Parameters	Manzala wetland			Burullus wetland			Idku wetland		
	Min.	Max	X±SE	Min.	Max	X±SE	Min.	Max.	X±SE
Depth cm	20	180	82±42	60	160	99.4±9	51	103	76.4±19
Temperature C̊	30	32	31±6	28	31	29.5±1	29	33	30.7±3
Transparency cm	15	100	36.3±30	20	39	26.2±4	20	40	30.9±11
pH	7.3	9.1	8.3±1	7.5	8.6	8.1±0.3	7.8	8.6	8.2±1
EC g/ l	0.6	29	6.3±13	1.0	8.5	3.2±3	1.1	2.6	1.7±1
TDS g/ l	0.3	14.6	3.6±6	1.2	2.8	1.6±1	0.6	1.0	0.8±0.2
DO mg/ l	2.6	8.5	6.1±5	6.3	9.4	8.9±2	6.8	9.4	9.1±2
BOD mg/ l	1.2	6.8	3.3±3	1.3	6.9	2.9±1.8	1.2	5.6	2.1±2
PO_4 µg/ l	2.7	9.8	5.4±2	1.4	13	5.1±2	16.5	43	29.8±4
NH_4 µg/ l	10.1	26.0	16.3±6	1.1	20.1	8.6±4	12	40.5	29.8±3
NO_3 µg/ l	4.2	13.0	8.7±4	1.3	13.9	6.0±5	11.3	42.0	24.6±8
NO_2 µg/ l	1.2	5.0	2.8±1	0.4	9.0	3.1±3	9.0	13.3	10.4±2
SiO_2 µg/ l	19	93	58.6±19	40.1	91	70.7±11	34	92.4	70.1±5
Cu. µg/ l	9	43	21.5±7	8.4	20.1	13.5±5	20.2	40.2	28.8±6
Zn µg/ l	46.5	116	99.3±8	6.3	41.2	19.9±9	10.5	126	60.6±20
Pb µg/ l	16	23	21.9±2	3.9	16.2	8.2±5	8.6	100	56.4±18
Cd µg/ l	11.6	40	21.8±10	1.3	8.1	4.7±3	4.1	16.2	11.5±3

Where: X = Average values SE = Standard Error

Min.=Minimum Max. = Maximum

Table 3. Physico-chemical characteristics of the water in the Nile Delta- wetlands during winter 2024

Parameters	Manzala wetland			Burullus wetland			Idku wetland		
	Min.	Max.	X±SE.	Min.	Max.	X±SE.	Min.	Max.	X±SE.
Depth cm	26	160	90±40	45	166	90 ± 30	45	110	77.5±30.5
Temperature C^0	16	19	18 ± 1	15	17	16 ± 1	16	20	18 ± 3.5
Transparency cm	16	50	35±10	22	38.6	35±3	18	36	28±7.3
pH	7.5	9.2	8.3±0.6	7.6	8.8	8.3±0.2	7.6	8.9	8.3± 0.6
EC g/ l	0.5	26	5.9±1.4	0.9	7.8	3±2	0.7	2.4	1.4±1.1
TDS g/ l	0.3	14.3	2.8±2	0.42	2.57	1.1±0.5	0.2	1.6	1.3±0.4
DO mg/ l	3.9	9	6.3±4	5.9	9.6	9.1±3	7.2	9.7	9.3±1.3
BOD mg/ l	1.1	4.8	3±1	1.5	5	2.4±2	1.8	5.2	1.9±1
PO_4 µg/ l	2.3	8.4	6±2	1	13.2	8±2	19	43	31±6
NH_4 µg/ l	10.3	28	25±4	8.3	38.1	23±6	11	43	28±10
NO_3 µg/ l	3.2	12.9	8±2	1.8	11.5	7.5±3	13	43.6	30±11
NO_2 µ/ l	1.4	5.1	3.2±1	0.63	5.8	4±2	9.5	22	17±4
SiO_2 µg/ l	24	91	64±17	21.6	66.5	51±10	37	93	80±20
Cu µg/ l	11	33	22±4	13.5	28.3	26±6	21.6	39.1	29±8
Zn µg/ l	30	63	51±9	16.2	44.1	33±10	11.6	124	66±15
Pb µg/ l	14	32	26±4	3.5	15.6	10±3	18.7	105	70±17
Cd µg/ l	36	50	43±10	4.1	20.2	14±3	4.3	17	12±3

Table 4. Physico-chemical characteristics of the sediment in the Delta- wetlands during summer 2023

Parameters	Manzala			Burullus			Idku		
	Min.	X±SE	Max.	Min.	X±SE	Max.	Min	X±SE	Max.
PH	7.5	8.2±1	9.2	6.9	8.2±1	9.3	7.7	8.1±0.3	8.7
TOC %	1.1	1.7±1	3	0.82	2±1	2.9	0.8	5.2±6	11.3
TN µg/g dry Wt.	3.1	7.8±2	11.2	30	59±10	95	11.8	27.4±10	50
TP µg/g dry Wt.	75	93±7	99	40	73.4±15	101	61.5	82.5±9	109
Cu µg/g dry Wt.	13.8	19±4	28.1	10.3	26.3±10	40	12.1	20±5	34
Zn µg/g dry Wt.	26.6	54±10	81.3	23	81.6±10	121	36.2	64±10	90
Pb µg/g dry Wt.	25	31.4±3	35.2	6.2	16.8±8	42	12.1	17.1±5	23
Cd µg/g dry Wt.	4.5	8.7±4	15.1	1.2	3.1±2	6.3	5.1	12.3±3	16
Sand %	21	58.5±15	85	3	20.7±6	40	6	36.0±10	86
Silt %	14	32.5±19	73	3	48.6±10	65	9	39.2±6	63
Clay %	1	9±10	27	0	30.8±15	69	4	24.8±8	44

Where: X : Average values SE:s Standard Error T M: Total organic matter T N: Total nitrogen
Min.: Minimum Max.=Maximum T P: Total phosphorus

Table 5. Physico-chemical characteristics of the sediment in the Nile Delta-wetlands during winter 2024

Parameters	Manzala wetland			Burullus wetland			Idku wetland		
	Min.	Max	X±SE.	Min.	Max.	X±SE.	Min.	Max.	X±SE.
PH	7.3	8.9	8.2±0.5	7.1	8.6	7.8±0.6	7.6	8.6	8.2±1
TOC %	1.3	4.1	2.6±0.4	0.61	2.7	1.6±0.5	0.61	11.6	6.1±5.1
TN µg/g dry Wt.	3.6	11.5	8±3	38	100	65±30	12	63	36±16

TP µg/g dry Wt.	73	110	94±13	50.1	111	81±19	61	113	87±30
Cu µg/g dry Wt.	14.2	26.2	20±4	10	40.5	25±10	11.4	33.8	21±10
Zn µg/g dry Wt.	24.2	81	50.4±19	20	110	67±30	40.1	82	63±19
Pb µg/g dry Wt.	23.1	36	31±10	6.5	33.1	21±6	10.6	22.1	16±6
Cd µg/g dry Wt.	3.5	15.6	13.3±4	0.95	5.9	3.5±2	9.3	11.8	10±1
Sand %	20	91	56.5±20	3	41	22±16	6	88	45±20
Silt %	8	75	32.5±19	5	75	41±19	6	63	36±16
Clay %	1	30	11±19	1	62	37±22	2	50	19±10

Table 6. Presence (%) of the hydrophytic vegetation in the Nile delta- wetlands

No.	Percentage % / Species	Manzala wetland P %	Burullus wetland P %	Idku wetland P %
a- Submerged species				
1	*Ceratophyllum demersum L.*	90	95	95
2	*Potamogeton pectinatus (L.) Böerner*	90	95	95
3	*Potmogeton crispus (Linnaeus, 1753)*	65	30	5
4	*Najas armata L*	5	65	10
b- Floating species				
1	*Eichhornia crassipes L.*	65	80	80
2	*Pistia stratiotes L.*	45	-	-
3	*Lemna gibba L.*	35	45	70
4	*Lemna minor L.*	15	40	65
5	*Nymphaea coerulea L.*	10	5	5
6	*Marsellia aegyptiaca L.*	15	5	65
7	*Azolla filiculoides Lam.*	15	30	45
8	*Spirodella polyrrhiza l.*	10	5	30
c- Emerged species :				

1	*Phragmites australis L.*	95	90	95
2	*Typha domingensis Pers.*	90	85	95
3	*Panicum repens L.*	80	70	90
4	*Ludwigia stolonifera (Cav.trin)*	85	60	80
5	*Persicaria salicifolia* Brouss. ex Willd.) Assenov	45	10	20
6	*Persicaria senegalensis*	75	30	65
7	*Echinochloa stagnina* L.	70	30	75
8	*Saccharum spontaneum L.*	65	55	65
9	*Scirpus maritimus L.*	30	50	10
10	*Scirpus litoralis L.*	15	45	30
11	*Juncus rigidus L.*	15	5	60
12	*Cynanchum acutumL.*	40	15	50
13	*Juncus subulatusL.*	5	5	60
14	*Cyperus articulatusL.*	-	15	20

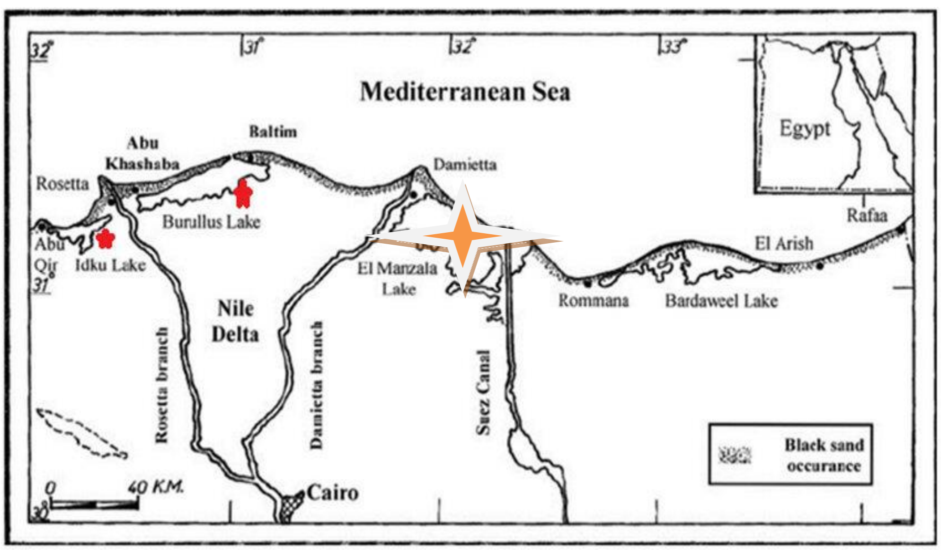

Fig. 1. Locations of the study area

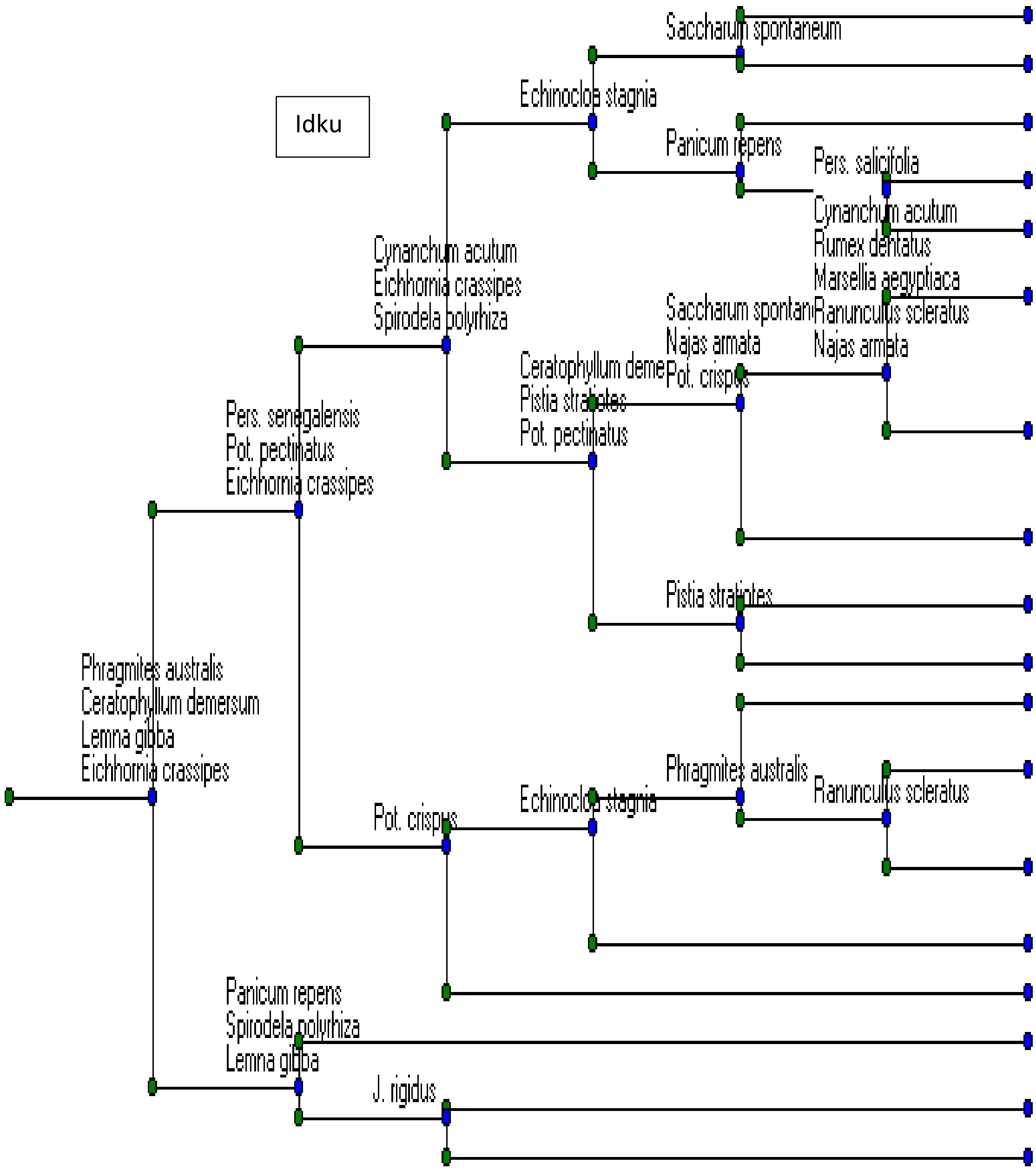

Fig. 2. A dendrogram of TWINSPAN classification of 45 stands of aquatic vegetation in the Nile Delta welands. The indicator species are indicated

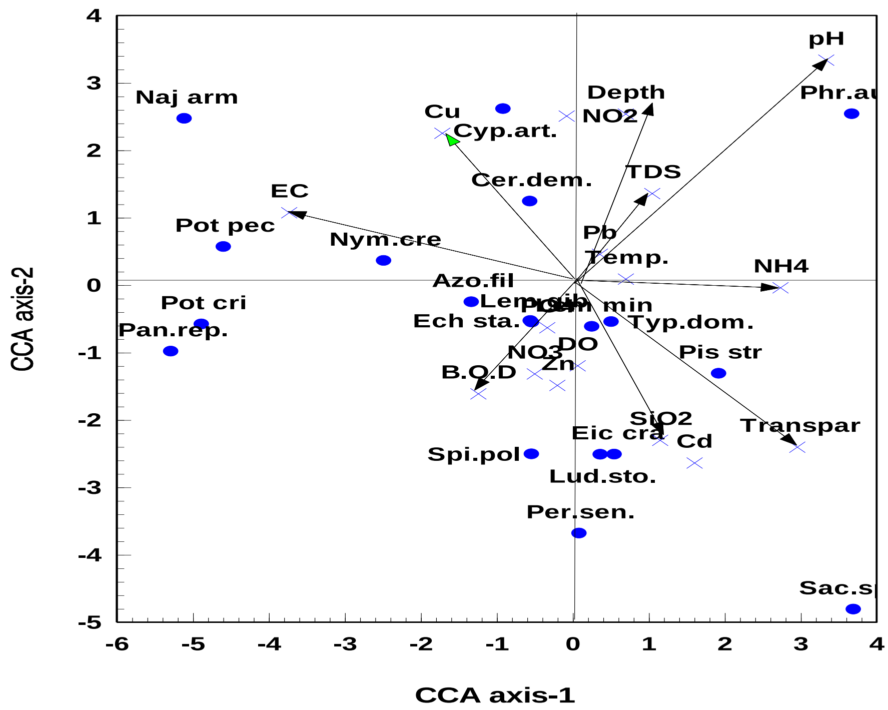

Fig. 3. Canonical correspondence analysis (CCA) ordination of aquatic vegetation along a gradient of environmental variable (arrows) in water at northern wetlands. The indicator and preferential species are indicated by the first three letters of genus and species

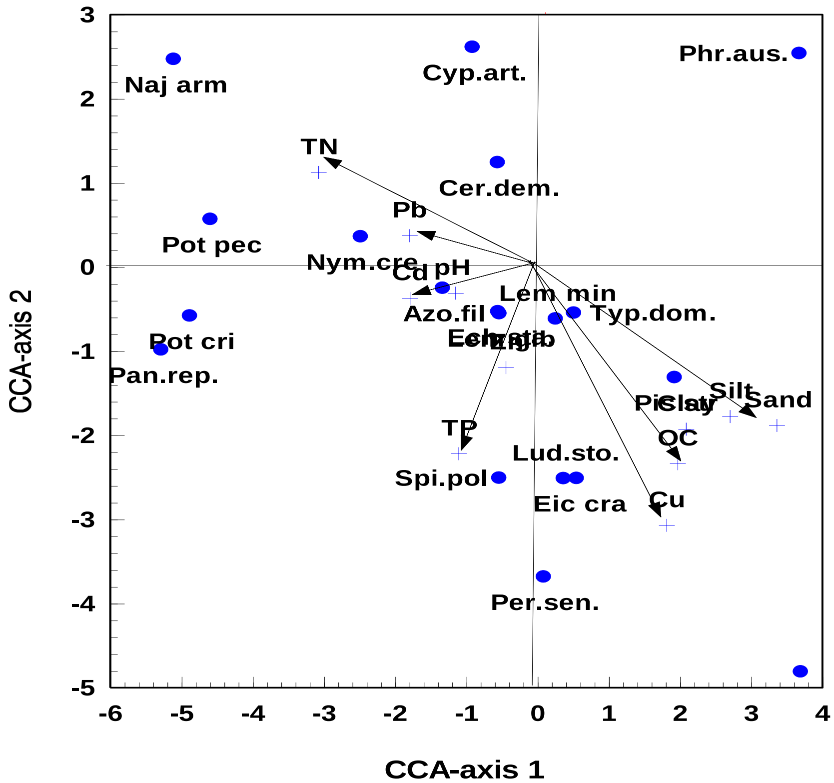

Fig. 4. Canonical correspondence analysis (CCA) ordination of aquatic vegetation along a gradient of environmental variable (arrows) in sediment at northern wetlands The indicator and preferential species are indicated by the first three letters of genus and species

Some photos for the aquatic plants at northern wetlands

Pistia stratiotes free floating hydrophte

Eichhornia crassipes floating hydrophytes

Lemna gibba L. free floating hydrophtes

Mix of aquatic plants at Burullus wetland with aquatic plants and birds

Ceratophylum demersum L., *Najas armata* submerged, and hdydrophytes *Myriophyllum spicatum*

Potamogeton pectinatus submerged and *Phragmites australis* emerged

Scripus litoralis emerged hydrophytes

Ludwegia stolonifera emerged and *Typha domigensis* emerged