

Physical and Chemical Properties of Egypt's Coastal Wetlands; Burullus Wetland as a Case Study



Magdy T. Khalil

Abstract Egypt's coastal wetlands are located along the Mediterranean coast; four in the northern part of the Nile Delta (Manzala, Burullus, Mariout and Edko) and one in the northern part of the Sinai (Bardawil). According to the map of the world distribution of arid areas, northern Egypt belongs to the Mediterranean arid region. The climatic conditions are warm summer (20–30°C) and mild winter (10–20°C). The aridity index ranges between 0.03 and 0.2 in the northern areas and less than 0.03 in the south (hyperarid region).

In the Delta wetlands, the annual mean water temperature is 22.3°C, while the annual mean water transparency and water depths are 31.0 and 115.8 cm respectively. The annual mean water chlorosity is 1.9 g l⁻¹, while in Bardawil salinity ranges between 38.5 and 74.5‰. Water in these wetlands is alkaline throughout the year. The annual mean pH is 8.6. On the other hand, the annual mean alkalinity was 257.8 mg l⁻¹.

The annual mean dissolved oxygen (DO), chemical (COD) and biological (BOD) oxygen demands are 8.6, 4.6 and 3.6 mg l⁻¹, respectively. The concentrations of dissolved salts have the following sequence: SiO₂ > NO₃ > PO₄ > NO₂, with annual means of 41.7, 2.8, 1.2 and 1.1 µg-at. l⁻¹. The concentrations of heavy metals have the following sequence: Zn > Fe > Cu > Cd > Pb, with annual means of 8.5, 6.2, 5.9, 3.8 and 3.6 µg-at. l⁻¹. Most of the estimated heavy metals of the water near to the southern shores were higher than those near the northern shores due to pollutants of drainage water. The comparison of the dissolved salts in the water of Delta wetlands in 2015, with those of the 1980s, indicates a tremendous increase due to an increases of agricultural drainage waters that are rich in fertilizers and discharge into these wetlands from the southern drains.

Keywords Burullus, Chemical characteristics, Mediterranean coast, Physical properties, Wetlands

M. T. Khalil (✉)

Faculty of Science, Ain Shams University, Cairo, Egypt

e-mail: mtkhalil52@hotmail.com

Contents

1	Introduction	84
1.1	Shape and Dimensions	85
1.2	Wetland Depth	86
2	Physical and Aggregate Properties	88
2.1	Climatology	88
2.2	Water Balance	88
2.3	Water Temperature	89
2.4	Water Transparency	90
2.5	Salinity	90
2.6	Chlorosity	91
2.7	The pH	91
2.8	Alkalinity	91
3	Oxygen Properties	92
3.1	Dissolved Oxygen (DO)	92
3.2	Chemical Oxygen Demand (COD)	92
3.3	Biological Oxygen Demand (BOD)	93
4	Dissolved Salts	93
4.1	Phosphate (PO ₄)	93
4.2	Nitrate (NO ₃)	94
4.3	Nitrite (NO ₂)	94
4.4	Silicate (SiO ₂)	95
5	Heavy Metals	96
5.1	Copper (Cu)	96
5.2	Iron (Fe)	97
5.3	Cadmium (Cd)	97
5.4	Lead (Pb)	97
5.5	Zinc (Zn)	97
6	Long-Term Changes in Water Chemistry	98
7	Correlations Between Water Properties	98
8	Conclusions	99
9	Recommendations	99
	References	100

1 Introduction

Egypt has an extensive surface area of coastal wetlands (roughly 2,500 km²); the most characteristics of these are found in Delta region (Fig. 1). Manzala, Burullus and Edku Wetland are similar in that they are permanently connected to the open sea by a narrow natural channel (Boughaz). The Mariout Wetland, on the contrary, is permanently cut off from the sea by the Mex pumping station; its surface level being maintained at up to 3 m below sea level. All these wetlands are shallow (<3 m deep), fluctuating seasonally and varying in salinity from 2.5 to 28.5%. Physical, chemical and biological characters are similar in these wetlands. Therefore, we will focus on the most important wetland, i.e. the Burullus one.

The Burullus Wetland has rich productivity; sources and transformers of numerous biological, chemical and genetic materials and valuable habitats for wildlife and fisheries. Moreover, it is an internationally important wetland for wintering water birds. Consequently, Bird Life International has designated it as an Important Bird Area (IBA).

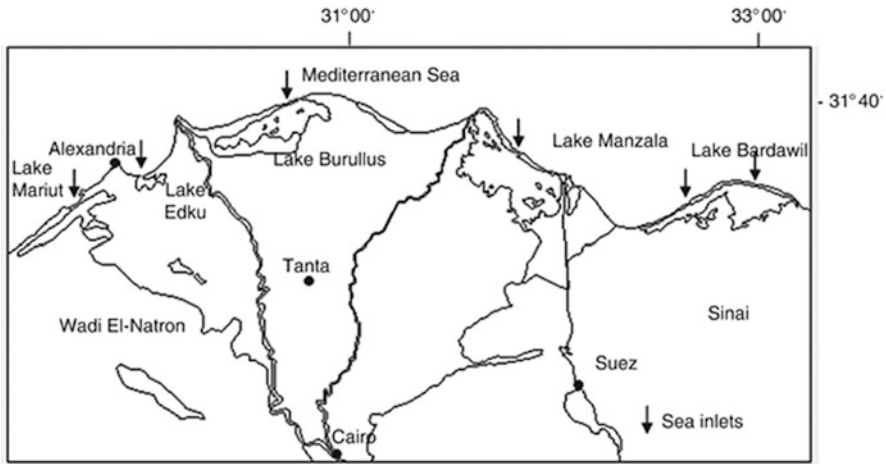


Fig. 1 Northern part of Egypt showing the coastal wetlands

Therefore, Conservation associations worldwide have noted and described the alarming changes in these important habitats. This led to the Convention on Wetlands known as RAMSAR Convention in 1971, and it was declared as a natural protectorate in 1998.

The Burullus Wetland is formed along the Mediterranean coast in the northern part of the Nile Delta. It is bordered from the north by the Mediterranean Sea and from the south by the agricultural lands of the north Nile Delta. The Burullus Wetland belongs administratively to Kafr El-Sheikh Governorate. It lies centrally between the two branches of the Nile: Damietta to the east and Rosetta to the west. Its coordinates are $31^{\circ} 36' N$ and $30^{\circ} 33' E$ in north-west, $31^{\circ} 36' N$ and $31^{\circ} 07' E$ in the north-east, $31^{\circ} 22' N$ and $30^{\circ} 33' E$ in the south-east, $31^{\circ} 22' N$ and $31^{\circ} 07' E$ in the south-east. It has a total area of 460 km^2 , which includes the entire area of Burullus open area with numerous islets inside it, as well as the sandbar separating the lake from the Mediterranean Sea, with a shoreline of about 65 km (Fig. 2).

1.1 Shape and Dimensions

The shoreline of Burullus Wetland takes several forms related basically to its formation, origin, and evolution. It has an oblong shape that extends for a distance of 47 km along NE-SW axis (Fig. 1). The width of the wetland from north to south varies from one site to another. The western sector has the least width which does not exceed 5 km, then it increases in the middle sector to reach an average of 11 km. As the area of the wetland changed with time, its dimensions changed also. It is obvious that the lake size had decreased from 502.7 km^2 in 1984 to 410 km^2 in 2015 (i.e. 18.4% reduction), the maximum length from 56 to 47 km (16.1% reduction) and the maximum width from 15 to 14 km (6.7% reduction). It is clear that Burullus



Fig. 2 Burullus Wetland at the Mediterranean Sea coast

Table 1 Evolution of the size of Burullus Wetland during the period from 1802 to 2015 [2]

Character	Year						
	1801	1913	1959	1962	1972	1984	2015
Area (km ²)	1,092	556.5	546.3	592.9	502.7	440	410
Reduction (%)	—	49.0	50.0	45.7	54.0	59.7	62.5

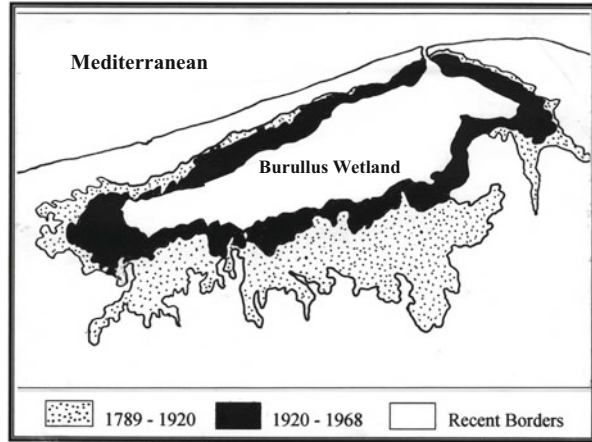
Wetland lost about 49% of its size during 112 years from 1801 (1,092 km²) to 1913 (556.5 km²), and about 62.5% by 2015 (410 km²) (Table 1 and Fig. 3).

The change in the size of the wetland basin is associated with changes in the prevailing natural phenomena. The rate of these changes was assessed using the GIS and remote sensing techniques [1]. The human impact in reduction of the size was represented by removal of sand dunes in some parts of the marine bar between the Mediterranean sea and the wetland and cultivation of some crops in the dried parts of the wetland (e.g. grapes and watermelons). Moreover, increase of the swamps and salt marshes particularly along the south-east and south-west areas and increase of the cultivated lands and human settlements contribute to this reduction.

1.2 Wetland Depth

Burullus Wetland is a shallow ecosystem; its depth varies between 40 cm near the shores and 200 cm near the sea outlet (Boughaz El-Burullus). Its main basin is classified into three sectors (eastern, middle and western), each with some homogeneity in hydrology, biology, and geomorphology. Remote sensing studies indicate that the deepest parts were in the middle sector of the wetland, where the depth

Fig. 3 The lost area from Burullus lake during the period from 1789 to 2015 [2]



reached 2 m, and also the southern parts of the western sector. The eastern sector is the shallowest where the depth does not exceed 20 cm near the shore but increases westwards until it reaches about 70 cm. Due to the continuous morphological and water budget changes, particularly after constructing many irrigation and drainage projects, and silting of Boughaz El-Burullus, the depth of the wetland changes from time to time. The changes that happened during the period from 1984 to 2015 were studied using GIS. The hypsographic analysis indicated that the contour line zero (i.e. the shoreline of the wetland) is about 143.5 km. The area between the shoreline and 75 cm depth approximates 58% of the total area of the wetland (236.6 km² out of 410 km²). Thus, it seems that the wetland lives its senility stage particularly with the continuation of drying and silting up processes which lead to the increase of shallow areas; the areas deeper than 130 cm have already decreased to about 20.6 km² (5% of the wetland size) [2].

Being so shallow, there is a rather broad ecotone between the dry land and the wetland; most of which is overgrown with *Phragmites* reeds. There are also several large and countless small islands, and large parts of the wetland are invaded by floating, emergent, and submerged water macrophytes.

A canal (Brimbal), connecting Burullus to the Rashid branch of the Nile, used to supply up to half the fresh water of the wetland; after 1964, this amount of water rapidly declined to 5% because the Rosetta (Rashid) branch of the Nile was largely inactivated. This small amount of brackish water has only a negligible influence on the wetland. Agricultural drains are the main source of fresh water in the wetland, and they have now taken over the function of Brimbal.

The year 1964 was the last one with an unregulated Nile flood, and by 1967, all water reaching the Nile delta area was used for irrigation purposes. The contribution from the Nile via the Brimbal canal rapidly dropped, and the southern sector of the wetland started receiving a steady inflow of agricultural and domestic drainage water

through eight drains, instead of a flood waters. These are Drain 7, Drain 8, Drain 9, Teira drain; El-Khashaa drain, Burullus drain west, Burullus drain east and Huksa drain.

2 Physical and Aggregate Properties

2.1 Climatology

According to the map of the world distribution of arid regions [3], the northern part of Nile Delta belongs to the Mediterranean arid region. The climatic conditions are warm during summer (20–30°C) and mild during winter (10–20°C). The aridity index (P/PET: where P is the annual precipitation and PET is the potential evapotranspiration) ranges between 0.03 and 0.2 at the north Delta (arid region), and less than 0.03 at the south (hyperarid region). Long-term climatic averages of three meteorological stations distributed within Burullus Wetland were used to draw their climatic profile.

In general, January is the coldest month, while July and August are the hottest. The annual mean maximum temperature varies between 24°C at Baltim and 27.4°C at Sakha, and the minimum temperature varies between 12.9°C at Sakha and 17.3°C at Baltim. The annual mean wind speed varies between 2.9 knots at Sakha and 6.6 knots at Baltim. The annual mean relative humidity, evaporation and sky cover exhibit narrow ranges of variation among stations. The total annual rainfall has a maximum value at Rosetta (190.8 mm year⁻¹) and a minimum at Sakha (69.6 mm year⁻¹). The isohytes of the mean annual rainfall in Egypt [4] indicates that Burullus Wetland is among the isohyte 200 mm at its northern border and the isohyte 150 mm at its south (Fig. 4). In general, the distribution of the mean annual rainfall in this region shows a maximum close to the Mediterranean coast and then decreases rapidly toward the south. More than 80% of the rain falls during the winter, and less than 10% falls during the spring.

The mean annual evaporation is 1,583.3 mm. This value approximates about 646.5 million m³ of water loss from Burullus Wetland. Maximum evaporation takes place during May–September, while the minimum occurs during December–February [5].

2.2 Water Balance

A water balance is often used to estimate the magnitudes of unknown hydrologic components such as outflow and change in storage within the wetland. To evaluate the change in storage for Burullus Wetland, the water budget was estimated as follows: $dS/dt = \text{Inflow} - \text{outflow}$, where dS/dt represents the change of storage within the wetland over a specified time interval, inflow represents water bodies contribution to the wetland, and outflow represents water losses and water interaction with the sea.

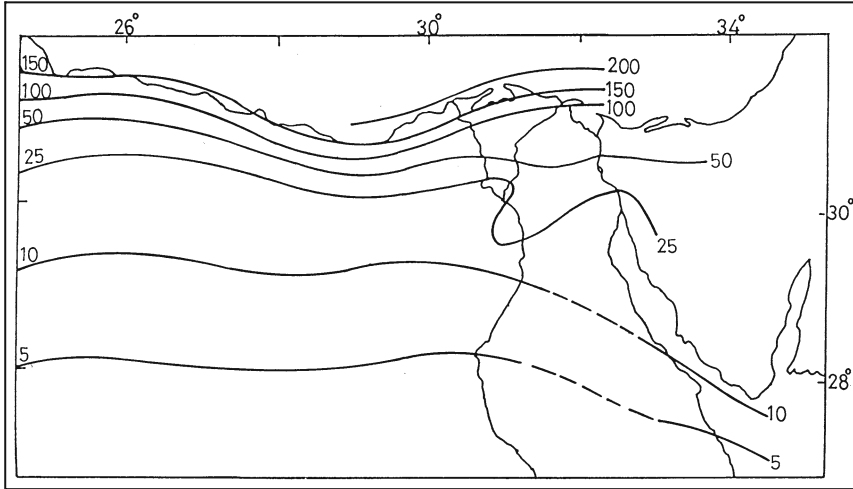


Fig. 4 The isohyets of the mean annual rainfall in Egypt (after Griffiths 1972)

Results of the annual water balance indicate that the drainage water contributes about 97%, while the contribution of rainfall is less than 2% and groundwater is less than 1% of the total water resources in the wetland ecosystem (Fig. 5). On the other hand, evaporation losses represent about 16% of the total water resources in the system, while the drainage system discharges about 3.2 billion m^3 to the sea through the wetland. This amount represents, in addition to the change of storage in the reservoir, about 84% of the total water resources in the system.

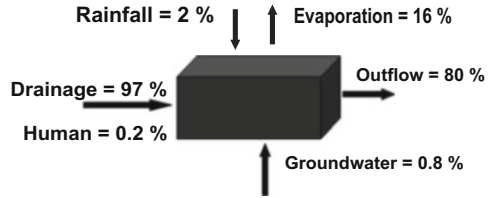
To re-establish the equilibrium status of salt balance in the wetland, 84% of the water resources should be discharged outside the lake. This represents about 3.4 billion m^3 annually. This volume of excess water resources within the system makes water level in the wetland during the whole year above the mean sea level. Accordingly, the salt balance in Burullus Wetland has been deteriorated. To make use of this huge amount of drainage water, it is recommended to convert this water to the areas of development projects at the east of the lake and to make use of Al-Moheet Drain to discharge water outside the wetland [5].

Volumes of outflow and change of storage represent monthly excess water to be used in developing plans. Due to the winter closure in January, the water level in the wetland becomes below the sea level with about 26 cm. This case allows sea water to move into the wetland with a volume of about 110 million m^3 .

2.3 Water Temperature

The annual mean surface water temperature was $22.3 \pm 5.2^\circ\text{C}$, with a minimum value of 21.8°C at the middle sector and a maximum of 23.3°C at the western sector.

Fig. 5 Water balance in Burullus Wetland [5]



Regarding the variation from the eastern to the western sectors of the wetland, the annual mean was 22.9°C at the east, 22.2°C at the middle and 23.0°C at the west. On the other hand, the annual mean was 22.4°C at the north and 22.6°C at the south. The monthly surface water temperature ranged from a minimum of 16.0°C during February and a maximum of 29.4°C during June.

2.4 Water Transparency

In general, the transparency of the wetland water is affected by inflowing water from sea outlet (Boughaz Al-Burullus) and drains, wind action, and suspended matters [6]. The annual mean water transparency is 31.0 ± 11.1 cm, with a minimum value of 22.3 cm in the eastern sector and a maximum of 49.6 cm at the western sector. Regarding the variation from the eastern to the western sectors of the wetland, the annual mean is 26.3 cm at the east (the most turbid), 31.3 cm at the middle and 41.4 cm at the west (the clearest). On the other hand, the transparency decreases from north (39.7 cm) to south (25.1 cm). The monthly mean ranges between a minimum of 25.3 cm during March and a maximum of 40.0 cm during October.

2.5 Salinity

The salinity distribution in the water of Burullus Wetland, as noted in electrical conductivity measurements, is heterogeneous. This depends on the water drained by the drains and the fresh water of Berembal Canal, the water invading the wetland from the sea (Boughaz El-Burullus) and the degree of mixing. The annual mean water salinity was 5.4 ± 4.8 mS cm⁻¹, with a minimum of 1.6 mS cm⁻¹ in the western section and a maximum of 16.8 mS cm⁻¹ at the eastern sector (the nearest to the sea outlet). Regarding the variation from the eastern to the western sectors of the wetland, the annual mean decreased from the east (8.4 mS cm⁻¹) to the west (2.4 mS cm⁻¹), and from the north (5.7 mS cm⁻¹) to the south (4.2 mS cm⁻¹). The salinity decreases during March (3.9 mS cm⁻¹), and increases during January and February (6.6 and 6.7 mS cm⁻¹, respectively). Figure 6 shows how the average salinity levels of Burullus decreased dramatically from 14‰ in 1966 to 3‰ in 2015, due to increasing of drainage water discharge into the wetland [2].

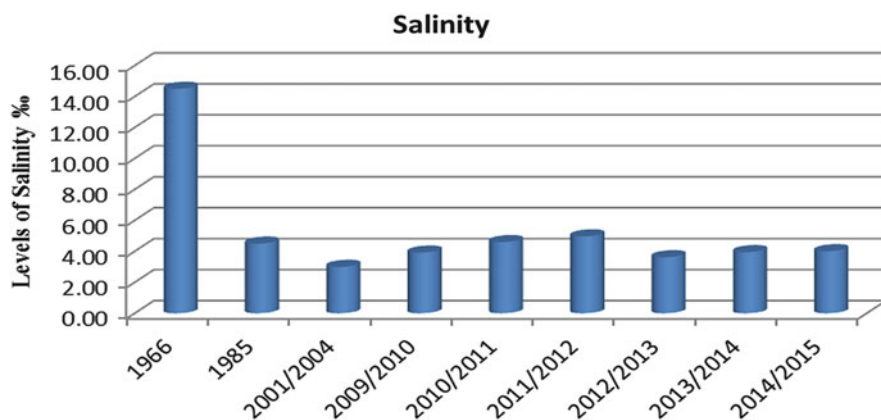


Fig. 6 Salinity levels in the Burullus Wetland during the period 1966–2015

2.6 Chlorosity

The annual mean chlorosity is $1.9 \pm 1.8 \text{ g l}^{-1}$, with a minimum of 0.6 g l^{-1} in the western sector and a maximum of 6.6 g l^{-1} in the eastern sector. Regarding the variation from the east to the west, the annual mean was the highest in the eastern sector (3.1 g l^{-1}), and the lowest in the western sector (0.7 g l^{-1}). On the other hand, the chlorosity is slightly higher at the north (2.0 g l^{-1}) than the south (1.5 g l^{-1}). Temporally, chlorosity had the same trend of salinity where it decreased during March (1.3 g l^{-1}), and increased in January and February having 2.1 and 2.3 g l^{-1} , respectively [7, 8].

2.7 The pH

Water in Burullus Wetland is alkaline throughout the year. The annual mean pH is 8.6 ± 0.6 , with a minimum of 8.4 in the western sector and a maximum of 8.9 in the middle sector. The variation from the eastern to the western sectors of the wetland indicated an annual mean 8.7 at the eastern and middle sectors and 8.5 in the western sector. On the other hand, pH was 8.7 at the north and 8.6 at the south. The monthly annual mean ranged between 8.0 during June and 9.2 during November [2].

2.8 Alkalinity

The annual mean alkalinity is $257.8 \pm 53.7 \text{ g l}^{-1}$, with a minimum of 188.0 g l^{-1} in the western sector and a maximum of 309.6 g l^{-1} in the middle sector. Regarding the

variation along the east-west axis, the middle sector had the highest alkalinity (274.4 g l^{-1}), followed by the eastern (266.9 g l^{-1}), while the western sector had the lowest one (208.9 g l^{-1}). On the other hand, the annual mean alkalinity increased from the north to the south (240.0 g l^{-1} at the north, 258.2 g l^{-1} at the middle and 272.4 g l^{-1} at the south of the wetland. This variable increased during August (272.0 g l^{-1}) and October (279.6 g l^{-1}) and decreased during March (213.7 g l^{-1}).

3 Oxygen Properties

These properties include dissolved oxygen (DO), chemical oxygen demand (COD) and biological oxygen demand (BOD). DO levels in natural and waste waters depend on the physical, chemical and biochemical properties. The analysis of DO is a key test in water pollution and waste treatment process control [9]. On the other hand, BOD is an empirical test used to determine the relative oxygen requirements needed for the biochemical degradation and oxidation of organic and inorganic materials. COD is a measure of the oxygen equivalent of the organic matter content of a water sample that is susceptible to oxidation by a strong chemical oxidant. For water samples from a specific source, COD can be related empirically to BOD, organic carbon or organic matter [2].

3.1 Dissolved Oxygen (DO)

The annual mean dissolved oxygen was $8.6 \pm 2.3 \text{ mg l}^{-1}$ [2], with a minimum of 6.6 mg l^{-1} in the eastern sector and a maximum of 10.4 mg l^{-1} the western sector. Regarding the variation from the eastern to the western sectors of the wetland, the maximum dissolved oxygen was observed in the middle and western sectors (9.1 and 9.0 mg l^{-1} , respectively), while the minimum was recorded in the eastern sector (8.1 mg l^{-1}). On the other hand, the dissolved oxygen decreased from north (9.5 mg l^{-1}) to south (8.0 mg l^{-1}). This trend may be related to the oxidation-reduction processes, as well as photosynthetic activities, which in turn correlated with a load of organic matters discharged into the wetland through the drains. The monthly mean dissolved oxygen varied between 10.2 mg l^{-1} in June and 7.5 mg l^{-1} in August.

3.2 Chemical Oxygen Demand (COD)

The annual mean chemical oxygen demand was $4.6 \pm 1.7 \text{ mg l}^{-1}$, with a minimum of 3.6 mg l^{-1} in the eastern sector and a maximum of 5.4 mg l^{-1} in the eastern sector [2]. COD is slightly higher in the eastern and western sectors (4.7 mg l^{-1}) than the middle one (4.3 mg l^{-1}). On the other hand, COD is lower in the north (4.5 mg l^{-1})

than the south (5.0 mg l^{-1}). It had the highest value during August (6.4 mg l^{-1}) and the lowest during November (2.4 mg l^{-1}).

3.3 *Biological Oxygen Demand (BOD)*

The annual mean biological oxygen demand is $3.6 \pm 1.6 \text{ mg l}^{-1}$ with a minimum of 2.7 mg l^{-1} in the middle sector and a maximum of 4.6 mg l^{-1} in the same sector [2]. Regarding the variation along the east-west axis, BOD was similar to the chemical oxygen demand, where it was higher in the eastern and western sectors (3.7 and 4.0 mg l^{-1} , respectively) than the middle one (3.2 mg l^{-1}). On the other hand, it was lower in the north (3.4 mg l^{-1}) than the south (4.0 mg l^{-1}). Comparable to COD, BOD had a maximum value during the August (5.4 mg l^{-1}) and a minimum during November (1.7 mg l^{-1}).

4 Dissolved Salts

The contents of dissolved salts in the water of Burullus Wetland have the following sequence: $\text{SiO}_2 > \text{NO}_3 > \text{PO}_4 > \text{NO}_2$ [2]. The presence of silicate may be due to the nature of the sandy bottom sediments of the lake, while the presence of nitrite, nitrate, and phosphate may be due to the drainage of fertilizers from the agricultural land into the drains which discharge water into the wetland. In general, the nutrient concentrations in Burullus relate to the input of all domestic, industrial and mainly agricultural wastes from the reclaimed lands surrounding the lake.

4.1 *Phosphate (PO₄)*

The annual mean phosphate content in Burullus Wetland is $1.2 \pm 1.1 \text{ } \mu\text{g-at. l}^{-1}$, with a minimum of $0.6 \text{ } \mu\text{g-at. l}^{-1}$ at the eastern and the middle sectors; and a maximum of $2.7 \text{ } \mu\text{g-at. l}^{-1}$ at the eastern sector [2]. The mean phosphate content was higher in the eastern sector of the wetland ($1.6 \text{ } \mu\text{g-at. l}^{-1}$) than both in the middle and western sectors viz (1.0 and $1.1 \text{ } \mu\text{g-at. l}^{-1}$, respectively). It was lower in the north ($0.8 \text{ } \mu\text{g-at. l}^{-1}$) than in the south ($1.9 \text{ } \mu\text{g-at. l}^{-1}$). On the other hand, the monthly fluctuation indicated a minimum value during January ($0.6 \text{ } \mu\text{g-at. l}^{-1}$) and a maximum during March ($1.8 \text{ } \mu\text{g-at. l}^{-1}$). Figure 7 shows phosphate levels in Burullus Wetland during the period 1985–2015 [2].

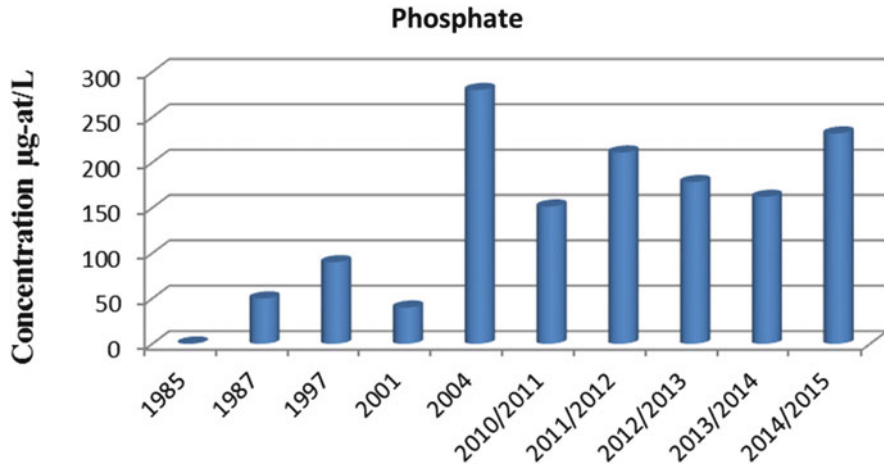


Fig. 7 Phosphate levels in the Burullus Wetland during the period 1985–2015

4.2 Nitrate (NO_3)

The annual mean nitrate in the water of Burullus Wetland is $2.8 \pm 2.3 \mu\text{g-at. l}^{-1}$, with a minimum of $0.8 \mu\text{g-at. l}^{-1}$ at the eastern sector and a maximum of $6.5 \mu\text{g-at. l}^{-1}$ at the same sector [5]. The mean nitrate content in the eastern and western sectors of the wetland ($3.2 \mu\text{g-at. l}^{-1}$) was higher than in the middle sector ($2.0 \mu\text{g-at. l}^{-1}$). On the other hand, it increased from the north ($1.8 \mu\text{g-at. l}^{-1}$) to the south ($4.3 \mu\text{g-at. l}^{-1}$). Regarding the monthly variation, the minimum value was recorded during January ($1.6 \mu\text{g-at. l}^{-1}$) and the maximum during March and May (4.7 and $4.6 \mu\text{g-at. l}^{-1}$, respectively). Figure 8 shows nitrate levels in Burullus Wetland during the period 1987–2015 [2].

4.3 Nitrite (NO_2)

The annual mean nitrite in Burullus Wetland is $1.1 \pm 0.8 \mu\text{g-at. l}^{-1}$, with a minimum of $0.3 \mu\text{g-at. l}^{-1}$ at the eastern sector and a maximum of $2.0 \mu\text{g-at. l}^{-1}$ at the same sector. Regarding the variation from the eastern to the western sectors of the wetland, mean nitrite was higher in the western sector ($1.4 \mu\text{g-at. l}^{-1}$) than the eastern and middle sectors (1.0 and $0.9 \mu\text{g-at. l}^{-1}$, respectively). On the other hand, the nitrite increased in the north ($0.9 \mu\text{g-at. l}^{-1}$) than the south ($1.4 \mu\text{g-at. l}^{-1}$). The monthly mean had a minimum value during April ($0.7 \mu\text{g-at. l}^{-1}$) and a maximum during February ($1.4 \mu\text{g-at. l}^{-1}$). Figure 9 shows nitrite levels in the Burullus Wetland during the period 1985–2015.

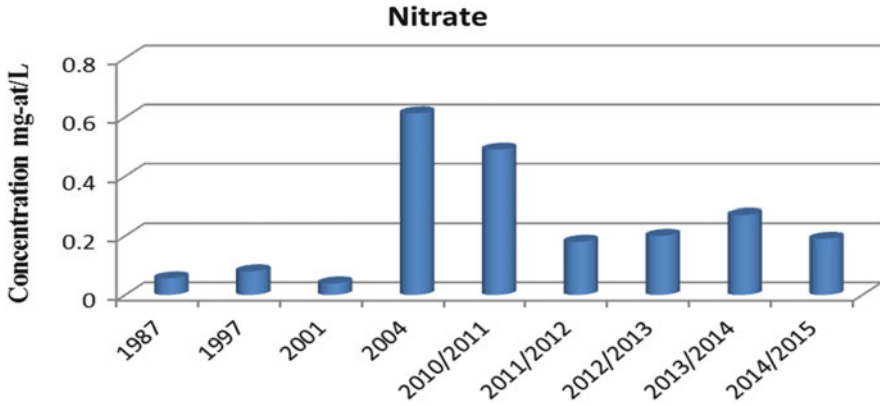


Fig. 8 Nitrate levels in the Burullus Wetland during the period 1987–2015

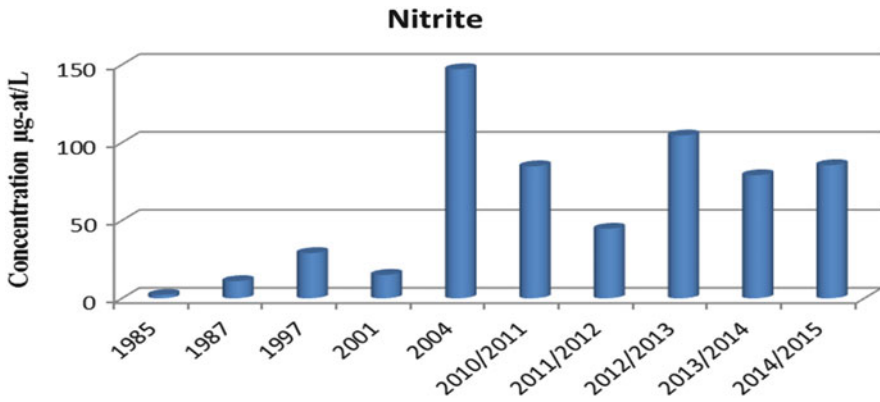


Fig. 9 Nitrite levels in the Burullus wetland during the period 1985–2015

4.4 Silicate (SiO₂)

The annual mean silicate in Burullus Wetland is $41.7 \pm 25.1 \mu\text{g-at. l}^{-1}$, with a minimum of $29.8 \mu\text{g-at. l}^{-1}$ at the eastern sector and a maximum of $51.9 \mu\text{g-at. l}^{-1}$ in the western sector. It increased from the east ($36.9 \mu\text{g-at. l}^{-1}$) to the west ($50.3 \mu\text{g-at. l}^{-1}$), and decreased from the north ($45.6 \mu\text{g-at. l}^{-1}$) to south ($39.5 \mu\text{g-at. l}^{-1}$). On the other hand, the minimum value was obtained ($19.5 \mu\text{g-at. l}^{-1}$) during July, while the maximum ($81.9 \mu\text{g-at. l}^{-1}$) was during April. Figure 8 shows silicate levels in Burullus Wetland during the period 1985–2015 [2] (Fig. 10).

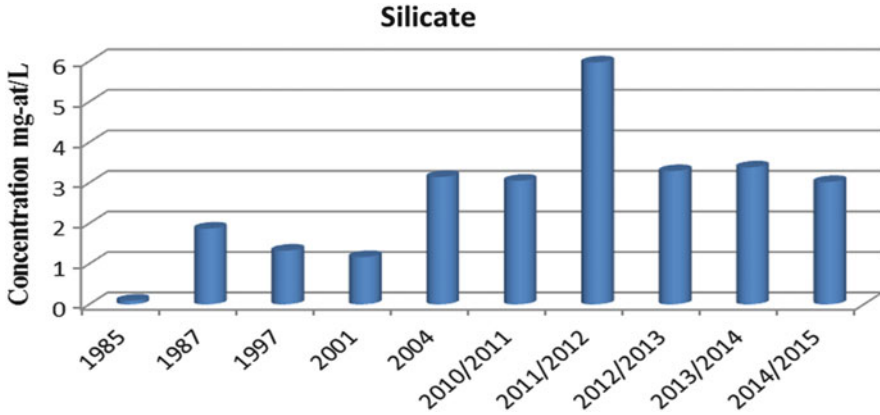


Fig. 10 Silicate levels in Burullus Wetland during the period 1985–2015

5 Heavy Metals

The content of heavy metals in the water of Burullus Wetland had the following sequence: Zn > Fe > Cu > Cd > Pb [5]. Most of the estimated heavy metals of the water near to the southern shore of the wetland were higher than those near the northern shore. This trend could be attributed to the effect of sewage effluents from the drains at the south particularly at the locations near to the mouths of drains with increasing levels of organic matter and the clay nature of the sediments. Also, the trend of variation along east-west axis is as follows: eastern sector > western sector > middle sector for all the estimated heavy metals except Zn (east > middle > west). On the other hand, the period from February to May showed heavy metals increase, while the period from June to September was characterized by a remarkable decrease in heavy metals [2].

5.1 Copper (Cu)

The annual mean copper was $5.9 \pm 4.0 \mu\text{g-at. l}^{-1}$, with a minimum of $2.6 \mu\text{g-at. l}^{-1}$ at the middle sector and a maximum of $8.8 \mu\text{g-at. l}^{-1}$ in the eastern sector. Regarding the variation from the eastern to the western sectors of the wetland, the mean values were $7.2 \mu\text{g-at. l}^{-1}$ at the east, $3.8 \mu\text{g-at. l}^{-1}$ at the middle and $6.3 \mu\text{g-at. l}^{-1}$ at the west. On the other hand, the copper increased from the north ($4.7 \mu\text{g-at. l}^{-1}$) to the south ($7.4 \mu\text{g-at. l}^{-1}$). The monthly mean copper ranged between $3.6 \mu\text{g-at. l}^{-1}$ during June and August and $11.5 \mu\text{g-at. l}^{-1}$ during May.

5.2 Iron (Fe)

The annual mean iron was $6.2 \pm 6.2 \mu\text{g-at. l}^{-1}$, with a minimum of $1.9 \mu\text{g-at. l}^{-1}$ at the middle sector and a maximum of $13.7 \mu\text{g-at. l}^{-1}$ in the eastern sector [5]. Regarding the variation from the east to the west, the mean values were $8.7 \mu\text{g-at. l}^{-1}$ in the east, $3.1 \mu\text{g-at. l}^{-1}$ in the middle and $5.7 \mu\text{g-at. l}^{-1}$ in the west. On the other hand, the iron, similar to the other heavy metals, increased from the north ($4.6 \mu\text{g-at. l}^{-1}$) to the south ($8.6 \mu\text{g-at. l}^{-1}$). The monthly mean iron ranged between $0.7 \mu\text{g-at. l}^{-1}$ during June and $13.2 \mu\text{g-at. l}^{-1}$ during May.

5.3 Cadmium (Cd)

The annual mean cadmium was $3.8 \pm 3.2 \mu\text{g-at. l}^{-1}$, with a minimum of $1.6 \mu\text{g-at. l}^{-1}$ at the middle sector and a maximum of $8.4 \mu\text{g-at. l}^{-1}$ in the eastern sector. Regarding the variation from the east to the west, the mean value in the east ($5.5 \mu\text{g-at. l}^{-1}$) was higher than that of the middle ($2.2 \mu\text{g-at. l}^{-1}$) and west ($2.4 \mu\text{g-at. l}^{-1}$). On the other hand, the cadmium, similar to the other heavy metals, increased from the north ($3.1 \mu\text{g-at. l}^{-1}$) to the south ($4.4 \mu\text{g-at. l}^{-1}$). The monthly mean ranged between $1.7 \mu\text{g-at. l}^{-1}$ during August and $6.6 \mu\text{g-at. l}^{-1}$ during March.

5.4 Lead (Pb)

The lead had the lowest value of all the estimated heavy metals in Burullus Wetland, with an annual mean $3.6 \pm 3.2 \mu\text{g-at. l}^{-1}$ (it approximates the annual mean cadmium). It had a minimum value of $1.1 \mu\text{g-at. l}^{-1}$ at the middle sector and a maximum of $6.3 \mu\text{g-at. l}^{-1}$ in the western sector. Regarding the variation along the east-west axis, the mean value in the east was $4.4 \mu\text{g-at. l}^{-1}$, that in the middle was $1.9 \mu\text{g-at. l}^{-1}$ and that of the west was $4.3 \mu\text{g-at. l}^{-1}$. On the other hand, the lead increased from the north ($2.5 \mu\text{g-at. l}^{-1}$) to the south ($4.8 \mu\text{g-at. l}^{-1}$). The monthly mean ranged between $1.2 \mu\text{g-at. l}^{-1}$ during July and $6.2 \mu\text{g-at. l}^{-1}$ during April.

5.5 Zinc (Zn)

Zinc has the highest values of heavy metals in Burullus Wetland, with an annual mean $8.5 \pm 5.7 \mu\text{g-at. l}^{-1}$. It had a minimum of $3.5 \mu\text{g-at. l}^{-1}$ in the western sector and a maximum of $17.2 \mu\text{g-at. l}^{-1}$ in the eastern sector. Regarding the variation along the east-west axis, the mean value decreased from $12.1 \mu\text{g-at. l}^{-1}$ in the east to $4.9 \mu\text{g-at. l}^{-1}$ in the west. On the

other hand, it increased from the north ($7.1 \mu\text{g-at. l}^{-1}$) to the south ($9.4 \mu\text{g-at. l}^{-1}$). The monthly mean ranged between $4.3 \mu\text{g-at. l}^{-1}$ during July and $12.7 \mu\text{g-at. l}^{-1}$ during March.

In conclusion, most of the estimated heavy metals of the water near to the southern shore were higher than those near the northern shore. In addition, the trend of variation along east-west axis was as follows: eastern sector > western sector > middle sector for all metals except Zn (east > middle > west). The spatial ranges in $\mu\text{g-at. l}^{-1}$ were 3.5–17.2 (Zn), 1.9–13.7 (Fe), 2.6–8.8 (Cu), 1.6–8.4 (Cd) and 1.1–6.3 (Pb). On the other hand, the period extended from February to May had the peak of heavy metals increase, while the period from June to September had the reverse. The monthly ranges in $\mu\text{g-at. l}^{-1}$ were 4.3–12.7 (Zn), 0.7–13.2 (Fe), 3.6–11.5 (Cu), 1.7–6.6 (Cd) and 1.2–6.2 (Pb).

6 Long-Term Changes in Water Chemistry

The comparison of the dissolved salts in the water of Burullus Wetland in 2015, with those of 1987, 1997 2001 indicated an increase of nitrate, nitrite, and phosphate from 1987 to 1997, but a decrease in 2001 and 2015. On the other hand, silicate had a decreasing pattern from $66.8 \mu\text{g-at. l}^{-1}$ in 1987 to $47.3 \mu\text{g-at. l}^{-1}$ in 1997 and $41.7 \mu\text{g-at. l}^{-1}$ in 2001. Regarding the heavy metals, there was a continuous increase in Cu, Zn, Pb and Cd contents from 1987 to 1997 and then to 2001 and 2015 (Table 2).

7 Correlations Between Water Properties

The simple linear correlation analysis of the water properties in Burullus Wetland indicates that the salinity and chlorosity are positively correlated with each other ($r = 0.99$, $P < 0.001$). In addition, Cd and Zn are positively correlated with each other on one hand ($r = 0.94$, $P < 0.001$), and with the salinity and chlorosity on the other hand ($r = 0.84$ – 0.86 , $P < 0.001$). These correlations indicate that a

Table 2 Changes in water chemistry in Burullus Wetland

Year	NO ₃	NO ₂	PO ₄	SiO ₂	Reference
(a) Dissolved salts ($\mu\text{g-at. l}^{-1}$)					
1987	4.0	0.8	1.6	66.8	[11]
1997	5.7	2.1	2.9	47.3	[7]
2001	2.8	1.1	1.3	41.7	[5]
2015	1.9	7.7	2,3	13.5	[12]
Year	Cu	Zn	Pb	Cd	Reference
(b) Heavy metals ($\mu\text{g-at. l}^{-1}$)					
1987	2.3	5.5	1.9	1.6	[11]
1997	3.5	6.8	2.7	1.9	[7]
2001	5.9	8.5	3.6	3.0	[5]
2015	14.1	21.1	6.7	3.1	[12]

considerable portion of the Cd and Zn in the water of Burullus Wetland is due to the sea water (the main source for increasing water salinity in this wetland). The pollution from detergents that come mainly from the sea may partially interpret the increase of Zn. No doubt that the drains which carry the liquid industrial wastes are among the main sources of heavy metal pollution in Burullus [10].

Phosphates, nitrates, and nitrites that are used as fertilizers for the agricultural land in the catchment area of Burullus Wetland are positively correlated with each other (they are washed with the agricultural drainage into the wetland). Also, Cu, Fe, and Pb are positively correlated with each other on the one hand, and with the previously mentioned dissolved salts on the other hand. This may indicate that the main source of pollution with these heavy metals in the agricultural drainage water. This conclusion is supported by the fact that the levels of these heavy metals are much higher in the south (where all the drains pour their drainage water into the wetland) than the north.

8 Conclusions

It is concluded that most of the estimated heavy metals of the water near to the southern shores of Burullus and other Delta wetlands [13, 14] are higher than those near the northern shores due to pollutants of drainage water. The comparison of the dissolved salts in the water of Delta wetlands in 2015, with those of the 1980s, indicates a tremendous increase due to an increase of agricultural drainage waters that rich with fertilizers and discharge into these wetlands from the southern drains.

Moreover, coastal wetlands in Egypt, including Burullus and its surrounding areas are subject to ecological constraints that relate to excessive use of resources and overwhelming flow of polluted drainage water. To this may be added the likely impacts of future climate change including sea-level rise. As well as, these wetlands are unique amongst Egypt's ecosystems areas because they are home to a substantial human population.

9 Recommendations

Authorities should propose a management plan for these wetlands and should not be conducted in isolation from the local inhabitants. Management objectives must take into consideration the fact that they are fully utilized wetlands with many human activities taking place and should seek to optimize their benefits to the local community, and in the meantime fulfill its role environmental quality, ecological equilibrium. The ideal or "principal" long-term objectives of this management plan have been proposed after accurate field studies and thorough evaluation:

1. Restoring ecological and landscape values which have been lost or damaged,
2. Maintaining and enhancing the ecological values of the site,
3. Improving socio-economic opportunities for local people, and
4. Developing public awareness for nature conservation for the Coastal Lakes.

To achieve each of the above objectives, some measures and tasks are required. Each of these needs its own “operational objective” to ensure that it complies with the general tenure of the plan, that the outcome or result can be assessed and that it relates directly to one or more of the principal objectives. Once the operational objectives have been determined, a series of measures or “projects” can be developed to achieve them. Thus there is a step-wise progression in devising a management plan from principal to operational objective and onto identification of projects or measures.

Decision-makers need to restore ecological and water quality values which have been lost or damaged, by:

1. Restoring salinity to a safe level.
2. Initiating and establishing a well-working network for monitoring water quantity and quality.
3. Treatment of the incoming water to the lake to fulfill the water quality standards.
4. Monitoring climate variables related to climate change to take the needed mitigation/adaptation measures.

References

1. Abdel Rahman SI, Sadek SA (1995) The application of multispectral remote sensing to the assessment of North Nile Delta, Egypt. Academy of Scientific Research and Technology, Cairo
2. Khalil MT (2016) Roadmap for sustainable environmental management of the Northern Egyptian Lakes; Case study: Burullus Wetland. Council of Environmental Research. Academy of Scientific Research & Technology, 113 pp
3. UNESCO (1977) Map of the world distribution of arid regions. MAB Technical Notes 7
4. Griffiths JF (1972) Climate of Africa. In: World survey of climatology, vol 10, The Netherlands
5. Shaltout KH, Khalil MT (2005) “Lake Burullus” (Burullus Protected Area) (Publication no. 13 of the National Biodiversity Unit, EEAA
6. Beltagy AI (1985) Sequences and consequences of pollution in northern Egyptian lakes. 1. Lake Burullus. *Bull Nat Inst Oceanogr Fish* 11:73–97
7. Radwan AM (2001) Report in water analysis: Lake Burullus site. MedWetCoast, Cairo
8. El-Shinnawy I (2002) Al-Burullus Wetland’s hydrological study. MedWetCoast, Global Environmental Facility (GEF) & Egyptian Environmental Affairs Agency (EEAA), Cairo
9. Greenberg AF, Clesceri LS, Eaton AD (1992). Standard methods for the examination of water and wastewater. American Public Health Association, American Water Works Association and Water Environmental Federation, EPS Group. Inc., Hanover, MD
10. Mahmoud TH, Beltag AI (1988) Detergents in Lake Burullus. *Rapp Comm Int Mer Medit* 31:2–72
11. Abdel-Moati AR, Beltagy AI, El-Mamoney MH (1988) Chemistry of Lake Burullus. 1. Changes in nutrients chemistry between 1970 and 1987. *Rapp Comm Int Mer Medit* 31(2):68–83
12. EEAA (2012) Monitoring program for Northern Lakes; Lake Burullus. Egyptian Environmental Agency Affairs, Cairo, Egypt

13. Hossen H, Negm A (2017) Sustainability of water bodies of Edko Lake, Northwest of Nile Delta, Egypt: RS/GIS approach. *Procedia Eng* 181:404–411
14. El-Badry AA (2016) Distribution of heavy metals in contaminated water and bottom deposits of Manzala Lake, Egypt. *J Environ Anal Toxicol* 6(1):1–8