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Water Quality and Microbiological Assessment of Burullus Lake and Its Surrounding Drains

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Abstract Burullus Lake, which is the second-largest coastal lagoon in Egypt, is deteriorating due to nutrient enrichment and pollutant loading. The study aims to assess the lake's water quality using water quality indices and microbiological assessment. Surface water samples were collected from Burullus Lake in winter and summer, as well as samples from drains that discharge waste into the lake. Most lake stations are classified in the marginal category based on the water quality index (WQI). Dissolved oxygen, ammonia, copper, and cadmium have the greatest impact on WQI, reflecting pollution loads. Based on the contamination index, heavy metal classification results ranged from "lowly polluted" to "highly polluted." According to the Nemerow Index, human activity has significantly impaired the ecology of the lake and surrounding drains through copper and cadmium pollution. The fecal coliform/fecal streptococci ratio was less than 0.6 in lake water samples, suggesting fecal contamination from domesticated animal wastes. Drain water contaminated with fecal streptococci indicated frequent contamination. Several drains allow a significant amount of effluent, including high amounts of pesticides and fertilizers, to enter the lake, causing serious metal and microbiological pollution Dredging and deepening the inlet link between the lake and Mediterranean Sea have had a positive impact on water quality. However, there are still other options for improving the lake's health. Therefore, it is recommended to routinely check Burullus Lake's water quality and its surrounding drains to keep track of its condition and assess any improvement efforts' effectiveness.

Keywords Burullus Lake · Water quality · Heavy metals · Bacteriological analysis

Abbreviations

WQI	Water quality index
Cd	Contamination index
P	Nemerow index
EC	Electrical conductivity
TDS	Total dissolved solids
DO	Dissolved oxygen
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
MPN	Most probable number
TC	Total coliform
FC	Fecal coliform
FS	Fecal streptococci
Ortho-P	Orthophosphate
Total-P	Total phosphorous
P_i	Single factor index
TBC	Total bacterial counts
SD	Standard deviation

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1 Introduction

Water has a profound impact on every aspect of our lives, including our health, safety, and economy (Abd-Elaty et al., 2022b). Lake water quality is an important factor in determining the health of a lake and its surrounding environment. The quality of lake water can be affected by a variety of factors, including pollution, runoff from land, and climate change. Poor water quality can lead to algal blooms, decreased oxygen levels, and other negative impacts on aquatic life. Many wetlands and lakes experience a decline in water quality and environmental imbalance as a result of rising anthropogenic activity, particularly in developing nations, which may endanger both human health and the eco-function of water resources (Xie et al., 2019).

Lakes in semiarid/arid areas struggle with inadequate inflow and water quality degradation, which endangers the lake ecosystem (Han et al., 2022). Eutrophication has been accelerated worldwide because of human activities that have increased the nutrients entering water bodies. Monitoring is needed to accurately analyze the health of lakes ecosystem, which is necessary for lake water quality management (Tammeorg et al., 2022).

The dumping of raw wastewater may have detrimental hygienic implications because of its impact on fauna and flora in the aquatic environment. Almost every country globally has pollution issues brought on by anthropogenic causes such as sewage, agricultural runoff, and industrial effluents. In some situations, the pollution has been so harmful that it has caused environmental disasters and ecosystem collapse (Mousa et al., 2018). The discharge of wastewater (e.g., brine) degrades water quality, and thus water cannot be directly used for potable water (via desalination) and industrial applications (Panagopoulos, 2022; Panagopoulos & Giannika, 2022). The discharge of high heavy metal levels into natural water may result in severe pollution that will impact aquatic life since heavy metal pollution is thought to be the most serious pollutant in the aquatic ecosystem. Various industries and agricultural activities may be the root of their vast distribution of metals in the environment (Abu Kassim et al., 2022). Various human activities have caused many lakes around the world to degrade, resulting in higher levels of metals in the water. Such concerns have recently compelled countries to raise public awareness about pollution control through thorough water quality monitoring programs (Ye et al., 2021).

In aquatic ecosystems, bacteria are one of the most common types of microorganisms, and they play many roles in maintaining the ecosystem's stability. They can operate as the ecosystem's primary decomposers and preserve the carbon, nitrogen, and phosphorus microbial cycles (Niu et al., 2019). These organisms may influence human and animal health in addition to contributing significantly to the food chain by providing abundant nutrition for aquatic life at a higher level (Miah et al., 2016). Furthermore, microbiological pollution leads to harm and even loss of other aquatic organisms (Akkan et al., 2019). Indicator microorganisms like coliform bacteria are used to assess the bacterial quality of the aquatic environment, where the presence of fecal coliform bacteria in any aquatic ecosystem indicates water contamination (Altinoluk et al., 2014).

The environment of Burullus Lake, the second-largest coastal lagoon in Egypt, has deteriorated as a result of its strategic location within the Nile Delta, where the lake receives the majority of the Nile Delta region's drainage water through several agricultural drains. The drainage water is primarily nutrient-rich freshwater contaminated by heavy metals and agricultural fertilizer (Hany et al., 2022; Sheta, 2019). Burullus Lake is rich in phytoplankton and organic matter, whereas the lake is categorized as a hypereutrophic water body with poor and declining water quality based on the trophic state index (Elsayed et al., 2019).

The main causes of lake water contamination, where the concentrations of heavy metals and nutrients are increasing, are the inflow of untreated domestic wastewater, effluent from aquaculture ponds close to the lake shoreline, and the expansion of irrigated fields. The economic alternatives for improving the lake's water quality were adding another artificial outlet and adding treatment facilities for drains discharge (Elshemy et al., 2020).

Twelve Landsat images and two water indices were used to identify spatiotemporal changes in Burullus Lake from 1972 to 2015. The results indicated that the lake's water area had shrunk by about 49% of its surface area (Mohsen et al., 2018). Mohsen et al., (2021) stated that the water quality of Burullus Lake is in a critical state due to drain effluents and reclamation activities in the southern part of the lake, according to the spatial distribution of chlorophyll-a, total suspended solid, pH, Fe, Zn, Cr, and NH_4 levels.

Shalby et al. (2020) showed that the current hydrological, hydrodynamic, and water quality properties of Burullus Lake will likely change as a result of climate change and sea level rise, which will have a significant impact on the ecosystem's health.

Khalil (2018) determined that the concentrations of Zn, Fe, Cu, Cd, and Pb in the Burullus Lake water adjacent to the southern shores were higher than those close to the northern coastlines as a result of drainage water pollution. El-Alfy et al. (2020) estimated the concentrations of metals in the sediments along the Burullus Lake coastline, with the mean heavy metal levels declining in the following order: Mn > Fe > Zn > Co > Cu > Cd > Ni > Pb > Cr. All samples exceeded the criteria for sediment quality based on Cd levels. The findings of Hany et al. (2022) demonstrated that the lake inlet and the eastern part, where the dredging operation was done, had a significant improvement in the evaluated water quality indicators, while the western part showed less improvement.

To ensure healthy lake ecosystems, it is important to monitor and manage lake water quality through regular testing and monitoring programs. Indices of water quality are essential in integrated water resource management (Abd-Elaty et al., 2022a). The degree of water quality in lakes is indicated by the water quality index, which is a mathematical system that can condense the water quality data into a single integer value (Abdel Gawad et al., 2022; Abdel-Satar et al., 2017a; Shil et al., 2019). Additionally, metal indices (Nemerow index and contamination Index) have been used to evaluate the metal content in water (Abdel-Satar et al., 2017b; Al-Afify & Abdel-Satar, 2022).

Water quality monitoring seeks to comprehend the aquatic systems' water quality conditions. It can also help planners and decision-makers deal with issues relating to water bodies (Mohsen et al., 2021). The objective of the current study was to evaluate the current water quality and microbiological conditions of Burullus Lake and the surrounding drains using a variety of physical, chemical, and biological parameters as well as the water quality index, the Nemerow index, and the contamination index. Additionally, in the future, the data will be used to build models that require a lot of data to quantify the effect of drainage water on the lake. This aids in protecting this important water source, helps managers create workable policies for changing land use, and helps farmers improve fertilizer application.

2 Materials and Methods

2.1 Study Sites

Burullus Lake, a natural protectorate, is situated in the north-central Nile Delta region along the Egyptian Mediterranean shore. Lake location coordinates are 30° 22′–31° 35′N and 30° 33′–31° 08′E (El-Amier et al., 2021). The northern side, through Boughaz El-Burullus, connects it to the Mediterranean Sea. Also, the lake is connected to the River Nile via the Brimbal Canal. The lake receives regular freshwater drainage input after the Aswan High Dam was built, which caused the lake's water level to rise above sea level and prohibit seawater from entering the lake through Boughaz El-Burullus, while Burullus's Lake water level drops to around 26 cm below sea level during the winter closure of the Nile and seawater briefly infiltrates the lake (Zaghloul et al., 2022).

Burullus Lake provides around 50% of the fish produced in Egypt. Additionally, it is regarded as a valuable wetland and a resting place for several migratory birds. Since the early 1970s, the lake has been in a hypereutrophic state. The recent degradation of the lake environment is a result of excessive drainage system flows (Shaban & Farag, 2018).

Through several drains, agricultural runoff water (3.9 billion m^3/year), mixed with different types of waste from fish farms, and industrial and domestic effluents, is discharged into Burullus Lake, containing significant loads of pesticides, oxidized organic debris, and fertilizers that have caused serious eutrophication and water quality issues during the past 10 years (Shaban & Farag, 2018; Zaghloul et al., 2022). Also, the drainage water enters the lake at its southernmost drains, creating water dilution and a rise in the lake's water level above sea level.

2.2 Sample Collection and Analysis

Twelve surface water samples were collected seasonally in February (winter) and August (summer) covering Burullus Lake, in addition to ten surface samples from different drains that discharge the waste to the lake (Tables 1 and 2 and Fig. 1). Duplicate co-located samples were collected from each site, where the percentage of the laboratory result variation was less than 5%. Immediately, a number of variables including transparency, temperature, pH,

Table 1 GPS coordinates for sampling sites in Burullus Lake

Code	GPS position	
	Latitude	Longitude
1	31°32′44.10″	31°04′08.08″
2	31°34′06.08″	30°58′51.19″
3	31°32′55.74″	30°59′22.38″
4	31°27′20.19″	30°58′00.91″
5	31°28′55.35″	30°50′07.74″
6	31°27′30.04″	30°48′12.20″
7	31°24′54.59″	30°45′36.09″
8	31°29′05.26″	30°50′20.30″
9	31°25′57.36″	30°42′45.50″
10	31°25′28.69″	30°38′15.75″
11	31°23′54.51″	30°38′00.30″
12	31°24′28.38″	30°35′56.00″

Table 2 Code and name of examined drains that discharge their waste in Burullus Lake

Code	Name of drain
D1	Burullus East Drain
D2	Brimbal Canal
D3	Burullus west Drain
D4	Nasser Drain
D5	Zaghloul Drain
D6	El-Gharbia Drain
D7	Drain 7
D8	Drain 8
D9	Drain 9
D10	Drain 11

electrical conductivity, and total dissolved solids were examined in the field using Secchi-disc and Con 500 conductivity/TDS/temperature meter and combined meter pH/EC/TDS/temperature (Mi 805).

Chemical parameters were estimated according to APHA (2005) procedure, where the water samples were processed for dissolved oxygen, COD, BOD, chloride, sulphate, silicate, bicarbonate, phosphate, total phosphorus, nitrogen forms (nitrite, nitrate, and ammonia), and major cations (Na, K, Ca, and Mg) analysis. For heavy metal analysis (Fe, Mn, Zn, Cu, and Cd), concentrated HNO_3 was used to digest the water sample; total Cd, Cu, Zn, Mn, and Fe were analyzed using inductively coupled plasma mass spectrometry (iCAP TQ ICP-MS) Thermo Scientific—Germany with minimum detection limits ranging between 0.002 µg/L (Cd) and 0.4 µg/L (Fe). To ensure accuracy in the metal analysis, three readings were taken, and the mean value was determined with relative SD of less than 5%.

Surface water samples were collected aseptically, put in 200-mL sterile brown bottles, transported to the lab, and kept at 4 °C for bacteriological analysis. Within 48 h of sampling bacteriological analysis was completed. The most probable number procedure was used to determine the total coliform, fecal coliform, and fecal streptococci counts using lauryl tryptose broth (35 °C ± 0.5 °C at 28 ± 2 h) for TC, EC broth (44.5 °C ± 0.2 °C at 24 ± 2 h) for FC, and azide dextrose broth for FS (35 °C ± 0.5 °C at 28 2 h).

Total bacteria were enumerated on plate count agar medium at incubation temperatures of 22 °C and 37 °C, using the standard plate count method (APHA, 2012). Total diazotrophs were enumerated using the surface-inoculated plate method on N-deficient combined carbon source agar medium (Hegazi et al., 1998). Also, FC/FS ratio has been used to pinpoint the source of bacterial contamination in lake surface water. The water contaminated by human waste if $FC/FS = 4$, by domestic animal waste if $FC/FS = 0.1 - 0.6$, and by wild animal waste if $FC/FS = 0.1$. The lake water was considered to have mixed contamination if the ratio was between 0.6 and 4.0.

The lake's water quality degree was measured by the water quality index that summarizes water quality data in straightforward terms (such as excellent, good, bad). The Canadian Water Quality Index is used to determine the WQI (CCME, 2001). The supplemental materials provide a detailed description of the index used (Text S1).

To evaluate the metal ecological risk in lake water, Nemerow and contamination indices were used. The contamination index reveals the cumulative impact of all metals by measuring the relative contamination of each metal separately (Backman et al., 1997). However, the overall extent of metal pollution of the water lake was calculated using the Nemerow pollution index (Liu et al., 2015). These indices are covered in more detail in the supplemental information (Text S2).

2.3 Statistical Analysis

Using one- and two-way analysis of variance (ANOVA), the data from the water samples for variables were checked for any appreciable variations between the

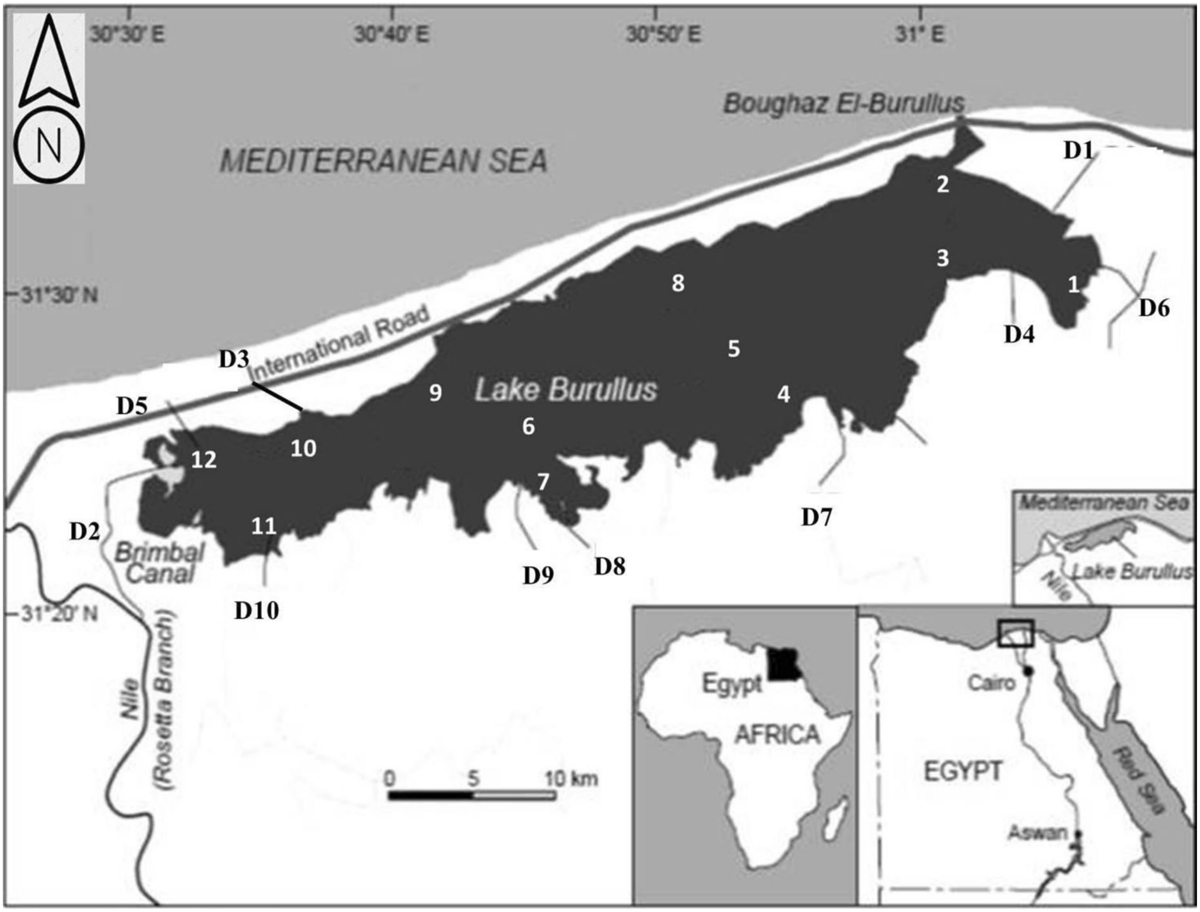

Fig. 1 Map of sampling sites at Burullus Lake and the surrounding examined drains

seasons and locations. The Fisher LSD test was used as a post hoc test to compare means at $P < 0.05$. Additionally, the Pearson correlation index was used to calculate the correlations between the examined variables in the water of Burullus Lake.

3 Results and Discussion

3.1 Water Quality of Lake

Coastal lakes ecosystem monitoring is crucial for assessing an ecosystem's present state and potential future changes, as well as for documenting the impacts of human activity. The major factor affecting lake water quality is land use within lakes; both urban and agricultural land use result in higher nutrient levels (Estifanos et al., 2022).

Burullus Lake has faced numerous major issues over the last four decades as a result of intensive aquaculture and agriculture activities along with uncontrolled urbanization. These activities have led to increasing pollution and area loss, which have accelerated the deterioration of its entire environmental system, including the water quality of lake (Hany et al., 2022). The Egyptian government developed the lake by dredging it, deepening the inlet link between the lake and the Mediterranean Sea, and removing weed (Zaghloul et al., 2022).

Table 3 depicts the distribution of water quality data for the variables evaluated. There was little variation in the water temperature between the sites, and it mirrored the air temperature.

EC showed high significant site variations ($P < 0.01$), where the EC values at stations 2 and 3 recorded the highest levels with the influx of seawater from Boughaz El-Burullus. The exchange of seawater in lake estuary environments helps to improve water quality of the lake (Kwak et al., 2023). Most lake stations showed high levels of EC during the winter, when there was little freshwater inflow into the lake due to the River Nile's drought.

The change in visibility of the lake is generally low with high turbidity that showed a high significant spatial difference ($P < 0.05$). Station 2 had the highest transparency among the sampling sites. The middle sector, which is impacted by domestic and agricultural drains, particularly drains 7, 8, and 9, saw a reduction in transparency. In general, water entering the lake through drains and Boughaz El-Burullus, wind, and suspended particles have an impact on the water's transparency (Khalil, 2018).

The constant flow of drainage water and the influx of seawater from Boughaz are the most significant influences on the TDS contents in the water of Lake. With the greatest values reported in the winter and the lowest in the summer, TDS demonstrated significant spatial variability without temporal variation. All sampling locations showed high pH values (7.56–9.01), where the winter season showed the highest levels. pH values between 6.5 and 9.0 are appropriate for supporting aquatic species (Eh Rak et al., 2022).

Dissolved oxygen ranged from 4.58 to 15.5 mg/L, with locations 8, 9, and 10 having the highest DO (9.70–15.50 mg/L) among the sampling sites, while locations 1, 3, 5, and 7 had the lowest (4.58–6.90 mg/L). The drop in DO may be caused by drainage water where organic wastes and some inorganic compounds exert an oxygen demand upon decomposition that lowers the level of dissolved oxygen below needed by aquatic life (Abdel-Satar, 2008). However, a high value of DO in the water system may result from the presence of photosynthetic phytoplankton (Eh Rak et al., 2022). Therefore, oxidation–reduction processes along with photosynthetic activity and a load of organic materials discharged into the lake through the drains are the main factors controlling DO distribution (Khalil, 2018). It has been observed that there is a significant increase in the average DO value (8.06 mg/L) for this result compared to that of Hany et al. (2022) (6.0 mg/L). Generally, most DO values of the sampling sites indicate that the lake is healthy and can sustain aquatic organisms' needs.

COD and BOD are critical variables for characterizing aquatic systems, industrial and agricultural wastes, and treatment plant effluents (Hany et al., 2022). COD and BOD of lake water were found to vary between 8.04 and 21.32 mg/L and 2.00 and 14.66 mg/L, respectively. The eastern sector values, which are closest to Boughaz El-Burullus, had lower COD and BOD levels than the western sector. The increase in COD values reflects the high load of organic matter discharged in the western and middle sectors, especially at stations 8, 9, and 10, which receive high amounts of agricultural and sewage waste via different drains. The decrease in BOD at stations 11 and 12 reflects the freshwater discharge via the Brimbal Canal, especially during the flood period (summer season). BOD displayed significant spatial variation ($P < 0.05$), without any temporal variation, while COD did not exhibit any spatial or temporal variations. The dredging and deepening of the inlet link between the lake and the Mediterranean Sea, as well as the removal of weeds, significantly affect the BOD and COD levels in the lake. There is a decrease in their levels compared with the findings of Elsayed et al. (2019) (5.82–29.16 and 10.29–48.51, respectively) for the period of 2017.

According to lake sites, water bicarbonate concentrations varied significantly ($P < 0.01$); station 12, which received Nile freshwater via the Brimbal Canal, had the lowest levels (132.5–163.0 mg/L), while stations 7 and 10 had the highest levels (340.0–425.0 mg/L). This rise was attributed to the presence of a significant amount of organic matter that was readily decomposable by bacteria and produced bicarbonate as one of the byproducts (Ferreira et al., 2020). The carbonate readings showed significant amplitude (0.0–74.0 mg/L), random distribution across sites, and temporal differences, with the summer showing high levels.

The dominant anion (Cl^-) and major cations (Na, K, Ca, and Mg) were primarily controlled by the infiltration of drainage water through various drains, the influx of seawater, and finally, the received freshwater from the Nile via the Brimbal Canal. By evaluating the results obtained on a mass basis, it seems that the levels of major anions exhibited a proportion of $Cl^- > HCO_3^- > SO_4^{2-} > CO_3^{2-}$ and major cations of Na > Mg > Ca > K.

Table 3 Basic statistics of variables in water of Burullus Lake and the surrounding examined drains

Variable		Lake		Drains	
		Winter	Summer	Winter	Summer
Temperature (°C)	Range	15.30–19.60	27.40–34.70	15.51–19.00	28.50–35.60
	Mean ± SD	17.14 ± 1.26	31.64 ± 2.61	17.52 ± 1.09	31.79 ± 2.33
Transparency (cm)	Range	15.0–60.0	20.0–120.0	20.00–50.00	15.00–50.00
	Mean ± SD	30.0 ± 16.7	37.1 ± 27.6	32.50 ± 11.61	23.00 ± 10.33
EC (mS /cm)	Range	2.88–46.80	2.04–26.60	2.38–32.80	1.96–8.96
	Mean ± SD	12.31 ± 14.33	9.44 ± 8.33	8.06 ± 8.86	3.91 ± 2.19
TDS (g/L)	Range	2.91–20.03	1.2–17.16	0.83–3.72	0.24–3.78
	Mean ± SD	6.88 ± 5.93	5.70 ± 5.39	2.42 ± 0.84	1.87 ± 1.16
pH	Range	7.74–9.01	7.56–8.86	7.53–8.90	8.65–8.90
	Mean ± SD	8.58 ± 0.45	8.53 ± 0.35	8.14 ± 0.42	8.73 ± 0.09
DO (mg /L)	Range	4.80–10.30	4.58–15.50	3.80–10.40	4.80–12.50
	Mean ± SD	7.54 ± 1.99	8.58 ± 3.44	6.27 ± 2.12	8.34 ± 2.79
COD (mg/L)	Range	9.36–18.60	8.04–21.32	9.00–16.00	6.50–21.48
	Mean ± SD	14.26 ± 3.20	14.84 ± 4.47	11.75 ± 2.56	14.79 ± 4.32
BOD (mg/L)	Range	2.00–9.00	3.66–14.66	6.00–10.00	5.98–13.58
	Mean ± SD	6.19 ± 2.14	7.00 ± 3.82	7.56 ± 1.33	9.52 ± 2.57
NO_2-N (µg/L)	Range	32.86–447.81	15.64–172.32	120.68–331.01	13.77–352.55
	Mean ± SD	124.71 ± 119.29	68.98 ± 61.77	208.73 ± 69.41	141.93 ± 127.57
NO_3-N (µg/L)	Range	33.08–837.23	40.07–1314.7	85.52–1690.94	74.33–493.24
	Mean ± SD	184.47 ± 223.84	187.09 ± 359.56	560.59 ± 574.53	140.00 ± 160.51
NH_3-N (µg/L)	Range	128.99–7012.2	143.01–2354.3	662.25–6441.77	260.31–2760.94
	Mean ± SD	1772.7 ± 2550.5	671.05 ± 785.79	3532.56 ± 1616.84	898.37 ± 762.03
PO_4-P (µg/L)	Range	154.10–1512.1	56.75–734.88	185.33–1449.21	65.61–606.74
	Mean ± SD	436.41 ± 412.90	285.06 ± 222.41	885.37 ± 367.35	296.57 ± 182.78
Total-P (µg/L)	Range	293.10–2150.0	512.60–1458.6	430.20–1980.84	560.44–1065.24
	Mean ± SD	767.37 ± 508.05	747.37 ± 265.49	1237.15 ± 443.87	781.10 ± 162.68
Silicate (mg/L)	Range	6.00–29.23	5.91–28.65	7.41–27.34	4.62–10.23
	Mean ± SD	18.91 ± 6.07	12.28 ± 6.40	17.34 ± 6.18	7.75 ± 1.94
HCO_3^- (mg/L)	Range	132.050–375.00	163.00–425.00	222.50–475.00	230.00–460.00
	Mean ± SD	280.63 ± 76.43	313.38 ± 79.42	364.75 ± 74.32	365.50 ± 79.10
Cl^- (g/L)	Range	0.79–15.35	0.75–11.52	0.63–2.21	0.35–2.91
	Mean ± SD	3.70 ± 4.73	3.48 ± 3.61	1.30 ± 0.51	1.18 ± 0.78
SO_4^{2-} (mg/L)	Range	140.80–300.60	71.09–255.75	35.24–278.90	53.50–135.38
	Mean ± SD	208.91 ± 45.48	138.01 ± 70.01	162.40 ± 73.60	94.97 ± 24.81
Na (mg/L)	Range	813.77–5884.2	533.72–2333.1	813.77–4507.01	135.50–296.85
	Mean ± SD	2263.9 ± 1560.5	1323.0 ± 689.76	1543.79 ± 1105.60	189.22 ± 50.37
K (mg/L)	Range	44.95–361.10	29.72–331.13	34.95–232.97	24.46–152.01
	Mean ± SD	98.87 ± 101.08	80.11 ± 95.79	73.38 ± 59.91	49.59 ± 39.14
Ca (mg/L)	Range	39.28–329.46	24.05–236.47	91.38–137.88	9.62–54.51
	Mean ± SD	119.57 ± 94.53	76.81 ± 65.56	108.06 ± 15.90	31.18 ± 16.16
Mg (mg/L)	Range	105.55–894.46	99.85–676.10	54.48–355.38	42.80–291.35
	Mean ± SD	281.79 ± 258.79	258.39 ± 201.11	166.56 ± 78.49	163.48 ± 73.08

The last few decades have seen the most pronounced increases in individual nutrient concentrations and fluxes from anthropogenic sources to aquatic systems (Abdel-Satar, 2008). The presence of NO_2^-, NO_3^-, and PO_4^{3-} in Burullus water may be caused by fertilizer runoff from agricultural regions into the drains that discharge water into the lake, demonstrating the influence of cultivated land on nutrient loading behavior at the lake (Badrzadeh et al., 2022). In general, Burullus Lake's water contains nutrient salts in the following order: $SiO_3^{2-} > NO_3^- > PO_4^{3-} > NO_2^-$.

Most of the total soluble inorganic nitrogen was found to be NH_4^+-N. It varied widely (129–7012 μg/L) and showed a remarkable increase at sites 1, 7, 10, and 11, but there were no obvious seasonal tendencies. Ammonia levels exceeded the Canadian guidelines (CCME, 2010) for the protection of aquatic life in lake water during the summer season. There was a significant increase in the present average NH_4-N concentration (1221 μg/L), which was higher than the result of Mohsen et al. (2021) (853 μg/L) and lower than the result of Elsayed et al. (2019) (1636.2 μg/L). In harmony with ammonia variation, nitrite and nitrate mostly showed the highest levels at the same sites. Because of nitrifying bacteria and the quick conversion of nitrite to nitrate, lake water had lower levels of nitrite than nitrate (Abdel-Satar et al., 2010). The agricultural wastes from the reclaimed lands near the lake in addition to domestic and industrial effluents are responsible for the nutrient concentrations in Burullus Lake (Khalil, 2018).

During the winter season, Ortho-P level (average 436 μg/L with SD of 413) were approximately twice as high as they were during the summer season (average 285 μg/L with SD of 222), reflecting the impact of the drought period of River Nile in addition to agricultural and plantation activities around the lake. Ortho-P and Total-P exhibited significant spatial variation ($P < 0.05$), with the highest values recorded at sites 7 and 11, particularly during the winter season. Anthropogenic sources such as fertilizer runoff may introduce phosphorus into the water system in organic or inorganic forms, which can perpetually cycle through the water column and promote algae blooms (Abdel-Satar et al., 2010). The deepening and broadening of the seawater inlet improved water quality for the lake and subsequently reduced nutrient salts. Additionally, dredging of the lake and removal of floating and rooted plants may have influenced nutrient salt distribution (Zaghloul et al., 2022).

The distribution of reactive silica in lake water was not significantly influenced by released wastewater, according to spatial variations in dissolved silica levels ($P = 0.12$). The presence of silicate may be related to the composition of the lake's sandy bottom sediments (Khalil, 2018). Typically, silica levels are the consequence of diatoms absorbing it along with weathering of sandy sediments (Abdel-Satar et al., 2017a).

Heavy metals may be present in Burullus Lake as a result of agricultural wastes from fertilizer leaking into the water system (Lee & Wendy, 2011). The distribution of Fe, Mn, Cu, Zn, and Cd varied as follows: 308–765, 43.4–97.8, 16.2–38.6, 28.0–92.8, and 0.40–4.60 μg/L, respectively (Fig. 2). The metal concentrations showed remarkable differences among sites and seasons ($P < 0.05$). This tendency may be explained by the impact of sewage effluents from several drains, where organic matter levels are rising, and sediments are clay-like (Khalil, 2018). However, many samples contained Cu and Cd concentrations exceeding the fresh (10.6 and 0.46 μg/L, respectively) and saltwater (2 and 0.12 μg/L) chronic guidelines set by British Columbia Ministry of Environment and Climate Change Strategy. On the other hand, Cd is found to be an impurity in many compounds including phosphate fertilizers (El-Alfy et al., 2020). This is frequently attributed to drainage water becoming contaminated with Cu and Cd with agricultural materials being one of the main sources of metals (Bouida et al., 2022). The positive correlations ($n = 12$, $P < 0.05$) between Cu/Cd levels in the winter ($r = 0.83$) and summer seasons ($r = 0.77$) indicated their common origin (agricultural pesticides). As a result, the lake's water was contaminated with Cu and Cd which negatively impact ecology damaging flora and other natural inhabitants (Sayed & Abdel-Satar, 2009). When compared to the findings of Mohsen et al. (2021), the present average Fe showed a significant increase (486 μg/L) compared to 176 μg/L. Meanwhile, the average Zn levels showed a significant decrease in their level (44 μg/L) compared to 131 μg/L.

Bacteriological analysis of the water source is crucial to identify the bacteria that are being transported into fish and, consequently, into humans (Othman & Haroon, 2020). An ANOVA of total bacterial counts developed at 22 or 37 °C revealed significant seasonal

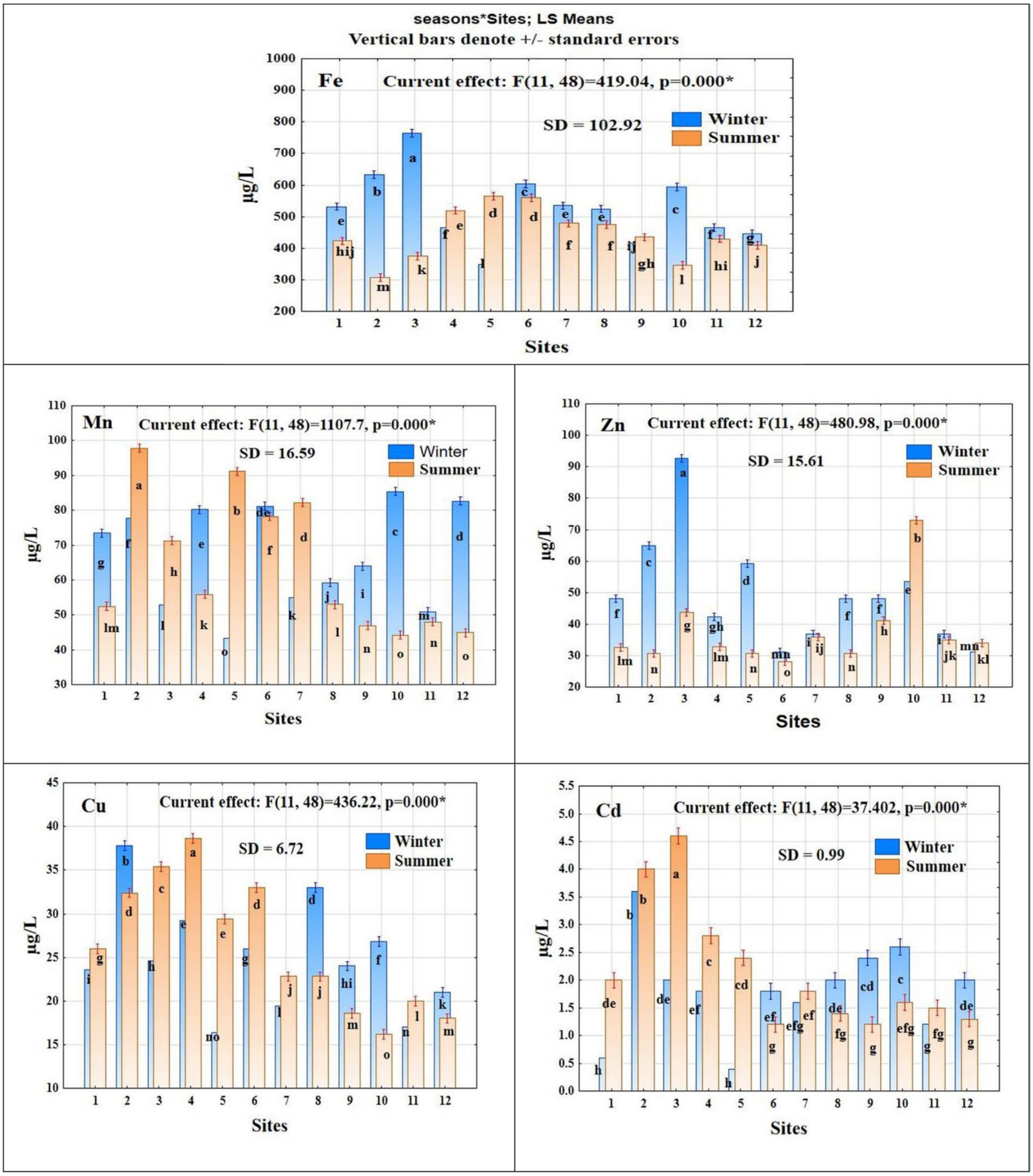

Fig. 2 Spatial changes in heavy metals along Burullus Lake, ANOVA; means followed by the same letter are not significantly different ($P < 0.05$)

and site differences (Fig. 3). Total bacteria developed at 22 or 37 °C were significantly higher in the winter (up to 10^5 cfu/ml) than in the summer. The high bacterial loads may be attributed to using animal manure as the direct source of organic fertilizer in fish farms, with leftover organic matter originating from fish excreta. Site 6 showed the highest bacterial count in the winter, with the discharge of agricultural runoff containing a considerable amount of fertilizers and organic material, discharged from drains 8 and 9. In general, the application of livestock and manure as a fertilizer is considered the main factors influencing bacterial contamination (Altinoluk-Mimiroglu & Camur-Elipek, 2018; Othman & Haroon, 2020).

High population densities of the associated nitrogen-fixing bacteria (diazotrophs) were found in the lake water, suggesting the terrestrial replenishment provided to the lake by agricultural drainage water (Othman et al., 2016). There were significant differences between the seasons, where the winter season registering the highest count. In the winter, the diazotroph counts varied from 3.50×10^3 cfu/ml to 2.00×10^5 cfu/ml, while in the summer, they ranged from 5.00×10^2 cfu/ml to 5.60×10^4 cfu/ml.

The total coliform count gives an overview of the water's microbiological quality. Even though most coliform group bacteria do not pose a threat to humans or animals,

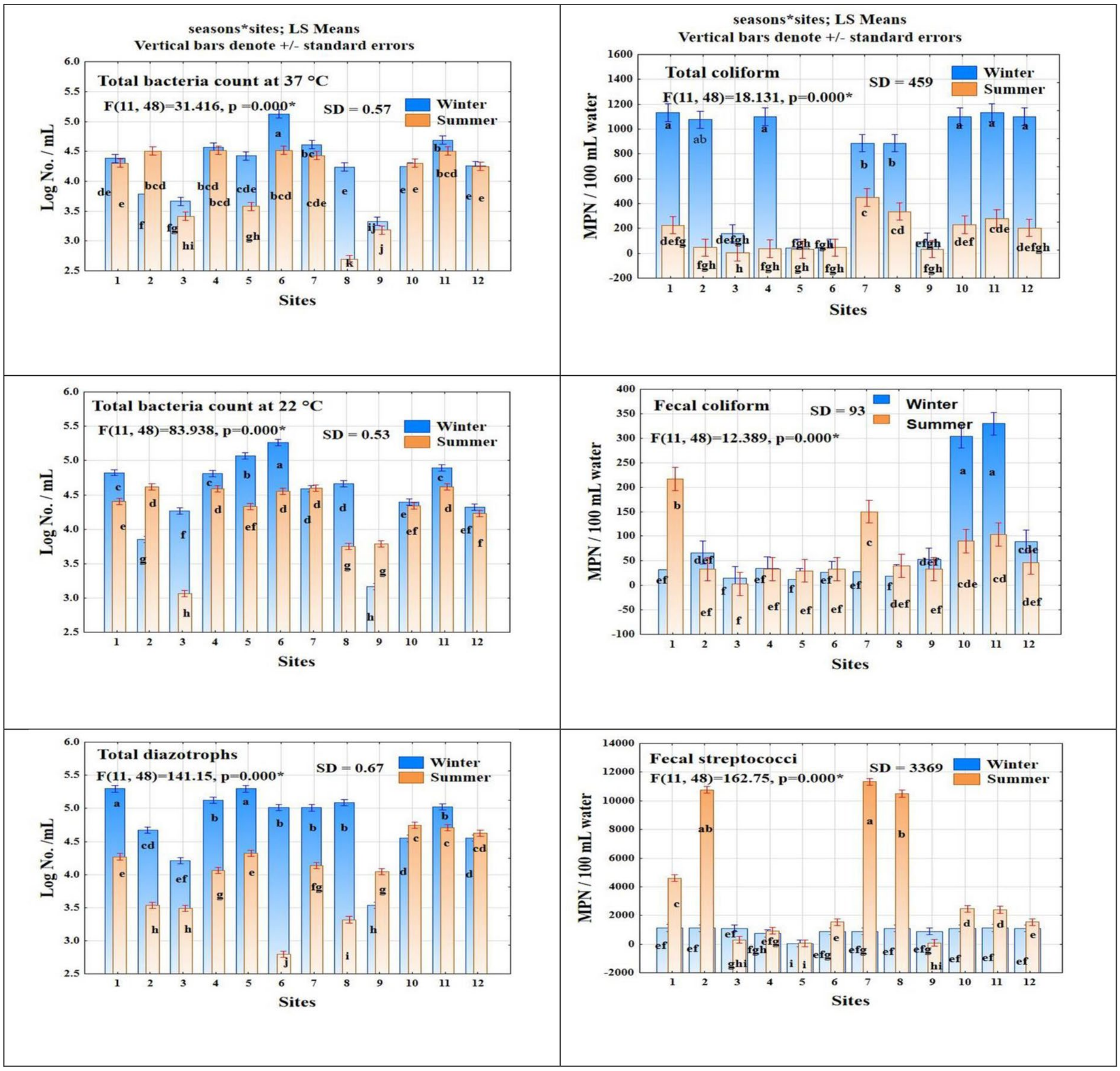

Fig. 3 Spatial changes in various bacterial groups along Burullus Lake, ANOVA; means followed by the same letter are not significantly different ($P < 0.05$)

they do reveal the presence of other disease-causing bacteria in aquatic systems (Othman & Haroon, 2020). The fecal coliform bacterial count is a specific marker of contamination originating from animal or human intestines and is closely tied to either municipal sewage or animal waste (Hamli et al., 2019). Fecal streptococci are bacteria that only exist in the gastrointestinal tract of animals and are incapable of withstanding external environments, so their presence in an environment indicates that it has recently been contaminated (Saker et al., 2022).

The measured counts of total coliform, fecal coliform, and fecal streptococci are shown in Fig. 3, along with their spatial and temporal variations. The TC bacteria count in winter had a range 47–1100 MPN/100 ml, the FC bacteria count range was 11–340 MPN/100 ml, and the FS bacteria count was 44–1100 MPN/100 ml. In summer, the count of TC bacteria was determined to be between 7 and 450 MPN/100 ml, the FC bacteria count varied between 3 and 210 MPN/100 ml, and the FS bacteria count was $60 - > 11{,}000$ MPN/100 ml. The high levels of total coliform detected in the winter may be related to the rise in organic matter during the River Nile's drought and the sewage from nearby municipalities. This result is consistent with those of Mousa et al. (2018) and Othman and Haroon (2020), who claimed that untreated sewage discharged into aquatic systems in rural areas greatly affects the levels of coliform bacteria. Total coliform and fecal coliform exhibit significant negative correlations ($n = 12$, $P < 0.05$) with EC levels ($r = -0.59$ and -0.51, respectively) and TDS levels ($r = -0.58$ and -0.49) in the summer. In winter all bacterial groups except fecal streptococci show negative correlations ($n = 12$, $P < 0.05$) with EC levels. The same outcomes, which confirm the fecal bacteria's tolerance to salinity, were noted by Kherifi and Bousnoubra-Kherici (2016). FC/FS ratio in lake samples below 0.6 indicated fecal contamination from domesticated animal wastes. Fecal streptococci have stronger tolerance to salinity and physical conditions than fecal coliform. Gabutti et al. (2000) found that FS lasted longer in brackish water than FC.

3.2 Water Quality Assessment

Using water quality indices is essential for contaminated water systems assessment to provide and implement practical solutions for water information specialists, stockholders, and decision-makers, such as eliminating pollution and overfishing from such significant water bodies (Deoli et al., 2022). WQI recorded its highest value at site 4 (fair), stayed continuously fair at stations 1, 6, and 8, and declined to marginal at most lake stations that suffer from agricultural drainage runoff, as seen in Fig. 4. Due to the extensive use of agro-chemicals such as growth regulators, pesticides, and fertilizers in agricultural activities, the aquatic ecosystems have been most affected by agricultural source pollution (Badrzadeh et al., 2022).

Dissolved oxygen, NH_3-N, Cu, and Cd have the greatest impact on WQI. Due to the fluctuating nature of water quality, the WQI trend along the lake is not as clear. The discharge of return irrigation water through different drains into lake water, containing high levels of nutrient salts and heavy metals, deteriorates the water quality of lake.

An assessment of heavy metals in the aquatic system can reveal crucial details about the level of environmental pollution (El-Khayat et al., 2018). With regard to the risky metallic pollution of lake water, 29% of water samples were categorized as having low metallic pollution ($Cd < 1$), 33% of samples were found to be moderately polluted by heavy metals ($Cd \leq 3$), and finally, 38% of water samples were considered to have high metallic pollution ($Cd > 3$) (Fig. 5). The long-term discharge of agricultural and industrial wastewater by several drains entering the lake has contributed to an increase in heavy metals. Therefore, it is essential to take all necessary precautions to limit the entry of heavy metals into the lake ecosystem.

The Nemerow index values of Cu and Cd exceeded 1, indicating the seriousness of the heavy metal pollution (Table 4). The highest P value was 7.83, which was detected for Cd metal at site 2, where the single factor index values (Pi) of Cu and Cd also exceeded 1 in 100% of the monitoring samples along the lake, reflecting the effects of agricultural wastes through drains. The Nemerow integrated pollution index for Fe, Mn, and Zn in lake water is less than 1, indicating no pollution by these metals. The results of P showed that metals (Cu and Cd) substantially harm and degrade the lake ecology because of human activity. Generally, the order of metal risk degree in the two seasons was $Cd > Cu > Fe > Zn > Mn$ in lake water. Considerable discharges carrying high concentrations of fertilizer and pesticide enter the lake through several drains, leading to severe metal pollution (Junqueira Dorta

& Palma de Oliveira, 2022). Improved farming methods that focus on reducing pesticides and fertilizers can significantly enhance the water quality of the lake (Shaban & Farag, 2018).

3.3 Physical and Chemical Properties of Drains Water

Burullus lagoon is impacted by agricultural drainage water that has been combined with other wastes from fish farms, industrial wastewater, and domestic wastes via several drains (Fig. 1). Pollutant mass is transported to aquatic systems by a variety of mechanisms including reactivity, dispersion, advection, absorption, and sedimentation. The type of pollutant, its physicochemical characters, and flow properties all influence these mechanisms (Badrzadeh et al., 2022).

The ranges of the water quality variables in the drains water samples are presented in Table 3. The water quality analysis revealed that the effluent from several drains contained total dissolved solids ranging from 0.24 to 3.78 g/L, with no statistically significant differences

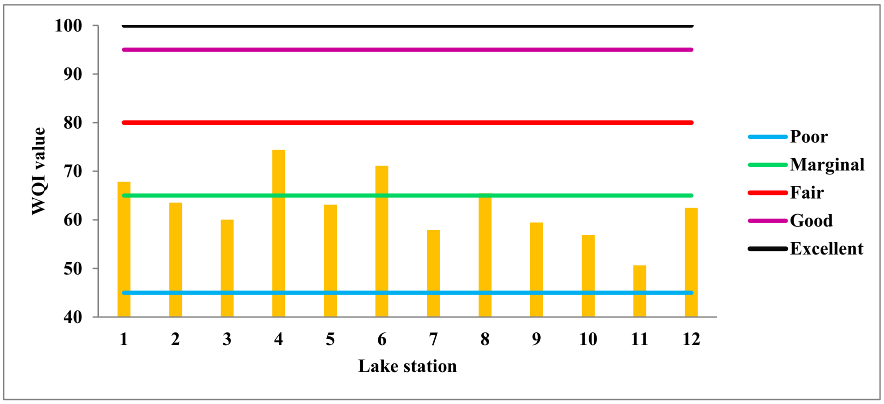

Fig. 4 Aquatic water quality index for Burullus Lake water samples

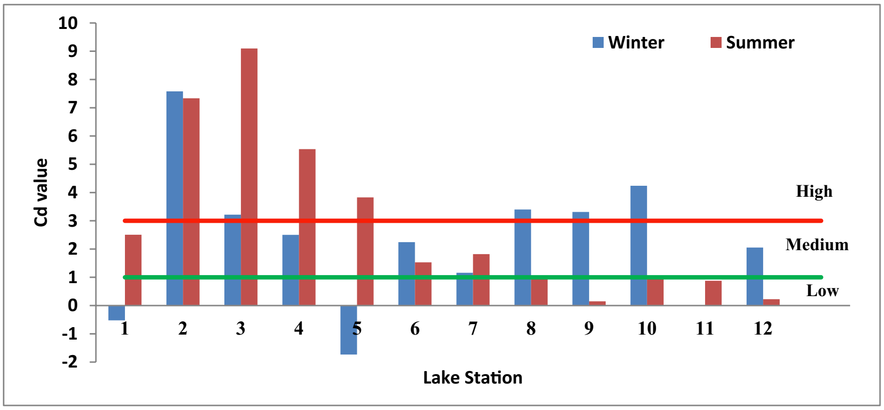

Fig. 5 Values of contamination index in Burullus Lake water samples

Table 4 Descriptive of Burullus Lake water heavy metals pollution indices (P_i and P)

		Winter					Summer				
		Fe	Mn	Zn	Cu	Cd	Fe	Mn	Zn	Cu	Cd
Pi	Range	0.35–0.76	0.01–0.02	0.26–0.77	1.55–3.57	0.87–7.83	0.31–0.56	0.01–.02	0.23–0.61	1.53–3.64	2.61–10.00
	Average	0.53	0.01	0.41	2.35	3.99	0.44	0.01	0.31	2.46	4.67
	SD	0.11	0.00	0.14	0.60	1.87	0.08	0.00	0.10	0.71	2.44
P		0.66	0.02	0.62	3.02	6.21	0.51	0.02	0.48	3.11	7.81

between drains**.** Dissolved oxygen showed low levels in the water of drains 7, 8, 9, and 10, especially in the winter season, and was less than the guideline value (5.5 mg/L) cited by the USEPA (1999) for the protection of aquatic life. COD of drains water showed lower values than those recorded in Burullus Lake, while the BOD values had comparable values with lake stations.

The drain's effluent was slightly enriched in Ca, Mg, K, and Na, where the order of abundance was Na > Mg > Ca > K on a mass basis. There were non-significant differences in nutrient salt distribution along several drains. The dominant nitrogen species, NH_3-N, displayed significant temporal variation, with the lowest levels observed during the summer season**.** The results showed that ammonia levels in drains water were approximately twice as high as those in lake water (Table 3). The elevated amount of NH_3-N could be attributed to agricultural waste leaking into the drain systems. Drains contain large amounts of pesticide and fertilizer-contaminated water, resulting in nutrient enrichment (Abdel-Satar, 2008).

Total phosphorus levels in drain waters were high (average 1237 and 781 µg/L with SD of 444 and 163 for winter and summer, respectively) compared to its levels in lake water (average 767 and 747 µg/L with SD of 508 and 265 for winter and summer, respectively). Poor agricultural management and overuse of land cause excessive phosphorus and nitrogen in water drains (Badrzadeh et al., 2022). Excessive nitrogen and phosphorus in water can cause algal blooms that harm water quality and decrease oxygen levels that fish, and other aquatic life need to survive. This explains the decrease in DO in drain waters (average 6.27 and 8.34 mg/L with SD of 2.12 and 2.79 for winter and summer, respectively) compared to lake water (average 7.54 and 8.58 mg/L with SD of 1.99 and 3.44 for winter and summer, respectively). Ortho and total phosphorus showed significant seasonal variation with irregular spatial variation. The winter season had the highest levels, reflecting the drought period's impact.

The results of heavy metals for drain water showed that there were small differences between the concentrations of metals in lake and drain water, as shown in Figs. 2 and 6. To better understand the level of contamination in drain effluent, WQI, Cd, and Nemerow index were also applied. Except for D7, which showed fair water quality, all the drain water fell into the marginal category, where the WQI range was 50–69, as shown in Fig. 7. Heavy metals present in drain water can be harmful to the aquatic environment (Ye et al., 2021). However, excessive levels of these metals have an adverse effect on fish, impairing their growth, maturation, physiological activity, and/or survival, and possibly even causing death (El-Khayat et al., 2018).

In winter, water samples from D7 and D8 were classified as low metallic water pollution (Cd < 1), while those from D1, D3, D4, D6, and D9 were moderately contaminated by heavy metals. In summer, water samples from D8, D9, and D10 were classified as low metallic water pollution (Cd < 1), while those from D4, D5, D6, and D7 were moderately contaminated by heavy metals. Water samples from D2, D5, and D10 in winter and from D1, D2, and D3 in summer were severely polluted by heavy metals (Cd > 3), as shown in Fig. 8. For Fe, Mn, and Zn in the drain water, the Nemerow pollution index is less than 1, suggesting that these metals have not contaminated the water (Table 5). However, Cu and Cd had Nemerow index values greater than 1, indicating a major problem with heavy metal pollution. Overall, the order of metal risk degree was Cd > Cu > Fe > Zn > Mn in drain water during the winter and Cu > Cd > Zn > Fe > Mn during the summer season.

Both harmful and nonpathogenic bacteria thrive in the wastewater environment. Table 6 shows the microbial load and ANOVA of wastewaters from several drains and Brimbal Canal. ANOVA in various bacterial groups indicates significant differences among seasons and sites. The total bacterial counts determined at 22 °C and 37 °C were 2.0×10^3 to 1.5×10^5 and 6.0×10^2 to 1.8×10^5 cfu/g, respectively. All samples collected during various seasons contained a high population density of associative nitrogen-fixing bacteria (diazotrophs) with a range of 5.0×10^3 – 6.0×10^5 cfu/g. According to the Egypt National Rural Sanitation Strategy of 2008, wastewater treatment plant facilities discharge their treated effluents to the nearest agricultural drain, which may cause high bacterial loads in drain water that carry sewage and agricultural drainage water to Burullus Lake.

Coliform bacteria are frequently employed as markers of water quality. MPN of indicator bacteria ranged from 700 to 120×10^3, from 300 to 52×10^3 and from 13×10^2 to 210×10^3 MPN/100 ml water for total coliforms, fecal coliforms, and fecal strepococci, respectively. High levels of total coliforms were observed in D3 and D5, while drains D4, D6, D7, and D10 showed the highest count of fecal coliforms in

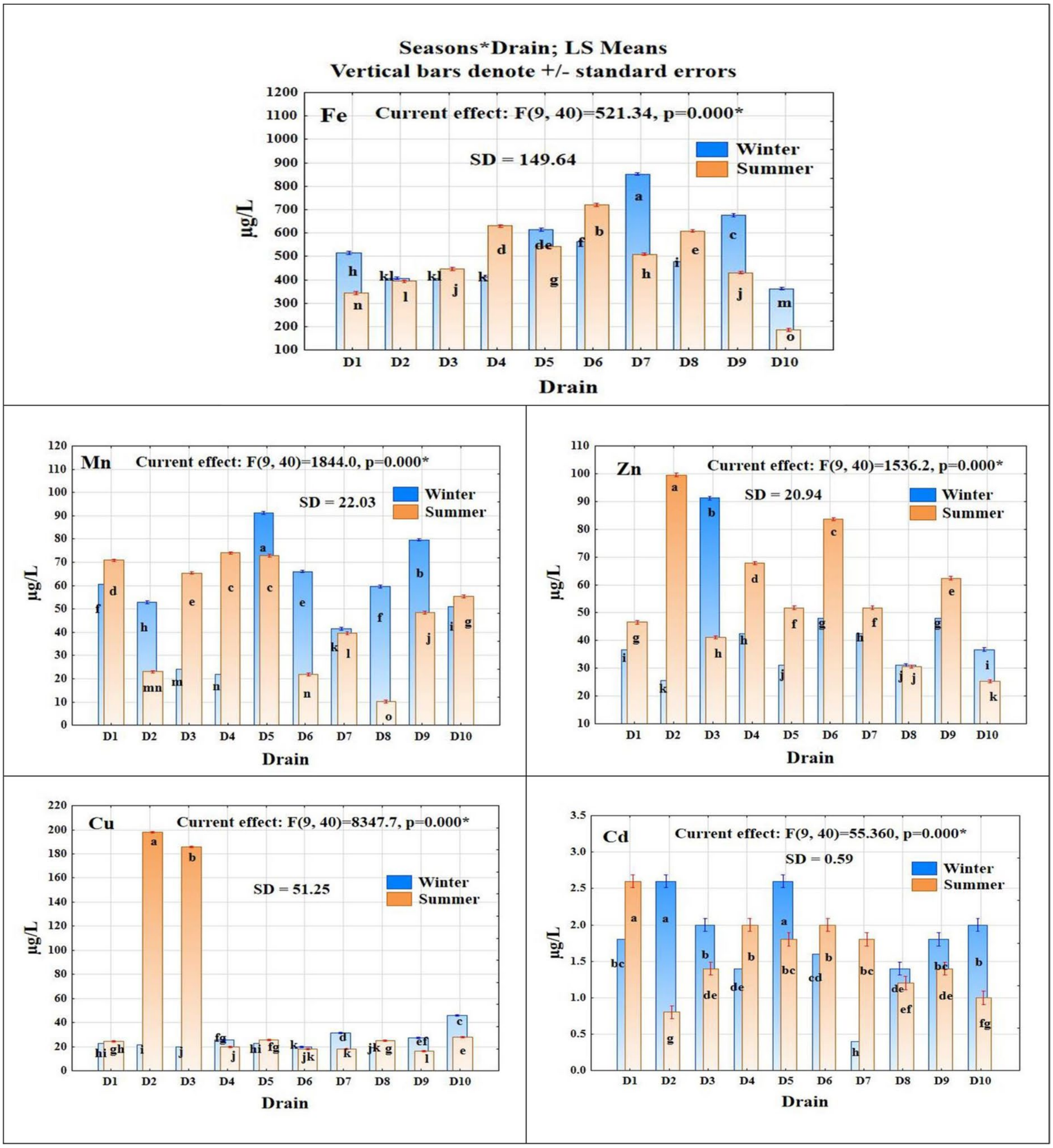

Fig. 6 Spatial changes in heavy metals along examined drains, ANOVA; means followed by the same letter are not significantly different ($P < 0.05$)

summer season, while in winter season D5 recorded high count of fecal coliforms.

The abundance of fecal streptococci in the drains water suggested that these areas were continuously contaminated. Fecal streptococci were common in the summer in the water of D1 and D7, whereas they were abundant in the winter in the water of D3 and D6. While the minimum counts were observed in the Brimbal Canal during the two seasons and in D7 and D9 in winter. Nile water is transferred from Rosetta Branch to Burullus Lake via

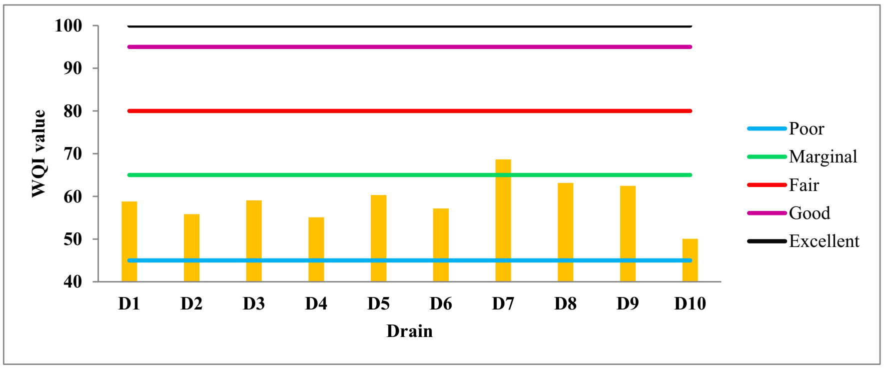

Fig. 7 Aquatic water quality index for examined drains water samples

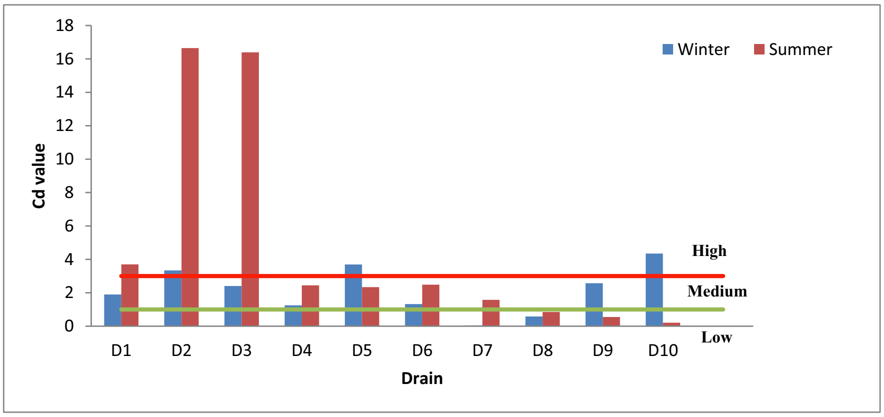

Fig. 8 Values of contamination index in water samples of examined drains

Table 5 Descriptive of drains water heavy metals pollution indices (P_i and P)

		Winter					Summer				
		Fe	Mn	Zn	Cu	Cd	Fe	Mn	Zn	Cu	Cd
Pi	Range	0.36–0.85	0.00–0.02	0.21–0.76	1.79–4.32	0.87–6.65	0.19–0.72	0.00–0.02	0.21–0.83	1.55–18.68	1.74–5.65
	Average	0.53	0.01	0.36	2.42	3.83	0.48	0.01	0.47	5.28	3.48
	SD	0.15	0.00	0.15	0.76	1.39	0.16	0.00	0.19	6.78	1.18
P		0.71	0.02	0.60	3.50	4.83	0.61	0.01	0.67	13.73	4.69

the Brimbal Canal. Brimbal Canal currently receives only minor amounts of Nile water, coupled with various types of wastewaters from nearby drains, due to Egypt's current freshwater scarcity (Elsayed et al., 2019).

4 Conclusion

Urban and agricultural development around Burullus Lake affects the levels of contaminants in the lake's water, including nutrients, heavy metals, and bacterial count. According to WQI, the lake water was marginal in most lake stations, where DO, NH_3-N, Cu, and Cd have the biggest effect on WQI, reflecting the runoff from agricultural drains. Twenty-nine percent of lake water samples had low metallic pollution, 33% of samples had moderate heavy metal pollution, and lastly, 38% had high metallic pollution. Cu and Cd substantially harm and degrade the lake and the surrounding drains ecology as a result of human activity according to Nemerow index. FC/FS ratio in lake water samples below 0.6 indicated fecal contamination from domesticated animal's wastes. Environmental conditions in Burullus Lake and its

Table 6 Average number of various bacterial groups in the water of drains

Drain	Seasons	Total bacteria count at 22 °C	Total bacteria count at 37 °C	Total diazotrophs	Total coliform	Fecal coliform	Fecal streptococci
		Log no./ml			MPN/100 ml $\times 10^3$		
D1	Winter	4.15^{fg}	4.64^{def}	5.42^{bcd}	9.3^{de}	1.3^{c}	24^{d}
	Summer	3.90^{h}	4.45^{g}	4.78^{hi}	46^{c}	2.8^{c}	110^{b}
D2	Winter	3.90^{gh}	4.86^{bc}	5.35^{cde}	4.3^{e}	2.7^{c}	2.8^{e}
	Summer	5.16^{a}	5.16^{a}	5.85^{a}	5.9^{e}	1.5^{c}	2.9^{e}
D3	Winter	4.76^{cd}	4.79^{cde}	5.36^{cde}	78^{b}	24.8^{b}	150^{a}
	Summer	4.82^{bcd}	4.81^{cd}	5.47^{bcd}	110^{a}	4.4^{c}	46^{c}
D4	Winter	4.15^{fg}	4.45^{g}	5.34^{de}	46^{c}	0.55^{c}	3.9^{de}
	Summer	4.64^{de}	4.64^{efg}	4.88^{h}	46^{c}	46^{a}	46^{c}
D5	Winter	5.05^{ab}	5.16^{a}	5.81^{a}	110^{a}	46^{a}	21de
	Summer	4.98^{abc}	5.04^{ab}	5.78^{a}	110^{a}	3.6^{c}	9.3^{de}
D6	Winter	4.62^{de}	5.20^{a}	5.54^{b}	24^{d}	0.55^{c}	110^{b}
	Summer	4.96^{abc}	4.89^{bc}	5.52^{bc}	46^{c}	46^{a}	15de
D7	Winter	4.00^{gh}	3.43^{i}	3.82^{j}	0.9^{e}	0.4^{c}	1.5^{e}
	Summer	5.10^{a}	5.04^{ab}	5.04^{fg}	46^{c}	46^{a}	110^{b}
D8	Winter	3.90^{h}	4.15^{h}	4.88^{h}	46^{c}	6.8^{c}	9.3^{de}
	Summer	4.36^{ef}	4.51^{fg}	4.95^{gh}	9.3^{de}	1.5^{c}	24^{d}
D9	Winter	4.08^{gh}	4.00^{h}	4.65^{i}	1.5^{e}	0.4^{c}	2.1^{e}
	Summer	4.08^{gh}	4.60^{efg}	4.78^{hi}	0.9^{e}	0.7^{c}	24^{d}
D10	Winter	3.60^{i}	3.00^{j}	4.65^{i}	2.3^{e}	0.4^{c}	3.6^{de}
	Summer	4.62^{d}	4.68^{def}	5.23^{ef}	46^{c}	46^{a}	46^{c}
SD		0.51	0.58	0.50	37.8	19.6	45.6

*Mean values followed by the same letter are not significantly different

surrounding drains can limit bacterial populations and distribution in water. All the drains' water, with the exception of D7, which had fair water quality, fell into the marginal category according to WQI. Freshwater from several drains containing agricultural runoff water and industrial and domestic effluents has caused extreme environmental stress in Burullus Lake. Dredging and deepening the inlet link between the lake and the Mediterranean Sea in the eastern part have had a positive impact on water quality. However, there are still other options for improving the lake's health. These include using freshwater entering the lake for construction projects, creating an additional seawater inlet to the west, and investigating various drainage water management options to enhance the balance between salt and fresh water entering the lake. Additionally, improved farming methods that focus on lowering fertilizers and pesticides can significantly impact the quality of drain water. Therefore, it is recommended to routinely check the water quality of Burullus Lake and its surrounding drains to keep track of the lake's condition and assess the effectiveness of any lake improvement efforts.

Author Contribution **ADGA:** conceptualization, collection of samples, heavy metals analysis, and writing the original draft. **MHA**: conceptualization, collection of samples, chemical sample analysis. **AAO**: microbiological analysis, data curation, and writing the original draft. **AMAS:** chemical data curation, writing, review, and final editing for the manuscript.

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Data Availability The data can be available on request.

Declarations

Ethics Approval and Consent to Participate Not applicable.

Consent for Publication Not applicable.

Conflict of Interest The authors declare no competing interests.

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