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Assessment of Water Quality, Eutrophication, and Zooplankton Community in Lake Burullus, Egypt

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Abstract: Burullus Lake is Egypt's second most important coastal lagoon. The present study aimed to shed light on the different types of polluted waters entering the lake from various drains, as well as to evaluate the zooplankton community, determine the physical and chemical characteristics of the waters, and study the eutrophication state based on three years of seasonal monitoring from 2017 to 2019 at 12 stations. The results revealed that Rotifera, Copepoda, Protozoa, and Cladocera dominated the zooplankton population across the three-year study period, with a total of 98 taxa from 59 genera and 10 groups detected in the whole-body lake in 2018 and 2019, compared to 93 species from 52 genera in 2017. Twelve representative surface water samples were collected from the lake to determine physicochemical parameters, i.e., temperature, pH, salinity, dissolved oxygen, biological oxygen demand, chemical oxygen demand, ammonia-N, nitrate–N, nitrate-N, total nitrogen, total phosphorus, dissolved reactive phosphorus, and chlorophyll-a, as well as Fe, Cu, Zn, Cr, Ni, Cd, and Pb ions. Based on the calculations of the water quality index (WQI), the lake was classified as having good water quality. However, the trophic state is ranked as hyper-eutrophic and high trophic conditions.

Keywords: zooplankton community; marine pollution; water quality; eutrophication state; heavy metals; Burullus Lake

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1. Introduction

The Deltaic Mediterranean coastline of Egypt, especially the middle part, has economic importance. From the west coast to the east coast, there are three Deltaic shallow lakes (Edku, Burullus, and Manzala Lakes). Burullus Lake is the second-largest natural lake in Egypt and is situated close to the Mediterranean Sea among the two main branches of the Nile. The importance of lakes as natural resources includes fish production, as they account for more than 40% of the overall fish production in Egypt. As a result of anthropogenic activity and pollution, its production has decreased to less than 12.22% now [1]. Burullus Lake is one of a network of protected areas throughout Egypt, designated and managed by the Egyptian Environmental Affairs Agency. It is registered as a Ramsar site in 1998. Additionally, Birdlife International has identified it as an important bird area (IBA) [2], due to its importance for refuge, migratory foraging, and breeding of water birds [3]. It covers an area of 410 km^2 [4] of which 220 km^2 are open water [5]. It is observable that the open water surface in the lake had reduced from 1092 km^2 in 1801 [6] to 434.6 km^2 in 1972 then reduced to 220 km^2 in 2015 with a reduction of about 80.0% of the water area [5].

Coastal lakes are heavily influenced by anthropogenic activities from watersheds, as they receive inputs of freshwater and polluted waters containing organic and inorganic compounds from different sources [7]. These lakes collect massive amounts of drainage water from various drains around the Nile delta and connect to the Mediterranean Sea via El-Boughaz outlets [2]. Contamination of the marine environment is a major factor that poses a substantial threat to marine creatures' survival [8]. Among the several pollutants, heavy metals are toxic, persistent, and abundant owing to their accumulation in the food chain and continued persistence in the ecosystem and their concentration increases through biomagnification [9]. The impacts of pollution have far-reaching consequences for public health, the economy, and the environment [10].

The process of eutrophication is driven by an increase in nutrients in the aquatic systems, particularly nitrogen and phosphorus in the ecosystem, which leads to an increase in primary production (photosynthesis) and an accumulation of organic matter in the lakes. In addition, silt from the drainage basins will accumulate over time, which makes the lake shallower and warmer. Eutrophication can also have a negative impact on the reservoir ecology as well as the natural stability of the lake, affecting practically all of the biological communities and their interactions in the water body [11]. Under natural conditions, the rate of this process is very slow and it takes hundreds or thousands of years.

Zooplankton are aquatic species with poor swimming abilities that float in the water column of ocean, seas, or freshwater bodies to travel for long distances [8,12,13]. Zooplanktons are important in the ecosystem because they connect the primary production and the higher levels, monitoring water quality, pollution, and the state of eutrophication [14,15]. In addition, zooplankton play an important role in the natural cycle of carbon and other elements in the sea [16]. On the other hand, zooplankton are the main suitable feeds for larval stages of many fish and shellfish species in marine hatcheries [8,12].

Seasonal zooplankton movement and the factors driving their inconstancy are very sensitive to changes in ecological variables, particularly in shallow, semi-enclosed inlets with densely populated shores, where increasing anthropogenic nutrient input has a serious influence on marine communities [17,18]. Monitoring of water quality is the first step that can lead to management and conservation of aquatic ecosystems. The chemical and physical factors influencing the marine environment include temperature, pH, salinity, dissolved oxygen, biological oxygen demand, chemical oxygen demand, nutrients, reactive phosphate, heavy metal pollutants, and others. These parameters are considered the most limiting factors affecting the survival and growth of aquatic organisms [19–21]. Poor water quality could be produced via low aquatic flow, municipal discharges, and wastewater effluents [22]. In this study, Burullus Lake was chosen because of its economic importance in Egypt, based on its various uses and surroundings, such as tourism, fisheries activity, nutrient enrichment, and industrial water sources, among others. Furthermore, any noticeable change in water quality has an impact on the health, structure, and growth of the fish population, so this paper aims to determine most of the parameters related to water quality and identify the major sources of pollution in Burullus Lake, Egypt over the course of three years, from 2017–2019, in conjunction with the study of eutrophication state and an assessment of potential ecological concerns. In addition, it aims to assess the community, occurrence, diversity, and abundance of zooplankton in Burullus Lake. Moreover, the current study will be a useful tool in assisting decision makers and authorities in charge for sustainable marine management and increasing the lake production.

2. Materials and Methods

2.1. Study Area and Sampling

Burullus Lake is located at (30°22′–31°35′ N; 30°33′–31°08′ E) with an area of about 460 km^2, length of about 47 km, and width ranges between 6 and 16 km. It has an irregular elongated shape with 0.4–2.5 m depth. The lake receives seawater through a long canal

(Boughaz El-Burullus) that connects the lake to the sea. Fresh water enters the lake through 8 drains and 1 freshwater canal. The lake is divided into 3 basins; eastern, middle, and western. It is situated on the eastern port of Rosetta side of the River Nile.

Water samples were collected seasonally for the period from winter 2017 to autumn 2019 in sterile containers and maintained in an icebox on the site. A total of 12 surface water samples were collected from 12 sites representing different environmental habitats. Information of the sampling sites with their latitude and longitude are presented in Table 1 and Figure 1.

2.2. Methods

Analyses of the physicochemical parameters of collected water samples were investigated according to the standard methods APHA [23] to estimate various factors, such as biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia-N, nitrate–N, nitrate-N, total nitrogen, dissolved reactive phosphorus, total phosphorus, and chlorophyll-a (*Chlo-a*).

Water temperature was determined by a mercury thermometer. The concentration of hydrogen ion (pH) was determined by pH meter Model 59003-20 USA. Salinity (‰) was measured by the Cole–Parmer model Check-mate 90 (CORNING) conductivity meter. Dissolved oxygen (DO) was measured by using the modified Winkler method.

2.2.1. Determination of Heavy Metals in Water

Water samples were filtered by 0.45 µm membrane filters. The filtrate water samples were preconcentrated individually with ammonium pyrrolidine di-thiocarbamate (APDC)-methyl isobutyl ketone (MIBK) extraction procedure APHA [23]. The Fe, Cu, Zn, Cr, Ni, Cd, and Pb were determined by atomic absorption spectrometer according to standard methods.

2.2.2. Zooplankton Quantitative Analysis

A horizontal quantitative sample was taken at each site. Zooplankton sampling from Burullus Lake was obtained by filtering 50 L of water through a small standard plankton net (mesh size 55 µm) using a 10 L plastic container. The collected samples were preserved directly with 4% neutral formalin solution in 250 mL polyethylene bottles. The volume of all samples was concentrated to 100 mL, and the whole sample was examined in a Petri dish under a research binocular microscope. For zooplankton count purposes, at any rate, two aliquots (2 mL of well-shaken suspension) were removed from each example utilizing a graduated pipette, set in an including chamber, and the number of individuals of every species was enumerated. The average number of duplicated assessments for each example was assessed, and enumerations were communicated as the number of organisms per cubic meter [11]. The organisms were identified and counted. The total number of zooplankton present in a cubic meter (m^3) of water sample was calculated according to the following equation: [24]

$$N = n\,(v/V) * 1000 \tag{1}$$

where N = total number of zooplankton per cubic meter of filtered water; n = average number of zooplankton in 1 mL of zooplankton sample, v = volume of zooplankton concentrates (ml), V = volume of total water filtered (L).

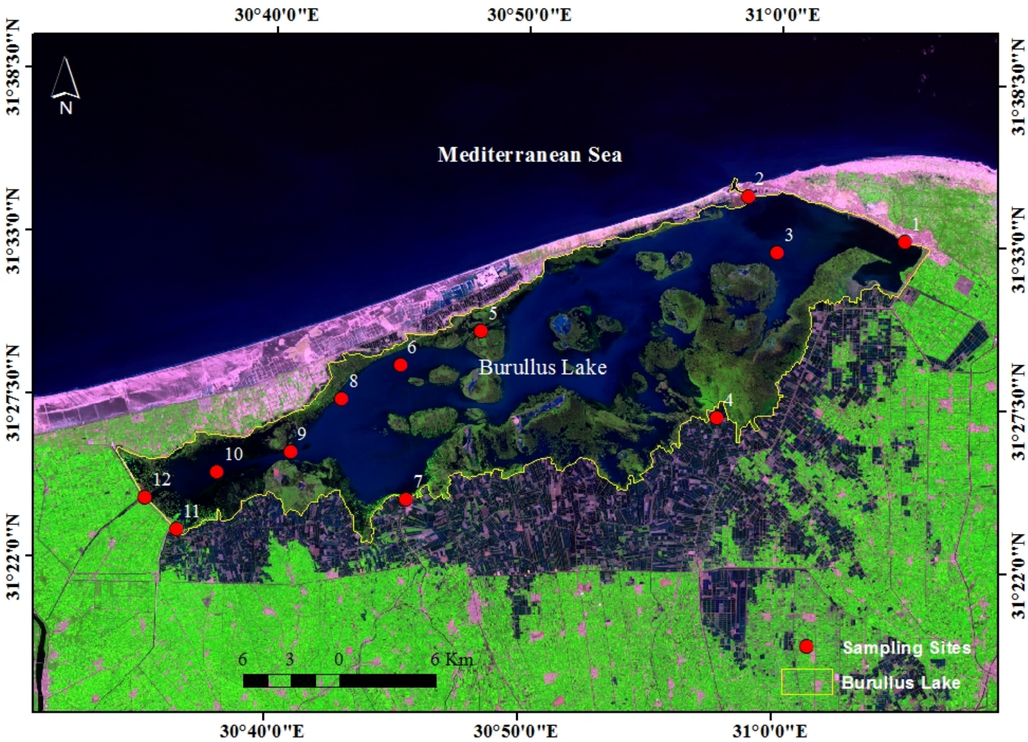

Figure 1. Location map of the study area.

Table 1. Sites description in Burullus Lake.

Site No.	Description	Coordinates	
		N	E
1	In front of East El-Burullus drain	31.0826	31.5529
2	In front of El-Boughaz	30.9789	31.5771
3	El-Bellaq	30.9986	31.5456
4	In front of drain 7	30.9610	31.4520
5	El-Zanqa	30.8047	31.4982
6	El-Maqsaba	30.7519	31.4784
7	El Shakhlouba	30.7575	31.4028
8	Mastrou	30.7134	31.4583
9	Abou Amer	30.6806	31.4281
10	El-Berka El-Gharbia	30.6325	31.4160
11	In front of drain El-Hoks	30.6065	31.3831
12	In front of Brinbal Canal	30.5854	31.4009

2.2.3. Trophic State Index (TSI)

Carlson's trophic state index (TSI) is used to provide a single assessable index for classifying lakes according to the trophic state of the lake. Recently, Carlson's index has been usually accepted in the limnological community as a reasonable approach for this problem. It is used as an assessment of the trophic state for a marine body by some water quality factors containing: turbidity or transparency by the concentrations of Secchi disk depth (SD), ortho-phosphate (PO_4), and chlorophyll-a (*Chlo-a*) [25]. The higher values correspond to the increase in fertility, which shows further eutrophic conditions. Each augments in TSI via 10 units relates to a decrease in the Secchi disk (SD) transparency through moiety and augment in the concentration of phosphorus via double. The spatial proration of the TSI data was recorded by the ordinary Kriging methodology [25] as follows:

$$\text{CTSI} = [\text{TSI (TP)} + \text{TSI (CA)}]/2 \tag{2}$$

The formulas for calculating TSI values from TP and Chlo-a are:

$$\text{a- TSI for Chlorophyll-a (CA) TSI} = 6 - [(2.04 - 0.68\ (chl - a))/(Ln\ (2)] \tag{3}$$

$$\text{b- TSI for Total phosphorus (TP) TSI} = 10[6 - (21.67/po_4)/(Ln\ (2)] \tag{4}$$

where *Ln* is natural logarithm. Po_4 is dissolved phosphorus in ($\mu g\ L^{-1}$), Chlo-a is chlorophyll-a, in ($\mu g\ L^{-1}$). The TSI index was calculated using Carlson's trophic status index as the most important, in addition to the popular TSI process designated for the present research [26]. On the Carlson's scale, if TSI is <30 characterizes oligotrophic, from 30 to 50 characterizes mesotrophic, from 50 to 70 eutrophic, and >80 hypereutrophic.

Ecological risks of nitrogen and phosphorus were evaluated by using the following equation of the trophic index (TRIX) [1]:

$$\text{TRIX} = (\text{LOG (Chlo-a} \times [\%\ \text{DO}] \times \text{DIN} \times \text{SRP} + 1.5))/1.2 \tag{5}$$

where SRP, DIN, and Chlo-a are the concentrations of soluble reactive phosphorus, dissolved inorganic nitrogen, and chlorophyll-a, respectively. A percentage of DO is the absolute results of oxygen saturation deviation and is calculated as [100% DO]. Trophic index levels were defined in following Table 2.

Table 2. Trophic index levels.

Level	Value	Water Quality State
Low trophic level	TRIX < 4	excellent
Moderate trophic level	4 < TRIX level < 5	very good
High trophic level	5 < TRIX < 6	good
Very high trophic level	TRIX > 6	fair

2.2.4. Water Quality Index (WQI)

The water quality index (WQI) is described as a technique of rating that provides the composite effect of individual water quality factors on the general water quality [23]. The pollution index is a beneficial approach to give information about water quality. It was described as a rating reflecting the compound effect of different water quality factors on the total quality of water [27]. WQI is a mathematical way of summarizing multiple properties into a single value. Moreover, WQI is useful for comparing alterations in water quality across a region, or for measurement changes in water quality over time. In the current study, WQI was calculated using the equation developed by Tiwari and Manzoor [28]. The quality rating (q_i) for the water quality factor was obtained by the following relation [28]:

$$q_i = 100 \times [V_i/S_i] \tag{6}$$

where S_i is the standard of the stream water quality, and V_i is the observed data of the factor at a known sampling site according to all parameters. The equation confirms that q_i = 100 if the presented data are impartial and equal to its standard data. Therefore, the larger data of q_i revealed polluted water. To compute the WQI, the quality rating qi corresponding to factor can be delimiting using Equation (6):

$$\text{WQI} = \Sigma\ \text{qi} \tag{7}$$

where i = 1. The average water quality index (AWQI) for n factors was computed using the following equation:

$$\text{AWQI} = \Sigma\text{qi}/\text{n} \tag{8}$$

where n = number of factors. AWQI was classified into 4 categories: good (0.0–100), medium (100–150), bad (150–200), and very bad (over 200).

2.3. Descriptive Statistics

The relationships between different factors were calculated from the correlation matrix formed in IBM SPSS statistics, version 22 programs. The correlation coefficients are considered significant at 0.01 levels (2-tailed) and 95% confidence level ($p \leq 0.05$). Statistical for zooplankton was performed by the primer 5 (Plymouth Routines in Multivariate Environmental Research) program to measure both the Shannon index (H), the evenness index (E), species richness (D), and the similarity index.

3. Results and Discussion

3.1. Water Characteristics and Physicochemical Parameters

The physicochemical parameters recorded at the sampled stations from 2017 to 2019 are summarized in Table 3. The temperature value is a crucial parameter for all biological processes [16]. The mean water temperature in the lakes fluctuated between a minimum mean value of 14.47 °C in the winter season of 2018 and a high of 31.23 °C in the summer. In the current study, the maximum value was observed in the year 2017 in the summer season, and the annual average of three years was 21.77 °C. According to EPA [29], the water temperature ranged from 15.1 to 32.6 °C in lake water, which is suitable for fish growth.

Table 3. The annual averages, minimum, and maximum values of physicochemical parameters.

Max	Min	Average	Year			Parameter *
			2019	2018	2017	
31.23	14.47	21.77	19.11	24.21	22.01	Temp °C
9.36	7.32	8.09	8.18	7.56	8.55	pH
38.91	0.62	4.60	3.94	3.88	6.00	Salinity‰
19.87	0.9	8.83	10.23	8.58	7.68	DO (mg L^{-1})
176.66	1.67	23.63	24.09	22.53	24.29	BOD (mg L^{-1})
423.98	30.12	100.39	151.31	59.98	89.88	COD (mg L^{-1})
4.45	0.013	0.61	0.66	0.47	0.71	NH_4 (mg L^{-1})
419.71	2.98	126.95	116.21	131.55	133.1	NO_2 (mg L^{-1})
1.64	0.013	0.283	0.35	0.19	0.31	NO_3 (mg L^{-1})
10.33	0.52	3.40	5.04	2.15	3.03	Total N (mg L^{-1})
2105.77	60.96	640.56	1017.88	399.8	504.01	Total P (µg L^{-1})
383.81	6.25	62.93	70.69	70.71	47.39	*Chlo-a* (µg L^{-1})

* Temp: temperature, DO: dissolved oxygen, BOD: biological oxygen demand, COD: chemical oxygen demand, NH_4: ammonia, NO_2: nitrite, NO_3: nitrate, TN: total nitrogen, Total P: total phosphorus, Chlo-a: chlorophyll-a.

The pH values can affect the biological activities of microbial metabolites that can influence the further utilization of succeeding metabolic products. In the current study, the values of pH of water samples ranged between 7.32 and 9.36 with an annual mean of 8.09. The highest value was observed in front of El-Kashaa drain in the summer season of 2017, while the lowest result was noted at station 11 in the winter season of 2019.

According to the annual average values, the hot season (summer) recorded a higher pH level than the cold season (winter), which is correlated, mainly, to the increase in CO_2 uptake because of the rise in the photosynthetic activity, which leads to high pH values [3,30]. High pH values occur according to the nature of effluent in the lake in addition to the fermentation process, decay of organic matter, and release of organic acids by bacterial activity [28]. These results were in the same ranges stated by Okbah and Hussein [31]. El-Alfy et al. [32] at the Burullus Lake showed that the dominant alkaline pH was >7.0. Additionally, Khairy et al. [33] showed that the average of pH values in Burullus Lake was 8.1.

Salinity has a significant influence on measuring numerous conditions of the aquatic biological processes and the chemistry of natural waters [34,35]. In the present study, salinities exhibited wide variations between 0.62 and 38.9‰, with the maximum value being noted in station 2, in front of El-Boughaz in 2017 in the winter season; whereas, the highest values were related to marine water intrusion along the Boughaz area. Conversely, the lowest value was recorded in front of drain El-Hoks (station 11) in 2018 in the summer season, with an average value of 0.62‰. Low salinity values indicate that the water content in the lake was mainly freshwater due to human activities and the quantity and quality of drainages runoff in the lake. Salinity distribution in the lagoon water reflects a decreased gradient from the east to the west. This gradient depends on the amount of drainage water that comes from the south drains, fresh Nile water from Brimbal Canal at the west, and sea water from the sea outlet at the east, and therefore, marine plankton species are restricted only in the eastern basin and in some cases dominate the community. According to previous references, the salinity of the lagoon increased from year to year, which creates high brackish water conditions especially in the eastern basin (>17 PSU) [36]. El-Shinnawy [37] reported that the high salinity and presence of marine forms in the eastern basin at Burullus Lake could be due to the closure policy of the pumping drain stations, which diminish the water level to be below sea level and permits seawater to enter the lagoon. As well, Nassar and Gharib [38] reported that the average salinity of the Burullus Lake in the year 2013 was 3.6‰.

Dissolved oxygen (DO) is considered as one of the maximum important factors controlling the biota in the aquatic habitat [16]. In the current study, DO values varied from 0.9 to 19.87 mg L^{-1}. The higher value was obtained at the front of El-Kashaa drain in the year 2017 in the summer season, while the lowest value was documented at station 11 in the winter season of 2018, with an annual mean of the study period of 8.83 mg L^{-1}. Under low dissolved oxygen, many marine plants and animals may not survive [39]. The decrease in oxygen supply in the water showed a negative effect on aquatic life. The highest value occurs during the summer season due to the increase in photosynthetic activity during this season, which liberates an important quantity of oxygen to the surrounding water ecosystem, since the photosynthetic method was regarded as the highest source of oxygen in the aquatic environment [33]. Moreover, the quantity of DO in water could be based on the salinity and temperature of the water, as cold liquid can hold more DO than warmish liquid [40]. These results agreed with those achieved by Hereher et al. [41] and Khairy et al. [33] who showed that the average concentration of DO along the Burullus Lake was 7.6 mg L^{-1}.

Biological oxygen demand (BOD) gives data on the biological convertible amount of the content of organic content in marine samples. In the current work, BOD in the lakeshores habitat varied from 1.67 to 176.60 mg L^{-1}, with an average value of 23.63 mg L^{-1}. The maximum value was recorded at station 9 (Abou Amer) in the year 2018 in the autumn season, and the lowest result was showed in facing the El-Boughaz outlet in the spring season of 2019 due to the dilution effect of low organic matter loaded seawater. BOD values of 3 mg L^{-1} indicate pure water, but values that reach 5 mg L^{-1} give an indication of doubtful purity of water [42]. The high values of DO may be because of the abundance of plankton, which enhanced water quality with oxygen throughout photosynthesis activity [15,43,44]. In addition, augmented oxygen reduction is essential for oxidation of the organic matter in the aquatic body [45,46]. Younis and Nafea [47] recorded that the concentration of biological oxygen demand in the water samples at Burullus Lake ranged from 11.7 to 36.66 mg L^{-1}.

Chemical oxygen demand (COD) is an important parameter for determining the quality of water and wastewater quality. The COD test is used to monitor water treatment plant efficiency. In the current study, COD showed different values between different habitats. It varied from 30.12 to 423.98 mg L^{-1}. The maximum value was recorded in the year 2018 in the winter season, and the lowest value was recorded in the year 2018 in the autumn season, with an annual average value of 100.39 mg L^{-1}. The permissible limit for COD in marine water is 100 mg L^{-1} [48]. The average data of COD parameter in all environments were exceeding 40 mg L^{-1}, hence the lake is measured as polluted water as reported by Hassan et al. [45] who stated that water bodies contain COD > 40 mg L^{-1} are considered as polluted waters; however, those containing COD > 120 mg L^{-1} are extremely polluted.

Nitrogen and phosphorous are the nutrients most likely to remain deficient in the contaminated environment. Nutrients from anthropogenic pollution can degrade water quality and alter the balance of marine food webs [16,19]. Ammonia (NH_4) contents in the water of lakeshores habitat varied from 0.013 to 4.45 mg L^{-1}, which was the maximum value recorded in station 7 in front of downstream 8 and 9 drains in the winter season in the year 2017. The annual average value during the three-year period of the study was 0.613 mg L^{-1}. The minimum values may be related to increases in plankton biomass. The high phytoplankton population in water bodies utilizes a high content of ammonium ions in preference to other inorganic nitrogen [49]. Our results agree with Okbah and Hussien [25], who showed that in the regional variations of NH_4, the minimum mean concentration was 3.70 µmol L^{-1}. In contrast, the maximum mean value of NH_4 was 12.33 µmol L^{-1}.

Nitrite (NO_2) is the noxious via-creation of nitrifying bacteria (nitrospiration) in substrate consuming NH_3 or a filter. In the current study, nitrite ranged from 2.98 (summer season) to 419.71 mg L^{-1} in station 6, in the spring season in the year 2018, with a mean value throughout the three-year stage of this study of 126.93 mg L^{-1}. The highest value of water nitrite is related to human activities of diverse origin mainly from domestic drainage. It also occurs due to the nitrification of free ammonia and a reduction in nitrate to nitrite and use of ammonium fertilizers. Minimum values of nitrite are explicating to these places that are far away from any pollution sources. Nassar and Gharib [38] recorded that the average concentration of NO_2 in Burullus Lake was 0.1 µmol L^{-1}.

Nitrate (NO_3) is considered as the most stable and predominant inorganic nitrogen form in seawater, in addition to major nutrients for the phytoplankton growth [50]. Nitrate serves as another electron acceptor under anoxic conditions. The present values of nitrate ranged from 0.13 to 1.64 mg L^{-1}. The present study found that the highest value of nitrate was observed in the year 2017 in the winter season in station 6 in the north of the lake. The increase in nitrate values may be attributed to the discharge of sewage wastes and the increase in mineralization of organic matter. Additionally, it is noticed that the high results of nitrate are related to drainage 9 and 8 of the agricultural wastewater that are loaded by high amounts of nitrogenous fertilizers, discharged into these sites. The minimum value was recorded in station 5 in the middle of the lake, which related to the increase in aquatic plants that feed on nutrients and cause depletion in their concentration [51–53]. Abd El-Hamid [54] reported that NO_3 concentrations in water samples at Burullus Lake ranged from 0.15 to 0.47 mg L^{-1}.

Total nitrogen (TN) concentration in the investigated area showed narrow variation, ranging between a minimum value of 0.52 mg L^{-1} at sampling site 2 in front of El-Boughaz in the summer season and a maximum value of 10.33 mg L^{-1} at El-Shakhlouba in the winter season as a result of the effect of industrial, agricultural, and demotic wastes through drains 8 and 9, with an average concentration of 3.40 mg L^{-1}. It is obvious that the water of this lake surrounds a considerable quantity of particulate nitrogen related to organisms and products of their metabolism, besides decay [31]. These results agree with El-Zeiny and El-Kafrawy [55]; they showed that the highest concentrations of TN have been noticed in the parts polluted by fertilizer, run-off animal wastes, and domestic sewage at the southeastern and western part of the lake.

Phosphorous is needed for the formation of cellular enzymatic compounds used in the processes of synthesis and degradation. The most common sources of phosphorous in bacterial sources are K_2HPO_4, KH_2PO_4, NaH_2PO_4, Na_2HPO_4, or mixtures of them [56]. The current results found that total phosphorus content showed its high values in water in the year 2019, with a high value (60.96 mg L^{-1}) in winter in station 7 and a low value (2105.77 mg L^{-1}) in summer in station 2 at summer season. While the annual average through the three-year time of the study was 607.23 mg L^{-1}. Maximum values are related to industrial effluents and domestic sewage disposal to these sites. In contrast, the minimum values are related to an increase in plankton, which feed on nutrients and cause depletion in its concentration [56]. El-Zeiny and El-Kafrawy [55] documented that the concentration of total phosphorous in Burullus Lake ranged from 4.42 to 53.6 mg L^{-1}.

Chlorophyll-a (*Chlo-a*) is considered as the main pigment that can be used for the determination of phytoplankton biomass, and it is used as a trophic state indicator and reflected the water quality in the aquacultures ecosystem [57]. In the current study, the *Chlo-a* contents ranged from 6.25 to 383.81 μg L^{-1}. The average value for three years was 62.93 μg L^{-1}. In general, the higher result was found in station 4 in front of drain 7 in the autumn season, while the lowest value was exhibited at station 2 in the spring season of 2017. The high values of *Chlo-a* in the investigated area are undoubtedly due to the rich supply of reactive silicate and reactive phosphate; these nutrient salts contribute to the growth of phytoplankton expressed in high levels of *Chlo-a,* which lead to the eutrophication process in the Lake. Abd El-Hamid et al. [54] reported that chlorophyll-a concentrations in aquatic samples of Burullus Lake ranged from 3.1 to 108 μg L^{-1}.

Generally, it is notable that regarding the Chlo-a and NH_4 in Burullus Lake, the minimum results were recorded at the northern part of the lake especially in the next El-Boughaz part due to it receiving water from the sea by the Al-Boughaz outlet. On the other hand, the maximum values of Chlo-a and NH_4 were noted at the southern part of Burullus Lake; this may be due to a dense population of phytoplankton as a result of the huge amounts of discharged wastewater that is heavily loaded with nutrient. Moreover, NH_4, TN, and total P exhibited high contents in station 7 in front of drains 8 and 9 compared with the sampling sites.

3.2. Heavy Metals

The maximum, minimum, and average concentrations of heavy metal ions in the water samples collected from Burullus Lake are shown in Table 4.

Table 4. The annual averages, minimum, and maximum values of metals concentrations.

Max.	Min.	Annual Average	Year Averages			Metal *
			2019	2018	2017	
220.71	6.68	49.29	18.25	72.65	56.99	Fe (μg L^{-1})
34.65	1.64	8.81	3.16	17.77	5.5	Cu (μg L^{-1})
34.56	0.12	11.28	11.06	6.12	16.66	Zn (μg L^{-1})
34.98	2.29	10.19	11.35	16.01	3.21	Cr (μg L^{-1})
12.98	1.59	5.44	4.31	6.79	5.23	Ni (μg L^{-1})
3.35	0.04	1.18	0.43	1.82	1.31	Cd (μg L^{-1})
18.51	0.29	4.87	0.98	6.31	7.32	Pb (μg L^{-1})

* Fe: iron, Cu: copper, Zn: zinc, Cr: chromium, Ni: nickel, Cd: cadmium, and Pb: lead ions.

The different heavy metals, including Pb^{3+}, Cr^{3+}, Ni^{2+}, and Cd^{2+}, are toxic ions to living organisms even at quite low concentrations, whereas Zn^{2+} and Cu^{2+} are more biologically essential as natural constituents of aquatic ecosystems and, generally, only become toxic at very high concentrations. Heavy metals are normally entering the aquatic environment through erosion of the geological matrix, or due to anthropogenic activities caused by industrial effluents, domestic sewage, and mining wastes [58]. Fe^{2+} compounds in aquatic environments resulting in Fe^{2+} precipitate in alkaline and oxidizing conditions [34]. In the current work, the Fe^{2+} values in the water varied from 6.68 to 220.71 μg L^{-1}. The maximum value was recorded in the year 2018, while the annual average for three years was 49.29 μg L^{-1}. The high concentration of oxygen leads to Fe^{2+} oxidation and subsequent hydrolysis to form insoluble $Fe(OH)_3$. The maximum concentration of Fe^{2+} observed in the current study may be due to the industrial wastewater discharged to the coastal area of the Mediterranean Sea. High levels of Fe^{2+} may decrease the microbial degradation of hydrocarbon in seawater because excessive concentrations break down enzyme action [59]. Eid et al. [60] found that Fe^{2+} concentrations in Burullus Lake were high during the growing season.

Copper complexation in water is affected by dense phytoplankton blooms [61]. In the current study, the mean values of Cu^{2+} content in Burullus Lake ranged from 1.64 to 34.56 μg L^{-1}. The maximum value was recorded in the year 2017 in station 7, and the annual average of the three years was 8.81 μg L^{-1}. The maximum concentration of Cu^{2+} may lead to a negative impact on microbial degradation of hydrocarbon in seawater, which excessively breaks down the action of the enzyme [62]. Nafea and Zyada [63] noticed that the concentration of copper content in the water of Burullus Lake ranged between 19.2 and 35.8 36.9 mg L^{-1}.

Zinc is an essential ion for the growth of marine organisms, and its concentration is affected by plankton communities [59]. The current work observed that Zn^{2+} showed its high mean value in water (34.56 μg L^{-1}) in station 2 in the year 2017 and the low one (0.12 μg L^{-1}), and the average low value was 11.28 μg L^{-1}. The relatively high Zn^{2+} level is suggestive of the influence of refuse dump and domestic sewage sources. It could also be attributed to industrial effluents and urbanization. High temperature and low dissolved oxygen concentration lead to an increase in toxicity of Zn^{2+} [22]. Cr is one of the biochemically active transition metals in the aquatic environment [64]. In the current study, dissolved chromium values in the water of the lake varied from 2.29 to 34.98 μg L^{-1}. The maximum value was recorded in 2019, and the annual average of three years was 10.19 μg L^{-1}. The values in the lake are within the EPA limit (100 μg L^{-1}) [64]. Cr oxidizes easily from trivalent to hexavalent. Cr^{3+} ion is not toxic, but an essential nutrient, but Cr^{6+} ion is very toxic and may damage adrenals, livers, and lungs.

Ni^{2+} contents in water bodies are attributed as results from industrial and urban activities and may accumulate in many types of fishes and macrophytes [65]. In the current study, Ni^{2+} ions contents ranged between 1.59 and 12.98 μg L^{-1}. The maximum value was observed in the year 2018, and the annual average of three years was 5.44 μg L^{-1}. The higher value of Ni is associated with Fe and Mn, because of the fact that Ni^{2+} has been scavenged directly from water by hydrous MnO_2 [59]. El-Amier et al. [64] showed that nickel concentration along Burullus Lake ranged from 1.26 to 9.37 μg L^{-1} with an average value of 5.10 μg L^{-1}. Cd^{2+} is one of the greatest poisonous metals with widespread carcinogenic effects in humans and is considered to be toxic if its concentration exceeds 0.01 mg L^{-1} both in drinking and irrigation water [9,12]. Cd^{2+} ions are extremely toxic to fish. Cd^{2+} contents ranged from 0.04 to 3.35 μg L^{-1} in front of Burullus east drain in the year 2018 as a result of agricultural wastes, especially agricultural fertilizers, and the annual average was 1.186 μg L^{-1}.

Pb^{2+} is a very significant ion in the aquatic system [66]. Lead contents in the current study showed its high mean values in water (18.51 μg L^{-1}) at station 7 in the year 2019, while it showed a low mean value of 0.29 μg L^{-1} with annual averages from three years of 4.87 μg L^{-1}. The highest values of lead can disrupt the health system of phytoplankton, which is an important source of oxygen production in seas. The great level of lead may be attributed to the agricultural and industrial effluents in addition to the spill of fishing boats, which are distributed along the coast of the study area. However, many ships have been painted by a dye containing a high concentration of Pb^{2+} metal. Pb^{2+} in high concentrations causes hemorrhages and congestion of the gastrointestinal tract and kidneys of fish [67].

Masoud et al. [68] recorded that the concentration of lead content along Burullus Lake ranged from 4.5 to 10.1 µg L^{-1}.

3.3. Water Quality Indices and Carlson Trophic State Index

The water quality index (WQI) is the most effective way to communicate water quality. The present values of WQI and AWQI were calculated according to standard limits of drinking water parameters of WHO [22] (maximum permissible limits), as presented in Table 5. Average WQI values along Northern Delta Lake Burullus across three years were 80.67, 68.23, and 90.24, for the years 2017, 2018, and 2019, respectively. In general, this means that the waters of Burullus Lake are classified under good water quality (suitable for all uses) during the sampling period at most sites. Contamination levels of the water of Burullus Lake are coved by industrial effluents, untreated domestic and sewage water coming from drainage water. Eutrophication and organic pollutants are still the major pollution problems in aquatic environments. Eutrophication is the method by which aquatic lakes are supplemented with nutrients, increasing the production of rooted aquatic plants and algae to levels considered to be an interference with desirable water uses such as recreation, fish maintenance, and water supply [26].

Table 5. Water quality indices and average water quality indices of Burullus Lake water.

2019		2018		2017		Si	Parameter
q_i	V_i	q_i	V_i	q_i	V_i		
96.23	8.18	88.94	7.56	100.58	8.55	8.5	pH
330	0.66	235	0.47	355	0.71	0.2	NH_3 (mg L^{-1})
204.6	10.23	171.6	8.58	153.6	7.68	5	DO (mg L^{-1})
0.77	0.35	0.42	0.19	0.68	0.31	45	NO_3 (mg L^{-1})
151.31	151.31	59.98	59.98	89.88	89.88	100	COD (mg L^{-1})
6.08	0.018	24.21	0.0726	18.99	0.056	0.3	Fe (mg L^{-1})
0.22	0.011	0.12	0.0061	0.333	0.01666	5	Zn (mg L^{-1})
0.316	0.003	1.77	0.017	0.55	0.0055	1	Cu (mg L^{-1})
22.7	0.01	32.02	0.016	6.42	0.00321	0.05	Cr (mg L^{-1})
812.24		614.07		726.05		WQI	
90.24		68.23		80.67		AWQI	

According to average TSI values during the period from 2017 to spring 2019, the Burullus Lake in this study is classified as hypertrophic, as shown in Table 6. This classification is a result of different human activities, domestic, industrial sewage, and agricultural runoff from the River Nile and their related drainage systems. This causes over-enrichment of nutrients in the water bodies leading to algal blooms. The decaying method of dead alga can produce the exhaustion of dissolved oxygen in the aquatic lake producing an anoxic environment [14].

Table 6. Carlson's trophic state index of Burullus Lake during the sampling period.

Year	[TSI] PO_4	[TSI] C	[TSI] SD	Average [TSI]	Tropic State
2017	93.87	155.91	326.06	191.95	Hypereutrophic
2018	90.53	172.08	325.13	195.91	Hypereutrophic
2019	104.01	172.07	324.18	200.09	Hypereutrophic

The water quality index provides a convenient means of summarizing complex water quality data. To recognize the trophic condition of Lake Burullus, the trophic index (TRIX) of water quality was calculated [69]. It is a linear mixture of four state factors correlated to the primary production of oxygen and chlorophyll-a, in addition to nutritional conditions, for example, inorganic phosphors and dissolved inorganic nitrogen [70]. This scale was associated with the four-category scales for water quality state: excellent, very good, good, and fair [17]. According to the seasonal assessment of TRIX and Carlson's trophic state indices, the sites are categorized at a high eutrophic level in most stations for three years, as shown in Table 7, revealing the existence of anthropogenic pressure. Very high trophic level exposed high nutrient levels, low transparency, and recurrent hypoxia/anoxia in bottom waters [1].

Table 7. TRIX and Carlson's trophic state indices.

Year	TRIX Indices Values	Trophic State
2017	5.94	high trophic level
2018	5.22	high trophic level
2019	5.43	high trophic level

3.4. Zooplankton Community

Zooplankton serve in the evaluation and productivity of the ecosystem, since they are considered as an essential food for other organisms. The studies of the distributions of zooplankton are beneficial for the monitoring of definite characteristics of the environment such as hydrographic, pollution, eutrophication, and long-term changes, which are signs of environmental disturbances. Therefore, zooplankton studies becoming very important in both marine and freshwater ecosystems [27,28]. In the current study, the comparison among the three years (2017 to 2019 seasons) in the distribution, density, and occurrence of zooplankton was conducted. The zooplankton assemblage was dominated by Rotifera, Copepoda, Protozoa, and Cladocera, respectively, while other groups have rare occurrence so appear and disappear in different years and stations. Over the study period, mean zooplankton density was higher in the western basin (333,579 ind. M^{-3}) in the same trend with Khalil [71], Dumont and El-Shabrawy [72] and Saad et al. [73]. The middle and eastern basins (290,707 and 142,978 ind. M^{-3}, respectively) may be increased for phytoplankton in this area [28], while mean zooplankton density was higher in the 2017 year (301,664 ind. M^{-3}) than the 2019 and 2018 years (238,703 and 226,897 ind. M^{-3}, respectively) as shown in Table 8.

Table 8. Mean zooplankton in three years at Burullus Lake.

Basin	Year	Protozoa	Rotifera	Copepoda	Cladocera	Others	Mean
Eastern	2017	5417	919,000	143,750	6000	41,833	223,200
	2018	21,500	400,583	120,000	16,000	18,167	115,250
	2019	15,833	180,000	79,917	174,000	2667	90,483
Middle	2017	8750	1,556,100	280,000	83,500	7050	387,080
	2018	6900	1,264,000	137,850	65,550	3900	295,640
	2019	38,850	743,650	107,800	48,900	7800	189,400
Western	2017	8250	1,097,688	350,813	11,250	5563	294,713
	2018	5375	1,213,000	128,250	1000	1375	269,800
	2019	28,875	1,915,250	207,250	4875	24,875	436,225
Mean	2017	7472	1,190,929	258,188	33,583	18,149	301,664
	2018	11,258	959,194	128,700	27,517	7814	226,897
	2019	27,853	946,300	131,656	75,925	11,781	238,703

In 2017, a total of 93 taxa from 52 genera and 10 groups were noted for the study, namely, Protozoa (16 taxa); Rotifera (34 taxa), the same number in Saad et al. [73], the dominant species being *Brachionus angularis*, *Brachionus calyciflorus*, and *Keratella valga*; Copepoda

(28 taxa), the dominant species being *Acanthocyclpos vernalis*, *Mesocyclops leuckarti,* and *Thermocyclops crassus*; Cladocera (nine taxa), the dominant species being *Daphnia hyaline* and *Daphnia longispina,* and taxon for each of Ostacoda, Cirripeda, Nematoda, Annelid, Decapoda, and Velliger of lamellibranchs.

In 2018, a total of 98 taxa from 59 genera and 10 groups with larvae were documented for the study, namely, Protozoa (20 taxa from 16 genera); Rotifera (35 taxa), the dominant species being *Brachionus angularis*, *Brachionus calyciflorus*, *Keratella valga,* and *Keratella quadrata*; Copepoda (28 taxa), the dominant species being *Acanthocyclpos vernalis*, *Mesocyclops leuckarti*, and *Thermocyclops crassus*; Cladocera (nine taxa), the dominant species being *Moina micrura*, and taxon for each of Ostacoda, Cirripeda, Nematoda, Annelid, Decapoda, and Velliger of lamellibranchs.

In 2019, a total of 98 taxa from 59 genera and 10 groups with larvae were detailed for the study, namely, Protozoa (20 taxa from 16 genera); Rotifera (35 taxa), the dominant species being *Brachionus angularis, Brachionus calyciflorus, Keratella valga,* and *Keratella quadrata*; Copepoda (28 taxa), the dominant species being *Acanthocyclpos vernalis, Mesocyclops leuckarti*, and *Thermocyclops crassus*; Cladocera (nine taxa), the dominant species being *Moina micrura*, and taxon for each of Ostacoda, Cirripeda, Nematoda, Annelid, Decapoda, and Velliger of lamellibranchs. While, Shaltout [74] recorded 90 taxa in Burullus Lake.

The lowest population densities of zooplankton at the sites of the eastern sector are perhaps due to their vertical migration far of sunlight. Many authors concluded that the zooplankton has a high population density in the summer season, but their lowest one happens in winter [14,16,75]. Additionally, it is difficult to distinguish between the effects of most environmental factors on the abundance at most aquatic ecosystems due to inter-relation between them; also, the biological and ecological factors have the same effects of environmental factors on zooplankton abundance inside any aquatic system [12,76]. So, it is not surprising that the standing crop of zooplankton decline in autumn, although environmental conditions are good; this is perhaps due to the great amounts of fish fries that are received at these zones. Heneash et al. [77] reported that Copepoda were related (twice) mainly to domestic activities, while Rotifera were related to aquaculture activities [12,16].

3.5. Biostatistics for Seasonal Zooplankton Population

The data representing the diversity indices of the stations calculated from annual data are presented in Table 9. The total of species, in general, ranged between 16 in the middle sector in 2018 to 29 species in the western sector in 2019. The index of richness was found to be varied between 0.1 in the eastern sector St. 1 in 2018 and 2.14 in the western sector St. 9 in 2019. The results of the Evenness index analysis showed that the value was 1.0 to all stations except for stations number 1 and 3 in the eastern sector in 2018. The values of the Shannon species diversity index varied between 0.67 in the western sector St. 12 in 2018 and 2.50 in the middle sector St. 5 in 2019. Saad et al. [78] reported that the population density of zooplankton was noticeably higher in the western part of the lake, with a major peak of an average of 1,764,333 org. m^3. Moreover, regarding seasonal variation, there was a gradual growth in zooplankton standing crop from a minimum of 523,300 org. m^3 in autumn until reaching a maximum of 1,353,182 org.m^3 in summer, with an overall average of 902,911 org. m^3.

3.6. Similarity between Sites

During the year 2017, the data indicated the presence of three clusters (Figure 2A). The first cluster included station 3 in the seaside of El-Burullus Boughaz with relatively low similarity to the other stations being 75% on average. The second cluster included three stations 9,4, and 10 with 92% similarity between them, but a sub-cluster was found between stations 4 and 10 with 97.5% being the highest similarity in this period. However, the third cluster included other stations being 86% (stations 7, 8, 1, 5, 12, 2, 6, and 11). However, this cluster contains three sub-clusters (between stations 7and 8, sub-cluster station 1, sub-cluster between 5, 12, 2, 6, and 11).

During the year 2018, the data indicated the presence of four clusters (Figure 2B). The first cluster included station 3 in the seaside of El-Boughaz with relatively low similarity to the other stations being 76% on average. The second cluster included station 1 with 82% on average near to El-Boughaz. The third cluster included six stations with 88% (stations 12, 9, 10, 11, 2, and 4), and the highest similarity was between station 9 and 10 with 98%. The fourth cluster was between stations 7, 8, 5, and 6, but the highest similar one was between 5 and 6 with 94%.

During the year 2019, the data were found to be similar to that obtained in 2018 with slight differences in the arrangement of stations. Four major clusters were documented during this year. The first cluster was El-Boughaz station 3 with 76%. The second cluster included three stations with 81% on average nearby El-Boughaz. The third cluster included some the rest of the stations with four sub-clusters. The first included station 12, which had 93.5%. The second sub-cluster was between stations 9 and 10, with 98% highest similarity. The third sub-cluster included stations 11 with 90% (Figure 2C). The fourth sub-cluster was between stations 2 and 4 with 93% on average. The fourth cluster was between stations 7, 8, 5, and 6, but the highest similarity was between 5 and 6 with 94%.

The changes in the character of the water are also reflected in the zooplankton population. Changes in the zooplankton population may be due to the changes in water conditions, introducing freshwater species and eliminating marine ones. Dumont and El-Shabrawy [72] conclude that, from the early onset of dam construction in the Nile valley, slight changes happened in the zooplankton of Lake Burullus and three other delta lakes.

3.7. Spatial and Temporal Patterns of Zooplankton Community

Zooplankton density was higher in the western basin with value 333,579 ind. m^{-3} than in the middle and eastern basins (290,707 and 142,978 ind. m^{-3}, respectively); this may be due to the increase in phytoplankton in this area, and it is near freshwater sources as reported by Saad et al. [78].

However, mean zooplankton density was higher in the 2017 year (301,664 ind. m^{-3}) than in 2019 and 2018 (238,703 and 226,897 ind. m^{-3}, respectively). Seasonally, at both eastern and middle sectors, the autumn season recorded the highest mean in 2017 and 2018, but in the 2019 summer season, we found a high abundance of zooplankton. In the western sector, in winter, we registered the highest zooplankton abundance (Figure 3 and Table 10).

3.8. The Correlation between Physicochemical Parameters and Zooplankton Groups

Correlation analysis was achieved by Pearson's correlation coefficient. The correlation matrix was calculated for the water quality parameters. A result of the correlation coefficient was evaluated as follows: 0.0 (no); 0.3–0.5 (low); 0.5–0.7 (medium); 0.7–0.9 (high); 0.9–1 (very high). In the present study, there were high significant correlations between many parameters such as Protozoa with Rotifera, Cirriped larvae, Velliger of lamellibranchs, salinity, and Zn ions (r = 0.925, 0.991, 0.946, 0.998, 0.897, respectively). Rotifera also showed a significant correlation with Copepoda, Cirriped larvae, pH, salinity, *Chlo-a*, and Pb ions (r = 0.954, 0.984, 0.925, 0.968, 0.961, 0.814, respectively). There is a significant positive correlation between Copepoda and Cirriped larvae, Velliger of lamellibranchs, salinity, and Zn ions (r = 0.992, 0.944, 0.999, 0.894, respectively). Cirriped larvae correlated negatively and some parameters such as salinity, NO_3, and *Chlor-a* (r = −0.995, −0.970, −0.999, respectively). Ostracoda showed a negatively significant correlation with BOD, NH_4, NO_3, and Fe (r = −0.995, −0.981, −0.970, −0.959, respectively).

Cladocera correlated positively with parameters such as Ostracoda and Annelida with r = 0.97 and 0.94, respectively; while, it correlated negatively with parameters such as BOD, NH_4, NO_3, and Fe ions (r = −0.041, −0.91, −1.00, −0.999, respectively).

Table 9. Biostatics for seasonal zooplankton in 2017–2019.

Basin/Station		Species	No. Indi. m^{-3}	Richness (d)	Evenness (j)	Diversity (H)
2017						
Eastern	St. 1	15	1,592,750	1.02	0.54	1.48
	St. 2	19	1,171,000	1.31	0.68	1.91
	St. 3	15	584,250	1.05	0.66	1.65
Middle	St. 4	19	1,942,500	1.23	0.65	1.90
	St. 5	19	1,309,500	1.31	0.52	1.53
	St. 6	21	1,917,500	1.38	0.73	2.19
	St. 7	16	3,411,500	0.98	0.64	1.71
	St. 8	21	1,096,000	1.46	0.58	1.76
Western	St. 9	20	1,623,750	1.30	0.65	1.92
	St. 10	19	1,308,500	1.30	0.64	1.88
	St. 11	20	911,250	1.35	0.65	1.91
	St. 12	19	2,050,750	1.26	0.57	1.68
2018						
Eastern	St. 1	13	552,000	0.88	0.77	1.60
	St. 2	16	653,000	1.19	0.67	1.87
	St. 3	13	523,750	0.89	0.78	1.74
Middle	St. 4	18	1,042,750	1.21	0.65	1.82
	St. 5	15	1,733,250	1.00	0.56	1.52
	St. 6	15	1,179,500	1.01	0.60	1.64
	St. 7	16	2,318,500	1.02	0.54	1.48
	St. 8	17	1,517,500	1.10	0.61	1.70
Western	St. 9	15	2,379,500	0.94	0.48	1.26
	St. 10	15	1,850,500	0.99	0.41	1.12
	St. 11	15	303,000	1.10	0.64	1.71
	St. 12	11	672,000	0.74	0.53	1.15
2019						
Eastern	St. 1	13	673,500	0.95	0.61	1.45
	St. 2	16	355,750	1.18	0.71	1.76
	St. 3	14	328,000	1.07	0.53	1.40
Middle	St. 4	23	1,224,500	1.65	0.57	1.79
	St. 5	19	555,500	1.41	0.71	2.07
	St. 6	19	890,000	1.36	0.64	1.86
	St. 7	19	1,371,000	1.32	0.73	2.14
	St. 8	19	694,000	1.38	0.62	1.81
Western	St. 9	26	2,524,000	1.77	0.53	1.73
	St. 10	24	1,989,000	1.62	0.54	1.71
	St. 11	23	2,651,500	1.57	0.59	1.81
	St. 12	20	1,560,000	1.40	0.70	1.94

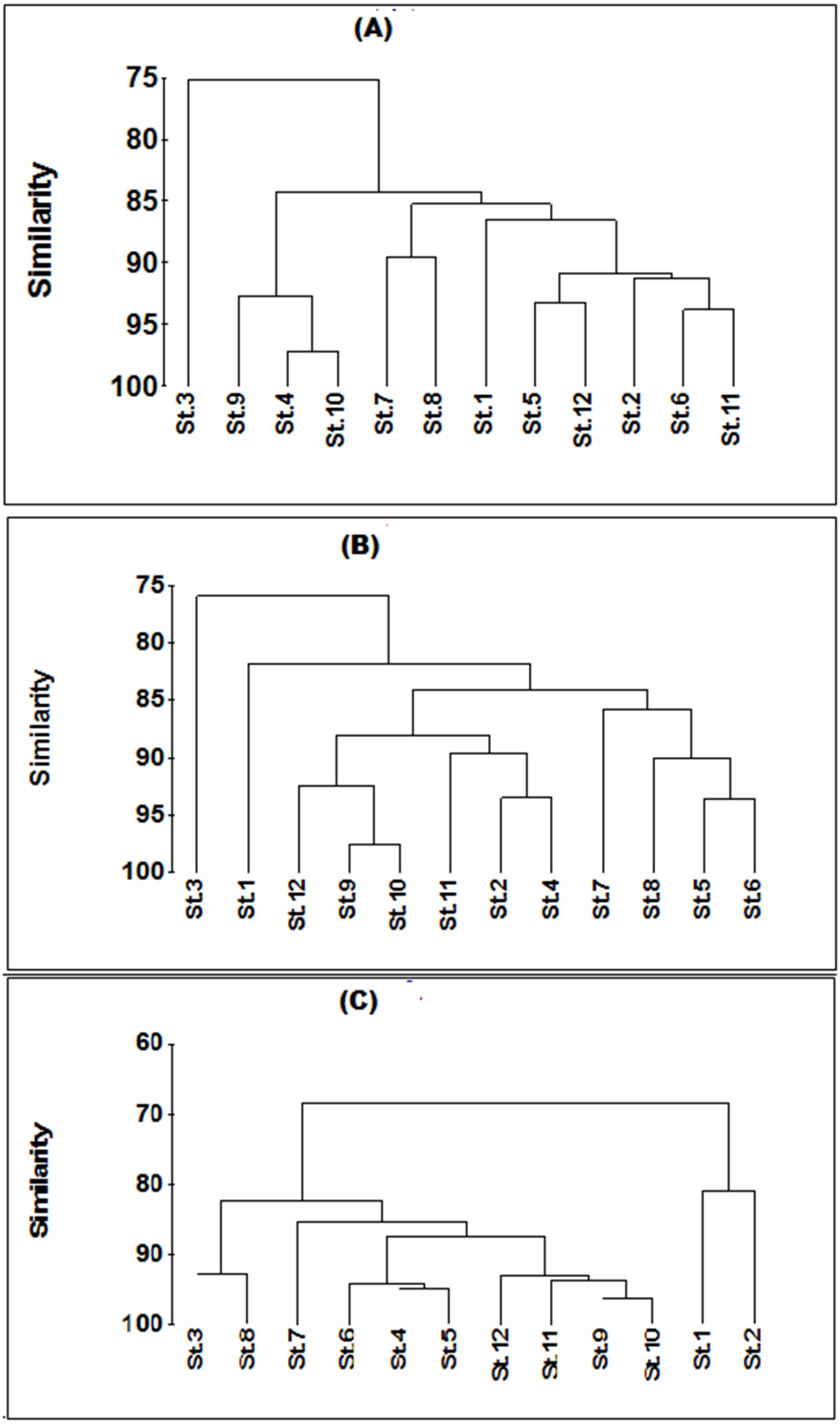

Figure 2. Dendrogram representing the similarity between Lake Burullus surveyed stations during years (**A**) 2017, (**B**) 2018, and (**C**) 2019.

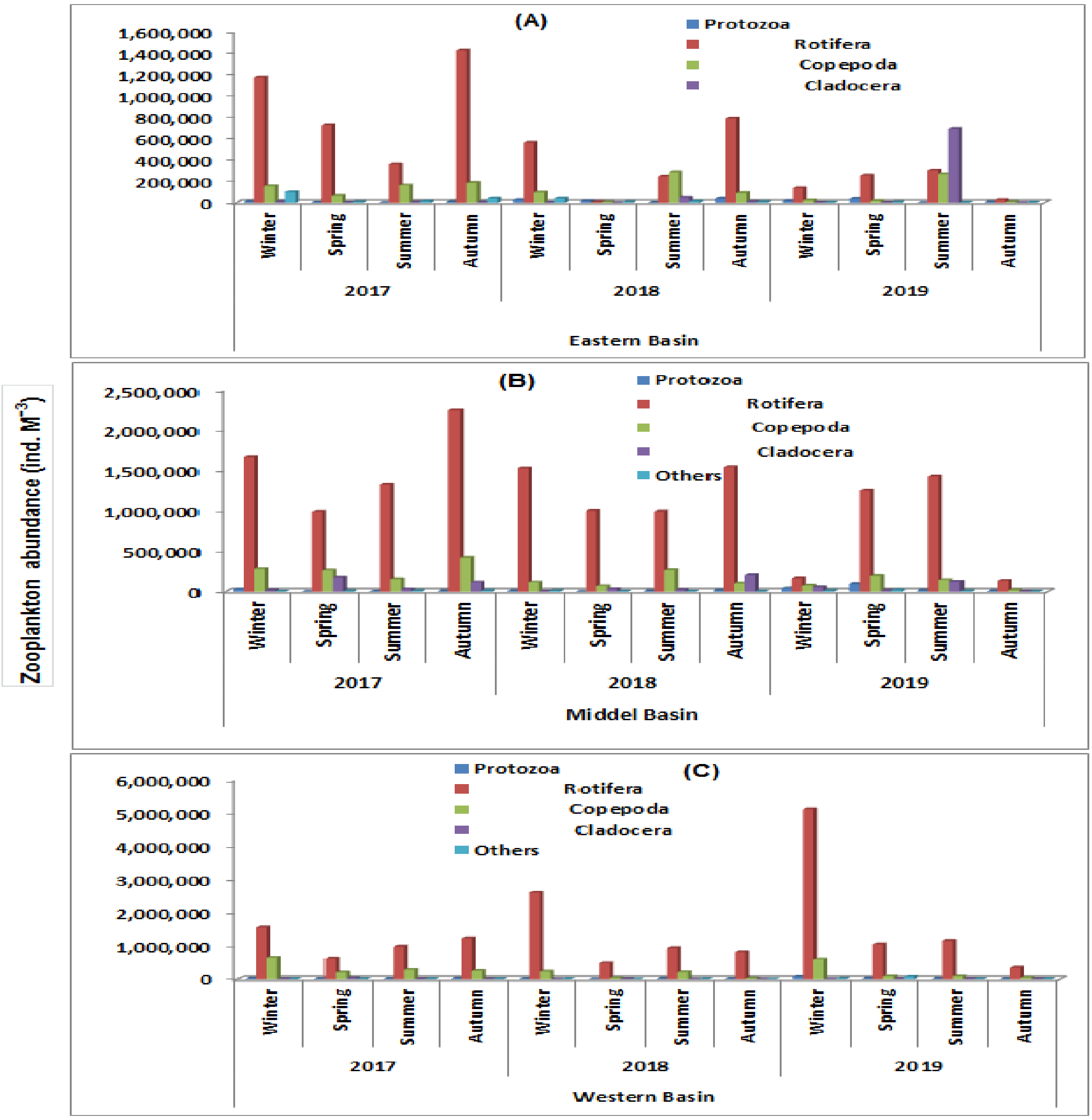

Figure 3. Seasonal mean of zooplankton densities (ind. m^3 ± standard deviation) in Burullus Lake by taxonomic division in various basins (**A**) eastern basin, (**B**) middle basin, and (**C**) western basin.

Table 10. Seasonal average of zooplankton densities (ind./m^3 ± standard deviation) and distribution in Burullus Lake by taxonomic division in various basins.

Basin	Year	Season	Protozoa	Rotifera	Copepoda	Cladocera	Others	Mean
Eastern Basin	2017	Winter	10,667	1,170,667	158,000	10,667	102,667	290,533
		Spring	3667	724,667	66,000	2667	9333	161,267
		Summer	0	358,667	164,333	4667	14,000	108,333
		Autumn	7333	1,422,000	186,667	6000	41,333	332,667
	2018	Winter	28,667	561,333	98,667	2667	41,333	146,533
		Spring	16,000	7000	4667	0	7333	7000
		Summer	1333	245,333	284,000	49,333	14,667	118,933
		Autumn	40,000	788,667	92,667	12,000	9333	188,533

Table 10. *Cont.*

Basin	Year	Season	Protozoa	Rotifera	Copepoda	Cladocera	Others	Mean
	2019	Winter	18,000	138,000	23,667	2000	2667	36,867
		Spring	39,333	254,667	19,333	2667	5333	64,267
		Summer	0	300,667	269,333	690,667	1333	252,400
		Autumn	6000	26,667	7333	667	1333	8400
Middle Basin	2017	Winter	27,400	1,664,400	282,800	15,600	4200	398,880
		Spring	0	988,400	264,000	176,000	4400	286,560
		Summer	2800	1,323,600	154,000	29,200	9200	303,760
		Autumn	4800	2,248,000	419,200	113,200	10,400	559,120
	2018	Winter	6400	1,525,200	114,000	4000	9200	331,760
		Spring	0	1,000,000	70,200	32,200	2800	221,040
		Summer	7200	990,800	265,600	20,000	2400	257,200
		Autumn	14,000	1,540,000	101,600	206,000	1200	372,560
	2019	Winter	40,600	164,600	75,600	58,800	8800	69,680
		Spring	95,200	1,250,400	195,600	12,400	16,000	313,920
		Summer	13,600	1,424,800	142,400	121,600	5200	341,520
		Autumn	6000	134,800	17,600	2800	1200	32,480
Western Basin	2017	Winter	14,250	1,561,500	646,750	3500	2500	445,700
		Spring	4000	618,000	210,000	36,000	6000	174,800
		Summer	2000	982,000	288,000	2500	4000	255,700
		Autumn	12,750	1,229,250	258,500	3000	9750	302,650
	2018	Winter	4000	2,607,500	233,000	0	2500	569,400
		Spring	1000	490,000	36,500	3000	0	106,100
		Summer	10,500	936,500	218,500	0	2000	233,500
		Autumn	6000	818,000	25,000	1000	1000	170,200
	2019	Winter	74,500	5,109,500	592,500	0	16,500	1,158,600
		Spring	19,500	1,046,000	93,000	3000	74,500	247,200
		Summer	11,500	1,150,500	97,000	7500	5500	254,400
		Autumn	10,000	355,000	46,500	9000	3000	84,700

Velliger of lamellibranch showed correlations with DO, NO_2, PO_4, Cu, and Zn (r = 1, 0.96, −0.88, 0.89, and −0.975, respectively). Salinity has negative correlations with *Chlor-a* and Cr (r = −1 and −0.925, respectively). The variations in correlation coefficients between salinity and zooplankton groups are due to the difference in species. The variations of mean salinity of the lake water are a result of the amount of drain water entering the lake from the southern part (this part receives freshwater supply from six drains) and seawater inflow to the lake from the northern part through El-Boughaz as well as the amount of evaporation from the external area of the lake. Salinity can be considered as a limiting factor for the abundance and diversity of zooplankton populations in the lake and the reverse relation between salinity and zooplankton. The pH concentration lies on the alkaline side, the minimum value recorded in the western sector showing an inverse relation to zooplankton. El-Enany [79] stated that Protozoa, Cladocera, and Copepoda were abundant in the stations characterized by high TS, EC, PO_4, and Ca. The high numbers of drains from the River Nile, which carries high amounts of nutrients and salts, lead to the eutrophication of water.

3.9. Comparison of Burullus Lake with Other lakes

In current study, the physicochemical parameter values obtained from the Burullus Lake, in comparison to the most similar lakes in Egypt and the Mediterranean area, are presented in Table 11.

Table 11. Comparison between the physicochemical parameters values of Burullus Lake and the most similar lakes in Egypt and the Mediterranean area.

Lake	Burullus	Manzala	Idku	Mariout	Tunisian	Gölbaşı (Hatay)	Marmara (Manisa)
Country	**Egypt**	**Egypt**	**Egypt**	**Egypt**	**Tunisia**	**Turkey**	**Turkey**
Temp(°C)	21.77	15.3	22.3	24.2	19.7	21.8	19.8
Salinity‰	4.6	15.6	3.3	4.07		0.2	15
pH	8.09	8.7	8.4	8.15	8.49	7.52	7.9
DO(mg L^{-1})	8.83	9.2	4.1	9.07	8.7	5.94	6.8
NO_3(mg L^{-1})	0.283	0.37	0.16		0.72	16.35	
NO_2(mg L^{-1})	126.95	0.18	0.088		0.07	0.59	
NH_4(mg L^{-1})	0.61	0.05	4.5	5.25	0.58	0.61	
TP(mg L^{-1})	0.64	0.2	0.7	0.42	0.18	0.22	
COD(mg L^{-1})	100.39		48			42.5	
BOD(mg L^{-1})	23.63		12.6	19.4			
Chlo-a(mg L^{-1})	62.93	163	70.32	6.03			
References	This study	[26]	[40]	[77]	[80]	[81]	[11]

4. Conclusions

Lake Burullus is a very important lake in Egypt, due to its dimensions and economic activities. Burullus Lake is suffering from a high level of aquatic plants, expansion in fish farming, fishing, growing of human activities, and agricultural drainage effluents. In the current study, the properties of water quality, eutrophication, and zooplankton community of Burullus Lake were estimated based on three years (2017/2019) of seasonal monitoring at 12 stations. It could be concluded that water quality parameters showed wide variations, due to the discharge of drainage water from various pollution sources through different times and locations. The increase in pollution level may be due to the inflow of untreated water from industries and households around the drains of the lake, while the recorded increase in the eutrophication level may be attributed to the inflow of effluent of agricultural water with high nutrient levels. The heavy metal distribution in the lake depends on some factors, as characteristics, amounts, and type of input water. The current work is an attempt to examine the applicability of Carlson's indices and trophic state indices for ranging the eutrophication case of Burullus Lake in concert with a numeral of physicochemical descriptors, as described previously. On the other hand, zooplankton species in Burullus Lake preferred a freshwater habitat than a marine habitat. The current study concluded that zooplankton are composed of four main groups: Rotifer, Copepod, Protozoa, and Cladocera, in addition to rare groups, namely, Ostracoda, Nematoda, Annelid, Cirripeda, and Decapoda. During the period from 2017 to 2019, it observed about 98 zooplankton species in addition to six larval stages. Assessment of correlation matrix was carried out to check the significant relationship between biological and physicochemical factors. It is highly recommended that drainage water should be treated before reaching the lake, removing unwanted plants from the water bodies and providing decision-makers with data.

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