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Article

The Impacts of Land Use and Seasonal Effects on Phytoplankton Taxa and Physical-Chemical Variables in the Tigris River within the City of Mosul

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Abstract: We investigated the effect of land use based on the dominant phytoplankton and physical-chemical variables in the different areas of the Tigris River, within the city of Mosul. Agricultural and urban activities have a significant impact on the water quality of the river. Regardless of physical and chemical variables, phytoplankton act as a bio-indicator of water quality due to their fast and sensitive response to changes in the environment. Our research was conducted in the Tigris River within the city of Mosul by examining the phytoplankton species and the physical-chemical variables at 16 sites during each vegetation period. Point and non-point source pollutants have affected the Tigris River within the city of Mosul, getting into the river from upstream through agricultural activities and by urban activities in the middle section of the city, respectively from both banks. Based on our results, we observed the highest phytoplankton abundance during the October sampling periods, while the lowest occurred during the July sampling period, which was associated with maximum water temperature and absence of rain. According to our study, land use (e.g., agricultural, and urban activities) greatly affected the dominant phytoplankton species and physical-chemical variables of the Tigris River. *Oscillatoria* sp. dominated all seasons in the agricultural region, while at the same time, we observed an increase in the number of phytoplankton species caused by the nutrient availability upstream on the river. The effects of climate have very significant and characteristic effects in this area, which basically determine the community of organisms and the water quality; the effects resulting from anthropogenic activity significantly modify this. Based on our investigation, in the part of the Tigris River connected to Mosul, we found a clear connection between the pollution caused and the effects of different land uses, through the examination of the algal community and physical-chemical variables in different periods of the year.

Keywords: biomarkers; water quality; phytoplankton; physical-chemical variables; anthropogenic activities; land use; LDA

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1. Introduction

Rivers are essential to human existence and a natural ecology and refuge for many biological species, including eukaryotic and prokaryotic plankton, which are among the most diverse [1,2]. Human activity worldwide, such as the release of water contaminants due to rising urbanization and population, may intensify the contamination of aquatic environments [3–6]. The water quality of the river could be highly affected by the discharge of domestic wastes, sewage, and agricultural and industrial influents, which can contain substances varying from normal nutrients to highly toxic substances [7,8]. Anthropogenic activities e.g., deforestation, change in land use, expansion of agriculture, development of industry, urbanization, and increasing wastewater production can significantly affect the environment where people live and work [9–14].

Agricultural and urban areas are typically regarded as the major sources of contaminants (e.g., nutrients and organic pollution) in freshwater ecosystems [15–17]. Because of environmental and land use changes, these actions affect terrestrial and aquatic ecosystems, negatively affecting water quality [18,19].

With the dramatic expansion of urban land use and the global population over the last few decades, urbanization has become one of the most extreme forms of land-use alteration triggered by humans [20]. Ecosystems in urban regions are distinct from those in natural environments due to differences in air chemistry, geochemistry, temperature, hydrology, and plant covering [21]. Deterioration in water quality is often attributed to human activities and global environmental changes [22].

Land use changes can not only impact water quality but also serve as a driver of aquatic diversity [23–25]. Phytoplankton which form the most important component of aquatic ecosystems as primary producers, are very sensitive to the changing environmental conditions and respond accordingly. They play an important role in studying the impact of human activities and climate change on aquatic ecosystems [6,26].

Few studies have shown that Iraq's water bodies are suffering from deterioration of the water quality [27,28]. This change in water quality has resulted from the discharge of untreated municipal wastewater, the increase in urbanization, and the intensification of agricultural activities [6,29,30]. Therefore, the river in the city of Mosul is vulnerable to a wide range of diffuse and point pollution. However, little is known about the phytoplankton communities in the city of Mosul and how they are adapted to the altered water quality.

In our study, we explored (i) the relationship between land use and pollution in the Tigris River using physical and chemical variables (Figure 1). Additionally, we examined (ii) how these factors affect phytoplankton composition and whether (ii) these organisms can serve as indicators of pollution resulting from land use.

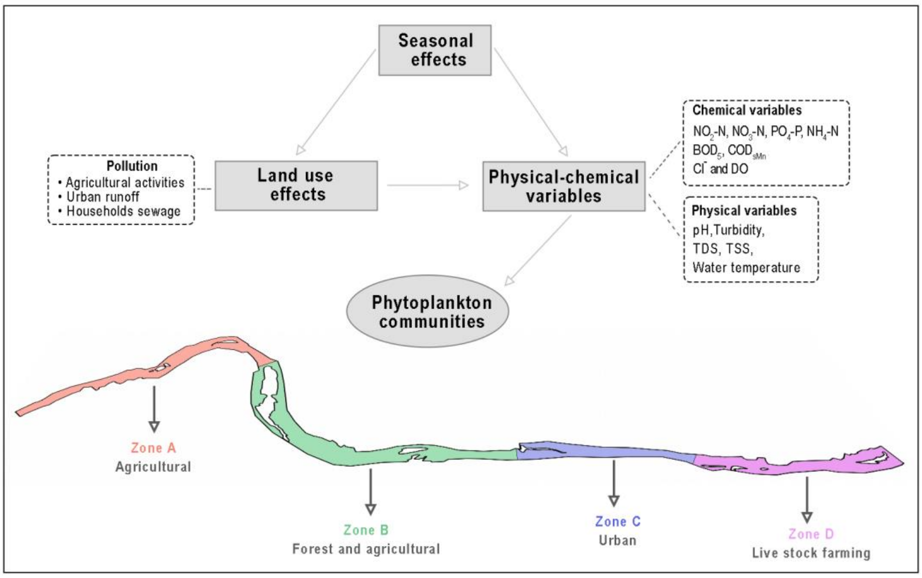

Figure 1. Conceptual framework represents the expected relationship between variables and effects. Abbreviations: DO: Dissolved Oxygen; NO_2-N: Nitrite; NO_3-N: Nitrate; PO_4-P: Orthophosphate; NH_4-N: ammonium; TDS: Total dissolved solids; COD_{sMn}: Chemical oxidation demand; TSS: Total suspended solids; Cl^-: Chloride; BOD_5: Biological oxygen demand.

2. Materials and Methods

2.1. Study Area

The current investigation was made in the Tigris River within the city of Mosul in Iraq (Figure 2a), located between latitude 36.34° N and longitude 43.13° N. Two sources of pollution are affecting the water quality of the Tigris River, point sources and non-point sources. The non-point source pollution is a result of agriculture activities, precipitation, and urban runoff while the point source pollution is wastewater discharge.

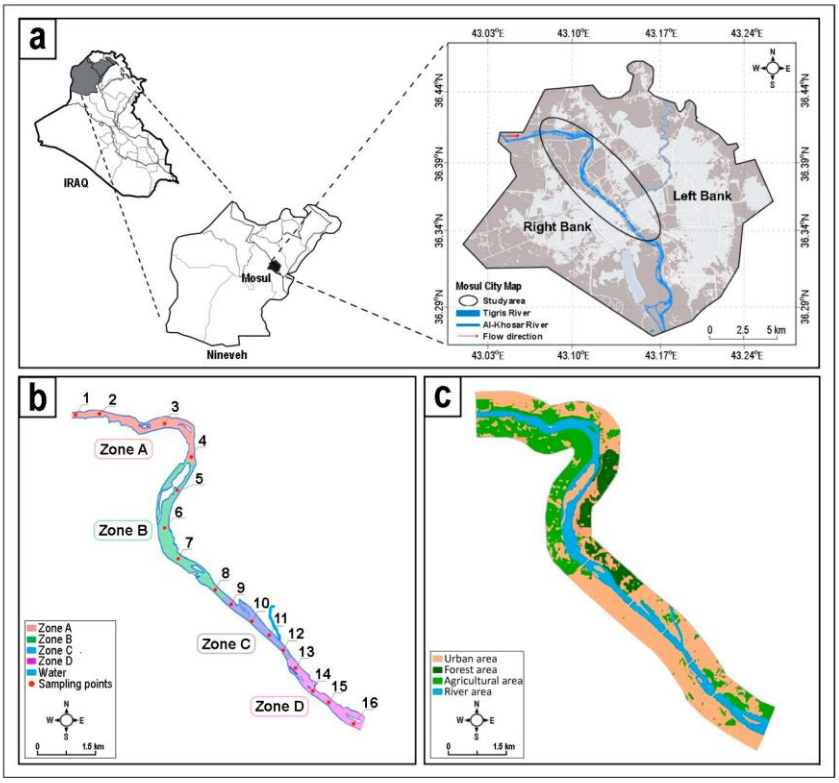

Figure 2. (**a**) Map showing the study area in Iraq; (**b**) Map showing the sampling points in red dots. The red area is Zone A; green area is Zone B; blue area is Zone C, and purple area is Zone D. (**c**) Map showing the land use in the Tigris River in the city of Mosul.

This area has a semi-arid climate, with an average humidity of 36% and an UV-index of 6. It is dry for 284 days a year. The highest average temperature occurs in July, reaching 42 °C, while the lowest temperature occurs in January, at 13 °C. From December to March, the area experiences rain on 7–10 days per month, with sunny days alternating with rainy periods. Nighttime temperatures can drop a few degrees below freezing (0 °C), and occasionally, it can even snow. During the summer months, the area is very hot, with temperatures reaching 43 °C in July and August and peaking at 48 °C. The air humidity is generally low during this time.

The Mosul Dam, located 50 km from the studied area, serves to generate hydroelectricity and provide water for downstream irrigation. Typically, balanced flow conditions occur downstream of the dam. The average water depth in the studied section is approximately 3 m, although depths of around 1 m or 5 m were observed in some sampling sites. The studied area was divided into four main zones (Figure 2b). Each area included four sampling points based on land use. Zone A, the upstream river, consisted of (1, 2, 3 and 4) sampling points which were affected by agricultural activities. Zone B was in the middle of the city, consisting of the sampling points from 5, 6, 7 and 8; this area is highly affected by agricultural activities and forestry. Zone C consisted of four points (9, 10, 11 and 12), mainly affected by urban activities (this zone is in the middle of the city). Lastly, Zone

D, containing four sampling points (13, 14, 15 and 16), was downstream and affected by agriculture activities and livestock farming.

2.2. Land Use Map

A cloudless LC08 image obtained on 27 June 2021 was used to classify the land use over the study area in the city of Mosul (Figure 2c). A supervised classification was used to classify the image into four main classes (river area, urban area, agriculture area, and forest area).

2.3. Sample Collection

During the study period, 16 water samples per season were collected from the Tigris River. Our study covered about 13 km of the river, where the first station was selected at the point where the river entered the city of Mosul (upstream river, Figure 2) and station number 16 was selected as the last station after leaving the city (downstream river, Figure 2). A total of 64 water samples were collected during the four sampling periods (16 samples each) to represent the seasonal variances (1st of April, 13th of July, 7th of October, and 29th December) in 2021. The samples were taken from a boat. Sampling was carried out in the middle of the river from the current, 20 cm from the water surface.

During our study, phytoplankton and physical-chemical variables were investigated. Samples for the chemical analysis and phytoplankton samples were collected with a weighted plastic bottle at each sampling point. At the time of sampling, 500 cm^3 water samples were taken for algal analysis.

At each sampling location in the field, water temperature (°C) and dissolved oxygen (mg/L) were directly measured using a digital portable ADWA AD630 dissolved oxygen meter (Adwa Instruments, Szeged, Hungary). pH was measured using a digital portable ADWA AD132 pH meter, total dissolved solids (TDS) were measured using a digital portable ADWA AD31 TDS meter, and turbidity (NTU) was measured using a Hach DR2010 device (hach, Loveland, CO, USA).

During the laboratorial work, we measured (NO_3-N µg/mL, NO_2-N µg/mL, PO_4-P µg/mL, NH_4-N µg/mL, Cl^- mg/L, COD_{sMn} mg/L, chlorophyll-a mg/L, TSS mg/L, HCO_3 mg/L, and BOD_5 mg/L) according to the analytical standards of the Hungarian water quality monitoring service (Hungarian National Standards, MSZ 12749:1993).

The phytoplankton samples were immediately fixed on the field with Lugol's iodine for subsequent phytoplankton counting with the Utermöhl inverted microscope technique [31]. Sedimentation chambers were used for microscopic analyses during counting. Their volumes were 5 cm^3, 10 cm^3, and 15 cm^3 depending on the amount of algae in the water sample. The microscopic investigation was done with an Olympus-IX73 (Olympus, Tokyo, Japan) inverted and an Olympus-BX53 microscope using phase-contrast and Nomarski-contrast technics. The investigation was done at 400 and 1000 magnification.

2.4. Data Analysis

The data of phytoplankton was counted as individuals/litre (ind. L^{-1}). A multivariate approach was used for statistical analysis to illustrate abiotic and biotic change patterns between phytoplankton distribution and environmental variables. Linear discriminant analysis (LDA) was applied by using the R add-on package "MASS" to reveal the pattern of phytoplankton variability in relation to physical-chemical characteristics. LDA belongs to a statistical technique that so-called "supervised pattern recognition methods", which maximizes the variance between the groups [32,33]. For LDA analysis, the phytoplankton taxa were only used at more than 2% of relative abundance. Canonical correspondence analysis (CCA) was performed using physical-chemical variables and phytoplankton taxa (relative abundance > 0.5%), using the R package "vegan". Both phytoplankton and environmental data were transformed (log+1) before being generated as LDA and CCA outputs.

The ANOVA test was used to compare phytoplankton in different seasons and was conducted using PAST ver. 2.17c [34]. To investigate the community structure, hierarchical clustering was performed using Ward′s method and Manhattan distance in SPSS package [35]. The data were linearized using a log+1 transformation for the cluster analysis.

3. Results

3.1. Seasonal Effects on the Phytoplankton Communities and Environmental Variables

Spring was a rainy season with a high-water discharge rate (Figure 3A). During April, the air and water temperatures were (25 °C, and 15.6 °C) respectively. The air and water temperatures in July (the summer season) reached their maxima (50 °C, 29.6 °C), and the summer season characterized by a low water discharge and no rain (Figure 3). In the autumn season (October), the air and water temperature were 35 °C and 17 °C respectively, with low water discharge rate and no rain (Figure 3A). While in December (the winter season), the air and water temperature dropped to the lowest (12 °C, 11 °C); winter was a rainy season with low water discharge (Figure 2a).

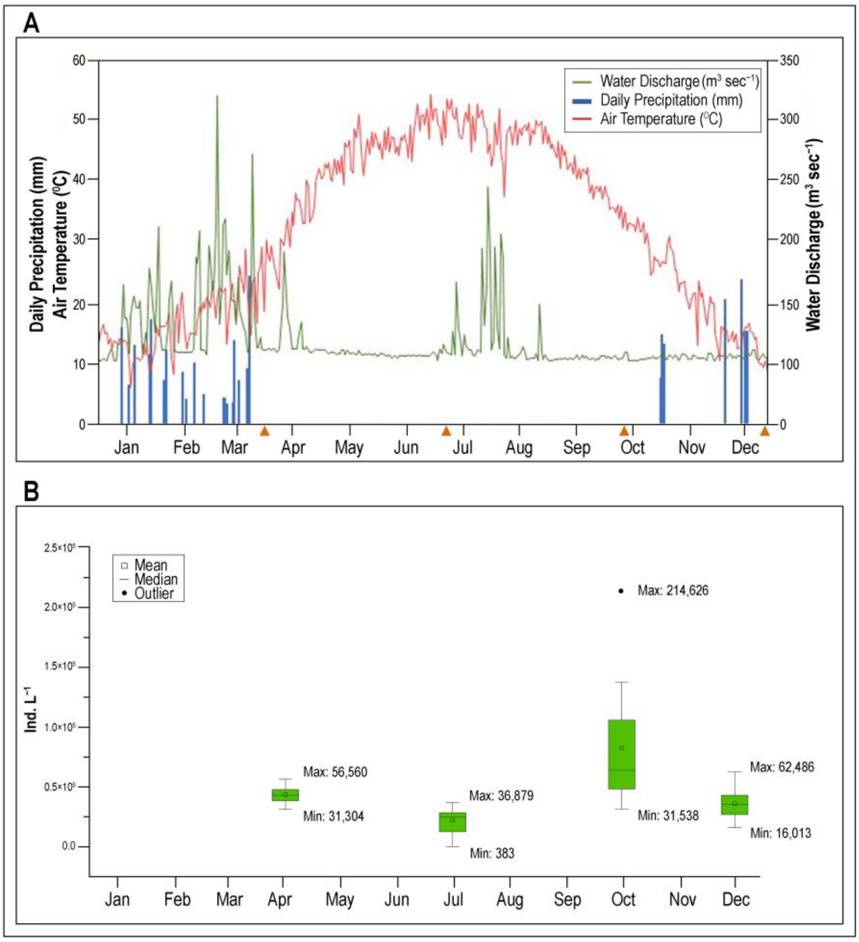

Figure 3. (**A**) Temperature, precipitation, and water discharge rate through the city of Mosul during 2021. The symbols "▲" designates the sampling dates; (**B**) total abundance of algal taxa in the sampling dates.

Figure (Figure 3B) shows that the October sampling period has the highest peak of phytoplankton total abundance, while April has the second highest peak during the study period. The lowest abundance of phytoplankton was in July. The total abundance of phytoplankton was moderate in December.

Fourteen variables were measured to investigate the different zones of the Tigris River near Mosul. These variables included pH, dissolved oxygen, BOD_5, COD_{sMn}, various forms of nitrogen (NH_4-N, NO_2-N, NO_3-N), PO_4-P, chloride, HCO_3-, total dissolved solids, total suspended solids, turbidity, and chlorophyll-a. The purpose of measuring these variables was to study changes in the algal community and the effects of different types of water uses. Table 1 displays the minimum, maximum, and median values of the physical and chemical variables measured in the examined section of the Tigris River during the four investigated periods.

Table 1. The maximum, minimum, and median values of the physical and chemical variables measured during the investigated periods.

Variables	Spring	Summer	Autumn	Winter
	Min-Max Median	Min-Max Median	Min-Max Median	Min-Max Median
BOD_5 (mg L^{-1})	0.06–1.85 0.3	0.7–2.2 1.6	0.5–2.5 1.9	1.5–2.7 2
Chlorophyll-a (mg L^{-1})	0.21–0.65 0.4	0.1–0.5 0.1	0.5–1.5 0.8	0.2–0.8 0.4
Chloride (mg L^{-1})	28–40 33	30.5–41.9 38	38.1–40 38	14.5–29.1 22
COD_{sMn} (mg L^{-1})	1.9–7.8 2.7	2.6–4.4 3.6 ± 0.4	2.4–6.1 3.1	2.8–4.7 3.5
DO (mg L^{-1})	3.4–5.9 4.2	0–2 0.0	4.2–12 5.6	4.5–9.8 6.9
H-CO_3^- (mg L^{-1})	172–246 222	170.8–195.2 171	195.2–244 220	110.9–244 155
NH_4-N (mg L^{-1})	0–0.056 0.009	0–0.055 0.012	0.017–0.059 0.026	0.002–0.011 0.005
NO_2-N (mg L^{-1})	0.004–0.018 0.006	0–0.0022 0.0	0–0.0065 0.002	0–0.0042 0.002
NO_3-N (mg L^{-1})	0.5–1.4 0.69	0.55–0.69 0.65	0.68–1.29 0.94	0.17–0.42 0.27
pH	8.1–8.1 8.1	7.8–8 7.8	7.8–8.2 8	8.3–8.4 8.4
PO_4-P (mg L^{-1})	0.001–0.06 0.0014	0.004–0.026 0.009	0–0.003 0.0	0.001–0.007 0.0043
TDS (mg L^{-1})	334–357 346	280–330 295	295–338 325	340–369 350
TSS (mg L^{-1})	3–25 5.5	12.5–29 16.5	11.4–43 17.5	8.3–45 20.4
Turbidity (NTU)	5–32 16.5	1–23 5	8–31 15	4–25 11

The Canonical correspondence analysis (CCA) (Figure 4) shows that spring and summer sampling periods strongly differed from autumn and winter sampling periods based on phytoplankton taxa and environmental variables. The first axis of CCA explained (57.7%) of the total variance, and the second axis explained (20.1%) of the variance.

3.2. Phytoplankton Species

According to the phytoplankton taxa abundance in April (Figure 5a), zone A differed from the other three zones. The first axis of April LDA explained (68.5%) of the total variance, and the second axis explained (26.9%) of the variance. Zone A has a high abundance of *Cymbella parva, Oscillatoria* sp. Zone B was characterized by a high abundance of the *Fragilaria tenera and Cryptomonas ovata* species. While zone C has a high abundance of *Euglena* sp. species. Lastly, zone D has a higher abundance of *Diatoma vulgaris* species.

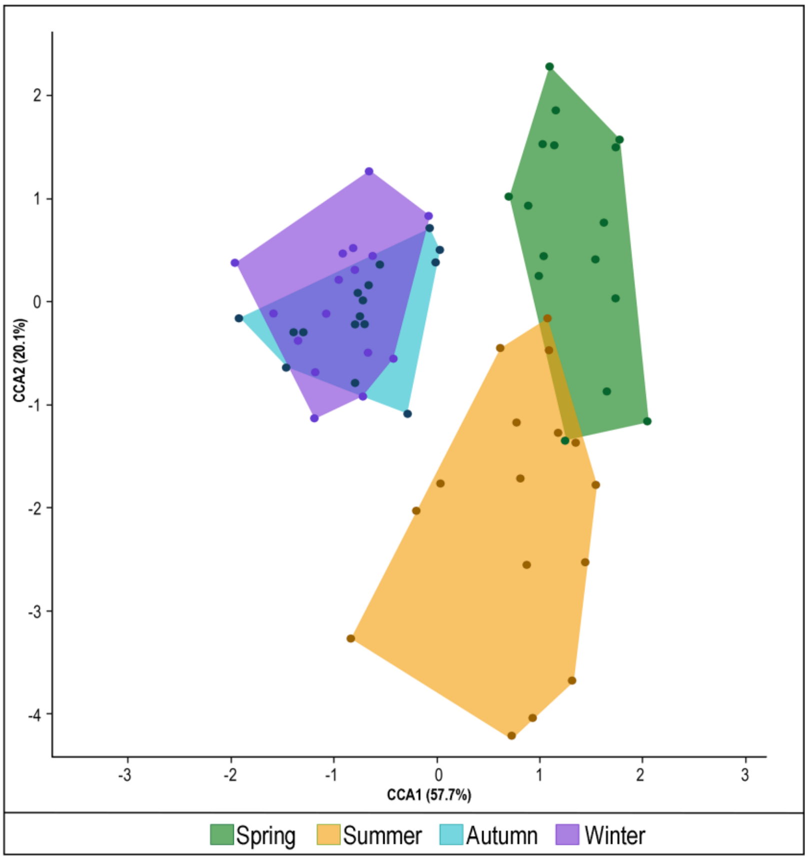

Figure 4. Canonical correspondence analysis (CCA) graph showing the differences between the seasons. The April sampling period represented the spring season, July represented the summer season, October represented the autumn season, and December represented the winter season.

In the summer season, the LDA (Figure 5b) showed that zone C and B differed from the other two zones based on the phytoplankton phylum. The first axis of July LDA explained (80.7%) of the total variance, and the second axis explained (15.5%) of the variance.

Zone A and D are characterized by a high abundance of *Oscillatoria* sp., *Cryptomonas ovata*, *Euglenaformis proxima*, and *Cocconeis pediculus* species. On the other hand, zone C and B are characterized by *Fragilaria* sp.

During the Autumn sampling, the LDA graph (Figure 5c) indicated that according to the abundance of phytoplankton, zones A and B differed from the other two zones. The C and D zones also differ from each other. The first axis of October LDA explained (61.3%) of the total variance, and the second axis explained (26.5%) of the variance. Zone A and B are characterized by the high abundance of *Oscillatoria* sp. While zone C is characterized by a high abundance of *Cryptomonas ovata*. Moreover, zone D has a higher abundance of *Cocconeis pediculus*, *Surirella tenera*, *Fragilaria tenera*, and *Ulnaria ulna* species.

According to the LDA graph in the winter season during December (Figure 5d),—based on the abundance of phytoplankton taxa—three different groups were separated. Every zone differed from the other in the winter season. The first axis of the LDA explained (93.9%) of the total variance, and the second axis explained (4.5%) of the variance. Zone A characterized by the highest abundance of *Cryptomonas ovata*, *Oscillatoria* sp. Zone B is characterized by *Fragilaria tenera* species. While zone C is characterized by a high abundance of *S. ecornis*. Zone D has the highest abundance of *Cyclotella* sp. and *Cocconeis pediculus* species.

Data on phytoplankton abundance in the different sampling periods are included in Supplementary Materials (Table S1).

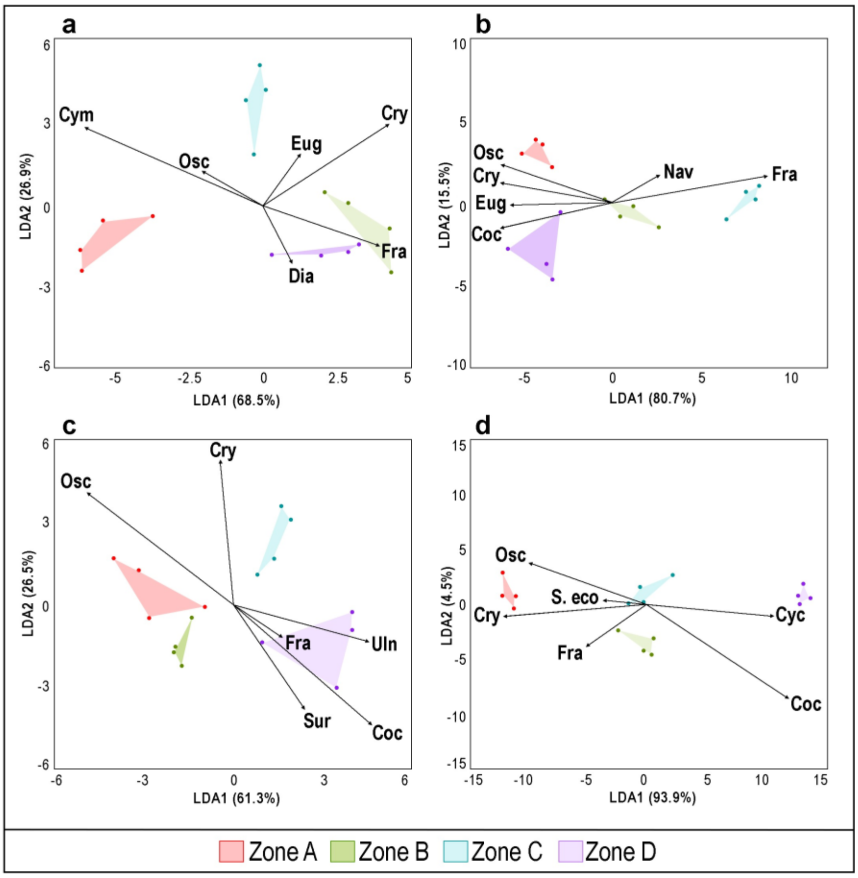

Figure 5. Graphs representing linear discriminant analysis (LDA) based on the phytoplankton taxa. (**a**): April; Graphs (**b**): July; Graphs (**c**): October; Graphs (**d**): December. Whereas Coc: *Cocconeis pediculus*; Uln: *Ulnaria ulna*; Dia: *Diatoma vulgaris.*; Cry: *Cryptomonas ovata*; Osc: *Oscilatoria* sp.; Cym: *Cymbla parva*; Fra: *Fragilaria tenera*; *Desmodesmus opoliensis*; Cyc: *Cyclotella* sp.; S. eco: *Scenedesmus ecornis*, Spi: *Spirogyra* sp., Sur: *Surirella tenera*, and Eug: *Euglenaformis proxima* A zone: upstream river affected by agricultural activities, B zone: forest and agricultural area, C zone: urban area, D zone: downstream river affected by agricultural and livestock farming.

3.3. Physical-Chemical Variables

According to the physical-chemical variables at spring (Figure 6a), zone A differed strongly from the other three zones. The first axis of April LDA explained (96.7%) of the total variance, and the second axis explained (2.17%) of the variance. During April, zone A was characterized by a high concentration of PO_4^{3-}-P, NO_3-N. The zones B, C, and D have a high concentration of NH_4-N, NO_2-N, TSS, and high turbidity.

During the summer season in July, the graph of LDA (Figure 6b) showed that zone A and B are similar, but zone C and D differed from each other and from zones A and B based on the physical-chemical variables. The first axis of July LDA explained (64.74%) of the total variance, and the second axis explained (24.2%) of the variance. Zone C is characterized by a high concentration of COD_{sMn} and TSS. Zone D has the maximum concentration of chlorophyll-a, PO_4-P, and NO_2-N. Zone A and B have a high concentration of NH_4-N.

During the season of Autumn in October, the LDA graph (Figure 6c)—according to the physical-chemical variables—indicates that zones A and B differed from the C and D zones. The C and D zones also differed from each other. The first axis of July LDA explained (74.31%) of the total variance, and the second axis explained (23.51%) of the variance. At zones A and B, the concentration of NH_4-N and the concentration of NO_3-N was the highest. Zone C is characterized by the maximum concentration of TSS, and COD_{sMn}. Furthermore, zone D has a high concentration of NO_2-N.

According to the LDA graph, in the winter season during December (Figure 6d) all zones differed from each other. The first axis of April LDA explained (72.1%) of the total variance, and the second axis explained (20.26%) of the variance. Zone A is characterised by a high concentration of DO, and high turbidity. Zone B has the highest concentration of PO_4-P, TDS. Zone C is characterized by a high concentration of TDS, and zone D has a high concentration of NO_2-N.

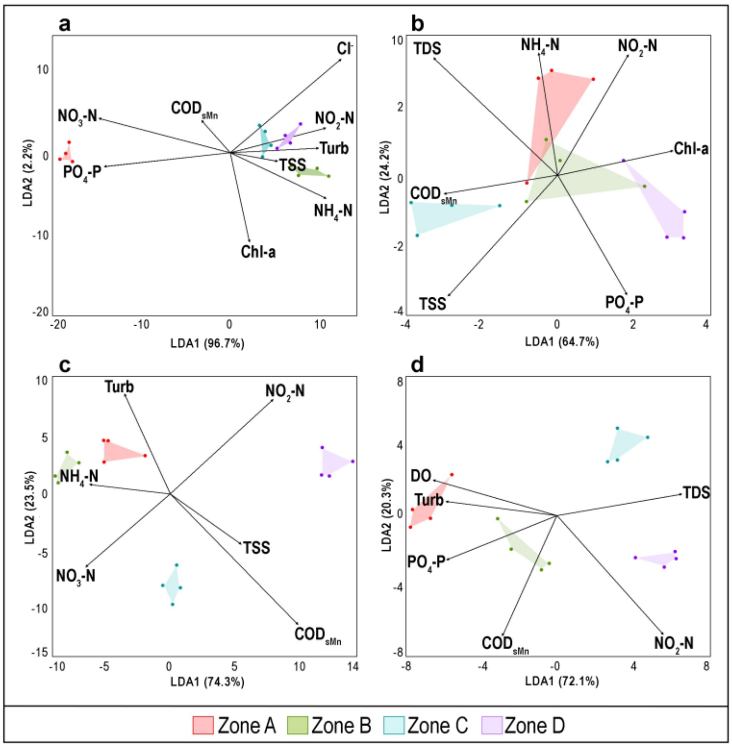

Figure 6. Linear discriminant analysis (LDA) based on the physical-chemical variables during the investigated four seasons. Graph (**a**): April; Graph (**b**): July; Graph (**c**): October; Graph (**d**): December. Where Turb: Turbidity; DO: Dissolved Oxygen; Chl-a: Chlorophyll-a; NO_2-N: Nitrite; NO_3-N: Nitrate; PO_4-P: Orthophosphate; NH_4-N: ammonium; TDS: Total dissolved solids; COD_{sMn}: Chemical oxidation demand; TSS: Total suspended solids; Cl^-: Chloride. A zone: upstream river affected by agricultural activities, B zone: forest and agricultural area, C zone: urban area, D zone: downstream river affected by agricultural and livestock farming.

3.4. Hiararchical Cluster Analysis

Both the physical-chemical variables and algal plankton exhibited clear seasonal patterns (Figure 7A,B). For the algal plankton surveys, April and July were grouped together, while October and December were distinct from each other and from the April and July group (Figure 7A). An overview of the study areas within each period revealed: (i) in April, study areas B and D formed one group, while A and C were separate from each other and from the group created by B and D; (ii) in July, two groups were formed, with study areas A and D in one group and study areas B and C in the other; (iii) in October, two groups were also formed, with study areas A and B in one group and study areas C and D in the other; and (iv) in December, study areas B and C formed one group, while A and D were separate from each other and from the group created by B and D. This paragraph describes the grouping of study areas based on their physical-chemical variables and algal plankton data. The results show that the seasons (April and July as one group, and October and December as another group) had a marked separation for both variables. In April, study areas B and D formed one group while A and C were separate. In July, study areas A and D formed one group while B and C formed another. In October, study areas A and B formed one group while C and D were separate, with study area C more similar to the group created by A and B. In December, two groups were formed, one consisting of study areas A and B, and the other consisting of study areas C and D. These findings suggest that there are distinct differences in physical-chemical variables and the algal plankton community in the Tigris River near Mosul during different seasons and in different study areas.

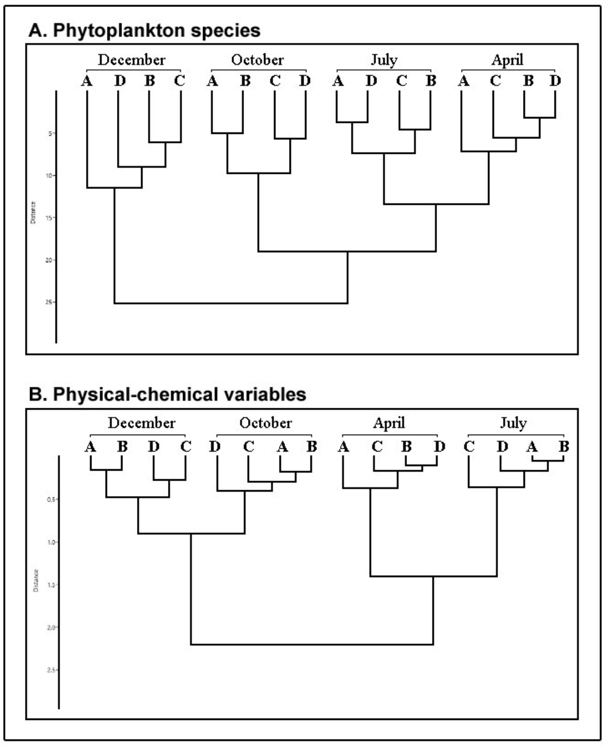

Figure 7. Hierarchical cluster analysis was performed on the algal composition (**A**) and physical-chemical variables (**B**) during the four investigated seasons. Zone A represents the upstream river area affected by agricultural activities, zone B represents the forest and agricultural area, zone C represents the urban area, and zone D represents the downstream river area affected by agricultural and livestock farming.

4. Discussion

Urbanization can result in changes in the community structure of living organisms in various running and standing water bodies [36,37]. Different pollution sources including point and non-point sources such as agriculture and wastewater resulting from domestic uses could significantly affect the water′s environmental conditions by introducing a load of nutrients and pollutants into the water [38,39]. Phytoplankton is an important component of river ecosystems and is easily affected by environmental alterations [40]. Because phytoplankton are sensitive to long-term changes in ecosystems, such as those caused by climate change and the way land is used, they are often used as bioindicators [41,42]. Former studies concluded that it is essential to study seasonal variations of nutrients—whether the P or N forms are related to climatic conditions and river flow—for their effect on the phytoplankton abundance and composition [43–47].

According to the CCA graph and based on the phytoplankton community and environmental variables (Figure 4), we observed an overlap in the autumn and winter sampling periods which indicates a relative similarity according to the water quality. There was no overlapping between the summer and spring suggesting strong differences between these sampling periods. However, during spring, the weather was characterized by rains and a relatively low water temperature of 15.6 °C which was reflected in the phytoplankton community, recording the second-highest peak of phytoplankton abundance within the study period (Figure 3B). Microalgae may be better adapted to low temperatures than to higher temperatures [48,49]. Our results indicated the lowest phytoplankton abundance in summer while the maximum was in autumn. The low-flow and high-water temperature (29 °C) contributed to the decline in the phytoplankton abundance and was associated with a very low amount of dissolved oxygen (>2 mg/L) in all sampling points in July. One of the main factors leading to the degradation of DO and resulting in hypoxia are the plant nutrients and organic loadings from different sources. These loadings can adversely affect the aquatic life system due to consuming a massive amount of dissolved oxygen [50–53]. Although, Chlorophyll-a concentration was at the minimum during July. Populations of phytoplankton are a significant component of the DO budget in rivers and are essential for maintaining DO levels [54]. In autumn, the temperature of water decreased to 17 °C with low water discharge which provides an appropriate condition for increasing the phytoplankton abundance to the maximum. This was consistent with the observation of Al-Shahri [55] as the phytoplankton species were at their maximum abundance during the spring and autumn seasons. The rains started appearing during the winter season, which caused the drop in the water temperature (11 °C), which has an obvious effect on the river water quality due to the nutrient wash off from agricultural areas.

There is a direct relationship between the land use surrounding freshwater ecosystems and the quality of the water in such systems. Several studies have shown that there is a strong connection between water quality and land use [56–58]. During our study the LDA (Figures 5 and 6) and the hierarchical cluster analysis (Figure 7) showed completely identical clustering for both physical-chemical variables and algae for all seasons. The agricultural area has a significant effect on the water quality in zone A during all seasons. This impact was distinctly visible in the LDA graph of physical-chemical variables (Figure 6) and the LDA of phytoplankton taxa (Figure 5) and cluster analysis (Figure 7A,B) by demonstrating a significant separation of the agricultural area from other zones in zone A along the Tigris River inside the city of Mosul. During spring, the sampling period is characterized by a high concentration of orthophosphate, nitrate, and COD_{sMn} in Zone A. The water discharge rate was high in spring having a direct effect on the nutrient loads from the agricultural areas upstream. One of the most important indicators of nutrient loading is the discharge rate [59,60]. Diffuse sources of nutrients that originated from runoff of surrounding agricultural areas and discharge rates can affect water quality in urban streams [61,62]. The high concentration of COD_{sMn} in the agriculture area could also be related to the organic content which may result from the detritus of phytoplankton and the release of dissolved organic matter from phytoplankton [63]. Typically, concentrations of various forms of nitrogen and orthophosphate ions were high in agricultural zones throughout the year (zone A and B). Orthophosphate can be used quickly in the area where autotrophic organisms are living, so its concentration can change quickly, but according to the minimum principle of Liebig, it can be the essential factor for eutrophication [64,65]. The highest concentration of orthophosphate and various forms of nitrogen in the agriculture area indicates the use of fertilizers along the area in which the river is crossing before reaching zone A.

The most characteristic species for the agriculture area were *Oscillatoria* sp., *Cryptomonas ovata, and Cymbella parva* (Figure 5). Our finding was consistent with many researchers who stated that the species of *Oscillatoria* sp. very often appears in water that is used for irrigation purposes for agricultural areas [66–69]. The genus *Oscillatoria* is typical at a low discharge rate [70]. Substantial cyanobacteria-related water quality issues may arise in surface water bodies [71,72]. There is conflicting evidence on whether cyanobacteria can out-compete other phytoplankton taxa in turbid systems [73,74]; some research suggests they can [75,76], while other research suggests their numbers decline in the presence of large concentrations of non-algal turbidity [73,77]. In our study, *Oscillatoria* sp. species were shown to have a negative relationship with total dissolved solids TSS (r = −0.73, p-value ≤0.05), turbidity (r = −0.62, p-value ≤ 0.05), and total dissolved solids TDS (r = −0.65, p-value ≤0.05) in July.

The second characteristic species in the agriculture area at zone A was *C. ovata* which appeared during winter. Cryptomonas favors growing in a nutrient-rich environment. The higher concentration of NH_4-N and NO_3-N might promote *Cryptomonas* growth [78,79]. Another characteristic taxon of this zone is the genus *C. parva*, which was identified during spring in the agricultural area. The species of *C. parva.* was identified in rivers that cross through agricultural areas [79,80].

In zone B, land use is characterized mainly by agriculture and forestry. Zone B had a higher concentration of COD_{sMn} and PO_4-P in winter, which could be washed off by rains from the agricultural areas [81]. In the rest of the year, the different forms of nitrogen are very typical in this area. *Oscillatoria* sp. Was a common taxon in zone B during summer. This may be connected to the availability of nutrients in this zone, which may derive from zone A. The appropriate temperature during summer also played an important role in increasing the number of *Oscillatoria* sp. In this zone. Another characteristic species in zone B was *Fragilaria* sp. (Figure 5). It is the well-known taxa considered, *Fragilaria tenera.* Characterized as an indicator of high-nutrient water bodies [82].

The urban area Impacted the water quality in zone C of the Tigris River inside the city, thus it varied greatly in other zones. Urbanization has the potential to produce significant hydrological alterations, which in turn affect the structure and function of aquatic communities [83]. It is also possible that increasing human activity along rivers would alter the nutrient types, proportions, and physical-chemical factors, which will have a negative impact on water quality [84]. This was obvious in the LDA graph of physical-chemical variables (Figure 6), the LDA of phytoplankton taxa (Figure 5), and hierarchical cluster analysis (Figure 7). Degraded water quality is more strongly associated with urban areas at small scales than at large scales [85,86].

Our research showed that *Oscillatoria* sp. was least common in zone C of the urban environment, perhaps as a direct effect of pollution discharge in that region. Previous studies have stated that toxic effect such as releasing pharmaceutical products, endocrine-disrupting chemicals, and disinfectants could have a negative effect on phytoplankton growth by affecting physiological and biochemical processes by inhibiting the enzymatic system [87–89]. Other studies suggested that submerged vegetations can effectively remove and absorb phosphorus and nitrogen in the water and inhibit the phytoplankton growth through the allelochemicals release [90,91]. The most characteristic species in the urban area were *Euglenaformis proxima*, *Fragilaria tenera*, *Navicula* sp., *Cryptomonas ovata* (Figure 5). The species of *Euglena* sp. have a higher abundance in spring in zone C. High abundance of *Euglena* sp. could be due to the rainfall, increasing nutrient loading and organic matter content [92]. Several studies have reported that Euglenophyceae species have significant importance due to their indicating organic pollution in water bodies [93,94]. *F. tenera* and *Navicula* sp. were characteristic species in the urban area in summer. *F. tenera* is a common species in urban areas and in a nutrient-rich environment [95,96]. *Cyclotella* sp. was another diatom species that was characteristic in the urban area. *Cyclotella* sp. is a typical species of urban zones [97], which was found in the urban area at zone C during winter. Furthermore, *Scenedesmus economic* also appeared within the urban area during winter. The species of *Scenedesmus* sp. have been reported in urban rivers that are polluted with raw sewage [98,99].

Zone D is located downstream of the Tigris River, and the land use is characterized by agricultural activities, as well as animal feces from animal husbandry. Area D during April has a high concentration of ammonium. A high concentration of ammonium in the surface water is commonly attributed to anthropogenic sources such as raw sewage and fertilizer from agricultural activities [48]. Zone D is characterized by a maximum concentration of NO_2-N during autumn, which could be the result of agricultural activities from the right bank of the river and animal feces. Moreover, a high concentration of nitrite in zone D indicated the presence of anaerobic bacteria, which promoted the formation of nitrite through the denitrification process [49]. The most characteristic species in zone D were *E. proxima*, *Oscillatoria* sp., and *Cryptomonas ovata*. According to LDA in spring and summer (Figure 5), *Euglenaformis proxima* dominated in zone D, which could result mainly from agriculture areas and nutrients that reached zone C. Increasing a load of nutrients and organic matter could provide appropriate environmental conditions for Euglenophyceae, where their structure depends on a variety of abiotic and biotic environmental factors [92,100].

5. Conclusions

Running water types and their catchments together comprise functional ecosystems. Studies that relate land use and rivers have generally focused on a single geographical or ecological region and mainly investigated the relationships between catchment land use and water chemistry, although primary producer microorganisms such as algae have not been addressed on this scale. Our research revealed the existence of substantial spatial variance in water quality and phytoplankton and their connection to the land use throughout the studied area of the Tigris River inside Mosul. Our results indicated a great separation between the four investigated zones (A, B, C, and D) based on changes in the phytoplankton communities and physical-chemical variables. These changes may be traced back to the different land uses: (i) released nutrients from the agricultural area into zone A; (ii) in addition to nutrients from agricultural areas, a high level of chemical oxygen demand and high suspended solids values were also typical in zone B; (iii) as well as the diffuse point pollution from urban areas, which caused a high level of COD_{sMn} and high TDS in zone C; and (iv) the effect of the urban area also includes the presence of reduced forms of nitrogen (the high concentration of nitrate-nitrogen is particularly characteristic), as well as high values of TSS, TDS, and orthophosphate-phosphate in zone D.

Based on our investigation, in the part of the Tigris River connected to Mosul, we found a clear connection between the pollution caused and the effects of different land uses through the examination of the algal community and physical-chemical variables in different periods of the year. Our study indicates that land use types can have a significant impact on the phytoplankton composition of large rivers, such as the Tigris. As such, it is important to consider phytoplankton composition in the development of river management plans.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w15061062/s1, Table S1. Abundance of phytoplankton species at the different seasons. (a) April; (b) july; (c) October; (d) December.

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