Short thesis for the degree of doctor of philosophy (PhD)

Phytoplankton composition and physical-chemical changes in inland water bodies, and their alterations as a response to the seasonality and anthropogenic impacts

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LIST OF ABBREVIATIONS

- **OW_R zone**: The open water zone near the Rakamaz area in the Nagy-Morotva oxbow lake.
- **T_R zone**: The transitional zone near the Rakamaz area in the Nagy-Morotva oxbow lake.
- **M zone**: The middle zone in the Nagy-Morotva oxbow lake, covered by macrophytes.
- **T_T zone**: The transitional zone near the Tiszanagyfalu area in the Nagy-Morotva oxbow lake.
- **OW_T zone**: The open water zone of the Tiszanagyfalu area in the Nagy-Morotva oxbow lake.
- **Zone A**: the water zone of the Tigris River which affected by Agricultural activities.
- **Zone B**: The water area of the Tigris River which mostly affected by forests and agricultural activities.
- **Zone C**: the water zone of the Tigris River which affected mainly by urban activities.
- **Zone D**: Represents the water area of the Tigris River which affected by Agricultural activities and livestock.
- **COD**: Chemical oxygen demand
- **BOD_5**: Five-day biochemical oxygen demand.
- **TDS**: Total dissolved solids.
- **EC**: Electrical conductivity.
- **TSS**: Total suspended solid.
- **DO**: Dissolved oxygen.
- **Kjl-N**: Kjeldahl nitrogen (organic nitrogen).
- **TP**: Total phosphorus.
- **PCA:** Principal component analysis.
- **LDA:** Linear discriminant analysis.
- **CCA:** Canonical correspondence analysis.

1. INTRODUCTION

Water is a crucial element that plays an important role in many aspects of human existence, including health, food production, industry, energy, and the environment (Tirkey et al., 2013). One of the most fundamental requirements for life on Earth is access to water. Water is something that all plants, animals, and people need in order to stay alive (Tirkey et al., 2013). The value of water is reflected in a wide variety of facets of human existence, including but not limited to agricultural production and industrial production (Sedik et al., 2001). The health of aquatic ecosystems and the animals that rely on water depends on the quality of the water in rivers, lakes, and seas, just as it does on the quality of drinking water (Pham & Utsumi, 2018). The accumulation of pollutants in water bodies from sources such as agricultural runoff, industrial discharges, and sewage may decrease water quality and have detrimental effects on aquatic life (Pham & Utsumi, 2018). Monitoring and assessment are crucial parts of any water quality management plan because they help identify pollution concentrations and evaluate the effectiveness of remediation efforts over time (Evans, 2013).

Water quality may be negatively impacted by climate change, which can have far-reaching consequences for human health and ecological function (Whitehead et al., 2009). Water availability and quality, as well as nutrient and pollutant cycles, are all affected by a warming planet due to shifting precipitation patterns and a rise in the frequency and intensity of severe weather events like floods and droughts (Allan et al., 2020). These changes, in turn, may significantly influence the health of our lakes, rivers, and seas (Kundzewicz, 2008). Harmful algal blooms, decreased oxygen levels, and increased acidity have all been linked to rising temperatures (Paerl et al., 2016). Sediment and nutrient discharge are two other ways in which altered precipitation patterns may harm water quality (Zhang & Zhi, 2020). Water quality during the rain periods could affected in many ways, one of which is by causing chemical changes in water sources (Rani et al., 2021). For instance, warmer temperatures may spur the widespread development of toxic algal blooms, which in turn can taint water sources and kill aquatic life (Moore et al., 2008). Variations in precipitation patterns may also modify the flow of water in rivers and streams, resulting in changes in the concentration of pollutants and nutrients in the water (Trenberth, 2011). Stream and river flow patterns and temperatures may shift as a result of factors such as glacier and snowpack melting or drought periods (Deelstra et al., 2011). Variations in water temperature may have substantial implications on aquatic ecosystems since various species of fish and other aquatic organisms have distinct temperature needs for survival and reproduction (Wilson et al., 2015).

The quality of water all over the world is affected by how the land is used (Fiquepron et al., 2013). Changes in the water cycle, including the rate and direction at which water moves through the ecosystem and the quality of available water, may be a direct result of human activities on the land (Luo & Moiwo, 2022). The quality and availability of water are vulnerable to the disruption of the natural water cycle caused by human activities, including agriculture and urbanization (Marsalek, 2014).

When it comes to water quality, for instance, agricultural operations may have a major effect (Berka et al., 2001). Agriculture uses a wide variety of chemicals, including fertilizers, insecticides, and herbicides, all of which may seep into groundwater or run off into neighbouring streams and rivers, polluting them with chemicals and nutrients that can be detrimental to aquatic life and people (Zia et al., 2013).

As a result of less vegetation, there is less chance of rain being intercepted and absorbed, which may have an effect on water quality (Dosskey et al., 2010). The outcome may be an increase in sedimentation and nutrient contamination in neighbouring streams due to sedimentation from surface runoff and erosion (Boven et al., 2008). The release of hazardous compounds and heavy metals into neighbouring streams and rivers is another way in which industries and household sewage may have a severe effect on water quality (Sadiq et al., 2005). Phytoplankton, which are also referred to as microalgae, serve as the base organisms in freshwater and marine ecosystems' food webs. They possess chlorophyll and rely on sunlight for their survival and growth. The majority of phytoplankton are buoyant, causing them to float in the upper regions of the water (Borics et al., 2021). Annual changes in light availability, temperature, stratification, and nutrient intake are all connected to phytoplankton dynamics. Climate change has the potential to affect the physical-chemical variables, hence influencing the structure and composition of phytoplankton. Phytoplankton can adapt directly through physiological changes, and they can also indirectly adapt by influencing environmental factors that affect primary production, such as nutrients and light availability

(Winder & Sommer, 2012).

Multiple research studies have demonstrated the notable impact of macrophytes on both the physical-chemical properties of water and the overall trophic structure. However, the most substantial influence is observed in the growth of algae, primarily due to the allelopathic secretions released by the macrophytes. Submerged macrophytes are vital to aquatic environments. macrophytes that live in water are useful for creating a microecological setting where aquatic animals and plants work together to suppress algae by competing with it for nutrition and light. Submerged macrophytes allelopathy keeps algal biomass low. Although microorganisms benefit from macrophytes' shelter, fish populations thrive under their care, and silt is kept from being resuspended thanks to their presence (Pereira et al., 2012). Water quality may be affected in a variety of ways by land use practices, some of which are universal while others are more localized (Tu, 2011).

2. OBJECTIVE OF THE STUDY

My study aims to investigate the water quality in two different types of water (standing and running water) based on the variation in phytoplankton composition and the physical-chemical properties resulting from seasonality change and anthropogenic effects.

1- The Nagy-Morotva oxbow shallow lake as a standing water type.
   a) *Did the composition of phytoplankton and the physical-chemical variables vary across different zones of the Nagy-Morotva oxbow shallow lake?*

b) *Are there any changes that have been seen in the phytoplankton and physical-chemical variables as a result of the shifts in temperature and precipitation?*
c) *Does the macrophyte coverage inside the oxbow lake have any effects on the distribution of phytoplankton and the physical-chemical characteristics of the water?*
d) *Does the trophic status vary among the different zones of the oxbow lake during the investigated seasons?*
e) *Does the composition of phytoplankton and the physical-chemical variables change as a result of land use activities?*

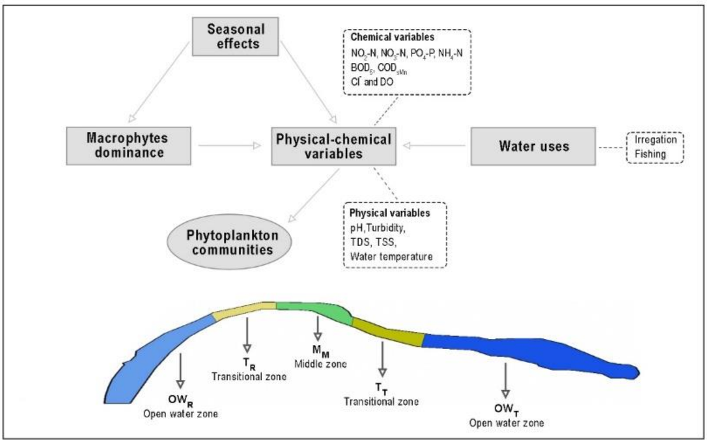

Figure 1: Conceptual figure for Nagy-Morotva oxbow shallow lake.

2- The Tigris River in Mosul city as a running water type.

a) *Did the composition of phytoplankton and the physical-chemical properties vary across different zones of the Tigris River?*

b) *Did the phytoplankton and physical-chemical variables exhibit any alterations as a result of temperature and precipitation variations?*

c) *Is there a variation in the physical-chemical characteristics and phytoplankton composition due to the change in seasons?*

d) *Does the composition of the phytoplankton and the physical-chemical variables alter as result of land use activities (agricultural and urban activities)?*

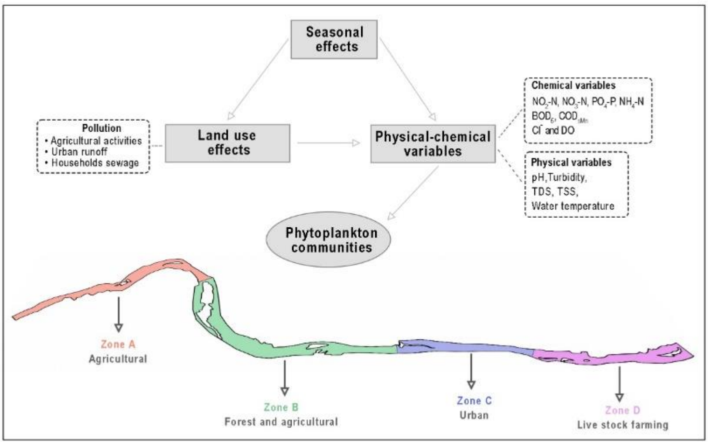

Figure 2: Conceptual figure for the Tigris River inside Mosul.

3. MATERIAL AND METHODS

3.1. The study area

3.1.1. The Nagy- Morotva Oxbow Lake

The Nagy-Morotva is an oxbow lake in north-eastern Hungary (Figure) between the settlements of Rakamaz and Tiszanagyfalu (Tumurtogoo et al., 2022). The oxbow belonging to the stated communities was produced naturally by cutting off one of the Tisza River's large meanders. The water body is about 5 km in length, 110–330 m in width, and has a vast surface area (100 hectares), but it was firmly filled, and as a result, it has shallow water with an average depth of 50–200 cm depending on the water level. The oxbow is situated on the Tisza River floodplain but is partially protected by a summer dam; thus, it is only flooded during very high river levels. The lake has no direct connection to the river, and it only gets fresh water during extreme flooding or when it is artificially pumped from the Tisza River (Tóth et al., 2012). Because of rising filling and the accelerated pace of succession, the water body is becoming marshier, and the fraction of open water continually diminishes. The Nagy-Morotva is a multipurpose body of water for irrigation, nature conservation in the middle area of the oxbow lake, fishing, and other leisure activities (Kiss et al., 2006; Yaqoob et al., 2021).

In order to capture the diverse characteristics of the Nagy-Morotva lotic system, a deliberate selection of evenly distributed sampling stations was made to obtain representative samples. A total of 21 locations were chosen within the oxbow lake, distributed across seven transects. The transects consisted of three samples taken from the left (L), middle (M), and right (R) sides, ensuring comprehensive coverage of the system. samples of water were obtained in April, July, June, and October of 2019.

Nagy-Morotva oxbow lake zones based on macrophyte coverage and land use (Figure 3):

- The open water-Rakamaz zone (OW_R) consisted from the water samples of OW_RR1, OW_RM1, OW_RL1, OW_RM2, OW_RR2, and OW_RL2 sampling points. This zone considered as open water zone and used for fishing activities.
- The transitional water-Rakamaz zone (T_R) consists from T_RM, T_RR, and T_RL sampling points. Moreover, the zone affected by the municipal sewage station on the right of the side of the zone and animal husbandry on the left side of the zone.
- The middle zone (M) consisted from MM, MR, and ML sampling points. The M zone is highly protected area and covered with microvegetation (mostly with water soldier and submerged vegetation). However, a pump station used for irrigation located in this zone.
- The transitional water-Tiszanagyfalu zone (T_T) consisted from T_TR, T_TM, and T_TL sampling points.
- The open water-Tiszanagyfalu zone (OW_T) consisted from OW_TR1, OW_TM1, OW_TL1, OW_TR2, OW_TM2, and OW_TL2 sampling points. This zone cosedered as open water zone and used for fishing activities.

Whereas the numbers 1 and 2 represent the transects inside the zones. The (L) represents the left part of transects, the (M) represents the middle part of transect, and the (R) represents the right part of transects; these abbreviations apply to all sampling points.

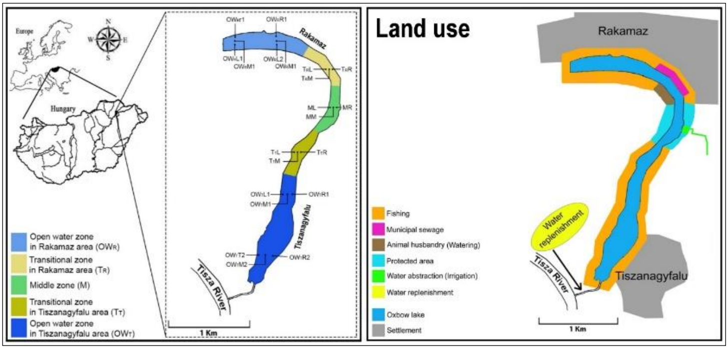

Figure 3: The sampling points and the land use of the studied area in the Nagy–Morotva oxbow shalow lake.

The Tisza River was the primary water source for the oxbow lake, which provided water to the lake through the zone of OW_T. The zone M contained a pump station specifically utilized for irrigation purposes and covered with a high coverage of microvegetation. Moreover, zone M considered as a highly protected area. The zone OW_R was considered a standing water area because there was a longer water retention, unlike in the zone OW_T. The zones of OW_T and OW_R were usually considered as a fishing area, while the macrophytes covered other zones and are highly protected area (mostly with submerged vegetation and water soldier).

3.1.2. The Tigris River in Mosul city

The Tigris River considered the largest river in Iraq, originates in the mountainous regions of southeast Turkey. From the Iraqi border to Mosul, it is approximately 188 kilometers; from Mosul downstream, it is around 1718 kilometers. At the same time, the river's entire length inside Mosul is approximately 22 kilometers, and its width is around 650 meters (Figure 4). Since the river's arrival in Mosul, a variety of contaminants have been washing downstream, reducing the water's quality and making it unsuitable for several purposes. The current research work was carried out on the Tigris River situated within Mosul city in Iraq, located between longitude 43.13ºN and latitude 36.34ºN.

In general, the water quality of the Tigris River is influenced by two main sources of pollution: non-point and point source pollution. Non-point source pollution stems from various activities including urban runoff, precipitation, and agriculture. On the other hand, point source pollution refers to the discharge of wastewater.

The studied area of Tigris River within the city were divided into 4 main zones based on the land use (Figure 4 4). Each zone consisted from 4 sampling points:

- Zone A: located in the upstream of the river, encompasses sampling points (1, 2, 3, and 4). This zone significantly impacted by the activities of the agriculture area.
- Zone B: located in the middle area of the Mosul city, encompasses sampling points (5, 6, 7, and 8). This zone significantly impacted by forested and agriculture activities.
- Zone C: located in the middle of the city, encompasses sampling points (9, 10, 11, and 12). This zone significantly impacted by activities of urban area.
- Zone D: located in the downstream of the river, encompasses sampling points (13, 14, 15, and 16). Zone D significantly impacted by livestock and agriculture activities.

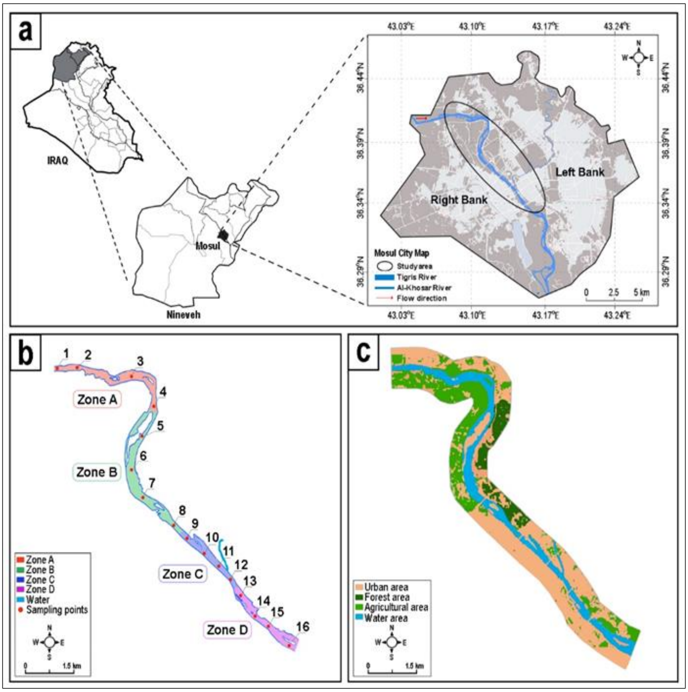

Figure 4: Figure showing the study area in the Tirgis River in hte Mosul city. (a) Location for the study area. (b) The sampling points in the studied are at the Tigris River in Mosul City.

3.2. Water Quality measurements

3.2.1. Field work

3.2.1.1. Sample collecting

Well distributed sampling points—in spatial and temporal scales—were selected, to ensure that the collected samples represented the mosaic nature of the Nagy–Morotva oxbow lake lotic system. Water samples were taken at 21 sites from the oxbow lake at (10th April for representing spring, 18^{th} June for representing early summer, 23^{rd} July for representing late summer, and 8^{th} October for representing autumn 2019), sampling was carried out 20 cm from the water surface.

At the Tigris River in the Mosul city, a total of 64 water samples were collected from Tigris River during the study in 2021 (1st of April for representing spring, 1st of April for representing spring, 7th of October for representing autumn, 29th of December for representing winter) from 16 stations (figure 4), and covered 13 km of the river.

In both water types, water chemistry samples were collected with a weighted plastic bottle at each sampling point, and the phytoplankton samples collected by using polyethylene bottles (500 ml) and fixed immediately by Lugol's iodine solution for preservation. During July sampling time, there was a high density of macrophytes in the M and T_T zones which was impossible to drive the boat inside and collect the water samples.

3.2.1.2. Field measurements

In the Nagy-Morotva oxbow lake, Optical dissolved oxygen (mg/l), conductivity (µS cm), and water temperature (°C) were measured at each sampling point using an YSI EXO-2-S3 field device. While the Secchi disk was used for determining the Transparency and depth.

In the Tigris River, dissolved oxygen (mg/l), water temperature (°C), pH, TDS (mg/l), and Turbidity (NTU) were measured at each sampling point using an ADWA AD630, ADWA AD132 pH, ADWA AD31 TDS, and Hach DR2010 portable devices.

3.2.2. Laboratory work

3.2.2.1. Water chemistry

During the laboratory phase in the Nagy-Morotva oxbow lake, various parameters were measured using the Chemical Analysis of Water and Wastes Methods. These included humic acid (mg/l), total alkalinity included (HCO_3^- and CO_3^{2-} mg/l), BOD_5 (mg/l), COD_{Cr} (mg/l) and COD_{sMn} (mg/l), dissolved orthophosphate PO_4^{3-} (mg/l) and total-phosphorus (mg/l), kjeldahl-nitrogen (mg/l), ammonium-ion NH_4^+ (mg/l), nitrate-nitrogen NO_3-N (mg/l), nitrite-nitrogen NO_2-N (mg/l), sulphate ion SO_4^{2-} (mg/l), Chlorophyll-a (µg/L), total suspended solids TSS (mg/l), pH, and ORP (mV).

While in the Tigris River, during the laboratorial analysis, we measured BOD_5 mg/l, HCO_3 mg/l, TSS mg/l, chlorophyll-a µg/L, COD_{sMn} mg/l, Cl^- mg/l, NH_4-N µg/ml, PO_4-P µg/ml, NO_2-N µg/ml, and NO_3-N µg/ml according to the Hungarian Standards.

3.2.2.2. Microscopic identification and counting

In the both of Nagy-Morotva oxbow lake and the Tigris River, inverted microscope of Olympus-IX73 was used for phytoplankton counting (ind./L^{-1}) at a magnification of 1000 (100X) and 400 (40X) and the normal microscope of Olympus-BX53 was used for identifying the phytoplankton species.

The phytoplankton samples were immediately fixed on the field with Lugol's iodine for subsequent phytoplankton counting with the Utermöhl inverted microscope technique (Sakshaug, 1981), then counted everything until reached a total of 400 individuals. Sedimentation chambers were used for microscopic analyses during counting. The settled volumes were 5 cm^3 and 10 cm^3 depending on the amount of algae in the water sample then left to sediment 24 hours before start counting. The taxonomic identification of phytoplankton species was made with the guides (John et al., 2011; Wehr et al., 2015).

3.3. Data analysis

In the statistical analysis, PAST v. 2.17 statistical program was used for conducting PCA (Principal component analysis) analysis for both physical-chemical and phytoplankton data abundance (Ind/L) after normalizing the data (Log+1). Rsutdio was used for conducting CCA (Canonical correspondence analysis) after normalizing the data (Log+1), phytoplankton species abundance (Ind/L) with greater than 2% relative abundance was chosen in CCA. PAST v. 2.17 statistical program was used for Pearson's correlation after normalizing the data (Log+1) for both physical-chemical and phytoplankton data abundance (Ind/L). ARCGIS PRO was used in classifying the land use in the studied area of the Tigris River in Mosul city (cloudless image LC08 from June 27, 2021 was used for the landuse classification).

4. RESULTS AND DISCUSSION

The results are presented as follows: in the sub-chapters, we discuss topics formulated in the objectives, which contain the specific objectives in italics for each water type.

4.1. Nagy-Morotva oxbow shallow lake in Rakamaz as a standing lake

a) Did the composition of phytoplankton and the physical-chemical variables vary across different zones of the Nagy-Morotva oxbow shallow lake?

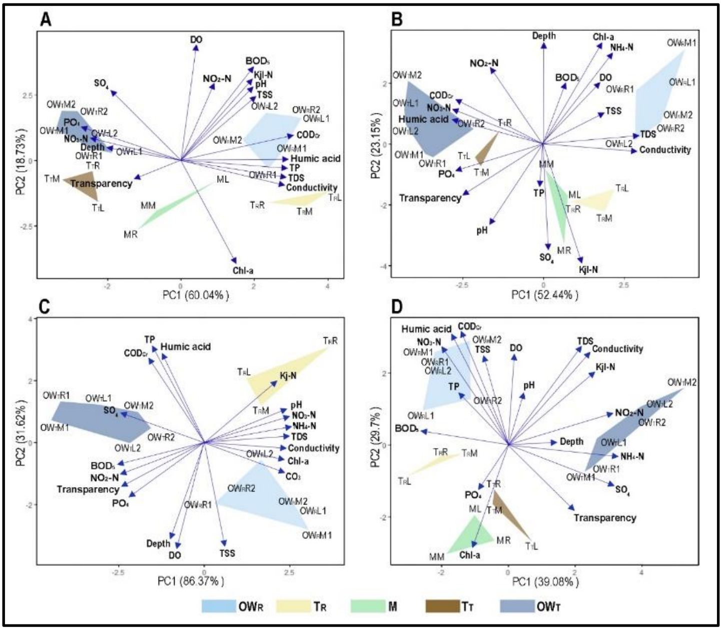

Figure 5: Principal component analysis based on the physical-chemical variables at each sampling point. Graph (A): Spring, Graph (B): Early Summer, Graph (C): Late Summer, Graph (D): Autumn. TP: total-phosphorus; Kjl-N: Kjeldahl-N; chl-a: chlorophyll-a; TSS: total suspended solids; TDS: total suspended solids; DO: dissolved oxygen.

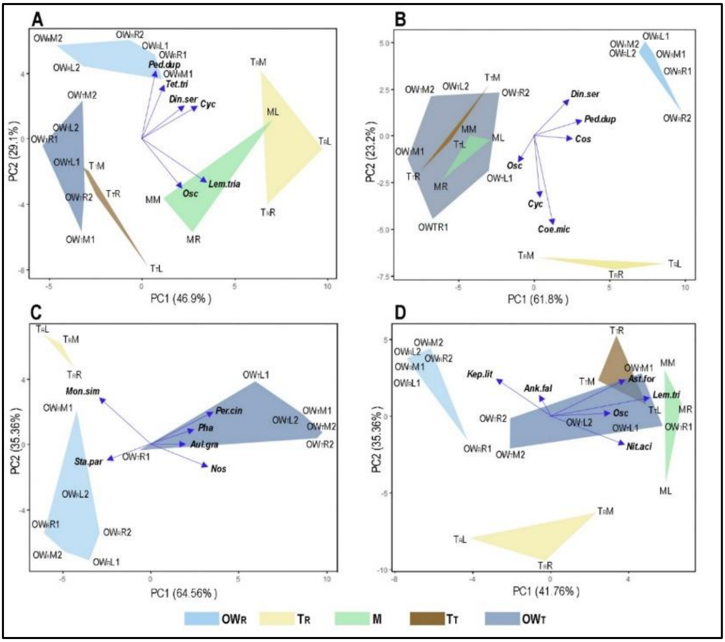

Figure 6: Principal component analysis PCA of the phytoplankton during the study period. Graph (**A**): spring, Graph (**B**): Early summer, Graph (**C**): Late summer, Graph (**D**): autumn. Phytoplankton name acronym, Ped.dup: *Pediastrum duplex*; Tet.tri: *Tetrastrum triangulare*; Din.ser: *Dinobryon sertularia*; Cyc: *Cyclotella* sp.; Lem.tri: *Lemmermannia triangularis*; Osc: *Oscillatoria* sp.; Cos: *Cosmarium* sp.; Coe.mic: *Coelastrum microporum*; Mon.sim: *Monactinus simplex*; Per.cin: *Peridinium cinctum*; Pha: *Phacus* sp.; Aul.gra: *Aulacoseira granulata*; Nos: *Nostoc* sp.; Sta.par: *Staurastrum paradoxum*; Kep.lit: *Kephyrion littorale*; Ast.for: *Asterionella formosa*; Nit.aci: *Nitzschia acicularis*.

The phytoplankton composition and physical-chemical variable varied between the sampling zones in the oxbow lake. The two open water zones (OW_R and OW_T) strongly separated based on both phytoplankton composition and physical-chemical variable during all the sampling times (figures 5,6). These affected on the water quality could be related to the macrophyte coverage, water source availability, and land use. Where are high nutrients concentration and high phytoplankton abundance was in the OW_R during spring sampling time, while phytoplankton and nutrients concentration was at maximum at the OW_T during both early and late summer sampling times, then in autumn phytoplankton and nutrients concentration became high in the OW_R zone.

b) *Are there any changes that have been seen in the phytoplankton and physical-chemical variables as a result of the shifts in temperature and precipitation?*
The investigation revealed that the highest abundance of phytoplankton was observed during the spring and autumn seasons.
However, the sampling periods of spring and autumn were observed to exhibit the highest abundance of *Ankistrodesmus falcatus*. Conversely, during the early and late summer sampling periods, *Oscillatoria* sp. was found to be the dominant species. During the spring season, the presence of high levels of orthophosphate ions was observed, which is indicative of anaerobic conditions in nearby areas of the sediment.

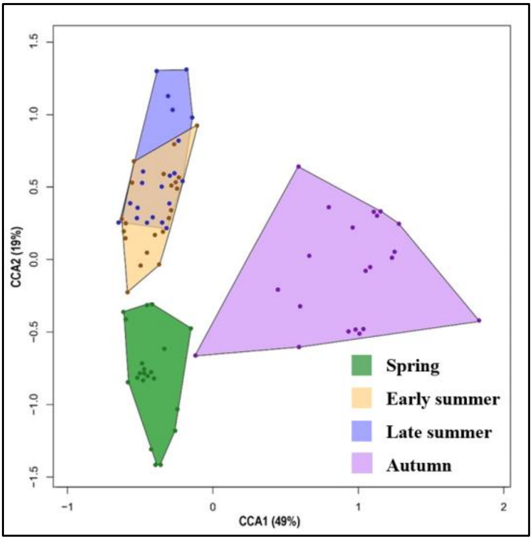

Figure 7: Canonical correspondence analysis CCA graph showing the differences between the four sampling times based on algal composition and physical-chemical variables.

Conversely, the concentration of nitrate-nitrogen was found to be higher, which suggests an external influx of nutrients that is typically associated with oxygen-rich conditions.

Elevated nutrient levels during the initial phase of summer are indicative of the phenomenon of eutrophication and the consequent raising of levels in trophic states. At the beginning of the irrigation season, a rise in temperature led to an increase in conductivity, which became a notable environmental feature due to the accompanying evaporative loss.

c) *Does the macrophyte coverage inside the oxbow lake have any effects on the distribution of phytoplankton and the physical-chemical characteristics of the water?*
The study's findings suggest that the impact of macrophytes, a defining feature of the M zone, is the reason for separating the OW_R zone from OW_T zone during all the sampling times based on phytoplankton composition and physical-chemical variables.

d) *Does the trophic status vary among the different zones of the oxbow lake during the investigated seasons?*
During the spring season, our findings pertaining to algal plankton and physical-chemical variables indicated the presence of meso-eutrophic conditions, characterized by elevated conductivityand reduced dissolved oxygen levels, within the OW_R zone.

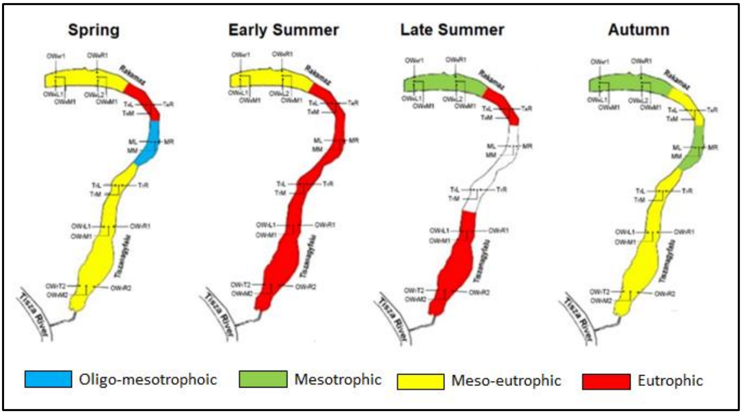

Figure 8: Trophic levels in various zones at Nagy-Morotva oxbow shallow lake.

Conversely, the T_R zone exhibited a higher trophic condition, as evidenced by the abundant nutrient levels. Elevated nutrient levels during the summer are indicative of the phenomenon of eutrophication and consequent escalation in trophic states. During the autumn season, there was a slight decrease in the trophic level, resulting in a meso-eutrophic state. However, the dominant species of algae observed during this autumn suggested an elevated trophic level. Despite the declining nutrient concentration, the trophic level persisted as mesotrophic within the OW_R zone.

e) *Does the composition of phytoplankton and the physical-chemical variables change as a result of land use activities?*

Land use in the Nagy-Morotva oxbow lake have a significant effect on the water quality in the different zones of the lake based on the physical-chemical variables and algal communities. Whereas the T_R zone mainly affected by the municipal sewage and animal husbandry pollutants which was very clear during summer sampling time. The zone M is a protected area which covered by macrophytes and it has a pumping station for irrigation using which is have a negative impact on the water quality. These zones characterized by the abundance of *Oscillatoria* sp. and *Cyclotella* sp. which are used as indicator of organic pollution and *Oscillatoria* sp. is a common taxon in the irrigation water, the T_R zone also have an elevated concentration of NO_3-N, PO_4^{3-}, Kjl-N, and TP during spring, summer, and autumn seasons.

4.2. Tigris River in Mosul city as a running water

a) Did the composition of phytoplankton and the physical-chemical properties vary across different zones of the Tigris River?

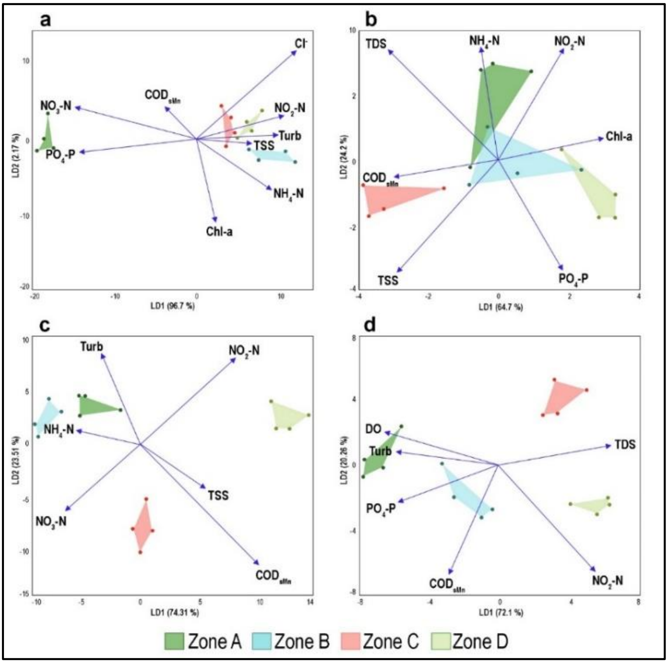

Figure 9: Linear discriminant analysis (LDA) based on the physical-chemical variables during the investigated four seasons. Graph (a): spring; (b): summer; Graph (c): autumn; Graph (d): winter. Chl-a: Chlorophyll-a; and Turb: Turbidity.

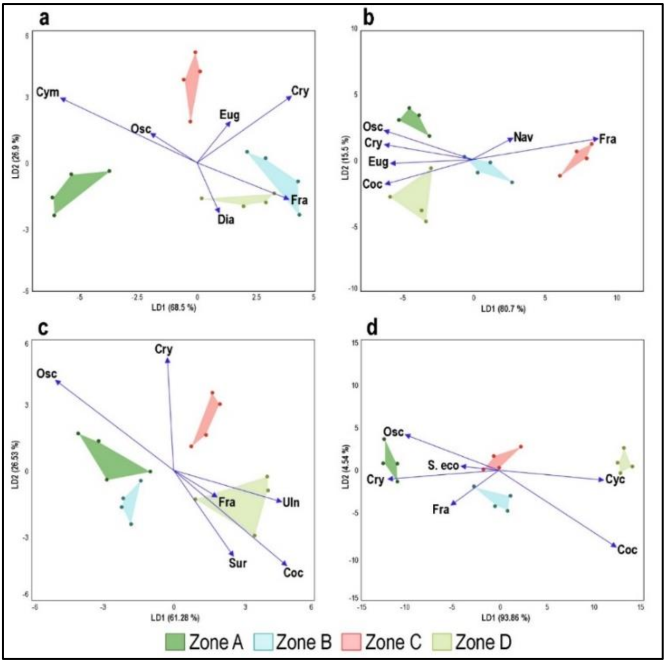

Figure 10**:** Graphs representing linear discriminant analysis (LDA) based on the phytoplankton taxa. (a): spring; (b): summer; Graphs (c): autumn; Graphs (d): winter. Whereas Eug: Euglena sp.; Sur: *Surirella* sp.; Sp.: *Spirogyra* sp.; S. eco: *Scenedesmus ecornis*; Cyc: *Cyclotella* sp.; Fra: *Fragilaria* sp.; Cym: *Cymbla* sp.; Osc: *Oscillatoria* sp.; Cry: *Cryptomonas ovata*; Dia: *Diatoma* sp.; Uln: *Ulnaria ulna*; and Coc: *Cocconeis* sp.

The composition of the algae composition and physical-chemical variables differed at each zone during the sampling times in different seasons based on the land use. Whereas zone A which mainly affected by the agricultural activities and zone C which affected by urban activities strongly separated from other zones based on both phytoplankton and physical-chemical variables (figures 9, 10).

b) *Did the phytoplankton and physical-chemical variables exhibit any alterations as a result of temperature and precipitation variations?*
The abundance of algae and physical-chemical variables are subject to precipitation, particularly during the spring and winter sampling period. This is due to the runoff from agricultural areas, which increases the nutrient content of the water and results in the emergence of *Oscillatoria* sp., particularly in zone A. The abundance of algae and physical-chemical variables were both influenced by temperature. During the summer sampling period, the algal abundance decreased to its lowest point. However, this resulted in an increase in the growth rates of *Oscillatoria* sp. which then became competitive with diatoms.

c) *Is there a variation in the physical-chemical characteristics and phytoplankton composition due to the change in seasons?*
The investigation revealed that the highest abundance of phytoplankton was observed during the spring and autumn seasons. However, in Spring sampling period, *Cocconeis pediculus* was the dominated species. Spring characterized by rain that washed the nutrients in the water body of the river and results in increasing the turbidity, NO_2-N, NO_3-N, TDS, and PO_4-P. Then in Summer the algal composition became more

diverse and it exhibited mainly by *Cocconeis pediculus*, *Cryptomonas ovata*, and *Oscillatoria* sp. summer sampling characterized by the maximum water temperature which affected negatively on the phytoplankton abundance and the turbidity was at the lowest but the PO_4-P was also high as it was in Spring. While *Cyclotella* sp., *Cocconeis pediculus*, and *Cryptomonas ovata* dominated the autumn sampling period.

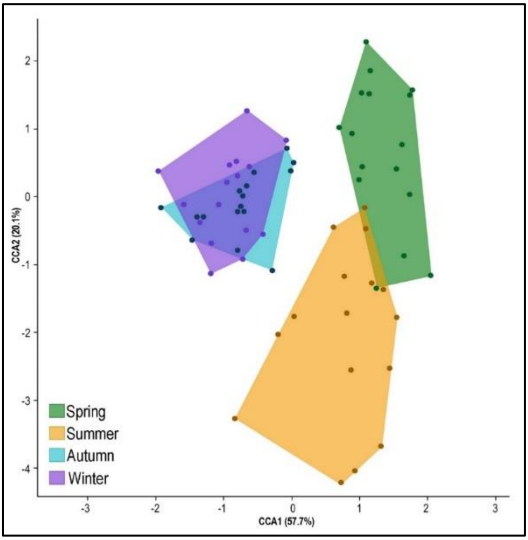

Figure 11: Canonical correspondence analysis CCA graph showing the separation of the four sampling times based on phytoplankton composition and physical-chemical variables.

Water temperature in autumn was relatively high but lowest than it was in summer which created a better condition for the algal communities which resulted in increasing the chlorophyll-a, also the NO_3-N, turbidity, and TSS was at the maximum. And in winter the *Cocconeis pediculus* return to dominate the spring season. At winter the rains appeared and resulted in increasing the TSS and TDS but the low water temperature was unfavorable condition to the phytoplankton which resulted in decreasing their abundance.

d) *Does the phytoplankton composition and the physical-chemical variables alter as result of land use activities (agricultural and urban activities)?*
The findings of the examined region of the Tigris River in Mosul city have revealed a significant differentiation among the four examined zones (A, B, C, and D) on the grounds of alterations in the physical-chemical variables and phytoplankton communities. These alterations can be attributed to the varying land utilization practices. The study found that the agricultural area contributed to the release of nutrients into zone A, which was dominated by *Oscillatoria* sp. Additionally, zone B exhibited high levels of chemical oxygen demand and suspended solids, in addition to agricultural nutrients. Zone C was impacted by diffuse point pollutants from urban areas, leading to high levels of COD_{sMn} and total dissolved solids. Finally, the urban area in zone D was characterized by the presence of reduced forms of nitrogen, particularly nitrate-nitrogen, as well as high levels of PO_4-P, TDS, and TSS resulting in the appearance of *Oscillatoria* sp. in this zone.

5. NEW SCIENTIFIC FINDINGS

- Our study indicated that the macrophyte coverage have a significant impact on the water quality in the based on both phytoplankton composition and physical-chemical variables in shallow standing water type.
- We determined that the alteration in temperature and precipitation has a significant effect on the water quality based on phytoplankton and physical-chemical variables in arid environment.
- Trophic states based on phytoplankton composition are able to determine the various landuse types in shallow water bodies by our results.
- We have demonstrated that the phytoplankton species are able to use as good indicator of the various land-use (agricultural, urban activities) both in standing and running water types as well during the all seasons continental and arid climate also.

6. REFERENCES

Allan, R. P., Barlow, M., Byrne, M. P., Cherchi, A., Douville, H., Fowler, H. J., Gan, T. Y., Pendergrass, A. G., Rosenfeld, D., Swann, A. L. S., Wilcox, L. J., & Zolina, O. (2020). Advances in understanding large-scale responses of the water cycle to climate change. *Annals of the New York Academy of Sciences*, *1472*(1), 49–75. https://doi.org/10.1111/nyas.14337

Berka, C., Schreier, H., & Hall, K. (2001). Linking Water Quality with Agricultural Intensification in a Rural Watershed. *Water, Air, and Soil Pollution*, *127*(1/4), 389–401. https://doi.org/10.1023/A:1005233005364

Borics, G., Abonyi, A., Salmaso, N., & Ptacnik, R. (2021). Freshwater phytoplankton diversity: models, drivers and implications for ecosystem properties. *Hydrobiologia*, *848*(1), 53–75. https://doi.org/10.1007/s10750-020-04332-9

Boven, L., Stoks, R., Forró, L., & Brendonck, L. (2008). Seasonal dynamics in water quality and vegetation cover in temporary pools with variable hydroperiods in Kiskunság (Hungary). *Wetlands*, *28*(2), 401–410. https://doi.org/10.1672/06-174.1

Deelstra, J., Øygarden, L., Blankenberg, A. B., & Olav Eggestad, H. (2011). Climate change and runoff from agricultural catchments in Norway. *International Journal of Climate Change Strategies and Management*, *3*(4), 345–360. https://doi.org/10.1108/17568691111175641

Dosskey, M. G., Vidon, P., Gurwick, N. P., Allan, C. J., Duval, T. P., & Lowrance, R. (2010). The Role of Riparian Vegetation in Protecting and Improving Chemical Water Quality in Streams [1]. *JAWRA Journal of the American Water Resources Association*, *46*(2), 261–277. https://doi.org/10.1111/j.1752-1688.2010.00419.x

Evans, R. (2013). Assessment and monitoring of accelerated water erosion of cultivated land - when will reality be acknowledged? *Soil Use and*

Management, *29*(1), 105–118. https://doi.org/10.1111/sum.12010
Fiquepron, J., Garcia, S., & Stenger, A. (2013). Land use impact on water quality: Valuing forest services in terms of the water supply sector. *Journal of Environmental Management*, *126*, 113–121. https://doi.org/10.1016/j.jenvman.2013.04.002
John, D., Brooks, A. J., & Whitton, B. (2011). The Freshwater Algal Flora of the British Isles. An Identification Guide to Freshwater and Terrestrial Algae.
Kiss, M. K., Tóth, A., Szabó, M., & Lakatos, G. (2006). Hydrobiological state of various oxbow lakes in Hungary. *SIL Proceedings, 1922-2010*, *29*(5), 2267–2270. https://doi.org/10.1080/03680770.2006.11903096
Kundzewicz, Z. W. (2008). Climate change impacts on the hydrological cycle. *Ecohydrology & Hydrobiology*, *8*(2–4), 195–203. https://doi.org/10.2478/v10104-009-0015-y
Luo, K., & Moiwo, J. P. (2022). Sensitivity of the land surface hydrological cycle to human activities in China. *Gondwana Research*. https://doi.org/10.1016/j.gr.2022.04.006
Marsalek, J. (2014). *Urban Water Cycle Processes and Interactions*. CRC Press. https://doi.org/10.1201/9781482288544
Moore, S. K., Trainer, V. L., Mantua, N. J., Parker, M. S., Laws, E. A., Backer, L. C., & Fleming, L. E. (2008). Impacts of climate variability and future climate change on harmful algal blooms and human health.

Environmental Health, *7*(Suppl 2), S4. https://doi.org/10.1186/1476-069X-7-S2-S4

Paerl, H. W., Gardner, W. S., Havens, K. E., Joyner, A. R., McCarthy, M. J., Newell, S. E., Qin, B., & Scott, J. T. (2016). Mitigating cyanobacterial harmful algal blooms in aquatic ecosystems impacted by climate change and anthropogenic nutrients. *Harmful Algae*, *54*, 213–222. https://doi.org/10.1016/j.hal.2015.09.009

Pereira, S. A., Trindade, C. R. T., Albertoni, E. F., & Palma-Silva, C. (2012). Aquatic macrophytes as indicators of water quality in subtropical shallow lakes, Southern Brazil. *Acta Limnologica Brasiliensia*, *24*(1), 52–63. https://doi.org/10.1590/S2179-975X2012005000026

Pham, T.-L., & Utsumi, M. (2018). An overview of the accumulation of microcystins in aquatic ecosystems. *Journal of Environmental Management*, *213*, 520–529. https://doi.org/10.1016/j.jenvman.2018.01.077

Rani, M., Joshi, H., Kumar, K., Bhatt, D. K., & Kumar, P. (2021). Climate change scenario of hydro-chemical analysis and mapping spatio-temporal changes in water chemistry of water springs in Kumaun Himalaya. *Environment, Development and Sustainability*, *23*(3), 4659–4674. https://doi.org/10.1007/s10668-020-00793-z

Sadiq Butt, M., Sharif, K., Ehsan Bajwa, B., & Aziz, A. (2005). Hazardous effects of sewage water on the environment. *Management of Environmental Quality: An International Journal*, *16*(4), 338–346. https://doi.org/10.1108/14777830510601217

Sakshaug, E. (1981). Phytoplankton manual — monographs on oceanographic methodology, 6. *Ocean Management*, *6*(2–3), 247–248. https://doi.org/10.1016/0302-184X(81)90053-6

Sedik, M., Youssef, H., Abbas, M., Hegazi, N., Ali, S., Monib, M., & Amal, H. (2001). Guidelines for Drinking-Water Quality. *Research Journal of Environmental Toxicology*, *10*, 114–123.

Tirkey, P., Bhattacharya, T., & Chakraborty, S. (2013). Water quality indices- important tools for water quality assessment: a review. 1.

Tóth, M., Móra, A., Kiss, B., Dévai, G., & Specziár, A. (2012). Are macrophyte-dwelling Chironomidae (Diptera) largely opportunistic in selecting plant species? *European Journal of Entomology*, *109*(2), 247–260. https://doi.org/10.14411/eje.2012.033

Trenberth, K. (2011). Changes in precipitation with climate change. *Climate Research*, *47*(1), 123–138. https://doi.org/10.3354/cr00953

Tu, J. (2011). Spatially varying relationships between land use and water quality across an urbanization gradient explored by geographically weighted regression. *Applied Geography*, *31*(1), 376–392. https://doi.org/10.1016/j.apgeog.2010.08.001

Tumurtogoo, U., Figler, A., Korponai, J., Sajtos, Z., Grigorszky, I., Berta, C., & Gyulai, I. (2022). Density and Diversity Differences of Contemporary and Subfossil Cladocera Assemblages: A Case Study in an Oxbow Lake. *Water*, *14*(14), 2149. https://doi.org/10.3390/w14142149

Wehr, J., Sheath, R., & Kociolek, P. (2015). *Freshwater Algae of North America: Ecology and Classification*.

Whitehead, P. G., Wilby, R. L., Battarbee, R. W., Kernan, M., & Wade, A. J. (2009). A review of the potential impacts of climate change on surface water quality. *Hydrological Sciences Journal*, *54*(1), 101–123. https://doi.org/10.1623/hysj.54.1.101

Wilson, K. L., Kay, L. M., Schmidt, A. L., & Lotze, H. K. (2015). Effects of increasing water temperatures on survival and growth of ecologically and economically important seaweeds in Atlantic Canada: implications for climate change. *Marine Biology*, *162*(12), 2431–2444. https://doi.org/10.1007/s00227-015-2769-7

Winder, M., & Sommer, U. (2012). Phytoplankton response to a changing climate. *Hydrobiologia*, *698*(1), 5–16. https://doi.org/10.1007/s10750-012-1149-2

Zhang, J., & Zhi, M. (2020). Effects of basin nutrient discharge variations coupled with climate change on water quality in Lake Erhai, China. *Environmental Science and Pollution Research*, *27*(35), 43700–43710. https://doi.org/10.1007/s11356-020-09179-0

Zia, H., Harris, N. R., Merrett, G. V., Rivers, M., & Coles, N. (2013). The impact of agricultural activities on water quality: A case for collaborative catchment-scale management using integrated wireless sensor networks. *Computers and Electronics in Agriculture*, *96*, 126–138. https://doi.org/10.1016/j.compag.2013.05.001

7. PUBLICATIONS

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Candidate: Majd Muwafaq Yaqoob
Doctoral School: Pál Juhász-Nagy Doctoral School of Biology and Environmental Sciences
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List of publications related to the dissertation

Foreign language scientific articles in international journals (2)

1. **Yaqoob, M. M.**, Somlyai, I., Berta, C., Bácsi, I., Al-Tayawi, A. N., Al-Ahmady, K. K., Mohammed, R. H., Alalami, O., Grigorszky, I.: The Impacts of Land Use and Seasonal Effects on Phytoplankton Taxa and Physical-Chemical Variables in the Tigris River within the City of Mosul.
   Water. 15 (6), 1-17, 2023. EISSN: 2073-4441.
   DOI: http://dx.doi.org/10.3390/w15061062
   IF: 3.4 (2022)

2. **Yaqoob, M. M.**, Berta, C., Szabó, L. J., Dévai, G., Szabó, S., Nagy, S. A., Bácsi, I., Simon, A., Nagy, J., Somlyai, I., Ács, É., Grigorszky, I.: Changes in algal plankton composition and physico-chemical variables in a shallow oxbow lake.
   Water. 13 (17), 1-20, 2021. ISSN: 2073-4441.
   DOI: http://dx.doi.org/10.3390/w13172339
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List of other publications

Foreign language scientific articles in international journals (1)

3. Grigorszky, I., Kiss, K. T., Szabó, L. J., Dévai, G., Nagy, S. A., Somlyai, I., Berta, C., Gligora-Udovič, M., Borics, G., Pór, G., **Yaqoob, M. M.**, Hajredini, A., Tumurtogoo, U., Ács, É.: Drivers of the Ceratium hirundinella and Microcystis aeruginosa coexistence in a drinking water reservoir.
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