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

Thesis for the Degree of Doctor of Philosophy (PhD)

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Hereby I declare that I prepared this thesis within the Doctoral Council of Natural Sciences and Technology, Juhász-Nagy Pál Doctoral School, University of Debrecen in order to obtain a PhD Degree in Natural Sciences at Debrecen University.
The results published in the thesis are not reported in any other PhD theses.

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Hereby I confirm that Majd Muwafaq Yaqoob candidate conducted his studies with my supervision within the Hydrobiology Doctoral Program of the Juhász-Nagy Pál Doctoral School between 2019 and 2023. The independent studies and research work of the candidate significantly contributed to the results published in the thesis.
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Phytoplankton composition and physical-chemical changes in inland water bodies, and their alterations as a response to the seasonality and anthropogenic impacts

Dissertation submitted in partial fulfilment of the requirements for the doctoral (PhD) degree
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List of Abbreviations

- **OW_R zone**: Represents the open water zone of the Rakamaz area in the Nagy-Morotva oxbow lake.

- **T_R zone**: Represents the water transitional zone between the open water zone of Rakamaz area (OW_R) in the Nagy-Morotva oxbow lake
- **M zone**: Represents the water middle zone which is characterized by a large macrovegetation coverage in the Nagy-Morotva oxbow lake.
- **T_T zone**: Represents the water Transitional zone between the open water zone of Tiszanagyfalu area (OW_T) and the middle zone (M) in the Nagy-Morotva oxbow lake.
- **OW_T zone**: Represents the open water zone of the Tiszanagyfalu area in the Nagy-Morotva oxbow lake.
- **Zone A**: Represents the water area of the Tigris River which affected by Agricultural activities.
- **Zone B**: Represents the water area of the Tigris River which mostly affected by forests and Agricultural activities.
- **Zone C**: Represents the water area 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_{Cr}**: Chemical oxygen demand by using potassium dichromate as oxidising reagent.
- **COD_{sMn}**: Chemical oxygen demand by using potassium permanganate as oxidising reagent
- **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 AND OBJECTIVES

1.1. 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 (Chaplin, 2001; Lavender & Lavender, 2023; 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; Sedik et al., 2001). 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 (Howell, 2001; 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; Poff et al., 2002; Postel et al., 1998). 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 (Ahmed et al., 2021; Pham & Utsumi, 2018; Singh et al., 2020). 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; Martínez-Gómez et al., 2010).

Water quality may be negatively impacted by climate change, which can have far-reaching consequences for human health and ecological function (Whitehead et al., 2009a). 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 (Bouraoui et al., 2004; Allan et al., 2020; Imaoka et al., 2010). These changes, in turn, may significantly influence the health of our lakes, rivers, and seas (Kundzewicz, 2008; Tang, 2020). Harmful algal blooms, decreased oxygen levels, and increased acidity have all been linked to rising temperatures (Gobler, 2020; Paerl et al., 2016). Sediment and nutrient discharge are two other ways in which altered precipitation patterns may harm water quality (J. Zhang & Zhi, 2020). Water quality during the rain periods could effected 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; Zwolsman & van Bokhoven, 2007). 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; Poloczanska et al., 2008).

The quality of water all over the world is affected by how the land is used (Abildtrup et al., 2013; 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 (Gornitz et al., 1997; 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 (Casalí et al., 2008; Brabec et al., 2002; 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 Butt et al., 2005; Zamora-Ledezma et al., 2021). 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 (Carpenter & Lodge, 1986; Gligora et al., 2007; Ozimek et al., 1990; Pereira et al., 2012; Väliranta et al., 2005; van Donk & van de Bund, 2002; S. Wang et al., 2020).

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). The quality and availability of water resources are affected differently by various land use patterns based on the local environment and climate (Tu & Xia, 2008). To provide two extremes, development in rainy places may increase stormwater runoff and floods, while agricultural activities in desert regions can increase water demand and deplete groundwater supplies.

1.2. Problem Statement

1.2.1. The Nagy-Morotva oxbow shallow lake

Shallow lakes are crucial to aquatic biodiversity and human requirements. Natural and human-caused factors have both contributed to significant shifts in a variety of aquatic habitats. Because of their importance in maintaining other ecosystems, disruptions to or overuse by humans in these places are a major reason to be concerned (Berta et al., 2019; Vincent, 2009). In contrast to deep lakes, which are rather rare, shallow lakes are abundant all over the globe (Meerhoff et al., 2012). Yet they are also particularly vulnerable to climate change and human influences, such as pollution with heavy metals (Nyeste et al., 2019). During the Weichselian glacier era, several shallow lakes formed at the ice's edge (Scheffer, 2004a). Many ponds and shallow lakes were formed over time as a result of human activity like mining for peat, sand, gravel, or clay, however some of these bodies of water may have formed naturally (Moss et al., 2003; Scheffer, 2004a).

Lakes have the potential to have major intakes and large outputs, depending on the other sources of water that go into and out of the lake (Bhateria & Jain, 2016). The additional water sources that flow into and out of the lake determine this potential. The water from rivers has the ability to have an effect on the many physical, chemical, and biological aspects of the ecosystems that are found in lakes. Because of this, the water that comes from rivers has the ability to have an effect on the many types of organisms that can be found in lakes (Bhateria & Jain, 2016; Hillbricht-Ilkowska, 1999).

There are at least two distinct types of aquatic environments, distinguished by the degree of transparency (Dembowska et al., 2018). High-transparency water bodies with a bottom layer of submerged macrophytes make up the first group, whereas low-transparency bodies of water with an abundance of phytoplankton make up the second (Song et al., 2019; van Donk & van de Bund, 2002).

Because of the significant influence they have on the social economy, biodiversity, and ecology of the communities that surround them, oxbow lakes should be given top attention for study and conservation efforts (Berta et al., 2019). As compared to post-glacial lakes, oxbow lakes are a completely unique sort of aquatic environment owing to their origin as well as the morphometric and hydrodynamic properties that they possess. The functionality of oxbow lakes is interconnected with the fluctuations in water level of the adjacent rivers, both through indirect and direct associations (Joniak & Kuczyńska-Kippen, 2016).

Oxbow lakes are commonly considered to be lakes that are either tiny or shallow in depth and are typical forms of standing waters found in lowland regions. The majority of oxbow lakes may be located in lowlands that are surrounded by dense populations, which often pose significant hazards from environmental deterioration (Borics et al., 2013). They provide habitats that are completely unique, which makes them very vital places of refuge for the protection of many forms of life. It is feasible to

infer information about the condition of the environment based on the composition of the communities and the range of aquatic species that are there (Biggs et al., 2017).
The lake trophic level relies significantly on the concentration of nutrient, which can be assessed by analysing the connection between the input and output of nutrients in the lake. With regard to the varied characteristics of the investigated bodies of water, some areas (open water areas) have oxygen level, phosphorus, and nitrogen concentrations typical of shallow aquatic systems, while other areas that have submerged vegetation have oxygen levels, phosphorus, and nitrogen concentrations typical of wetlands. The most essential variables in restricting algal development are nitrogen- and phosphorus-based forms, and as a result, lakes with more nutrient input encourage the phytoplankton and plants growth (Ferencz et al., 2018; Somlyai et al., 2019a).

The different characteristics of the varied flushing rates and inflow in the Nagy-Morotva oxbow lake, which is considered a lotic system and gets water from the Tisza River, significantly affect environmental factors for communities (Choudhury & Pal, 2010). There is a complicated interaction between physical-chemical and biological factors that causes shifts in phytoplankton dynamics (Choudhury & Pal, 2010). With just one main canal feeding into the Nagy-Morotva oxbow lake, it is assumed that the water quality varies between the upper and lower parts of the body of water. Hydrology, inputs, and biogeochemical processes all influence the freshwater ecosystem's ability to convert or retain anthropogenic solutes (Carpenter et al., 2011).

Water uses such as fishing and irrigation have a highly impact on the quality of water in the Nagy-Morotva oxbow shallow lake. Also, the protected area in the middle of the oxbow lake which dominated by macrophyte specially during the summer season can have a great effect on the water quality by filtering the nutrients from the one side to other side of the lake and affecting the phytoplankton dominance. These effects were investigated by studying the phytoplankton composition and physical-chemical variables.

1.2.2. The Tigris River in Mosul

Rivers play a vital role in supporting natural ecosystems and human life, providing a sanctuary for a diverse range of biological species, such as prokaryotic and eukaryotic plankton, among others (Abonyi et al., 2012; Aufdenkampe et al., 2011). Human activities, such as the release of water pollutants caused by the growth of population and urbanization, may make the pollution of aquatic environments worse around the world (Hajong & Ramanujam, 2017; Shehab et al., 2021; Wen et al., 2017a). The discharge of sewage from household, industrial, and agricultural effluents, which can have toxic or untoxic chemicals, could have a big impact on the water quality of the river's (Kilic & Yucel, 2019; Lehner et al., 2011). Human activities, such as deforestation, agricultural expansion, changes in land use, urbanization, the escalation of wastewater production, and industrial development, can have a profound impact on the environment in which people live and work (Poff et al., 2006; Cheng et al., 2022a; Phungela et al., 2022; Rodrigues et al., 2018). This can be the case when deforestation occurs, land use is altered, industrial development, agricultural expansion, and urbanization are all undertaken (Zieliński et al., 2016; M. R. Williams et al., 2015).

Both urban and agricultural regions are widely seen as the principal causes of pollutants such as organic and nutrient compounds in freshwater habitats due to changes in the environment and the land use (Giri & Qiu, 2016; Vrebos et al., 2017; Yadav et al., 2019). These activities have a negative influence on both aquatic and terrestrial ecosystems, which ultimately results in a decline in the quality of the available water (Xu et al., 2019; Yang et al., 2022).

Because of the dramatic increase in global population and the consequent growth of urban areas in recent decades, urbanization has emerged as highly significant forms of human-induced land-use changes. This is primarily due to the fact that urban areas have expanded greatly in recent decades (Hanashiro et al., 2019). The distinct characteristics of urban environments, including such variations in hydrology, air chemistry, temperature, geochemistry, and vegetation, produce ecosystems that are distinct from those that are found in natural habitats. These differences can be seen in both the flora and fauna that inhabit urban environments (Tran et al., 2022). The degradation of water quality could be related to both activities of human and shifting patterns in the global environment (Reid et al., 2005).

Phytoplankton are essential components of aquatic ecosystems because they are the main producers in such ecosystems. They react strongly to changes in the circumstances of their environment. Alterations to the usage of land may not only have an effect on water quality but also function as a factor in the variety of aquatic life (Camara et al., 2019a; Katsiapi et al., 2012; Russo et al., 2016). We may get a better understanding of the effects of climate change and human activities on aquatic ecosystems if we study the reactions of the organisms that live in such habitats (Luo et al., 2022).

It has been suggested by a few studies that the water quality of Iraq's bodies of water is deteriorating (Chabuk et al., 2020; Issa et al., 2013) because of the wastewater discharge from municipal sources, the growth of urbanization, and the expansion of agricultural operations (Al Obaidy & Al-Khateeb, 2013; Farhan et al., 2020a; Hajong & Ramanujam, 2017). As a result of this, the river that runs through the Mosul city is susceptible to a broad variety of point and diffuse pollution. Conversely, there is a notable gap in understanding the communities of phytoplankton present at the city of Mosul and their adaptation to the altered water quality.

Tigris River within Mosul city is subjected to different sources of pollution, which can be mainly resulted from the agricultural activities and anthropogenic activities in the urban areas. Phytoplankton is very important in indicating the changing in the water quality in different zones of the river as bioindicators, as well as the physical-chemical variables will indicate the changes in the water quality as result of the land use in the study area.

1.3. 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?*

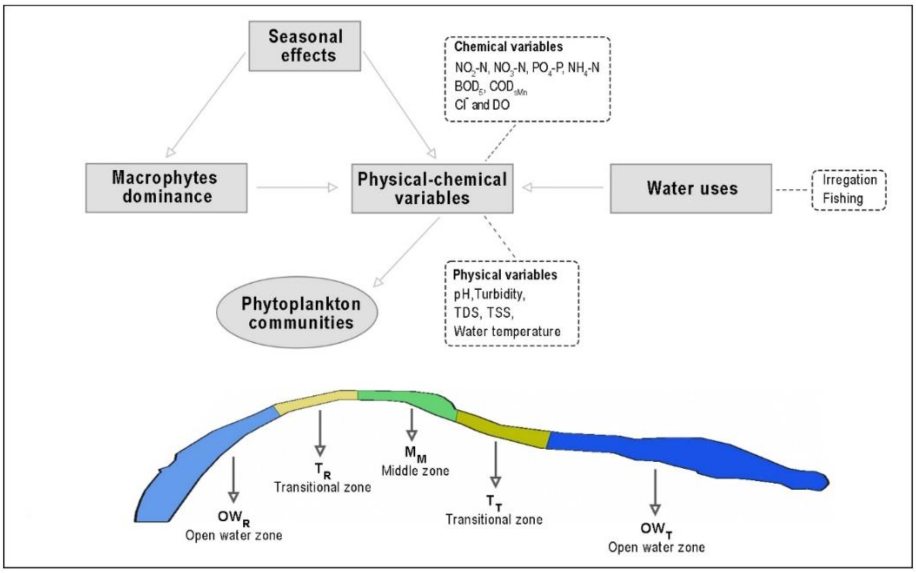


Figure 1: Conceptual figure for Nagy-Morotva oxbow shallow lake

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)?*

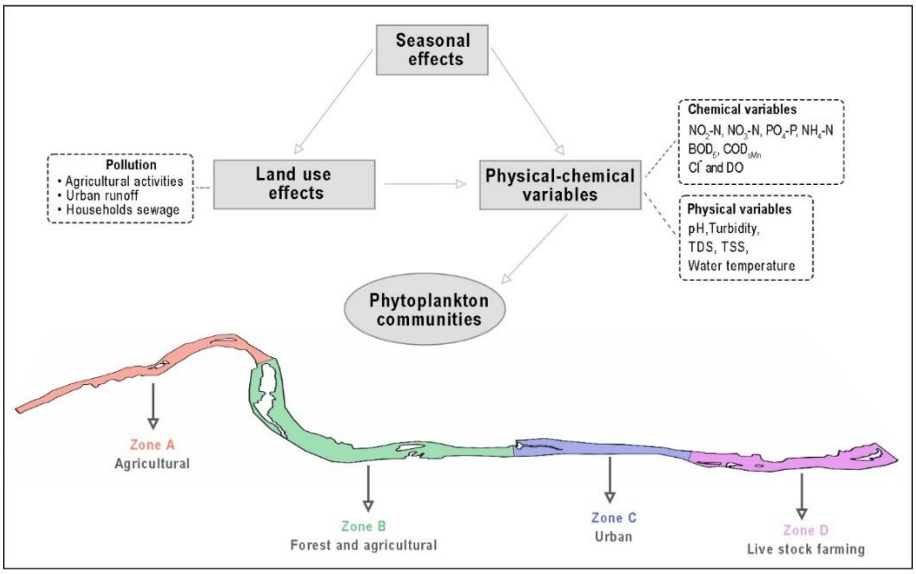


Figure 2: Conceptual figure for the Tigris River inside Mosul

2. LITERATURE REVIEW

2.1. Water quality

As humans worked on devising strategies to regulate water resources, they concurrently noticed variations in characteristics like odor, temperature, taste, color, and more among water derived from diverse sources. The characteristics of water quality exhibit variation based on the intended utilization of the water body water (Herrera-Silveira & Morales-Ojeda, 2009; K. Li, 2022).

Clear water is preferable for home use over turbid water, whereas salty water is not suited for human consumption, cattle consumption, or irrigation. People and animals may become ill or even die from drinking contaminated water (Cheng et al., 2022b). Any and all chemical, physical, or biological characteristics of water that have an effect on either human consumption or natural ecological systems are considered water quality factors. Irrigation water should be free of phytotoxic chemicals and have a mineral content that does not cause negative osmotic effects on plants (Ahmed et al., 2021). The quality of the water used in manufacturing is vital, and it must be suitable for the process. The quality of the structure and functionality of surface water ecosystems is determined by ecological state and potential. The ecological state is used as a proxy for the general condition of water bodies and is impacted by water quality (such as pollution). Water utilized for industrial, agricultural, or home reasons is ultimately released into natural water bodies, and this is a major contributor to the degradation of water quality (Boyd, 2000a; van Kats et al., 2022).

2.1.1. Seasonal changing effects

Seasonal fluctuations, particularly changes in temperature and precipitation, can significantly impact the quality of water. Rising temperatures are closely linked to eutrophication, a process that involves increased nutrient levels in water bodies. Based on a study conducted by Feuchtmayr (Feuchtmayr et al., 2009), higher water temperatures were found to be associated with elevated concentrations of dissolved phosphate, leading to greater plant biomass and reduced fish biomass. Excessive nitrogen levels combined with elevated temperatures also contributed to a decrease in plant species diversity. Additionally, it was observed that warming had a more pronounced effect on promoting the growth of macrophytes (aquatic plants) compared to phytoplankton.

Moreover, a study conducted by Kaushal et al. (2013) revealed that the growing concentration of atmospheric carbon dioxide had a significant impact on stream alkalinity and the solubility of limestone. The researchers put forward a hypothesis that the elevated alkalinity levels could enhance the availability of inorganic carbon for photosynthesis, potentially accelerating eutrophication in aquatic environments. Additionally, they suggested that elevated stream pH levels could exacerbate the problem of high concentrations of ammonia nitrogen by elevating the proportion of NH_3 which is toxic compared to NH_4^+.

2.1.2. Pollution effect

Pollutants should not contaminate surface water as much as possible. Organic compounds, radionuclides, heavy metals, microplastic, pharmaceuticals, and microbes are potential contaminants (Hemond & Elizabeth Fechner, 2015; Zhang et al., 2018a). Surface waterways may be contaminated by municipal discharges, agriculture, industry, and environmental alterations that create runoff. Human and animal waste may enter runoff and direct discharges (Werth, 2005). Faeces may include viral, bacterial, protozoan, and helminth infections. Ineffective water treatment and protection may expose the population to intestinal and other infectious diseases (Abel, 1996).

2.2. Surface water pollution source

The pollution that effecting the surface water can be came from different sources, which can be categorized into point and non-point source pollution. Point source pollution, refer to localized, discrete, and often readily measurable pollutants discharges. such as industrial outflows, pipe discharges, tributaries, or treatment plant wastewater outflows are relatively easy to regulate and define (Hemond & Fechner, 2015; Ritter & Adel Shirmohammadi, 2001).

Furthermore, non-point source pollution is generated by both human activities and natural factors. Contaminants can be transported into surface water bodies through snowmelt and rainfall. These contaminants include fertilizers, insecticides, and herbicides from agricultural fields and residential areas, as well as toxic chemicals, grease, and oil from urban runoff and energy plants. Sediment can also originate from inadequately managed construction sites, forest and croplands, and eroding stream banks. Additionally, salt can be a product of acid drainage and abandoned mine irrigation practices, while nutrients and bacteria can stem from livestock, malfunctioning septic systems, and pet waste can be source of polution (Hemond & Fechner, 2015). Non-point source pollution is difficult to control, which makes it a big concern for surface waterways since its source is hard to identify. Surveys of Land use and water quality testing are sometimes the only means to find non-point sources.

2.3. Pollution effects on surface water bodies

2.3.1. Water pollution in lakes

Lakes are characterized by lengthy hydraulic residence durations and a relatively limited capacity for decontamination (Liu & Wang, 2013). Lakes that are situated near cities are often used for a variety of purposes, including the provision of drinking water, the promotion of recreational activities, and the receiving of urban pollutants (Xu et al., 2020). Hence, it is crucial to find an equilibrium between the diverse demands placed on water resources. Deep lakes are often thermally stratified, with the water that has the greatest density situated at the lake bottom (the hypolimnion) and the water that has a lower density placed in (epilimnion) the top layer (Boehrer & Schultze, 2008). The hypolimnion is colder than the epilimnion, which is warmer than the surface layer of the water. The epilimnion is totally mixed by the wind and the waves. Both of these layers are separated from one another by a distinct physical boundary that is referred to as a thermocline and normally has a thickness that ranges from ten to twenty meters (Dake & Harleman, 1969; Yu et al., 2010). The wind's ability to stir up the water in shallow lakes prevents the formation of stratification. Evaporation is responsible for a significant portion of the water that is lost from lakes and reservoirs, which is one of their most distinguishing features (Monismith, 1985).

Acidification is one of the most significant concerns that has been reported in lakes that are found in temperate climates. It happens in lakes that are low in alkalinity, conductivity, dissolved solids, and hardness and is produced by acidic depositions that are generated by air pollution. These characteristics are often seen in lakes that are situated in regions that do not have carbonated soils (such as quartz sandstones or crystalline rocks) and that have climates that are classified as moderate (Moldan et al., 2013; Schindler et al., 1985).

The natural process of an increase in the salinity of lake waters takes place to a greater degree in rivers and lakes that have significant rates of evaporation. This kind of increase in salinity is known as halitosis. This process is sped up by saline inflows into lakes, which also restricts the uses that may be made of water (Williams, 1998). When the predominant minerals in a lake are bicarbonates and carbonates, the water undergoes alkalization and exhibits a soapy nature, resulting in the formation of soda lakes. These lakes are widely recognized as a major threat to water quality (Boros & Kolpakova, 2018).

Eutrophication is a natural process that happens as a body of water "ages," and pollution can speed up the process (Qin et al., 2013). There are four phases that a lake goes through on its way to becoming eutrophic: oligotrophic, mesotrophic, eutrophic, and hypereutrophic in extreme cases. Oligotrophic lakes are distinguished from other types of lakes by their low nutrient contents and low levels of biological production (Capblancq, 1990). When polluted water runoff and soil leaching can increase the nutrient content of the lake, fauna and flora also grow in lakes. Phytoplankton and other aquatic plants will begin to multiply unnaturally if huge quantities of nutrients, particularly phosphorus and nitrogen, are introduced (Balls et al., 1989). This will cause the surface of the lake to get covered, which will prevent sunlight and oxygen from entering the water (Herrera-Silveira & Morales-Ojeda, 2009). During the daytime hours, primary production is higher than the bacterial degradation of algae under these circumstances. In the middle of the day, the oxygen concentration may exceed 200% of its saturation level and the pH value may approach 10 or higher. During the night, the opposite occurs: the concentration of oxygen falls to fifty percent of its saturation level, and the pH falls to a level lower than 8.5. During the daytime, achieving oxygen saturation might be challenging if the lake is also subjected to the presence of biodegradable organic pollutants (Castaño, 2019; Zhang et al., 2009). Both the flora and the sediments become anaerobic because of a lack of sunshine, which ultimately leads to the death of the flora. When this happens, the natural ecosystem of lakes is disrupted, and lake subjected to eutrophication. During an extended period of time, the lake dries up and transforms into a marsh as a result of the buildup of silt and the increased rates of evapotranspiration induced by the plants that grow on its surface (Xu et al., 2023).

shallow lakes such as oxbow lakes are another kind of standing water which is that is regarded as an ecological hotspot inside river floodplains due to the numerous taxa of flora and fauna that may be found there (Ward et al., 2002). Several aquatic ecosystems have undergone substantial changes as a result of either natural or artificial influences. The significance of these ecosystems in delivering ecosystem services makes their disruption or human exploitation a source of widespread distress (Berta et al., 2019; Vincent, 2009).

The following are examples of common lake changes that may be attributed to eutrophication (Castaño, 2019):

- A reduction in the biodiversity of the area and the migration of the native species.
- Once eutrophic lakes are linked to irrigation zones or the supply channels of hydroelectric facilities, this may cause a clogging or blocking of these waterways.
- Tourism, leisure activities, and fishing might be restricted.

Reservoirs that were constructed need time to age before they have characteristics similar to those of natural lakes. The water levels in reservoirs constantly vary because they are used for a variety of functions, such as drinking water, storing, generating hydroelectric power, and preventing flooding. As a result of water abstraction, the normal thermal stratification is disturbed. The most obvious consequence of damming a river is the conversion of its flowing water into stagnant water, which in turn reduces the river's ability to self-purify and promotes eutrophication (Zhang et al., 2023).

2.3.2. Water pollution in rivers

River characteristics may differ greatly based on a variety of factors, including climate, sources of pollutants, flow velocities, catchment characteristics, etc. In general, river flows are very changeable both in space and time (cyclic and annual fluctuation) due to the fact that geography, climate, and basin conditions all play a role in the process (Du et al., 2022; Xu et al., 2022). Vertical mixing in rivers is often rather high because of the presence of turbulence and current, but complete lateral mixing may need some distance to occur (Jiang et al., 2022). Rivers play a crucial role in the movement of pollutants, particularly those that linger in the environment, from the site of pollutant input to the discharge point into other water bodies such as lakes, rivers, wetlands, aquifers, reservoirs, marine waters, and estuaries (Mokarram et al., 2022; Pendergraft et al., 2023). The natural variation in water quality in a river is caused by the interaction of a number of different environmental factors. These factors include the presence of highly soluble minerals, the thickness of the surface above the bedrock, the percentage of the annual precipitation amount of the river catchment to the annual river streamflow, the presence of peatbogs, wetlands, and marshes, and the contributions of phosphorus, nitrogen, silicon, magnesium, calcium, sodium, and potassium (Shu et al., 2022). Urban regions influence riverine suspended solids, temperature, turbidity, organic matter, and feculent pollution indicators through the discharge of wastewaters (Wang et al., 2022). Evaporation, flow turbulence, absorption by primary production, sediments, and organic matter oxidation are all examples of the self-purification processes that occur in rivers and regulate soluble chemicals in riverine water (Milišić et al., 2023). The levels of dissolved oxygen (DO) can be influenced by various factors, including the natural characteristics of water such as salinity and temperature, as well as the presence of an excessive number of aquatic organisms. Human activities, such as sewage waste, clearing land, and runoff, also exert an influence on DO levels in water (Liu et al., 2019). The electrical conductivity, pH, and precipitation of soluble compounds may all rise during evaporation (Stewart et al., 2022). Reduced amounts of nutrients, soluble metals, dissolved organic carbon, and organic micropollutants may be the outcome of sediment absorption (Castaño, 2019). Primary production may result in a decline in the amount of nutrients consumed, an increase in precipitates, and a rise in DO and dissolved organic carbon DOC (Bernhardt et al., 2022). In addition, the oxidation of organic matter in anoxic sediment or the water column with low pH, raises dissolved nutrients, decreases DO and DOC, and may even raise soluble metal concentrations through desorption (Shah & Parveen, 2022). Eutrophication in rivers could be brought on by an excess of nutrients, especially in cases where rivers are dammed for periods longer than a month (He et al., 2022). Reduced oxygen concentration will alter the pH and release ammonia (NH_3), which has a significant negative influence on fish. Issues with water's smell and flavor may arise when eutrophication leads to an overabundance of phytoplankton in rivers with extremely low flow rates (Rahangdale et al., 2022). Increased salinity (total dissolved solids TDS and total suspended solids TSS), acidity, and greater amounts of nitrates and trace elements are further consequences seen in rivers. The Cl^-, Na^+, SO_4^{2-}, and CO_3^{2-} concentrations in rivers rise due to industrial, sewage, and mining sewage discharges. Soil degradation and water evaporation may also contribute to elevated TDS in rivers (Li et al., 2022). More treatment expenditures are incurred for reducing TDS if such waters are utilized for water supply. Overall, nitrates may reach high amounts in certain rivers due to contaminated runoff from homes and factories. As oxygen levels drop in a river, a process known as denitrification occurs, releasing nitrogen from the riverbed into the water column. When the concentration of oxidized nitrogen in river water exceeds 10 mg N/L, it is no longer safe for human consumption (Cai et al., 2022; Castaño, 2019).

2.4. Impact of land use on surface water quality

The rise in worldwide population has led to an increase in the need for economic development, which includes, but is not limited to, greater food production as well as residential land for people (Baker, 2005). Much natural area has been intentionally transformed into housing and farming to meet people's needs for shelter and sustenance. Increasing the intensity of arable land usage and having a deleterious effect on environmental health and regional water is a direct result of people using excessive quantities of fertilizers and pesticides to counteract the consequences of declining arable land area and fertility (Mello et al., 2020). Urbanization, population growth, economic activity, energy needs, and climatic shifts have increased stress on the world's water supplies and the infrastructure that supports them (Huang et al., 2013). The hydraulic structures that provide irrigation and water resources as the world's population has grown (Cheng et al., 2022b). However, the rapid growth of both light and heavy industries around the world in recent years has led to a huge rise in the amount of water used. Urban areas, agricultural areas, and forested areas are the three categories of land use that have been shown by different studies to have the greatest impact on the water quality (Clark et al., 2022; Gorgoglione et al., 2020; Kronvang et al., 2020; Tahiru et al., 2020). When it comes to the aquatic environment, construction land and agricultural land are the worst adverse effect, while forested land is the least effect on the water quality. Agricultural land can have a large negative impact in large buffers, but has a lower effect in small buffers. Human activity is concentrated in domestic sewage discharge, and Industrial wastewater contribute to pollution (Zhang et al., 2022). As phosphorus, nitrogen, and other components are hardly absorbed by the soil during the migration process, the use of fertilizers and pesticides is the primary factor in pollution to the aquatic environment throughout agricultural land uses (Ahmed et al., 2022).

2.4.1. Impact of agricultural land use on surface water quality

According to Stoate (Stoate et al., 2009), the use of fertilizers, pesticides, and other agricultural chemicals in irrigation systems, as well as the growing of crops, have a detrimental impact on water quality. Many studies have demonstrated that row crops and other types of intensive planting, environment and biological combinations, and the expansion of agricultural land all have a significant influence on the conditions of rivers (Dillon & Kirchner, 1975; Wang et al., 2019). It has been shown that the yields of dissolved organic matter (DOM), sediment, total phosphorus (TP), and total nitrogen (TN) in surface water bodies in the region would rise as more area was reclaimed for agricultural use (Ni et al., 2021). A weakening of the riparian zone and declining values of many ecological indices are indicators of low ecological quality in rivers that are affected by agricultural use (Lacher et al., 2019a). Watersheds that contain a lot of farming activities have been shown in many research studies from a wide range of countries (Gu et al., 2015; Neill, 1989) to release more phosphorus and nitrogen into the environment. Large amounts of phosphorus and nitrogen fertilizers are often given to crops throughout their development, and the fertilizers that are not taken up by the plants are washed into rivers by splashing rain, runoff, and infiltration leaching, where they trigger chemical processes known as nitrification and denitrification (Camara et al., 2019b; Jaworski et al., 1992). Furthermore, runoff from fertile agriculture carries extra nitrogen and phosphorus into nearby waterways, where it increases eutrophication and decreases algae, microorganisms, aquatic higher plants, and many different taxa of invertebrates and vertebrates (Yang et al., 2020). Overuse of pesticides and chemical fertilizers may also harm water quality; for example, rising pesticide and fertilizer use was linked to higher nutrient fluxes and the extinction of aquatic plants in the Mississippi River (Turner & Rabalais, 1991), the Odense Fjord catchment (Molina-Navarro et al., 2018), and lake basin of Chaohu (Yang et al., 2020). Due to intensive fertilizer applications, agricultural nonpoint source contamination has become generally recognized as a crucial nutrient input into surface waterways (Huang et al., 2021). Researchers have also determined that surface water bodies in the environment were polluted even more by the direct discharge of untreated agricultural wastewater from heavily farmed rice fields (Thu Minh et al., 2020). In certain areas, raising livestock is a considerably more important part of agriculture than cultivating crops. Large quantities of phosphorus, nitrogen, and other fertilizer materials may be found in animal manure, and effluent from livestock barns is often dumped straight into waterways (Samways, 2022). Water pollution may also be caused by surface runoff and groundwater seepage from an abundance of the storage of sewage and manure in the field from animal barns in ponds (Cesoniene et al., 2019).

2.4.1.1. Impact on standing and running water bodies

Agriculture activities can negatively effect on both running and standing water bodies in different was. A study at Tonle Sap Lake in Cambodia revealed that the agriculture land use has a significant impact on the water quality on the lake due the agricultural runoff (Wai et al., 2022).

The water quality of Lake Balaton (596 km2) in Hungary declined substantially between 1970 and 1980 as a result of phosphorus-induced eutrophication, whereas primary production grew by a factor of four to eight and blooms of nitrogen-fixing cyanobacteria occurred often (Istvánovics et al., 2007). During the 1980s, most fish populations were already in trouble due to the loss of native fish and the introduction of new foreign species (Biró et al., 2008). There was a significant improvement in water quality and a decrease in phytoplankton biomass after the fall of communist agriculture, and the phosphorus output from agriculture was decreased by half between 1980–1988 and 1989–2002 (Hajnal & Padisák, 2008; Istvánovics et al., 2007).

The agricultural land use can have a high impact on the quality of the running water. A considerable proportion of agricultural land area in the basin is positively connected with total phosphorus content, which has a significant effect on water quality in Thailand. Which suggests that agricultural land acts as a source for the pollution load of biochemical oxygen demand (BOD) and phosphorus (TP) in the river (Tian et al., 2019).

2.4.2. Impact of urban land use on surface water quality

Deterioration of water quality is particularly common in regions where human activity and land use change are more prominent, especially in regions undergoing fast urbanization (Lacher et al., 2019b). As a result of ongoing fast population increase and urbanization, the rapidly rising industry and construction land area are having a significant negative impact on the natural environment, particularly the water and the soil

(Dewan & Yamaguchi, 2009). While nutrients, metals, pharmaceuticals, and harmful compounds all eventually find their way into water bodies, the amount of pollution has a direct effect. Increases in impervious surfaces are a common effect of fast urbanization and other changes in land use and land cover at the regional scale (Delphin et al., 2016; Z. Wang et al., 2020). A major contributor to the degradation of the aquatic environment is the expansion of impervious surfaces, which in turn causes an increase in surface runoff, soil erosion, and non-point source pollution (Lin et al., 2020). These consequences for water quality are caused by an increase in runoff and the facilitation of the spread of nonpoint source contaminants, both of which have a detrimental effect on water resources (Li et al., 2018; McGrane, 2016). Accelerating urbanization destroys and alters the natural environment, leading to a substantial rise in peak flows and runoff, which in turn alters the temporal and spatial patterns of water discharge and the processes of the hydrological cycle in urban areas, so altering the water balance in the region (Kumar, 2021). Sewage discharge may also cause regional and temporal fluctuations in nutrient flows in urbanized basins as a result of variations in nutrient removal and sewage treatment technology effectiveness, which results in impacting the water quality (Adeola Fashae et al., 2019; Hale et al., 2015). When it rains heavily or something similar happens in a city, a lot of water may rush through the watershed all at once, bringing a lot of nutrients, pollutants, and sediments with it (Zhang et al., 2020). Streams and rivers that drain heavily populated areas can have a lot of nitrogen and phosphorus in them (Marti et al., 2004). Due to point pollution sources like sewage farms, the amount of nutrients in waterways that flow into cities is quite high (Xian et al., 2019).

The destiny and erosion mode of water contaminants are linked to processes including runoff, interception, evapotranspiration, and emission. Simultaneously, large quantities of domestic sewage and industrial wastewater generated by human actions in diffused urban areas worsen water degradation (Ding et al., 2016). This is a reflection of how, despite improvements in urbanization, economy, and population in the basin, treatment and sewage collection facilities in distributed urban areas have not maintained with the growth speed and scale of city and population, putting heavy demands on river water bodies (Dong et al., 2020). Furthermore, the storage of water resources in the basin has been altered, the efficiency of water resource consumption has decreased, and the natural degradation operation of pollutants has been disrupted because of the building of dams and reservoirs to meet the increasing needs of urban population's water consumption (Zhao & Jin, 2021).

2.4.2.1. Impact on standing water and running water bodies

Urban areas can have a negative effect on the quality of water because of the anthropogenic activities which can decrease the quality of water in the both running and standing water bodies. The size and quality of the lake's water have both been affected by urbanization and changes in land use. When the area around the Nallurhalli lake expanded without proper planning (Mundoli et al., 2015), sewage from houses and waste from neighboring poultry businesses were emptied straight into the waterways that fed the lake. As a result, the lake's water seems visibly contaminated.

As cities grow and riparian zones get worse, most urban streams and rivers have a lot of nitrogen, phosphorus, and organic waste in them (França et al., 2019). The River das Velhas in Minas Gerais State is an example of how the water quality was severely deteriorated because of the pollution from industrial and domestic sewage in Belo Horizonte (de Oliveira et al., 2016; dos Santos Pompeu et al., 2005).

2.4.3. Impact of forest land use on surface water quality

Total nitrogen and total phosphorus levels in the watershed usually decrease as the extent of forested land grows due to the adsorption and fixation of pollutants by trees, which act as sources for river nutrients (Cheng et al., 2022a). Trees, with their highly developed leaves and roots, are superior than shrubs and grasses in their ability to remove nutrients from basin soils (Lintern et al., 2018). The chemical composition of rainfall is found to undergo substantial changes after it has passed over the forest canopy, according to several scientific investigations (Jachniak et al., 2019). Changes in nutrient content in penetrating rain flow are caused, for example, by rainwater showering on the surface exudates of vegetation bodies, the uptake of rainwater ions by leaves and branches, and the rinsing of solid sediments like dust and particles from the surface of branches and leaves (Rolando et al., 2017; van Dijk & Keenan, 2007; Vermaat et al., 2021).

Certain types of forests, such as riparian forests, alluvial forests, and hedgerow farmlands, are known to have a purifying influence on the environment (Bawa & Dwivedi, 2019; Gong et al., 2021). Important considerations in preserving river water quality include the wide distribution of forest land, the aggregation and connectedness of the basin, the management of contaminants entering the river, as well as the arrangement of forest land in the riverbanks (below 100 m) (Townsend et al., 2012). Consistent with studies stressing forests' capacity to lessen the amounts of nutrients and sediment in nearby bodies of water (Bawa & Dwivedi, 2019), several studies have shown a positive relationship between forest area and water quality.

2.4.3.1. Impact on standing water and running water quality

Reservoirs are often built in forested areas because forests are good places to catch water because of their natural features. For example, the plant's physiology can control how much water it loses through evaporation; the structure of the canopy determines how much water is caught and stored; and the depth, density, and structure of the roots affect how much water a plant can take in and how well it can soak it up (Sulaiman et al., 2018). Studies of the Coastal Mountains' hydrology have consistently shown that harvested regions create more runoff than wooded areas. Studies of how water moves through the Coastal Mountains have shown over and over that areas that have been deforested create more runoff than areas that have been left alone (Smerdon et al., 2009). Another study found that when forest land is turned into grassland or farmland, evapotranspiration values go down and surface flow goes up (Dwarakish & Ganasri, 2015).

Streams and rivers that flow through forested regions tend to have high water quality (Duffy et al., 2020). Yet, the aquatic ecosystem may be negatively impacted by the way forests are managed. Disperse pollution, carbon transfer, and negative impacts on freshwater ecosystem are major causes for concern (Shah et al., 2022). Douglas et al. (Ian Douglas et al., 1992; Oda et al., 2011) have shown how important it is to keep an eye on both base flows and storm flows when figuring out how harvesting affects the water quality in a stream. Nitrate levels in the base flow reached their highest level the next year after harvesting (at 28 eq L^{-1}) and then steadily dropped over the subsequent six years.

2.5. Water Quality Monitoring

Conducting water quality monitoring serves as a means to safeguard water sources by identifying pollutant locations and their concentrations within a water body. Monitoring activities are typically carried out several times throughout the year due to the potential variations in water quality associated with seasonal changes and weather events (Boyd, 2020b). The quality of water can be monitored by measuring chemical, physical, and biological characteristics of the water which can provide information on:

- Hydrological shifts as a result of environmental influences.
  Major changes in lake hydrology may be tracked by keeping an eye on the phytoplankton population. For example, diatoms that can tolerate water column mixing (such as *Cyclotella*, *Asterionella*) and coccoid green algae (such as *Kirchneriella*, *Schroederia*) are characteristic of floodplain lakes that are inundated during times of significant rainfall (Bellinger & Sigee, 2015a; Stević et al., 2013). Hydrological shifts such as runoff can affect significantly on rivers water quality, this effect determined by potential evapo-transpiration and seasonal precipitation distribution which results in changing the physical-chemcaical variables and phytoplankton composition in the river ecosystem (Qu et al., 2017).
- Changes in dynamics that occur over the seasons.
  In temperate lakes, they include hydrological measures (residence time and water flows), chemical and thermal stratification, and fluctuations in nutrient concentration at the lake's surface. Towards the late summer (end of stratification), levels of phosphates and nitrates in the epilimnion can drop to low concentrations. At this point, the lake may be occupied by algae such as Dinoflagellata (e.g. *Ceratium*) and colonial cyanobacteria (e.g. *Microcystis*), which can move out diurnal migrations into the nutrient-rich hypolimnion (Bellinger & Sigee, 2015a). Water quality in the river ecosystem varied between the seasons, Pesticides, fertilizer residues, and agriculture runoff reach the river mainly during the rainy season (Wen et al., 2017b).
- Ecosystems are categorized based on factors such as quality of water, productivity, and species composition.
  Eutrophic, mesotrophic, and oligotrophic systems are the categories that result from classifying ecosystems according to the concentrations of nutrients and chlorophyll concentration. This classification scheme is used for both lentic and lotic systems. Identifying and examining indicator algae may offer a speedy indication of the trophic state of freshwater bodies and the

possibility of human pollution (Baldy et al., 2007; Watanabe et al., 2015).

- Point or diffuse nutrient and pollutant loading dynamics.
  Benthic algal communities allow researchers to examine the localized or dispersed entry of pollutants. These littoral algae may be useful in lakes and rivers, because the quality of the water at the lake's border is largely determined by the kinds of runoff that enter the lake and river from the surrounding landscape (Scheffer, 2004b; Xia et al., 2020a).
- Impacts resulted by humans
  Eutrophication, a rise in organic pollutants, heavy metal pollution, and acidification are only some of the anthropogenic impacts that are being tracked over the long term in both river and lake ecosystem (Kling et al., 2001; Zia et al., 2013b).
- Safeness of drinking water and other uses for humans.
  It also involves ensuring the water is safe for drinking and swimming according to the rules. If colonial cyanobacteria populations build up and algal toxin concentrations rise, lakes and rivers may have to stop being used to provide drinking water and recreation places for people (Farhan et al., 2020b; Grigorszky et al., 2019).
  Cyanobacteria development throughout the summer season is now an integral aspect of water management for many aquatic systems, necessitating implementing a reactive monitoring strategy (Sigee, 2005).

2.5.1. Physical Characteristics of Water

Physical measurements encompass various aspects such as water temperature, electrical conductivity, flow velocity, total dissolved solids, turbidity, and the condition of stream or lake banks. These physical characteristics often have connections to chemical parameters. For instance, eroded stream banks can contribute to reduced flow, while high levels of suspended solids can lead to a decrease in dissolved oxygen content. The study in question involved the measurement of numerous physical parameters, including water temperature, conductivity, total dissolved solids, total suspended solids, turbidity, transparency (using a secchi-disk), and water depth.

2.5.1.1. Water Temperature

Water temperature has the potential to influence both biological and chemical variables of water, as many chemical and biological processes exhibit changes in their rates in response to temperature fluctuations (Delpla et al., 2009). The biological quality of water can be influenced by temperature, as it affects the survival rates of species at various temperature ranges. Consequently, changes in temperature can lead to fluctuations in the composition and overall quality of the aquatic ecosystem (Duque et al., 2020). Dissolved oxygen content and its saturation is significantly affected by the variation of chemical characteristic that varies with the temperature (Butcher & Covington, 1995). Under identical situations, turbid water temperatures are greater. Because suspended particles absorb heat, the water becomes cloudy (Boyd, 2015a).

2.5.1.2. Conductivity

Electrical conductivity is a fundamental property of materials that describes their ability to conduct electric current. The measure of the ability of water to conduct an electrical current is referred to as specific conductance (Walton, 1989). The presence of inorganic dissolved solids that carry a charge is responsible for the phenomenon of high conductivity. Calcium, iron, sulphate, and chloride ions are among the dissolved solids that exhibit electrical conductivity. Both natural and anthropogenic factors in the watershed can impact the specific conductance of surface water (Demir & doğan demir, 2019; G. Zhu et al., 2020).

The geographical characteristics of a region can have a notable impact on the inherent conductivity of water in a surface water body. The electrical conductivity of surface water may exhibit variability contingent upon the nature of the soil or rock with which it was in contact. Water that has undergone interaction with clay soils is typically characterized by elevated conductivity, whereas water that has undergone interaction with granite bedrock is typically characterized by reduced conductivity (Topp et al., 1988).

Biological activity is considered as another cause for the natural variation in surface water conductivity. For example, the conductivity of the water can be affected by biological processes such as decaying of organic matters. When the plant matter degradation increases the dissolved solids as well as the conductivity in water will increase (Aguado et al., 2006; Dexter et al., 1932). Therefore, seasonal variation in the biological activity can affect the trends of conductivity levels in different seasons.

Anthropogenic actions within a given catchment area have the potential to exert an impact on the electrical conductivity of water bodies at the surface. The conductivity of surface water can be altered by the introduction of pollutants via runoff, resulting in either an increase or decrease. The conductivity of water can be reduced by the presence of organic compounds, such as alcohol or oil, due to their inherent inability to carry an electric charge. The presence of impervious surfaces in a significant proportion of regions, particularly urban areas, can result in the production of runoff that contains oils. This may lead to a reduction in the conductivity of surface water located in close proximity (Rusydi, 2018; P. Zhu et al., 2022). Residential and agricultural land uses within a watershed have the potential to increase the conductivity of surface waters (McManus et al., 2020). A leakage in septic system near a surface water body could raise the surface water conductivity due to the presence of phosphate, chloride, and nitrate (Abong'o et al., 2016).

2.5.1.3. Transparency

Pure water appears colourless when it held in a clear drinking glass in sunlight, but clear water in larger amounts tend to have a blue hue which caused because of the selective absorption and scattering of light. However, the transparency and colour of natural water could be affected by suspended and dissolved substances. The illuminated, upper layer of a body of water in which phototrophic organisms grow is called the photic zone, the bottom of the photic zone is usually considered to receive 1% of light incident (Nielsen et al., 2002). The penetrated light in the surface of water will be scattered and absorbed during it passes through the column of water, and this phenomenon may affect the quality of water (Boyd, 2000b).

2.5.1.4. Turbidity

The amount of suspended particulates in surface water is measured by turbidity. Algal cells, soil particles, and microorganisms are examples of suspended solids (EPA, 2005n). These pollutants can enter a water body mostly through non-point sources of pollution including urban runoff and soil erosion as well as internal processes like algal growth.

Variations in precipitation and the proportion of impervious surface in a watershed can affect the turbidity levels in surface water. A study by

(Long & Plummer, 2004), changes in precipitation can affect the turbidity levels in a tiny stream. Another scientist (Volk et al., 2002) discovered that streams' turbidity levels could rise by up to 300 times during or after precipitation periods.

As a result of sediment loading from erosion and runoff, watersheds with high percentages of impermeable surfaces may have high levels of turbidity in their surface waters (Nelson & Booth, 2002; Mehaffey et al., 2005). On the other hand, (Schoonover et al., 2005) reported that watersheds with higher percentages of impervious surfaces saw lower turbidity concentrations during baseflow.

Turbidity in water bodies considered a limiting factor for phytoplankton abundance by limiting the penetration of light to higher depth and results in decreasing the ability of phytoplankton to live in these kinds of environments (Grobbelaar, 1985; May et al., 2003).

2.5.1.5. Total suspended solid (TSS)

Total suspended solid are all the suspended solid particles in water body, which consisting of abiotic and biotic components that can be trapped by a filter size of 0.45 μm. Suspended solid can be formed from sedimentation which causes many aquatic problems such as coastal erosion, silting of the river, coastline changes. Furthermore, suspended solid impact can increase the turbidity in river water, which effect negatively on the penetration of sunlight into the waters and negatively affecting on the phytoplankton (Taufik Ibrahim & Kusratmoko, 2018).

2.5.1.6. Total Dissolved Solids (TDS)

The concentration of Total Dissolved Solids serves as an indicator of the level of mineralization in freshwater systems (Bodkin et al., 2007). Elevated levels of total dissolved solids (TDS) have the potential to impede various advantageous applications of water. As the (TDS) increases in inland water bodies, the osmotic pressure will correspondingly increase, leading to a reduction in the number of aquatic species capable of tolerating such elevated osmotic pressure levels. The concentrations of TDS in aquatic ecosystems exhibit significant variations across diverse climatic and edaphic regions, thereby impacting the tolerance of aquatic species composition towards dissolved solids (Olson & Hawkins, 2017). Ecosystems harbouring a diverse and thriving freshwater fish population typically exhibit TDS below 1000 mg/l. Nonetheless, certain freshwater species of fish or other kinds of creatures have demonstrated the ability to endure TDS levels as low as 5000 mg/l (Samuel, 2022). The concentrations of Total Dissolved Solids (TDS) exhibit natural fluctuations within estuarine environments, to which the resident species have adapted. The evaluation of inland water's appropriateness for domestic, industrial, and agricultural purposes is heavily reliant on the measurement of the total dissolved solids concentration, which is considered a crucial variable (Deborah Chapman, 1996).

2.5.2. Chemical Characteristics of Water

Chemical water quality indicators can be connected to other biological or physical water quality indicators to help identify causes of pollution. Chemical monitoring in this study consisted of measuring pH, dissolved oxygen, biological oxidation demand (BOD_5), chemical oxygen demand (COD), chloride (Cl^-), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), ammonium nitrite (NH_4-N), orthophosphate (PO_4-P), total phosphorus, Kjeldahl nitrogen, sulphate ion (SO_4^{2-}), hydrogen carbonate (HCO_3^-), carbonate (CO_3^{2-}), humic acid, chlorophyll-a.

2.5.2.1. pH

Acid rain, nearby rock formations, and some wastewater discharges all have an impact on the pH, which is a measurement of the quantity of free H+ ions. The pH range that most freshwater aquatic species enjoy is 6.5 to 8.0. The groups of organisms found in surface water will alter depending on whether the pH is high or low since different groups of organisms require different pH ranges. Additionally, harmful substances and metals may become accessible and mobile for organism uptake when the pH is low (Boyd, 2020c).

Humid water areas that have high leaching soils tend to have lower pH than waters with the formation of limestone or those in arid or semi-arid regions. However, the pH in natural waters ranged between 6 to 9 (Sham et al., 2010).

2.5.2.2. Dissolved Oxygen (DO)

The presence of Dissolved Oxygen in aquatic environments is attributed to the oxygen produced by photosynthetic organisms that are living in water and atmospheric. The composition of the atmosphere comprises roughly 200,000 parts per million (ppm) or 20% oxygen.

Conversely, the oxygen levels in surface waters are typically around 10 ppm (Matsuoka et al., 2005).

There are several variables that can impact the dissolved oxygen levels in a body of water. Moving waters, such as rivers and streams, receive a greater influx of oxygen from the atmosphere compared to standing waters, such as lakes. The saturation of dissolved oxygen in water is higher at lower temperatures compared to higher temperatures. Additionally, it is worth noting that water located at higher altitudes exhibits a reduced saturation level in comparison to water situated at lower altitudes (Jacobsen et al., 2003; Null et al., 2017).

The turbidity of surface water has the potential to impact dissolved oxygen (DO) levels. The presence of elevated levels of turbidity in surface water can lead to a reduction in dissolved oxygen (DO) levels. This is due to the increase in water temperature and the subsequent decrease in photosynthesis, which is caused by the obstruction of sunlight by suspended solids (Irvine et al., 2011).

Dissolved oxygen (DO) levels can provide valuable insights into the presence of oxygen-demanding pollutants that may be introduced into a surface water body through both point and non-point sources. The degradation of organic matter in water by microorganisms results in a reduction in the concentration of dissolved oxygen (DO) due to their consumption of this vital gas. The aforementioned substances with high oxygen requirements may originate from urban runoff, farmland runoff, and septic systems. Specifically, the oxygen demand is increased by the presence of animal waste (from both wildlife and livestock), human waste, and fertilizers (Sánchez et al., 2007).

2.5.2.3. Total alkalinity

The comprehensive measure of titratable base concentration in water is referred to as total alkalinity, which is quantified in terms of calcium carbonate ($CaCO_3$). The alkalinity of water is a crucial parameter, as there exists a correlation between productivity and alkalinity owing to the interdependence between carbon and alkalinity accessibility (Lenka et al., 2020).

Water that have a total alkalinity value between 0 to 50 mg/l have lower productivity than those between 50 to 200 mg/l of total alkalinity concentration. However, productivity tends to decrease at higher alkalinities. Water use is significantly affected by the value of total alkalinity (Beldowski et al., 2010).

The process of dissolving limestone and other minerals in soils and geological formations results in the introduction of CO_3^- and HCO_3^- into natural bodies of water. In freshwater environments, it is typical for total alkalinity concentrations to fall within the range of 5 to 300 mg/l (Moyle, 1949). The process of organic matter decomposition in aquatic environments is a significant contributor to the production of carbon dioxide, which can result in the supersaturation of water with this gas. This phenomenon can lead to the manifestation of elevated levels of total alkalinity in water bodies, which may deviate from anticipated levels calculated based on the equilibrium levels of CO_2 (Beldowski et al., 2010).

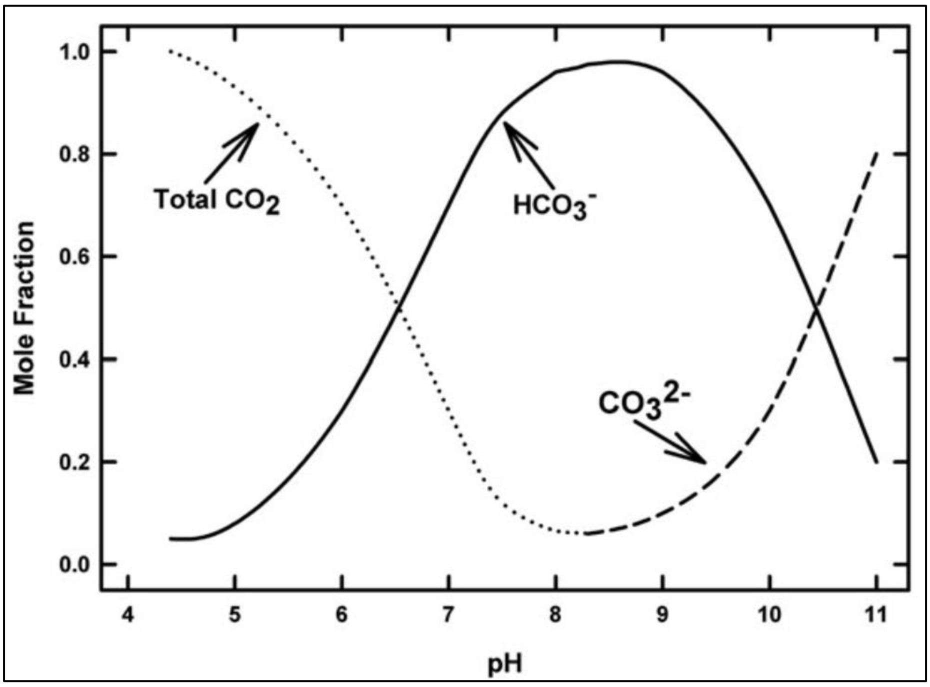


Figure 3: Effects of pH on the relative proportions of total CO_2, HCO_3^-, and CO_3^{2-}. The mole fraction of a component is its decimal fraction of all the moles present (Boyd, 2020b).

Aquatic flora that exhibits tolerance to elevated pH levels utilizes bicarbonate, leading to the accumulation of hydroxyde ions in the surrounding water and a subsequent increase in pH to exceedingly high levels. The aforementioned phenomenon is prevalent in aqueous settings characterized by a diminished presence of calcium, wherein the anions are primarily counterbalanced by magnesium and potassium. Moreover, calcium carbonate can be accumulated on the surfaces of some aquatic plants for using it in photosynthesis which uses bicarbonate as a source of carbon.

The quantity of inorganic carbon present in aquatic plants is contingent upon the levels of alkalinity and pH. At equivalent levels of alkalinity, an increase in pH results in a reduction in the quantity of CO_2. Conversely, at identical pH levels, an increase in alkalinity leads to an elevation in CO_2 concentration (Mandal & Boyd, 1980).

Figure 3 illustrates the interdependent relationship between pH, CO_2, carbonate, and bicarbonate. The graph depicts that inorganic carbon species are predominantly composed of CO_2 when the pH level is less than 5. At a pH level greater than 5, there is a notable increase in the proportion of bicarbonate in relation to CO_2. This trend continues until the HCO_3^- species becomes the predominant form at a pH level of approximately 8.3. At a pH level exceeding 8.3, the carbonate ion (CO_3) becomes evident and its significance surpasses that of the bicarbonate ion (HCO_3^-) as the pH level continues to escalate (Boyd, 2020c).

2.5.2.4. Nutrients

Phosphorus and nitrogen are essential nutrients controlling the productivity of aquatic plant and algae. Whereas, the ratios and amounts of these nutrients differ between species. Redfield (1934) reported that marine phytoplankton included about seven times more nitrogen than phosphorus on a weight basis. In the majority of ecosystems, a higher concentration of phosphorus relative to nitrogen is likely to elicit a more pronounced growth response in plants. The observed phenomenon can be attributed to the rapid elimination of phosphorus from the aqueous phase, followed by its sequestration in the sedimentary layer. Furthermore, the recycling of sediment-bound phosphorus within the water column appears to be constrained. Various mechanisms are involved in the elimination of nitrogen from aquatic systems. Nitrogen is observed to be present in the range of 20-10%, and it is deposited in sediment in the form of organic matter, which undergoes continuous mineralization.

2.5.2.4.1. Nitrogen

The nitrogen constitutes about 78% of the atmosphere. Living things constituent essentially from protein, it contains about 16% of nitrogen

(Boyd, 2020c). Proteins are composed of extended sequences of amino acids that are synthesized by plants utilizing nitrate (NO_3^-) or ammonium (NH_4^+) as nitrogenous substrates. Subsequently, specific microorganisms convert nitrogen to ammonia (Baldani et al., 1997). Amino acids are considered indispensable components of the diets of animals and saprophytic microorganisms due to their incapacity to endogenously produce specific amino acids from their nutritional intake. Nitrogen is a vital component of various biochemical compounds such as haemoglobin, chlorophyll, enzymes, cyanoglobin, and others, found in organisms. Nitrogen is recognized as a significant constituent of metabolic and digestive byproducts that are eliminated by animals, as per the findings of González-López (González-López et al., 2005). Nitrogen is present in various forms of fertilizers, including chemical and organic fertilizers, as well as in feeds utilized in aquaculture and agriculture. The nitrogen content in these substances varies, with urea fertilizer containing the highest amount at 45%, while feeds typically range between 4 to 10%. In contrast, the nitrogen content in livestock manures is less than 1% (Ladha et al., 2005). Atmospheric nitrogen is converted to ammonia by industrial conversion in the process of producing commercial fertilizers (Boyd, 2020a).

Runoff from animal feed lots and agricultural fields, wastes of the units of aquaculture production, many industries, municipal waste treatment plants, food processing plants, and other sources result in inorganic and organic nitrogen pollution of waterbodies (Camargo & Alonso, 2006). Microorganisms are working to decomposed organic nitrogen to ammonia, and increased concentrations of nitrate and ammonia stimulate aquatic plant and algae growth leading to a phenomenon as known eutrophication which is a major water quality problem. Unionized nitrite (NO_2^-) and ammonia (NH_3) at raised concentrations have negatively and toxic effect on aquatic organisms (Hodge et al., 2000). The process of nitrification involves the oxidation of ammonium and ammonia by specific bacterial species, resulting in a reduction of ammonia nitrogen levels. However, it is important to note that nitrification can lead to a decrease in dissolved oxygen levels within the water body and the production of acidity. Excessive nitrogen gas in water can have adverse effects on aquatic animals, including fish, leading to gas bubble trauma in these organisms (Pajares & Bohannan, 2016).

There are different kinds of nitrogen inputs and outputs to the aquatic ecosystems. The primary sources of nitrogen input include inflowing water that contains nitrogen from either anthropogenic or natural sources, precipitation, deliberate nitrogen addition (e.g., in aquaculture), and nitrogen fixation. The aforementioned outputs include water outflow, harvest of aquatic products, seepage, deliberate water withdrawal, ammonia spreading into the atmosphere, and denitrification (Vitousek et al., 2002).

From a biological standpoint, it can be observed that dissolved nitrogen gas lacks the level of reactivity exhibited by dissolved oxygen, and its amounts typically remain in close proximity to saturation levels. Typically, the levels of nitrate nitrogen and ammonia nitrogen in uncontaminated bodies of water are both below 0.25 mg/l. Nevertheless, it is possible for their levels to surpass one milligram per liter in contaminated bodies of water, and it is not unusual for their concentrations to reach 5 to 10 milligrams per liter in heavily polluted waters. In oxygenated water, the level of Nitrite nitrogen is typically below 0.05 mg/l. However, in bodies of water that have been contaminated, the amount of nitrite nitrogen may increase to several milligrams per litre, particularly in instances where the level of dissolved oxygen is low (Boyd, 2020a).

2.5.2.4.1.1. Nitrogen Cycle

The ultimate, natural source of nitrogen available for plants and algae is biological nitrogen fixation from atmosphere. Protein made by plants passes into the food web for making amino nitrogen needed by animals. Faecal material of dead plants and animals or that produced by animals become a congregation of organic matter that is decomposed by bacteria and other decay organisms. Ammonia is excreted by animals or released by organic matter decomposition, then nitrifying bacteria oxidize the ammonia to nitrite, and reduce the nitrate to nitrogen gas, subsequently the denitrifying bacteria is return nitrogen gas into the atmosphere to complete the cycle (Figure. 4) (Boyd, 2020c; Stein & Klotz, 2016).

2.5.2.4.1.1.1. Atmospheric Fixation by Lightning

The atmospheric nitrogen gas is transformed to nitrate or ammonia nitrogen to be used in plants. Lightning is work to transform nitrogen gas to nitric acid by oxidation process. The triple bond of nitrogen atoms breaks by lightning, then letting the nitrogen atoms react with oxygen molecules in the atmosphere in order forming nitric oxide. Rainfall washes nitric acid from the atmosphere. Lightning fixation considered as an important source of plant available nitrogen in high rainfall regions (Boyd, 2015b; Noxon, 1976).

2.5.2.4.1.1.2. Biological Fixation

Water has the ability to dissolve nitrogen gas depending on the tempreture. Although nitrogen is generally considered an unreactive gas, specific strains of bacteria and blue-green algae possess the capability to assimilate molecular nitrogen from the water, convert it into ammonia, and subsequently synthesize amino acids by reacting ammonia with intermediate carbohydrate compounds. Blue-green algae possess the ability to perform nitrogen fixation within their heterocysts. These heterocysts are large, spherical cells that are encased in a thick wall and are present in filaments of various genera such as *Gloeocapsa*, *Anabaena*, *Nostoc*, and a select few others (Boyd, 2000b; Burris & Roberts, 1993).

Certain blue-green algae possess the capability of nitrogen fixation, which confers upon them a competitive edge in terms of nutrient availability vis-à-vis other algae in conditions of low ammonium and nitrate concentrations. However, their rate of nitrogen fixation is subject to a decline when concentrations of ammonia and nitrate nitrogen experience an increase. Microorganisms are known to be more energy-efficient in utilizing nutrients that are already present rather than reducing atmospheric nitrogen. The process of nitrogen fixation exhibits a tendency to diminish in aquatic environments when the proportion of total nitrogen to phosphorus in said environment becomes elevated. At a ratio of 13 in total N: total P or more, nitrogen fixation will stop (Hendzel et al., 1994). This suggests that the rate of nitrogen fixation will increase when adding phosphorus to waters.

2.5.2.4.1.1.3. Industrial fixation

Ammonia can be oxidized to nitrate or used directly by an industrial process. Most N_2 that used for making fertilizers and for use in other industrial applications is from the Haber-Bosch process (Boyd, 2020c; Stein & Klotz, 2016).

2.5.2.4.1.1.4. Mineralization of organic nitrogen

When organic matter decomposed by fungi and bacteria, part of the organic matter that contains nitrogen is converted in microbial biomass to organic nitrogen, some remains in undecomposed organic matter, and the remainder is mineralized (released) to the environment mainly in ammonia form. The decomposition rate of an organic remains depends upon its composition and particularly its ratio of carbon:nitrogen (C/N) (Boyd, 2020a; Stein & Klotz, 2016).

2.5.2.4.1.1.5. Nitrification

During the nitrification, chemoautotrophic bacteria will work on oxidizing ammonia nitrogen to nitrate. The initial oxidation process is carried out by some taxa of Cyanobacteria such as *Nitrosomonas* genus, while the subsequent oxidation is performed by the *Nitrobacter* genus. Typically, the co-occurrence of the two bacterial genera is observed in the surrounding milieu. The nitrite generated in the initial reaction undergoes oxidation in the subsequent reaction to form nitrate, and the accumulation of nitrite is a rare occurrence. During the process of synthesizing the organic matter, light is not required. The nitrification process is highly dependent on the pH value and temperature, whereas the optimum temperature is 25 to 35 ^{0}C and pH between 7 and 8 for a rapid process. The anaerobic and aerobic processes of nitrification produce hydrogen ions, so the process of nitrification contributes to acidity. Aerobic nitrification is contributing highly to oxygen demand in the water bodies that receives high amount of ammonia nitrogen (Boyd, 2000b; Stein & Klotz, 2016).

2.5.2.4.1.1.6. Denitrification

Some bacteria under anaerobic conditions can use nitrate as a source of oxidant for oxidizing organic matter. Methanol is frequently employed as a carbon source in denitrification, particularly in sewage treatment plants. However, in natural settings, bacteria utilize various forms of organic matter for denitrification. Throughout the denitrification process, nitrate nitrogen undergoes conversion into nitrogen gas, which subsequently diffuses into the atmosphere. As result of denitrification process alkalinity of water will be increased (Boyd, 2020c; Stein & Klotz, 2016).

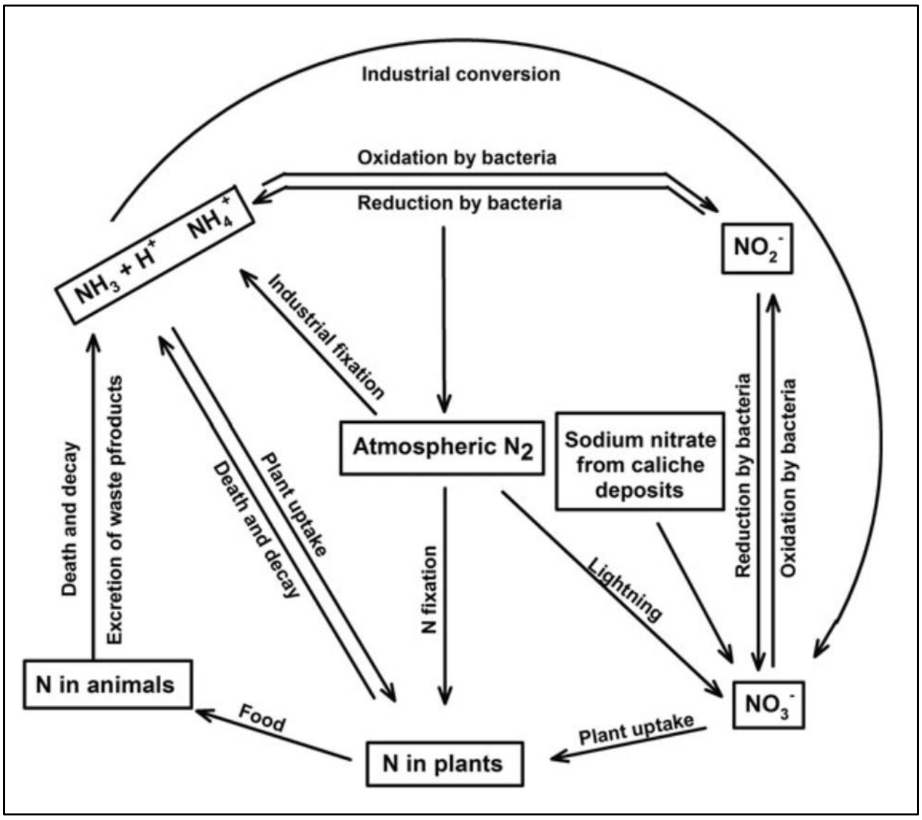


Figure 4: The nitrogen cycle (Boyd, 2020c).

2.5.2.4.1.2. Toxicity of ammonia and nitrite in water

Aquatic organisms primarily excrete ammonia as their nitrogenous waste product, which, similar to other excretory byproducts, can be toxic if not eliminated. An elevated concentration of ammonia in aquatic environments can pose a challenge for organisms to effectively excrete this compound. Consequently, the concentration of ammonia in the bloodstream of fish and other aquatic organisms rises proportionally with an increase in the concentration of environmental ammonia. The diurnal variability of ammonia concentration in aquatic systems is attributed to the modulation of the NH3 to total nitrogen ratio by variations in pH and temperature (Schubaur-Berigan et al., 1995). In aquatic environments, diurnal fluctuations in temperature and pH are commonly observed, with peak values occurring during the afternoon and nadirs being reached near dawn. According to (Doyle & Butler, 1990), various factors besides temperature and pH contribute to the potential toxicity of ammonia nitrogen at a particular concentration. The potential for toxicity of ammonia is comparatively higher in aquatic environments with a pH level that is significantly above neutral, as opposed to those with neutral or acidic pH levels. Numerous research endeavours have demonstrated that ammonia concentrations, even when below lethal thresholds, can result in sluggish growth, reduced appetite, and heightened vulnerability to illnesses (Thurston et al., 1981).

Fish and other organisms have the ability to absorb nitrite from the surrounding water. Methaemoglobin is formed in the fish blood as a result of the reaction between nitrite and haemoglobin. Methaemoglobin cannot be oxidized by oxygen. The presence of excessive amounts of nitrite in water can result in methemoglobinemia, a type of functional anaemia (Lewis & Morris, 1986).

2.5.2.4.2. Phosphorus

Phosphorus plays a crucial role in the environment as it is closely associated with the requirements of plants and algae, thereby serving as a pivotal factor in regulating the primary productivity of both agricultural and natural ecosystems. Phosphorus is an essential nutrient that regulates plant growth in various aquatic environments, and the introduction of excess phosphorus into natural water systems is widely believed to be a primary contributor to eutrophication. The sediment of water exhibits a high degree of absorption of phosphorus, which subsequently becomes bound to compounds of aluminium, iron, and calcium phosphate, and adsorbed onto hydroxides, as well as aluminium and iron oxides (Baldwin, 2013; Thiébaut, 2008).

The solubility of phosphorus mineral forms is pH-dependent, and in nature, instances of high solubility of phosphorus minerals are limited. Typically, the sediment can assimilate the mineralized inorganic phosphorus provided it is not rapidly taken up by bacteria or plants. Sediments serve as a reservoir for phosphorus accumulation, and the sustained proliferation of aquatic plants and algae necessitates a consistent influx of phosphorus (Ruttenberg, 2003).

2.5.2.4.2.1. Phosphorus in the environment

Phosphorus can manifest in various forms in water, such as soluble organic and inorganic phosphorus, as well as particulate forms, including dead detritus and living plankton for organic phosphorus, and suspended minerals for inorganic phosphorus (Holtan et al., 1988).

Generally, there is relatively low concentration of phosphorus in the surface water, whereas total phosphorus rarely exceeds 0.5 mg/l except in wastewater or highly eutrophic water. Most surface waters have smaller than 0.05 mg/l of soluble reactive phosphorus, and the concentration ranged from 0.001– to 0.005 mg/l in most unpolluted water bodies (Boyd, 2020c).

The rapid absorption of phosphorus by phytoplankton from water is regarded as a regulatory element for the amount of dissolved phosphorus in the water. Additionally, a significant proportion of the total phosphorus is contained within the cells of phytoplankton. In aquatic environments characterized by a high concentration of phytoplankton, it has been observed that phosphorus levels as low as 0.2-0.3 mg/l can be rapidly depleted within a matter of hours (Boyd & Musig, 1981). The macrophyte can also absorb the phosphorus quickly by their roots in the anaerobic zones of the sediment. Macrophytes could grow in good condition even if the concentration of phosphorus in the water was low because their roots can absorb it from the sediment, unlike the phytoplankton, which cannot deal with the phosphorus form in the sediment (Granéli & Solander, 1988; Shilton et al., 2012).

The principal origin of phosphorus can be attributed to the runoff of soil from the watershed and the dissolution of phosphorus sediment. The concentrations of Phosphorus in said waters are indicative of the solubilities and the levels of phosphorus minerals present in the sediment and soils. The atmospheric contribution of phosphorus is not considered to be significant (Filippelli, 2002).

Phosphorus finds diverse applications in farms, processing of food, beverage production, and various other industrial sectors, as well as in domestic settings. Phosphate fertilizers are extensively utilized in the field of agriculture to promote the growth of plants. Additionally, they constitute a constituent of animal nutrition and are integral to numerous pesticide formulations. Phosphate-based pesticides and fertilizers are commonly employed in the maintenance of gardens, golf courses, and landscapes. Soft drinks contain phosphoric acid, which serves the dual purpose of enhancing their flavour profile and acting as a growth inhibitor for microorganisms present in the sugar component of these beverages. Phosphorus finds application in various domains such as buffering, acidification, emulsification, and flavour enhancement in the food industry. Although water pollution could happen from phosphorus when it is applied to aquaculture ponds (Calvo & Uribarri, 2013; Cordell & White, 2011; Nelson & Janke, 2007).

Natural waters with elevated concentrations of phosphorus resulting from human activities usually promote the aquatic growth of the plant and mainly the growth of phytoplankton. When the natural water gets too high addition of phosphorus, eutrophication appears with extreme blooms of phytoplankton or disturbance aquatic macrophytes growths (Carpenter, 2008; Daniel et al., 1998).

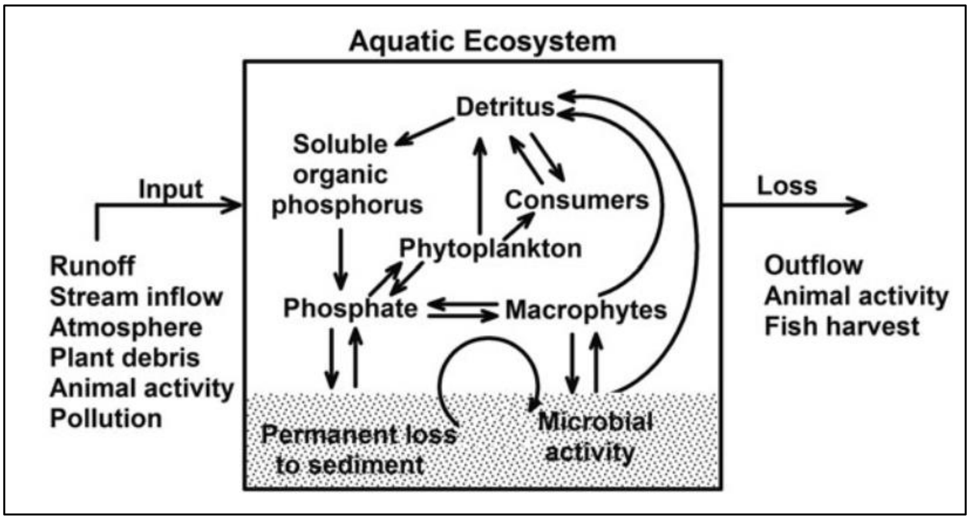


Figure 5: A qualitative model of the phosphorus cycle in an aquatic ecosystem (Boyd, 2020c).

Interactions of phosphorus in water bodies depend on the biological processes, while the phosphorus concentration is controlled by chemical principles in the water body of adsorption, precipitation, equilibrium, and dissolution. These processes impact the phosphorus mass balance which consists of concentration, storage, outflow, and inflow in the water (Vitousek et al., 2010).

Figure. 5 depicts the phosphorus dynamics within a water system. The introduction of particulate and dissolved phosphorus into aquatic systems is attributed to their respective watersheds. Plants and algae assimilate inorganic dissolved phosphorus and incorporate it into their biomass. Phosphorus present in plants is transferred to animals via the food web. Upon the demise of both plants and animals, their remains undergo mineralization, resulting in the release of phosphorus through microbial activity. But the sediment is considered phosphorus sinks because sediment strongly adsorbs the untaken dissolved inorganic phosphorus. Aquatic macrophytes with roots can use sediment phosphorus that would otherwise not go to the water column because their roots can extract dissolved phosphorus in sediment pore water. There is an equilibrium in the unpolluted natural waters between phosphorus storage, outputs, and inputs, and phosphorus increasing via water pollution disrupts this equilibrium (Boyd, 2020c; Filippelli, 2002).

2.5.3. Biological Characteristics of water

2.5.3.1. Biological monitoring Importance

The term "bioindicators" refers to specific species or communities that, just by existing, reveal information about the physical-chemical variable at a specific place in the environment. Freshwater algae can provide "long-term information" by detecting an extensive summer blooming of the colonial blue-green alga *Microcystis*, a sign of the previous high-nutrient (eutrophic) condition. And "short-term information" may indicate a shift to the eutrophic state by detecting a change in blue-green dominance in the following years from lower to higher (with increasing algal biomass). This shift might be a negative transition (perhaps brought on by human activities), necessitating management procedures and lake restoration adjustments (Bellinger & Sigee, 2015a; Boyd, 2020c).

2.5.3.2. Biological monitoring versus chemical measurements

Water quality, in chemical terms, comprises inorganic nutrients (especially nitrates and phosphates), organic pollutants such as pesticides, pharmaceuticals, humic substances, petroleum, and phenolic compounds (Mandal et al., 2016), inorganic pollutants such as lead, arsenic, aluminium, cadmium, chromium, mercury etc. (Chauhan & Srivastava, 2020).

The benefits of biomonitoring over physical-chemical analysis to evaluate water quality include (Boyd, 2020c):

- Indicates overall water quality while taking into account the cumulative impact of many stressors of longer period; physical-chemical tests only give information on a specific one point in time.

- Measures ecological effects of environmental factors on aquatic creatures directly.
- Enables the quick, accurate, and reasonably priced recording of environmental data across several sites.

2.5.3.3. Phytoplankton

Microalgae, including phytoplankton and microphytobenthos, are more commonly employed and considered more significant than macroalgae in determining water quality in freshwater habitats. Planktonic organisms are categorized in (Table 2.), according to their size, taxonomic group, and metabolic rate (Nollet & Gelder, 2014).

The algae encompasses both members of the Prokaryota (limited to the Cyanobacteria) and Eukaryota. Blue-green algae, also known as Cyanophyta, are a group of algae that are considered by taxonomists to be cyanobacteria, they are prokaryotic (John & Whitton, 2002). Eukaryotic algae encompass a wide array of distinct organisms that engage in photosynthesis within plastids, which are enduring organelles exhibiting green, brown, or bluish hues as a result of endosymbiotic processes. The term "algae" is commonly used to encompass a wide range of organisms that exhibit photosynthetic capabilities and/or possess plastids (Keeling, 2004). Within the Eukaryota, algae can be found in the supergroups TSAR (telonemids, stramenopiles, alveolates, and Rhizaria), Haptista, Cryptista (Cryptophyta), Excavata (Euglenida) and Archaeplastida encompassing Chloroplastida (green algae), Rhodophyta (red algae), and Glaucophyta (Adl et al., 2019; Burki et al., 2020; Guiry et al., 2023).

Most phytoplankton belong to the phyla Cryptophyta, Cyanophyta, Dinophyta, Euglenophyta, Chlorophyta, and Heterokontophyta. Like the Cryptophyta, Dinophyta, the Euglenophyta are flagellated, mobile organisms, and Euglena is the best-known genus. Euglenophyta have chlorophyll-a and chlorophyll-b, the major storage product is paramylon and stored in cytoplasm as grain. Cryptophyta have chlorophyll-a and chlorophyll-c, the major storage product is starch form and stored between the chloroplast envelope and the chloroplast endoplasmic reticulum. Chlorophyta (green algae) have chlorophylls a and b, major storage is starch and it is stored inside the chloroplast as grains. Chlorophyta are found in greatest diversity, often found in freshwater environments such as rivers and lakes and also grow on soil, trees, and rocks. Some examples of macroalgae in this phylum include the marine genus Ulva, while

Spirogyra is a freshwater genus, as well as several phytoplankton species. *Chlorella*, *Scenedesmus*, and *Closterium* are all examples of commonly found planktonic taxa (John & Whitton, 2002). Red algae forms have chlorophyll-a, chlorophyll-b, and phycobilin pigments, the major storage product is Floridian starch and stored in cytoplasm. Red algae also known as red seaweeds. Red algae also occur in freshwater, especially clean water streams (Adl et al., 2019; Burki et al., 2020; Guiry et al., 2023).

The impact of blue-green algae on water quality may be substantial. Several types of planktonic cyanobacteria are undesirable due to their abundance in nutrient-rich environments. Certain species may be harmful to fish and other aquatic life because of producing toxins (Chorus & Welker, 2021); they may cause scums on the water's surface; and they release foul-smelling substances when they die, which may alter the flavour of fish and other aquatic creatures that are consumed by humans (van der Merwe, 2015).

Table 1: Taxonomic diversity of the Algae (Adl et al., 2019; Burki et al., 2020; Guiry et al., 2023).

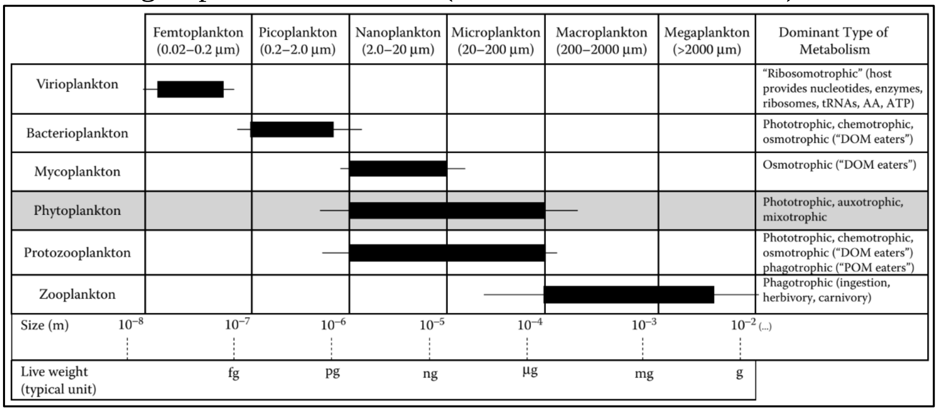
<table>
<tr><th></th><th>Empire</th><th>Supergroup/Clade</th><th>Division/Phylum</th></tr>
<tr><td rowspan="13">Algae</td><td>Prokaryota</td><td>Eubacteria</td><td>Cyanophyta/Cyanobacteria</td></tr>
<tr><td rowspan="12">Eukaryota</td><td rowspan="4">Archaeplastida (former Plantae)</td><td>Glaucophyta</td></tr>
<tr><td>Rhodophyta</td></tr>
<tr><td>Chloroplastida/Chlorophyta</td></tr>
<tr><td>Chloroplastida/Charophyta</td></tr>
<tr><td>Cryptista (former Chromista)</td><td>Cryptophyta</td></tr>
<tr><td>Haptista (former Chromista)</td><td>Haptophyta</td></tr>
<tr><td rowspan="2">TSAR/Alveolata</td><td>Dinoflagellata</td></tr>
<tr><td>Colpodellida (genus Chromera)</td></tr>
<tr><td>TSAR/Rhizaria</td><td>Chlorachniophyceae</td></tr>
<tr><td rowspan="2">TSAR/Stramenopiles</td><td>Ochrophyta/Diatomista</td></tr>
<tr><td>Ochrophyta/Chrysista</td></tr>
<tr><td>Excavates/Discoba</td><td>Euglenozoa</td></tr>
</table>

TSAR: Taxonomic ‘supergroup’ including telonemids, stramenopiles, alveolates, and Rhizaria.

Phytoplankton may be found in almost every body of water, and in areas where nutrients are abundant, there may be so many of them that they cause discoloration or turbidity. When phytoplankton blooms occur in the water, cause the water to change colour, producing shades of green, red, blue-green, brown, yellow, black, and grey (Kagalou et al., 2008).

Phytoplankton have a very limited lifespan, with single cells likely not surviving more than a few weeks (1 to 2 weeks). When the dead cells sink, they swiftly rupture, releasing their protoplasmic components into the waters. Dead phytoplankton are a common source of organic debris in natural waterways. The vast majority of phytoplankton species are able to easily spread. Many vegetative organisms and species' spores exist in the atmosphere. When exposing a flask containing a sterile nutrient solution to the air, algal populations will grow in a very brief period.

Table 2: Classification of planktonic organisms according to their size, taxonomic group, and metabolism (Nollet & De Gelder, 2014)



Wading birds are a major vector of phytoplankton dispersal from water body to another. This occurs when the animals ingest vegetative cells and algal spores that have adhered to their bodies. The capacity of a particular algal species to colonize a habitat is contingent on the quality of the environment into which its propagules were released (Boyd, 2020b).

2.5.3.3.1. Factors controlling phytoplankton growth

Phytoplankton abundance depends on the nutrient availability in the water body, the light is another limiting factor which is important for the photosynthesis. Another factor controlling the phytoplankton growth is the water velocity, fish prediction and zooplankton grazing (Bellinger & Sigee, 2015b; Li et al., 2013).

2.5.3.3.2. Phytoplankton in lakes

Nutrients can derive in the lake from different sources which can leads to eutrophication because of algal growth. Organic matter can be introduced in from the watershed, and the internal production of carbon is usually low. Ongoing eutrophication occurs from the autotrophic growth of internal organic matter by the lake's primary producers (i.e., photosynthetic algae and plants) from the nutrients contained in the lake. Nutrients are obtained from either an external source to the lake or from internal recycling from organic matter decomposition and dissolution in the sediments at the bottom. In terms of trophity, lakes may range from oligotrophic to hypereutrophic (Kitaka et al., 2002).

The development of macrophytes rather than phytoplankton may be an indicator of eutrophication in many shallow lakes. In lakes and other aquatic ecosystems, it takes a complicated food web for nutrients (organic matter) to move from the primary producers to the final consumers, which are usually fish. There are numerous ways for aquatic plants and phytoplankton produced organic matter to move up the food chain, with some of it eventually reaching the larger fish (Boyd, 2020c; figure 6).

The transferring carbon system in the lake highly depends on the phytoplankton community, which can be highly affected by the predation and grazing of phytoplankton by fish and zooplankton.

2.5.3.3.3. Phytoplankton in rivers

Since the 1970s, eutrophication has been a problem in rivers all over the world, especially in industrialized nations, due to the increased concentration of nitrates and phosphates entering rivers. Eutrophication promotes the development of macrophytes in small rivers, although phytoplankton predominates in large rivers. Very high chlorophyll concentrations (up to 200 mg m^{-3}) have been seen in such cases in the River Loire in France and the River Rhine in Germany. The construction of reservoirs may significantly reduce the flow velocities within a river, contributing to eutrophication (Boyd, 2020b; van der Struijk & Kroeze, 2010).

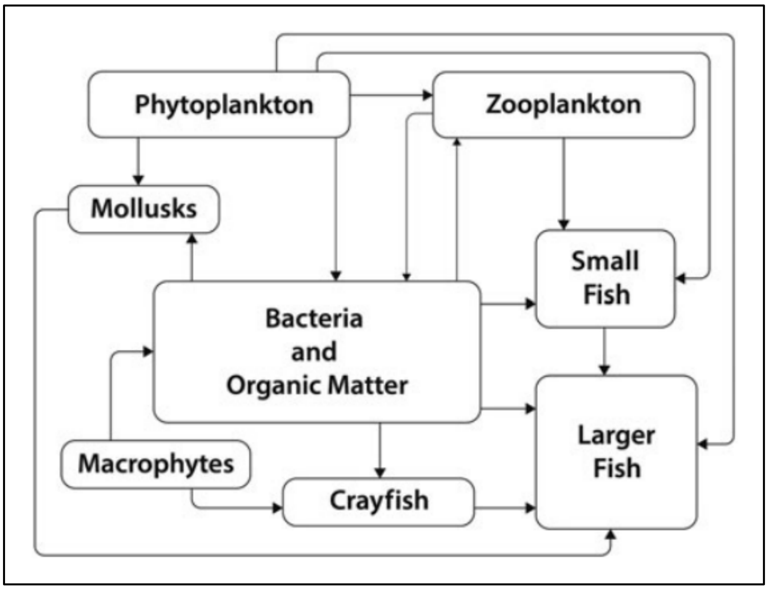


Figure 6: Diagram of aquatic food web (Boyd, 2020c)

Because of eutrophication, dissolved oxygen and pH levels in rivers may fluctuate greatly during the day and night. In certain cases, such as during the summer in turbid estuaries, this may lead to total anoxia. As a result of eutrophication, gaseous NH_3 is released (at high pH), which is very poisonous to fish and may have a significant impact on fish populations and health. Excessive phytoplankton growth in slow-flowing, eutrophic rivers may disrupt intakes and treatment operations for potable water (Zhang et al., 2018). Peterson indicated that the addition of phosphorus to a tundra river over four consecutive summers initially increased algal biomass and productivity, which ultimately led to a decrease in fish production (Peterson et al., 1993).

3. MATERIALS AND METHODS

3.1. The study area

3.1.1. Nagy- Morotva Oxbow Lake

The Nagy-Morotva is an oxbow lake in north-eastern Hungary (Figure 7) 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 middle part of the lake is mainly covered by thick aquatic vegetation by water soldier (*Stratiotes aloides* L.) (Yaqoob et al., 2021a). In contrast, the shoreline was covered mainly by broad and rich swamp vegetation, except for tiny areas frequented by fishermen. The Nagy-Morotva is a multipurpose body of water (irrigation, nature conservation in the middle area of the oxbow lake, fishing, and other leisure activities) (Kiss et al., 2006).

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 7; Figure 25):

- 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.

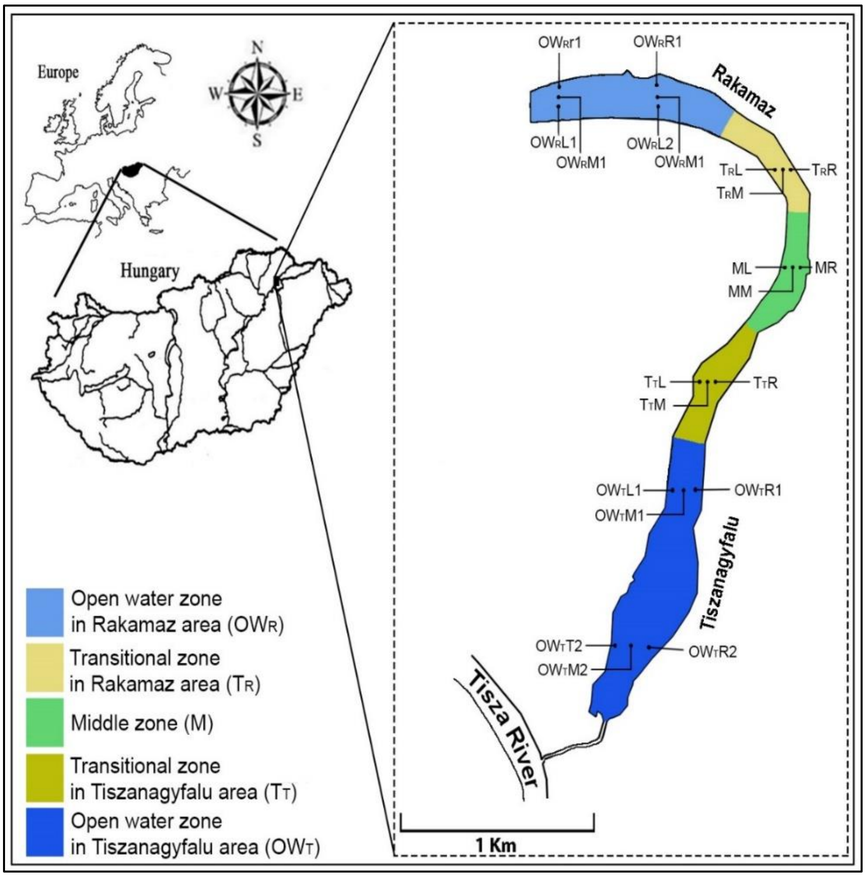


Figure 7: The sampling points of the studied area in the Nagy–Morotva oxbow lake.

- 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 considered as open water zone and used for fishing activities.

Wheras, 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.

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. 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 kilometres, and its width is around 650 meters (Figure 8). 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.

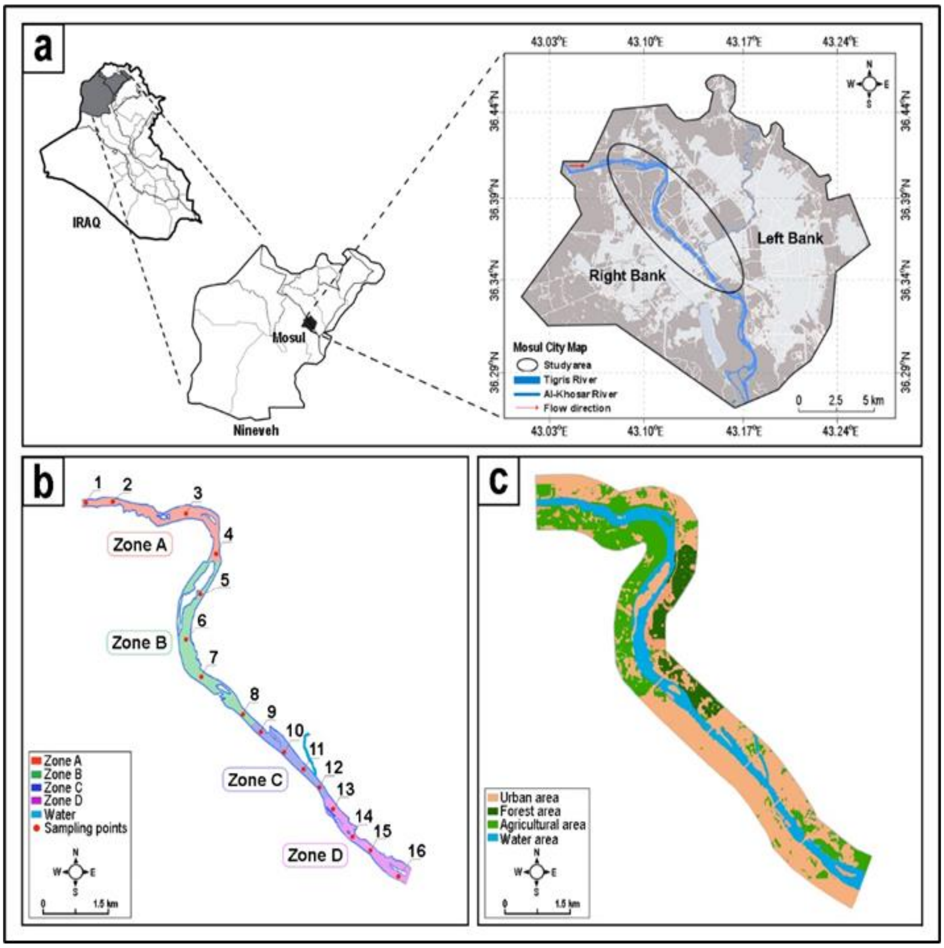


Figure 8: Figure showing the study area in the Tirgis River in hte Mosul city. (a) Location for the study area in Mosul city in Iraq. (b) The sampling points in the studied are at the Tigris River in Mosul City. Whereas the Zone A represented by red; Zone B represented by green ; Zone C represented by blue; Zone D represented by purple. (c) The land use in the Mosul city which affecting the Tigris River quality.

The studied area of Tigris River within the city were divided into 4 main zones based on the land use (Figure 8.b). Each area 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.

3.2. Water Quality measurements

3.2.1. Nagy-Morotva oxbow lake

3.2.1.1. Field work

3.2.1.1.1. 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, distributed on 7 transects, with each transect having 3 samples (left, middle, and right sides), sampling was carried out 20 cm from the water surface. A total of 78 water samples were collected from the Nagy-Morotva oxbow lake during the investigation in 2019 from 21 stations. Whereas 21 samples collected at 10th April for representing spring, 21 samples collected at 18th June for representing early summer, 15 samples collected at 23rd July for representing late summer, and 21 samples collected at 8th October for representing autumn. 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 sampiling time, there was a high density of macrophytes in the M and T_T zones which was imposible to drive the boat inside and collect the water samples.

3.2.1.1.2. On field measurements

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.

3.2.1.2. Laboratory work

3.2.1.2.1. Water chemistry

During the laboratory phase, various parameters were measured using the Chemical Analysis of Water and Wastes Methods. These included humic acid (mg/l) according the method HKE-3:2002 of Tisza River Regional Waterworks. Total alkalinity included (HCO_3^- and CO_3^{2-} mg/l) based to the MSZ448-11:1986 Hungarian Standard. BOD_5 (mg/l) according to the MSZ EN1899-2:2000 International Standard. Chemical oxygen demand included the COD_{Cr} (mg/l) based on MSZ ISO 6060:1991 Hungarian Standard and COD_{sMn} (mg/l) based on MSZ 448-20:1990 Hungarian Standard. Dissolved orthophosphate (mg/l) by using spectrophotometer of Hach Lange DR6000TM based on MSZ 12750-17:1974 Hungarian Standard and also total-phosphorus (mg/l). Kjeldahl-nitrogen (mg/l) based on MSZ 260-12:1987 Hungarian Standard. Ammonium-ion NH_4^+ (mg/l) based on MSZ ISO 7150-1:1992 Hungarian Standard. Nitrate-nitrogen NO_3^- (mg/l) based on MSZ 12750-18:1974 Hungarian Standard, nitrite-nitrogen NO_2^- (mg/l) based on MSZ 1484-13:2009 Hungarian Standard. Sulphate ion SO_4^{2-} (mg/l) based on ISO 15923-1 International Standard. Chlorophyll-a (µg/l) based on hot methanol extraction then read it by spectrophotometry. Total suspended solids (mg/l) based on MSZ 260-3:1973 Hungarian Standard. While pH and ORP (mV) measured by Hach Lange HQ30d flexi multimeter.

3.2.1.2.2. Microscopic identification and counting

The inverted microscope of Olympus-IX73 was used for phytoplankton counting (ind./L^{-1}) at a magnification of 1000 (100X) and 400 (40X) and the light 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 Komarek, 1998; Komarek & Anagnostidis, 2005; Ettl et al., 2007; Ettl & Gartner, 2008; Komarek, 2008; Krammer & Lange-Bertalot, 2008; Ettl, 2010; Krammer & Lange-Bertalot, 2010; John et al., 2011; Komárek, 2013; Moestrup & Calado, 2018; Wehr et al., 2015a).

3.2.2. Tigris River in Mosul city

3.2.2.1. Field work

3.2.2.1.1. Sample collecting

A total of 64 water samples were collected from Tigris River during the study in 2021 from 16 stations. 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 8) and station number 16 was selected as the last station after leaving the city (downstream river, figure 8). Sampling was carried out in the middle of the river from the current, 20 cm from the water surface. Whereas 16 samples collected at 1st of April for representing spring, 16 samples collected at 13th of July for representing summer, 16 samples collected at 7th of October for representing autumn, and 16 samples collected at 29th of December for representing winter to represent the seasonal variance. 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.

3.2.2.1.2. On field measurements

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.

3.2.2.2. Laboratory work

3.2.2.2.1. Water chemistry

In the laboratorial analysis, we measured BOD_5 mg/l, H-CO_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.

3.2.2.2.2. Microscopic identification and counting

The inverted microscope of Olympus-IX73 was used for phytoplankton counting (ind./L^{-1}) at a magnification of 1000 (100X) and 400 (40X) and the light 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 (John et al., 2011; Wehr et al., 2015a), 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 Komarek, 1998; Komarek & Anagnostidis, 2005; Ettl et al., 2007; Ettl & Gartner, 2008; Komarek, 2008; Krammer & Lange-Bertalot, 2008; Ettl, 2010; Krammer & Lange-Bertalot, 2010; John et al., 2011; Komárek, 2013; Moestrup & Calado, 2018; Wehr et al., 2015a).

3.3. Data analysis

3.3.1. Nagy-Morotva oxbow lake

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).

3.3.2. Tigris River in Mosul city

In the statistical analysis, Rsutdio was used for conducting LDA (Linear discriminant analysis) for both physical-chemical and phytoplankton data abundance (Ind/L) after normalizing the data (Log+1). Also, Rsudio was used for CCA after normalizing the data (Log+1).

phytoplankton species with greater than 2% relative abundance was chosen in LDA and greater than 1% relative abundance for 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 (cloudless image LC08 from June 27, 2021).

4. RESULTS

4.1. Nagy-Morotva Oxbow Lake

4.1.1. Physical-chemical variables of the Nagy-Morotva oxbow lake

4.1.1.1. Physicochemical variation during the study period

Throughout the research investigation conducted in the oxbow lake, the physical-chemical variables demonstrated a wide range of variation at sampling stations (Figure 9) and throughout the seasons (Table 3).

Table 3: Minimum, maximum, and median values of the physical-chemical variables during the investigation in the Nagy-Morotva oxbow lake.

Variables	Spring	Early summer	Late summer	Autumn
	Min-Max Median	Min-Max Median	Min-Max Median	Min-Max Median
BOD_5 (mg/l)	2.4-4.7 2.9	1-4.1 2.1	1.5-3.3 2.3	1.5-5 3.2
Chlorophyll-a (mg/l)	12.1-43.2 20	5.1-75.6 20.6	24.7-64.9 54.1	10.9-42.2 21.3
Cl^- (mg/l)	43.9-67.8 53.6	20.4-47.7 36.4	32.9-49.8 47.4	50.2-72.8 55.5
COD_{sMn} (mg/l)	5.3-8 7	7-11.7 8.4	3-7.8 5.1	11.4-22.1 16.9
COD_{Cr} (mg/l)	11-43 23	15-47 28	12.7-29.4 20.6	27.1-47 35
DO (mg/l)	7.7-14.8 9.6	0.1-8.8 5.3	0.3-5.4 3.7	6.6-9.9 8.4
HCO_3^- (mg/l)	18.8-164.5 84.6	111.3-199.5 157.7	125.3-199.5 185.6	143.8-231.9 176.3
CO_3^- (mg/l)	0-83.2 55.5	0-22.8 18.3±9.3	0-27.4 13.7±7	0-27.4 18.3±5.5
Kjl-N (mg/l)	0.6-4.1 1.7	1.2-5.4 2.7±1.2	1.5-3.4 2.2±0.5	0.6-5.8 1.9±1.2
NH_4-N (mg/l)	ND	ND-0.116 0	0.001-0.015 0.007	0.009-0.043 0.016
NO_2-N (mg/l)	0.0004-0.003 0.00123	0-0.0052 0.0004	0.0037-0.01 0.006	ND-0.00076 0
NO_3-N (mg/l)	0-0.306 0.114	0.045-0.125 0.079	0.23-2.773 0.336	0.292-0.446 0.349

TP (mg/l)	0.07-0.15 0.1	0.07-0.51 0.21	0.12-0.34 0.3	0.3-1.01 0.36
PO_4^{3-} (mg/l)	0-0.009 0.0019	0.009-0.09 0.0434	0.01-0.021 0.0162	ND-0.121 0.0071
SO_4^{2-} (mg/l)	0-0.046 0.01	ND-0.448 0	0-6.891 2.35	2.963-19.259 6.85
Humic acid (mg/l)	0.1-2.7 1.6	1.7-4.4 2.8	1-4.7 2.3	1.5-5 2.3
pH	7-8.1 7.5	6.4-7.9 7.2	6.2-6.9 6.8	6.3-7 6.8
TSS (mg/l)	2-19.5 10.5	2-41 13	10-81 17	3-15 6
TDS (mg/l)	268-371.7 327.3	206.3-301.7 257	250-338.7 331.3	318.3-363 334.3
Conductivity (µS/cm)	360.5-496.1 423.3	308.5-469.6 378.7	371.7-514.4 505.2	361.8-421 384.7
ORP (mV)	174.9-227.6 194.6	172.4-235.6 211	237-253 242.8	429-505 462
Transparency (cm)	40-100 57	51-101 78	29-72 45	50-120 80
Depth (cm)	54-200 84	74-188 123	58-145 82	50-170 103

ND, no detection (below detection limit)

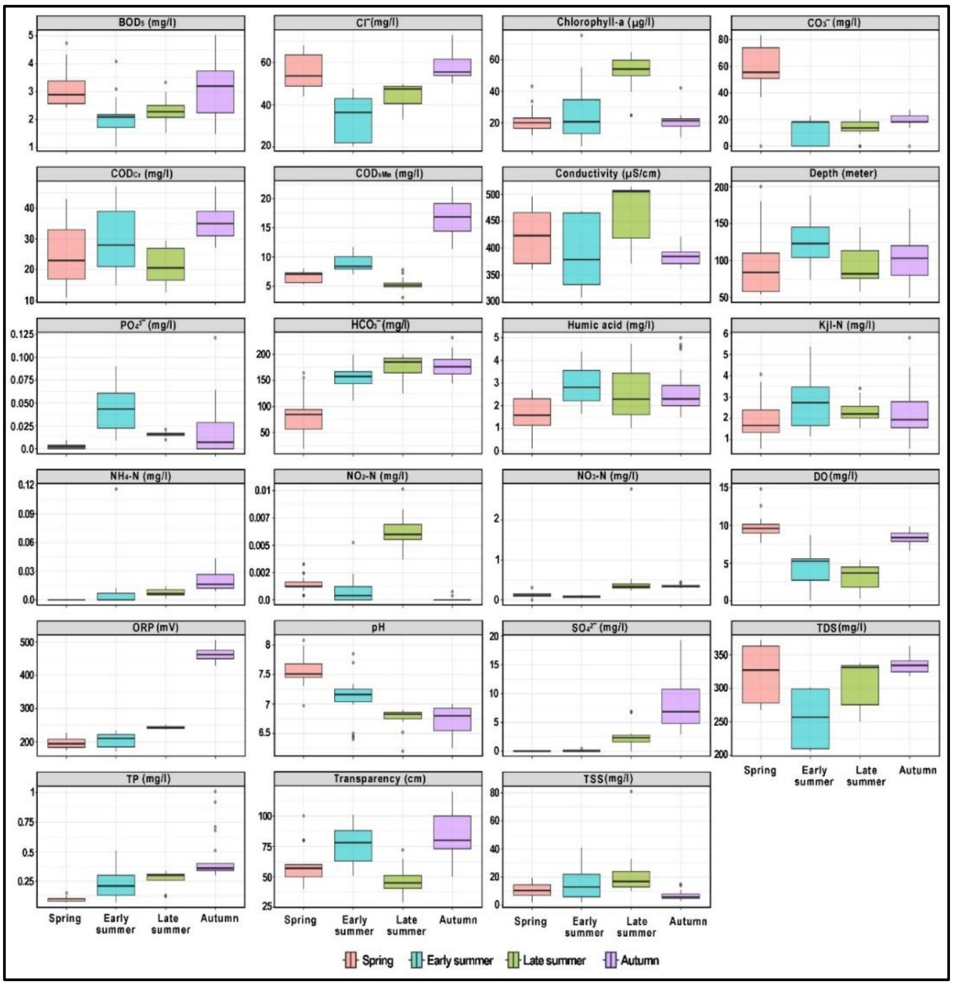


Figure 9: Boxplot of physical-chemical variables in the oxbow lake during the investigation. Whereas TP: total phosphorus; Kjl-N: Kjeldahl-N.

4.1.1.2. Physical-chemical variables during different seasons

4.1.1.2.1. Spring season

The zones of the Nagy-Morotva oxbow lake showed significant differences in physical-chemical variables during the spring sampling (Figure 10). Whereas Zone OW_R characterized by the maximum of TSS (100 mg/l), TDS (363 mg/l), conductivity (474 µS/cm), BOD_5 (4.74 mg/l), Cl^- (68 mg/l), CO_3 (83 mg/l), HCO_3^- (155 mg/l), COD_{Cr} (43 mg/l), COD_{sMn} (7.9 mg/l), humic acid (2.7 mg/l), Kjl-N (4.1 mg/l), NO_2-N (0.003 mg/l), pH (8.1), SO_4^{2-} (0.036 mg/l), and TP (0.15 mg/l). While the transparency was at the lowest (50 cm) in the OW_R zone. Zone T_R have higher concentration of TDS (371 mg/l), conductivity (496 µS/cm), chlorophyll-a (43.2 µg/l), HCO_3^- (164 mg/l), COD_{Cr} (36 mg/l), COD_{sMn} (8 mg/l), humic acid (2.7 mg/l), and TP (0.13 mg/l). While the lowest concentration was PO_4^{3-} (0.024 mg/l) and NO_3-N (0.09) in the T_R zone. Zone M characterized by maximum concentration of CO_3 (83 mg/l), COD_{sMn} (7.4 mg/l), and humic acid (2.7 mg/l), while Kjl-N (0.5 mg/l) was at the lowest concentration. Zone T_T characterized by the maximum concentration of transparency (180 cm), PO_4^{3-} (0.007 mg/l), and NO_3-N (0.3 mg/l). Zone OW_T characterized by the maximum concentration of transparency (100 cm), depth (200), ORP (228 mV), BOD_5 (4.3 mg/l), HCO_3^- (150 mg/l), PO_4^{3-} (0.009 mg/l), NO_2-N (0.003 mg/l), DO (14.8 mg/l), and SO_4^{2-} (0.05 mg/l), while TSS (2 mg/l) was at the lowest.

4.1.1.2.2. Early summer season

The Nagy-Morotva oxbow lake in early summer showed significant zonal variation in physical-chemical variables (Figure 11). Zone OW_R characterized by the maximum of depth (162 cm), ORP (236 mV), TSS (41 mg/l), TDS (302 mg/l), conductivity (470 µS/cm), Cl^- (48 mg/l), chlorophyll-a (75.6 µg/l), CO_3 (22.8 mg/l), and NH_4-N (0.12 mg/l), while COD_{Cr} (18 mg/l) and PO_4^{3-} (0.01 mg/l) was at the lowest concentration. Zone T_R have higher concentration of TSS (41 mg/l), TDS (290 mg/l), conductivity (441 µS/cm), Cl^- (43.5 mg/l), HCO_3^- (185 mg/l), Kjeldahl-N (5 mg/l), pH (7.8), and TP (0.51 mg/l), while NH_4-N was not ditictable in the T_R zone. Zone M characterized by maximum concentration of transparency (100 cm), HCO_3^- (199 mg/l), Kjl-N (5.4 mg/l), and DO (8.8 mg/l), while TP (0.15) was at the lowest. The NH_4-N and NO_2-N was not detectable in the M zone. Zone T_T characterized by maximum concentration of transparency (101 cm), BOD_5 (4.1 mg/l), COD_{Cr} (44 mg/l), COD_{sMn} (10.51 mg/l), PO_4^{3-} (0.092 mg/l), and NO_3-N (0.12 mg/l). Zone OW_T characterized by the high concentration of transparency (95 cm), COD_{Cr} (47 mg/l), COD_{sMn} (11.7 mg/l), PO_4^{3-} (0.09 mg/l), humic acid (4.4 mg/l), depth (188 cm), NO_2-N (0.005 mg/l), DO (4.5 mg/l), pH (7.7), NO_3-N (0.12 mg/l), and SO_4^{2-} (0.45 mg/l), while TSS (3 mg/l) was at the minimum concentration.

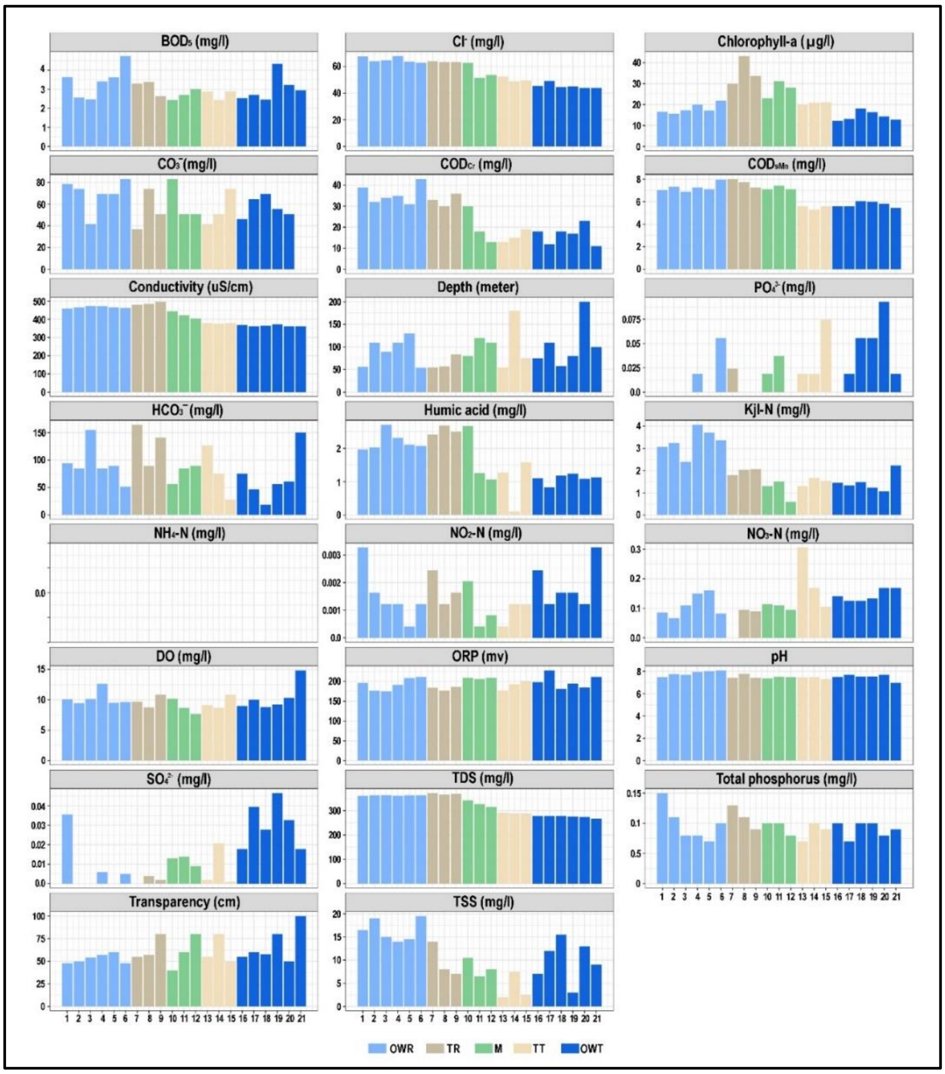


Figure 10: Physical-chemical variables of oxbow lake in each sampling point at spring. Whereas TP: total phosphorus; Kjl-N: Kjeldahl-N.

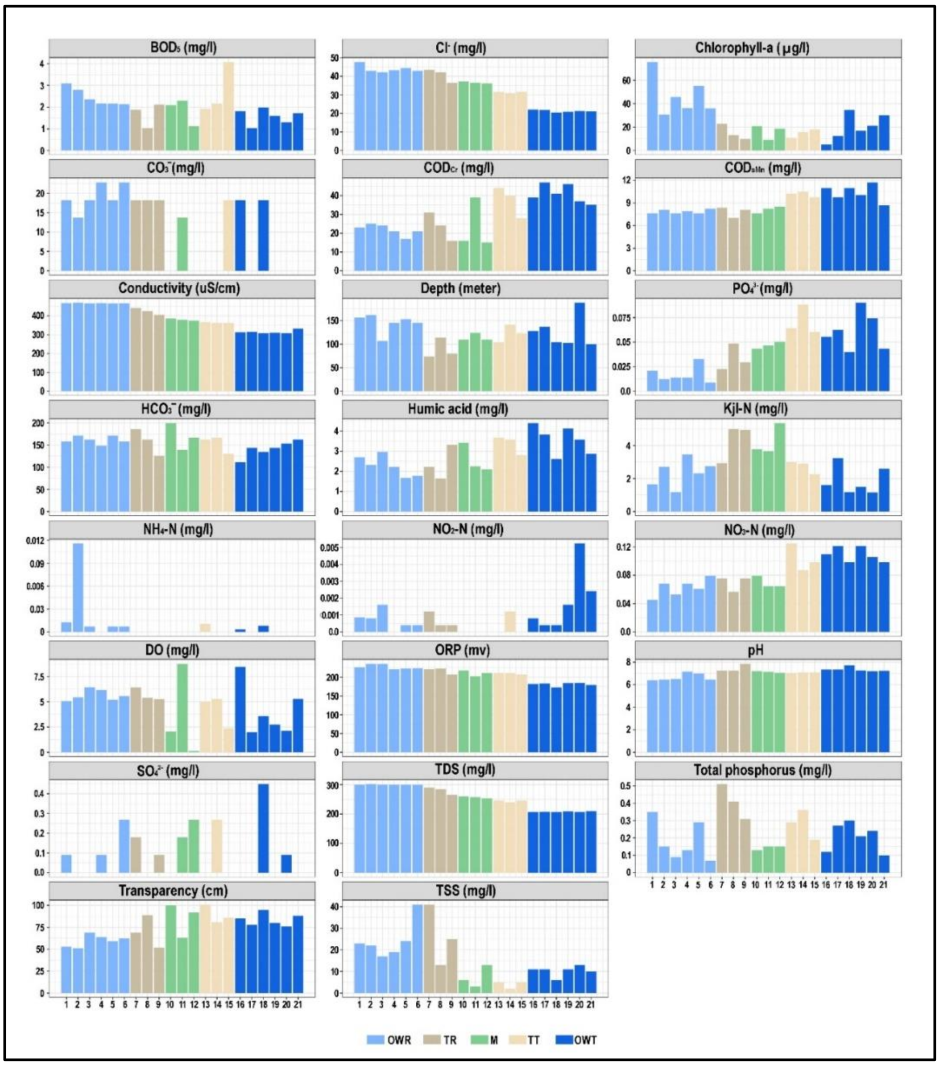


Figure 11: Physical-chemical variables of oxbow lake in each sampling point at early summer. Whereas TP: total phosphorus; Kjl-N: Kjeldahl-N.

4.1.1.2.3. Late summer season

During the sampling time in late summer, the zones of the Nagy-Morotva oxbow lake showed significant variation in their physical-chemical variables (Figure 12). Zone OW_R characterized by the maximum of depth (145 cm), TSS (81 mg/l), TDS (334 mg/l), conductivity (514 µS/cm), Cl^- (50 mg/l), chlorophyll-a (65 µg/l), CO_3 (27 mg/l), HCO_3^- (199 mg/l), Kjl-N (3.4 mg/l), NH_4-N (0.015 mg/l), NO_2-N (0.01 mg/l), DO (5.1

mg/l), and pH (6.9), while humic acid (1 mg/l) was at the lowest. Zone T_R have higher concentration of TDS (339 mg/l), conductivity (511 µS/cm), Cl^- (50 mg/l), chlorophyll-a (62 µg/l), HCO_3^- (195 mg/l), COD_{Cr} (28 mg/l), COD_{sMn} (6.5 mg/l), Kjl-N (3.2 mg/l), and NH_4-N (0.015 mg/l), while DO (2 mg/l) and TSS (10 mg/l) was at the lowest concentration. Zones M and T_T was fully covered with macrophytes, and for that we couldn't collect the water samples. Zone OW_T characterized by the high concentration of transparency (72 cm), depth (130), ORP (253 mV), BOD_5 (3.3 mg/l), COD_{Cr} (29 mg/l), COD_{sMn} (7.8 mg/l), PO_4^{3-} (0.02 mg/l), humic acid (4.7 mg/l), NO_2-N (0.008 mg/l), DO (5.4 mg/l), pH (6.89), NO_3-N (2.8 mg/l), and TP (0.34 mg/l), while conductivity (400 µS/cm) and TDS (270 mg/l) was at the lowest concentration.

4.1.1.2.4. Autumn season

The zones of the Nagy-Morotva oxbow lake varied significantly in physical-chemical variables across the sampling in autumn (Figure 13). Zone OW_R characterized by the maximum of ORP (480 mV), TSS (15 mg/l), TDS (342 mg/l), conductivity (395 µS/cm), HCO_3^- (232 mg/l), COD_{Cr} (47 mg/l), humic acid (5 mg/l), NO_3-N (0.45 mg/l), DO (9.6 mg/l), TP (1.01), and pH (6.9), while NH_4-N (0.01 mg/l) was at the lowest. Zone T_R have higher concentration of chlorophyll-a (42 µg/l) and pH (6.9). Zone M characterized by maximum concentration of CO_3 (27 mg/l), PO_4^{3-} (0.12 mg/l), and pH (7), while PO_4^{3-} (0.01 mg/l) was at the lowest. Zone T_T have high concentration of transparency (120 cm), COD_{sMn} (22.1 mg/l), Kjl-N (5.8 mg/l), NO_3-N (0.42 mg/l), and TP (0.92). While zone OW_T characterized by the high concentration of transparency (120 cm), depth (170 cm), ORP (505 mV), TDS (363 mg/l), conductivity (421 µS/cm), Cl^- (73 mg/l), COD_{Cr} (45 mg/l), humic acid (4.7 mg/l), NH_4-N (0.043 mg/l), NO_2-N (0.0007 mg/l), DO (9.8 mg/l), pH (6.9), and SO_4^{2-} (19.2 mg/l), while TP (0.25 mg/l) and PO_4^{3-} (0.01 mg/l) was at the lowest.

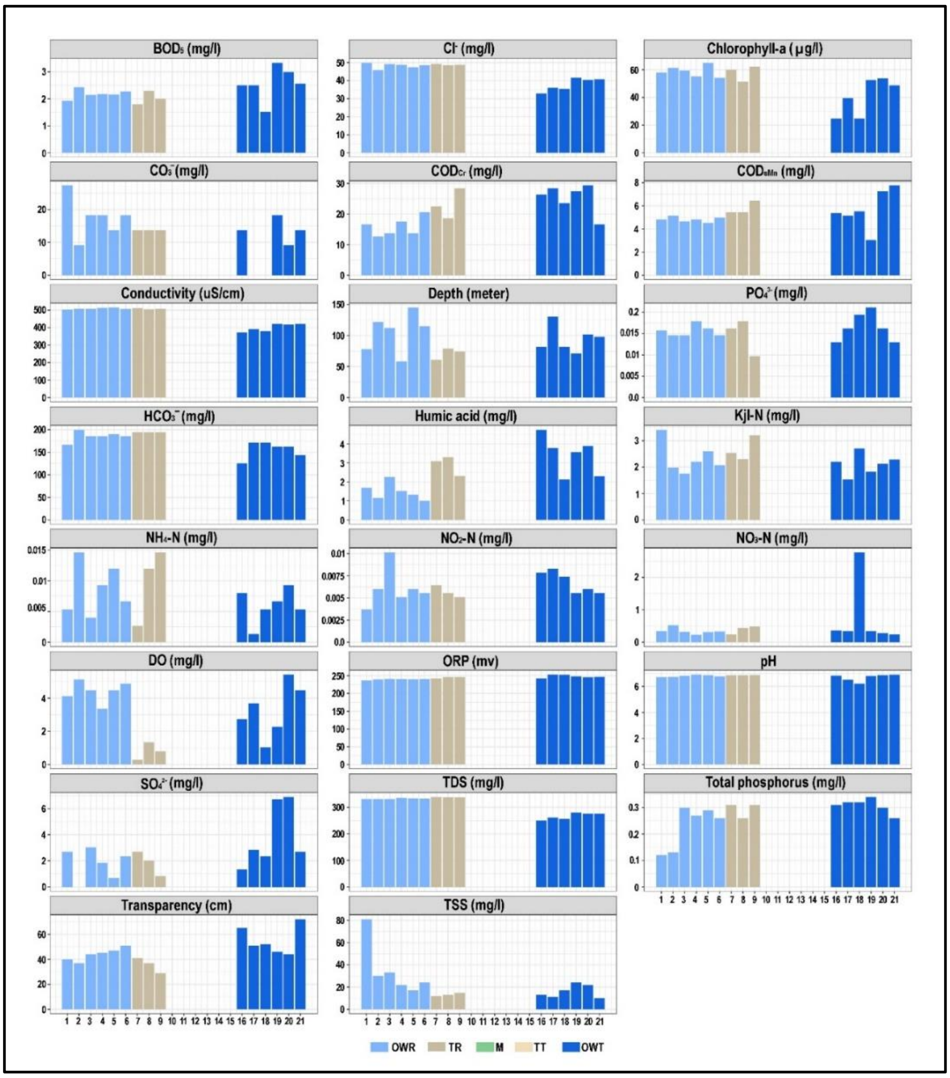


Figure 12: Physical-chemical variables of oxbow lake in each sampling point at late summer. Whereas TP: total phosphorus; Kjl-N: Kjeldahl-N.

Figure 13: Physicochemical variables of oxbow lake in each sampling point at autumn. Whereas TP: total phosphorus; Kjl-N: Kjeldahl-N.

4.1.1.3. Principal component analysis PCA of physical-chemical variables

In the spring sampling time, the physical-chemical properties were subjected to between-group PCA (principal component analysis), revealing that the OW_R, T_R, and M zones were differs from T_T and OW_T zones, as shown in (Figure 14.A). The PC1 expressed 60% and PC2 was 18.7% of the total variance. In the spring sampling time, zones OW_R and

T_R was influenced by elevated amounts of NO_2-N, chlorophyll-a, TP, TSS, BOD_5, Kjeldahl-N, humic acid, COD_{Cr}, EC, and TDS. Zone M exhibited lower concentrations of DO and NO_2-N. T_T and OW_T zones have elevated levels of NO_2-N, PO_4^{3-}, NO_3-N, transparency, and SO_4^{2-}.

In early summer (Figure 14.B), based on the PCA (Figue 6.4.B), zones OW_R and T_R differs from M, T_T, and OW_T zones. The PC1 expressed 52.4% and PC2 was 23.2% of the total variance. Zone OW_R was impacted by high levels of chlorophyll-a, TSS, BOD_5, NH_4-N, DO, and TDS concentrations. The Kjeldahl-N, SO_4^{2-}, and total-phosphorus concentrations were raised to the maximum in T_R and M zones. Zones T_T and OW_T had elevated transparency, NO_2-N, PO_4^{3-}, humic acid, COD_{Cr}, and NO_3-N.

In late summer (Figure 14.C), the zones OW_R and T_R separated from the OW_T zone based on the PCA (Figue 6.4.C). The PC1 expressed 68.4% and PC2 was 31.6% of the total variance. The results indicate that zone OW_R was significantly impacted by higher amounts of chlorophyll-a, total suspended solids, carbonate ion concentration, conductivity, and dissolved oxygen. Zone T_R exhibited significant susceptibility to elevated levels of NH_4-N, humic acid, COD_{sMn}, NO_3-N, pH, and Kjeldahl-N. The impact of elevated levels of NO_2-N, BOD_5, and sulphate ions was found to be significant in OW_T zone. The dense growth of macrophytes in the M and TT zones made it impossible to obtain representative samples from these areas..

In autumn (Figure 14.D), the zones OW_R have a deferent charactristics than OW_T, and the zones of T_R, M, and T_T differed from other zones based on the PCA (Figue 6.4.D). The PC1 expressed 39% and PC2 was 29.7% of the total variance. Zone OW_R was highly charactrized by high concentrations of BOD_5, total-phosphorus, humic acid, COD_{Cr}, total suspended solids, NO_3-N, and dissolved oxygen. While chlorophyll-a and PO_4^{3-} have higher concentrations in T_R, M, and OW_T zones. Zone OW_T charactrized by high transparency Kjeldahl-N, conductivity, total dissolved solids, NO_2-N, and NH_4^+, sulphate ion concentrations.

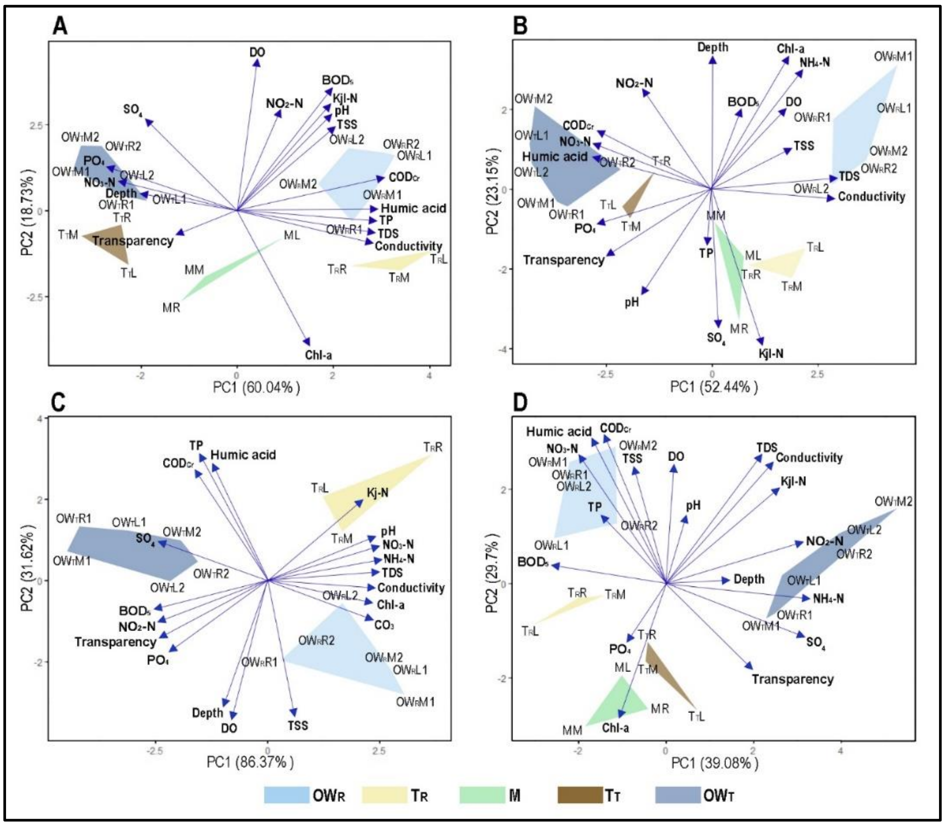


Figure 14: Principal component analysis based on the physical-chemical variables at each sampling point. Graph (A): Spring, Graph (B): Early Summer, Graph (C): Late Summer, Graph (D): Autumn. TP: total-phosphorus; Kjl-N: Kjeldahl-N; chl-a: chlorophyll-a; TSS: total suspended solids; TDS: total suspended solids; DO: dissolved oxygen.

4.1.2. Algal composition in the Nagy-Morotva Oxbow Lake

4.1.2.1. Algal composition during the investigation

Algal phylum

The Chlorophyta dominated the algal community in the Nagy-Morotva oxbow lake during the sampling periods which formed a 39% of the total algal. This was followed by Euglenophyta with a 23%, Cryptophyta 16%, Cyanobacteria 9%, Ochrophyta 7%, Bacillariophyta 4%, and Dinoflagellata 1% Figure 15.

However, the maximum abundance of Chlorophyta was (3,050,332 Ind. L^{-1}) during autumn sampling period, while the minimum was

(1,254,844 Ind. L^{-1}) at early summer. Euglenophyta have the maximum abundance (1,691,807 Ind. L^{-1}) at spring while the minimum was (550,819 Ind. L^{-1}) at late summer. The highest abundance of Cryptophyta was (1,521,231 Ind. L^{-1}) in autumn while the lowest was (625,483 Ind. L^{-1}) during early summer. Cyanobacteria have the maximum abundance (1,049,431 Ind. L^{-1}) during early summer while the minimum was (29,871 Ind. L^{-1}) in spring. Ochrophyta have the maximum abundance (942,585 Ind. L^{-1}) at spring while the minimum was (52,935 Ind. L^{-1}) at early summer. The maximum abundance of Bacillariophyta was (353,462 Ind. L^{-1}) during late summer sampling period, while the minimum was (73,328 Ind. L^{-1}) at spring, and Dinoflagellata have the maximum abundance (29,108 Ind. L^{-1}) during late summer while in early summer and autumn didn't appear.

Algal species abundance

During the sample periods, *Ankistrodesmus falcatus* was the most abundant species at (22%), followed by *Cryptomonas ovata* (17%), *Trachelomonas volvocina* (16%), *Oscillatoria* sp. (9%), *Kephyrion littorale* (5%), *Phacus* sp. (3%), *Closterium acutum* (3%), *Crucigenia tetrapedia* (3%), *Ankistrodesmus bibraianus* (2.5%), *Dinobryon* sp. (2%), *Desmodesmus* sp. (2%), *Tetraedron triangulare* (2%), *Nizschia acicularis* (1%), *Ankistrodesmus spiralis* (1%), *Acus* sp. (1%).

Furthermore, within the Chlorophyta phylum, *Ankistrodesmus falcatus* represented (49%) of the characterized genius, followed by Closterium acutum (8%), *Ankistrodesmus bibraianus* (7%), *Crucigenia tetrapedia* (6%), *Desmodesmus* sp. (5%), *Tetraedron triangulare* (4%), and *Monoraphidium contortum* (4%). About (76%) of the Euglenophyta phylum was made up of *Trachelomonas volvocina*, whereas only (19%) was *Phacus* sp. and *Euglena* sp. was (5%). Within the Cryptophyta phylum, only *Cryptomonas ovata* was found. The genus Oscillatoria sp. stands for 92% of all Cyanobacteria phylum, followed by Nostoc sp. (3%), *Hydrococcus* sp. (2%), *Gloeocapsa* sp. (2%), and *Anabaena* sp. (1%). The Ochrophyta phylum represented by *Kephyrion littorale* (71%) and *Dinobryon* (29%). While the phylum of Bacillariophyta characterized by the highest abundance of *Nizschia acicularis* was (40%), *Cyclotella* sp. was (18%), *Navicula* sp. was (16%), *Asterionella formosa* was (15%), *Aulacoseira granulata* was (5%), *Fragilaria* sp. was (3%), *Ulnaria ulna* was (2%), and *Gyrosigma* sp. was (1%). The species of *Peridinium cinctum* was the only characterized species of Dinoflagellata.

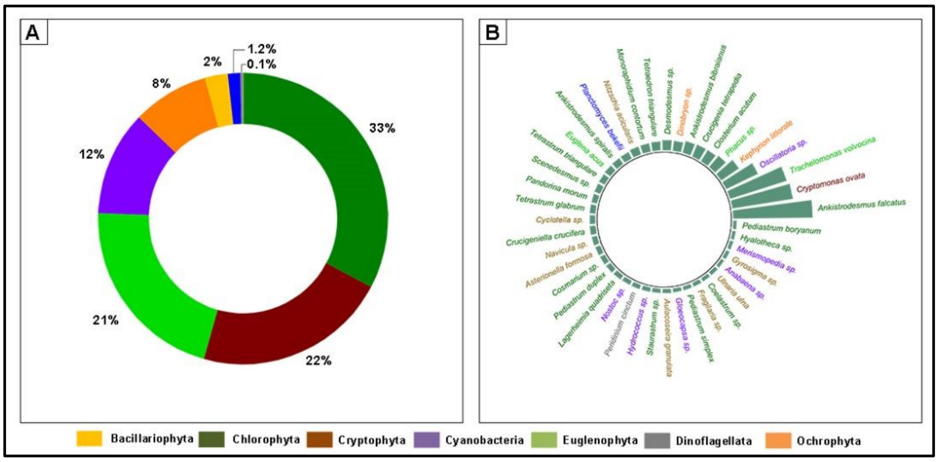


Figure 15: Phytoplankton community in the Nagy-Morotva oxbow lake during the investigation. Figure 15A showing algal phylum during the study period. Figure 15B showing the highest algal species during the study period.

4.1.2.2. Algal composition during different seasons

4.1.2.2.1. Spring season

Algal phylum

The Chlorophyta species was the most abundant phylum in the oxbow lake with a 41.7 % (473,364 - 554,3626 Ind. L^{-1}) of total algal abundance, then the second highest phylum was Euglenophyta with a 28.8% (530,584 - 3,468,968 Ind. L^{-1}) of total algal abundance, the third highest phylum was Ochrophyta with a 16.1% (453,789 - 1,754,653 Ind. L^{-1}) of total abundance. However, the Cryptophyta was 11.08% (0 - 1,967,093 Ind. L^{-1}), Bacillariophyta was 1.25% (0 - 383,200 Ind. L^{-1}), Cyanobacteria was 0.51% (0 - 170,311 Ind. L^{-1}), and Dinoflagellata was 0.44% (0 - 106,444 Ind. L^{-1}) (Figure 16.)

Algal species abundance.

Generally, *Ankistrodesmus falcatus* was 33.34% (428,282 - 5,185,973 Ind. L^{-1}), *Trachelomonas volvocina* was 27.25% (530,585 - 3,347,958 Ind. L^{-1}), *Kephyrion littorale* was 15.23% (393,284 - 1,512,632 Ind. L^{-1}), and *Cryptomonas ovata* was 11.08% (0 - 1,967,093 Ind. L^{-1}) of total species abundance during spring sampling (Figure 16).

Algal composition in the zones of the oxbow lake during spring

investigation

- Rakamaz Open water zone (OW_R)

  Rakamaz open water zone characterized by the maximum relative abundance of Chlorophyta 30.86%, followed by Euglenophyta 28.16%, Ochrophyta 20.32%, Cryptophyta 16.71%, Bacillariophyta 2.68%, Cyanobacteria 0.88%, and Dinoflagellata 0.40%.

  The most abundant algal species was *Ankistrodesmus falcatus* 42.04%, *Trachelomonas volvocina* 25.50%, and *Kephyrion littorale* 17.60% (Figure 17).
- Rakamaz transitional zone (T_R)

  Rakamaze transitional water zone characterized by the maximum relative abundance of Chlorophyta 45.45%, followed by Euglenophyta 32.49%, Ochrophyta 11.22%, Cryptophyta 7.31%, Bacillariophyta 2.00%, Cyanobacteria 0.78%, and Dinoflagellata 0.76%.

  The most abundant algal species was *Ankistrodesmus falcatus* 34.6%, *Trachelomonas volvocina* 30.5%, and *Kephyrion littorale* 9.46% (Figure 17).
- Middle Zone (M)

  The middle zone characterized by the maximum relative abundance of Chlorophyta 42.62%, followed by Euglenophyta 24.83%, Ochrophyta 16.86%, Cryptophyta 14.87%, Cyanobacteria 0.52% and Dinoflagellata 0.22%.

  The most abundant algal species was *Ankistrodesmus falcatus* 32.6%, *Trachelomonas volvocina* 23.04%, and *Kephyrion littorale* 16% (Figure 17).
- Tisza transitional zone (T_T)

  Tisza transitional water zone characterized by the maximum relative abundance of Euglenophyta 33.91%, followed by Chlorophyta 32.69%, Cryptophyta 19.55%, Ochrophyta 12.42%, Cyanobacteria 0.55%, Bacillariophyta 0.47% and Dinoflagellata 0.41%.

  The most abundant algal species was *Trachelomonas volvocina* 33.26%, *Ankistrodesmus falcatus* 27.68%, *Cryptomonas ovata* 19.55% and *Kephyrion littorale* 12.13% (Figure 17).

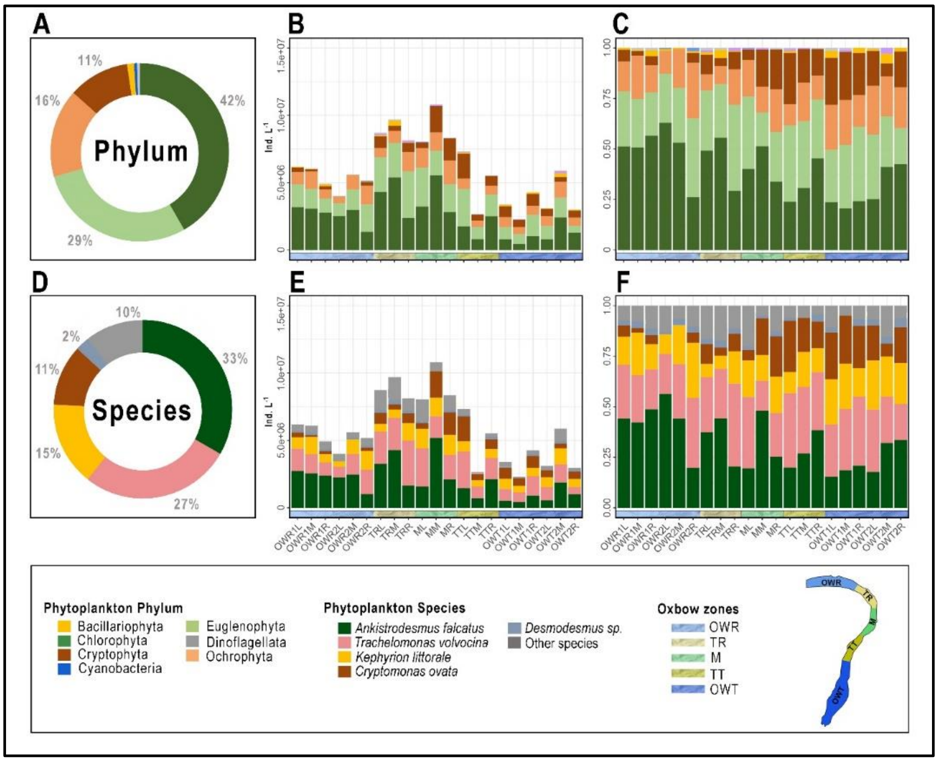


Figure 16: Phytoplankton abundance during spring time at each sampling point. (A, B, and C) graphs representing the phylum abundance level of the phytoplankton. (D, E, and F) graphs representing the species abundance level of the phytoplankton.

- Tisza open water zone (OW_T)

  Tisza open water zone characterized by the maximum relative abundance Chlorophyta 30.86%, followed by Euglenophyta 28.16%, Ochrophyta 20.32%, Cryptophyta 16.71%, Bacillariophyta 2.68%, Cyanobacteria 0.88%, and Dinoflagellata 0.40%.

  The most abundant algal species was *Trachelomonas volvocina* 26.80%, *Ankistrodesmus falcatus* 24.09%, *Kephyrion littorale* 20.02%, and *Cryptomonas ovata* 16.71% (Figure 17).

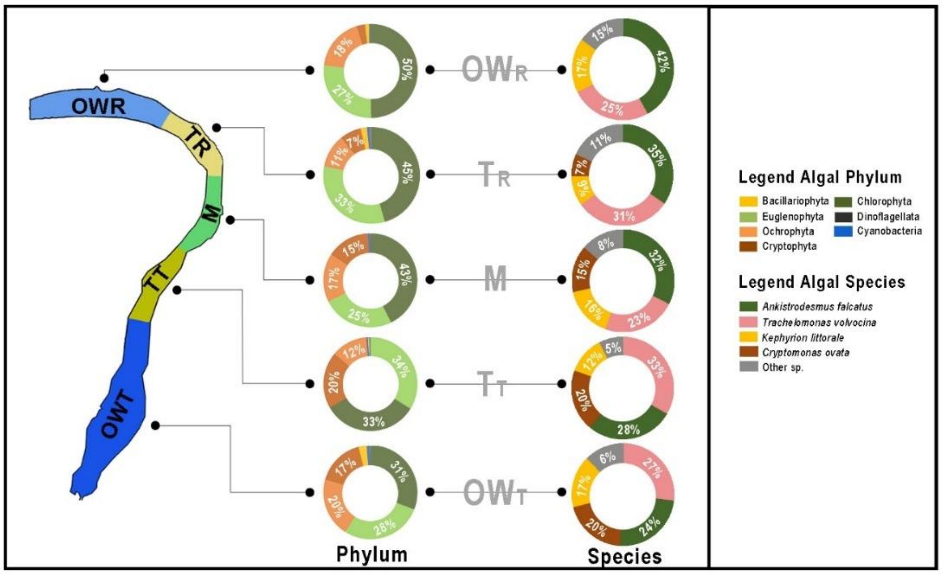


Figure 17: Phytoplankton abundance during spring sampling at the oxbow zones.

4.1.2.2.2. Early summer season

Algal phylum

The Chlorophyta species was the most abundant phylum in the oxbow lake with a 29.8% (30,369 - 3,448,800 Ind. L^{-1}) of total algal abundance (Figure 18), then the second highest phylum was Cyanobacteria with a 25% (174,182 - 2,954,674 Ind. L^{-1}) of total algal abundance, the third highest phylum was Euglenophyta with a 22.1% (21,692 - 2,214,044 Ind. L^{-1}) of total abundance. However, the Cryptophyta was 15% (325,139 - 1,372,553 Ind. L^{-1}), Bacillariophyta was 4% (750,543 – 0 Ind. L^{-1}), and Ochrophyta was 2% (0 - 632,280 Ind. L^{-1}).

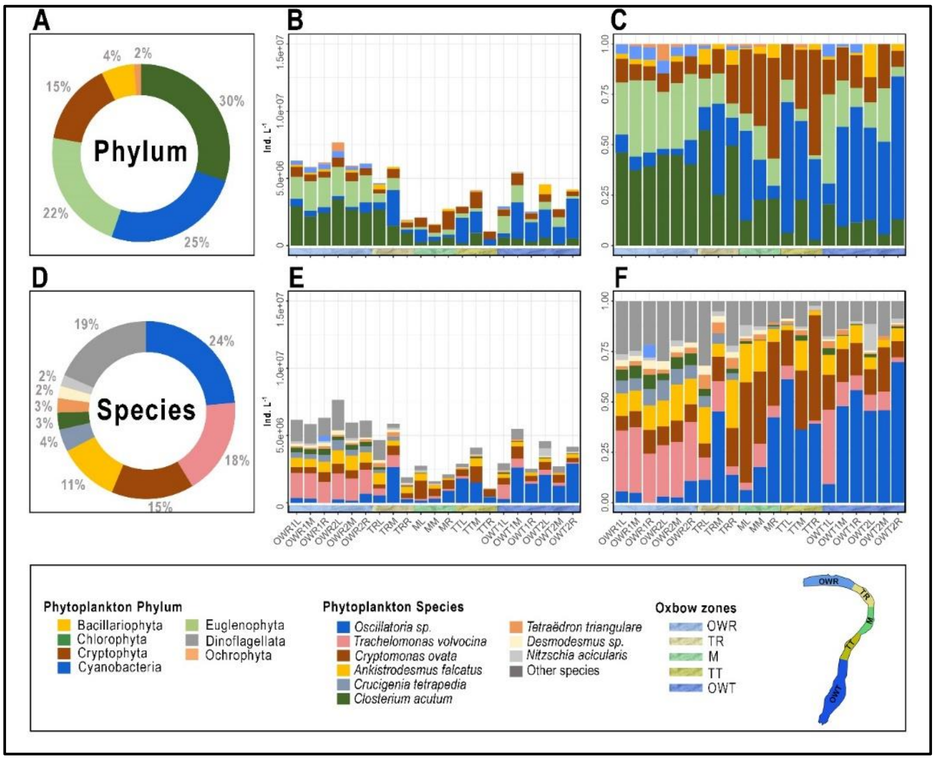


Figure 18: Phytoplankton abundance during early summer time at each sampling point. (A, B, and C) graphs representing the phylum abundance level of the phytoplankton. (D, E, and F) graphs representing the species abundance level of the phytoplankton.

Algal species abundance

Generally, the *Oscillatoria* sp. was 23.43% (0 - 2,904,253 Ind. L^{-1}), *Trachelomonas volvocina* was 17.44% (0 - 1,954,320 Ind. L^{-1}), *Cryptomonas ovata* was 14.87% (325,139 - 1,372,553 Ind. L^{-1}), and *Ankistrodesmus falcatus* was 10.96% (21,692 - 1,072,960 Ind. L^{-1}) of total species abundance during early summer sampling (Figure 18).

Algal composition in the zones of the oxbow lake during early summer investigation

- Rakamaz Open water zone (OW_R)

  Rakamaze open water zone characterized by the maximum relative abundance of Chlorophyta 42.38%, followed by Euglenophyta

31.95%, Cryptophyta 9.29%, Cyanobacteria 6.62%, Planctomyces 5.59%, Ochrophyta 2.45%, and Bacillariophyta 1.72%.

At the species level, *Trachelomonas volvocina* was 28.07%, *Ankistrodesmus falcatus* was 12.83%, *Cryptomonas ovata* was 9.29%, and *Crucigenia tetrapedia* was 7.63% (Figure 19).

- Rakamaz transitional zone (T_R)

  Rakamaz transitional water zone characterized by the maximum relative abundance of Chlorophyta 40.92%, followed by Cyanobacteria 27.75%, Euglenophyta 13.51%, Cryptophyta 11.23%, Bacillariophyta 5.20%, and Ochrophyta 0.43%.

  At the species level, Oscillatoria was 27.75%, Ankistrodesmus falcatus was 13.56%, Trachelomonas volvocina was 11.84%, and Cryptomonas ovata was 11.23% (Figure 19).

- Middle Zone (M)

  The middle zone characterized by the maximum relative abundance of Cryptophyta 40.55%, followed by Cyanobacteria 22.15%, Chlorophyta 19.63%, Euglenophyta 12.72%, Bacillariophyta 3.98%, and Ochrophyta 0.75%.

  At the species level, *Cryptomonas ov*ata was 40.55%, Oscillatoria sp. was 20.91%, *Ankistrodesmus falcatus* was 13.92%, and *Trachelomonas volvocina* was 6.16% (Figure 19).

- Tisza transitional zone (T_T)

  Tisza transitional water zone characterized by the maximum relative abundance of Cyanobacteria 48.48%, followed by Cryptophyta 28.17%, Chlorophyta 14.25%, Euglenophyta 7.28%, Ochrophyta 0.92%, and Bacillariophyta 0.90%.

  At the species level, *Oscillatoria* sp. was 45.65%, *Cryptomonas ovata* was 28.17%, and *Ankistrodesmus falcatus* was 8.62% (Figure 19).

- Tisza open water zone (OW_T)

  Tisza open water zone characterized by the maximum relative abundance of Cyanobacteria 46.11%, followed by Euglenophyta 18.41%, Cryptophyta 14.23%, Chlorophyta 11.62%, and Bacillariophyta 8.07%.

  At the species level, *Oscillatoria* sp. was 45.31%, *Cryptomonas ovata* was 14.23%, *Trachelomonas volvocina* was 11.32%, *Nitzschia acicularis* was 7.21%, and *Ankistrodesmus falcatus* was 6.49% (Figure 19).

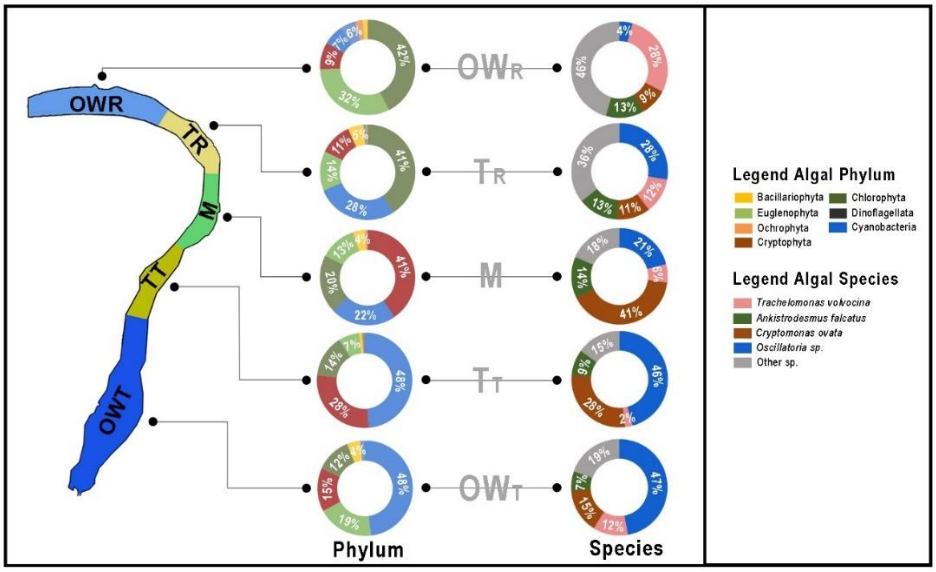


Figure 19: Phytoplankton abundance during early summer sampling at the oxbow zones.

4.1.2.2.3. Late summer season

Algal phylum

The Chlorophyta species was the most abundant phylum in the oxbow lake with a 36% (222,041 - 4,272,680 Ind. L^{-1}) of total algal abundance Figure 20, then the second highest phylum was Cyanobacteria with a 20.8% (35,237 - 2,315,861 Ind. L^{-1}) of total algal abundance, the third highest phylum was Cryptophyta with a 14% (0 - 1,466,157 Ind. L^{-1}) of total abundance. However, the Euglenophyta was 11.95% (91,968 - 1,290,107 Ind. L^{-1}), Bacillariophyta was 7.74% (862,200 – 15,416 Ind. L^{-1}), Ochrophyta was 6.86% (0 - 1,463,127 Ind. L^{-1}), and Dinoflagellata was 2.63% (0 - 122,624 Ind. L^{-1}).

Algal species abundance

Generally, the *Oscillatoria* sp. was 18.96% (35,237 - 2,315,861 Ind. L^{-1}), *Cryptomonas ovata* was 14.00% (0 - 1,466,157 Ind. L^{-1}), *Trachelomonas volvocina* was 10.26% (76,640 - 1,124,053 Ind. L^{-1}), *Ankistrodesmus falcatus* was 9.34% (0 - 1,532,800 Ind. L^{-1}), and

Closterium acutum was 8.22% (114,602 - 1,085,733 Ind. L^{-1}) of total species abundance during late summer sampling (Figure 20).

Algal composition in the zones of the oxbow lake during late summer investigation

- Rakamaz Open water zone (OW_R)

  Rakamaz open water zone characterized by the maximum relative abundance of Chlorophyta 31.61%, followed by Cyanobacteria 22.98%, Ochrophyta 16.57%, Cryptophyta 10.67%, Euglenophyta 10.32%, and Bacillariophyta 4.95%.

  At the species level, *Oscillatoria* sp. was 22.27%, *Dinobryon* sp. was 15.36%, *Cryptomonas ovata was 10.67%, Trachelomonas volvocina was 9.45%*, *Closterium acutum* was 9.23%, and *Crucigenia tetrapedia* was 7.25% Figure 21.

- Rakamaz transitional zone (T_R)

  Rakamaze transitional water zone characterized by the maximum relative abundance of Chlorophyta 35.80%, followed by Cyanobacteria 33.18%, Cryptophyta 15.82%, Bacillariophyta 8.18%, Euglenophyta 3.59%, Ochrophyta 3.06%, and Dinoflagellata 0.22%.

  At the species level, *Oscillatoria* sp. was 32.66%, *Cryptomonas ov*ata was 15.82%, *Closterium acutum* was 9.71%, and *Ankistrodesmus falcatus* was 8.42% (Figure 21).

- Middle Zone (M)

  Due to high macrophyte coverage percentage there was no space for the boat to move inside it then we couldn't collect samples from that area.

- Tisza transitional zone (T_T)

  Due to high macrophyte coverage percentage there was no space for the boat to move inside it then we couldn't collect samples from that area.

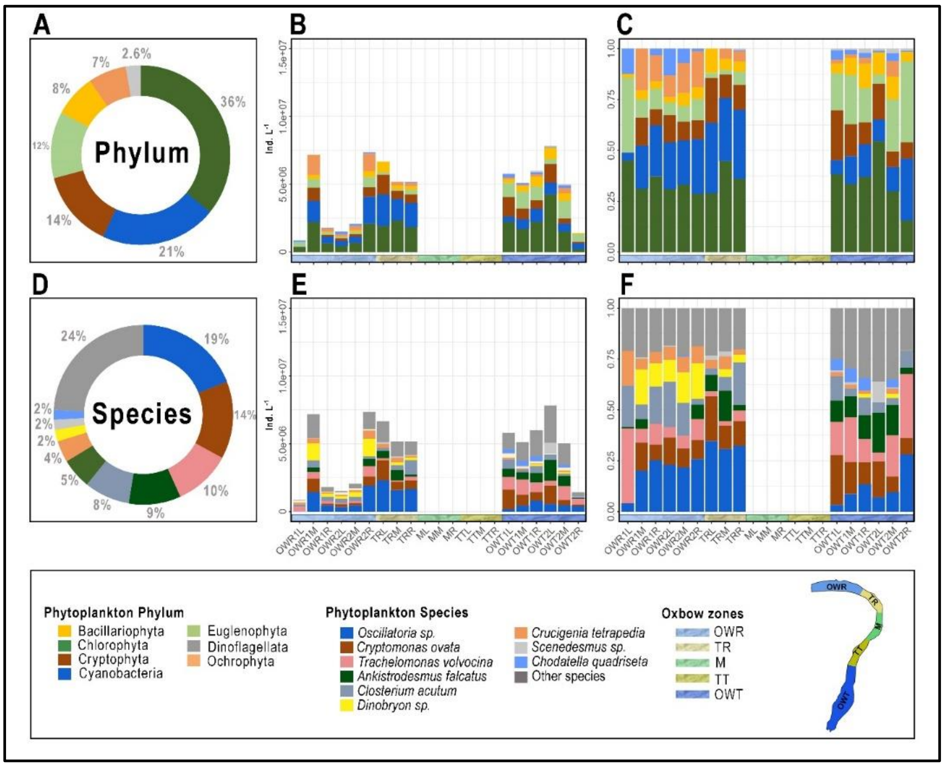


Figure 20: Phytoplankton abundance during late summer time at each sampling point. (A, B, and C) graphs representing the phylum abundance level of the phytoplankton. (D, E, and F) graphs representing the species abundance level of the phytoplankton.

- Tisza open water zone (OW_T)

  Tisza open water zone characterized by the maximum relative abundance of Chlorophyta 38.94%, followed by Euglenophyta 17.61%, Cryptophyta 15.22%, Cyanobacteria 12.62%, Bacillariophyta 9.37%, Ochrophyta 2.48%, and Dinoflagellata 1.28%.

  At the species level, *Cryptomonas ovata* was 15.22%, *Trachelomonas volvocina* was 14.65%, *Ankistrodesmus falcatus* was 13.33%, *Oscillatoria* sp. was 9.26%, and *Closterium acutum* was 6.73% (Figure 21).

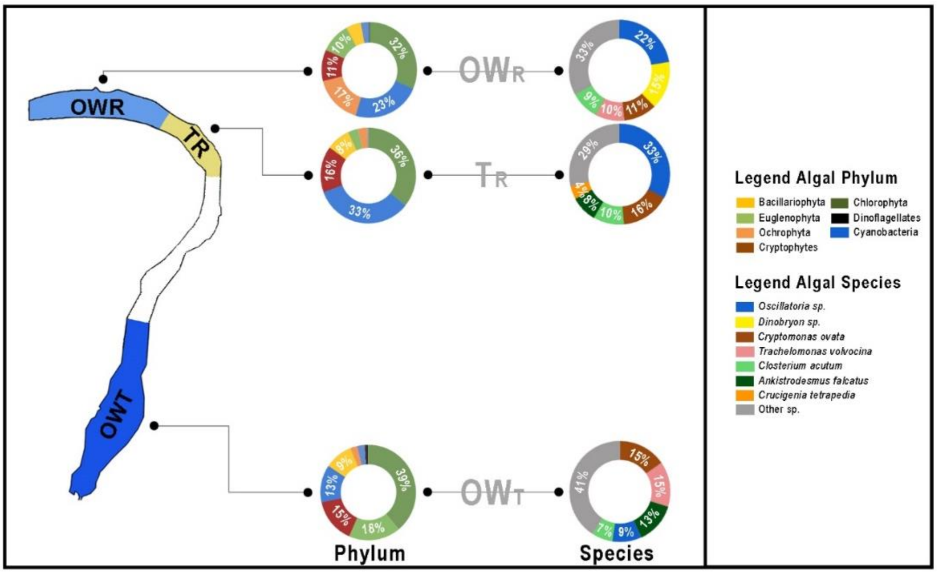


Figure 21: Phytoplankton abundance during late summer sampling at the oxbow zones.

4.1.2.2.4. Autumn season

Algal phylum

The Chlorophyta species was the most abundant phylum in the oxbow lake with a 45.4% (143,700 - 9,835,467 Ind. L^{-1}) of total algal abundance (Figure 22), then the second highest phylum was Euglenophyta with a 24.8% (28722 - 4,047,900 Ind. L^{-1}) of total algal abundance, the third highest phylum was Cryptophyta with a 22% (58,528 - 2,544,448 Ind. L^{-1}) of total abundance. However, the Ochrophyta was 4.26% (0 - 574,800 Ind. L^{-1}), Bacillariophyta was 3.10% (0 - 702,240 Ind. L^{-1}), and Cyanobacteria was 0.42% (0 - 125,127 Ind. L^{-1}).

Algal species abundance

Generally, the *Ankistrodesmus falcatus* was 24.27% (47,900 - 6,651,257 Ind. L^{-1}), *Cryptomonas ovata* was 21.95% (58,528 - 2,544,448 Ind. L^{-1}), *Phacus* sp. was 16.45% (0 - 4,000,000 Ind. L^{-1}), *Trachelomonas volvocina* was 8.10% (28,722 - 2,637,693 Ind. L^{-1}), and *Ankistrodesmus bibraianus* was 7.20% (0 - 1,505,429 Ind. L^{-1}) of total species abundance during autumn sampling (Figure 22).

Algal composition in the zones of the oxbow lake during autumn investigation

- Rakamaz Open water zone (OW_R)

  Rakamaze open water zone characterized by the maximum relative abundance of Chlorophyta 70.15%, then followed by Cryptophyta 17.37%, Euglenophyta 9.51%, and Ochrophyta 2.97%.

  At the species level, *Ankistrodesmus falcatus* was 52.71%, *Cryptomonas ovata* was 17.37%, *Trachelomonas volvocina* was 9.40%, *Ankistrodesmus bibraianus* was 8.29%, and *Ankistrodesmus spiralis* was 6.38% (Figure 23).

- Rakamaz transitional zone (T_R)

  Rakamaze transitional water zone characterized by the maximum relative abundance of Euglenophyta 87.89%, followed by Cryptophyta 5.60%, Chlorophyta 3.02%, Bacillariophyta 2.31%, Ochrophyta 0.82%, and Cyanobacteria 0.36%.

  At the species level, *Phacus* sp. was 87.10% and *Cryptomonas ovata* was 5.60% (Figure 23).

- Middle Zone (M)

  The middle zone characterized by the maximum relative abundance of Chlorophyta 50.24%, followed by Cryptophyta 22.05%, Euglenophyta 11.82%, Ochrophyta 9.03%, Bacillariophyta 6.45%, and Cyanobacteria 0.42%.

  At the species level, *Cryptomonas ovata* was 22.05%, *Ankistrodesmus falcatus* was 15.80%, *Monoraphidium contortum* was 12.95%, *Trachelomonas volvocina* was 11.12%, *Dinobryon* sp. was 9.03%, and *Crucigenia tetrapedia* was 8.06% (Figure 23).

- Tisza transitional zone (T_T)

  Tisza transitional water zone characterized by the maximum relative abundance of Cryptophyta 41.44%, followed by Chlorophyta 35.41%, Euglenophyta 10.24%, Bacillariophyta 7.27%, Ochrophyta 4.20% and Cyanobacteria 1.20%.

  At the species level, *Cryptomonas ovata* was 41.44%, *Ankistrodesmus bibraianus* was 15.25%, *Trachelomonas volvocina* was 9.63%, *Ankistrodesmus falcatus* was 9.30%, and *Asterionella formosa* was 6.97% (Figure 23).

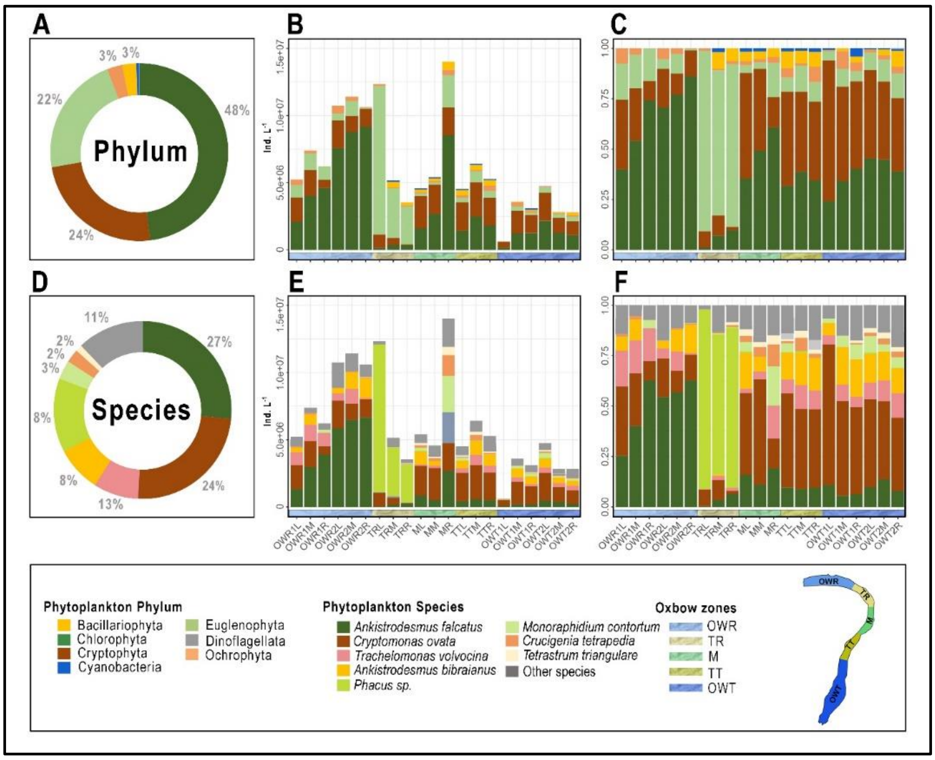


Figure 22: Phytoplankton abundance during autumn time at each sampling point. (A, B, and C) graphs representing the phylum abundance level of the phytoplankton. (D, E, and F) graphs representing the species abundance level of the phytoplankton.

- Tisza open water zone (OW_T)

  Tisza open water zone characterized by the maximum relative abundance of Cryptophyta 43.25%, followed by Chlorophyta 40.34%, Euglenophyta 8.89%, Ochrophyta 3.72%, Bacillariophyta 2.64% and Cyanobacteria 1.07%

  At the species level, *Cryptomonas ovata* was 43.25%, *Ankistrodesmus bibraianus* was 15.37%, *Ankistrodesmus falcatus* was 8.71%, *Trachelomonas volvocina* was 8.43%, and *Monoraphidium contortum* was 6.06% (Figure 23).

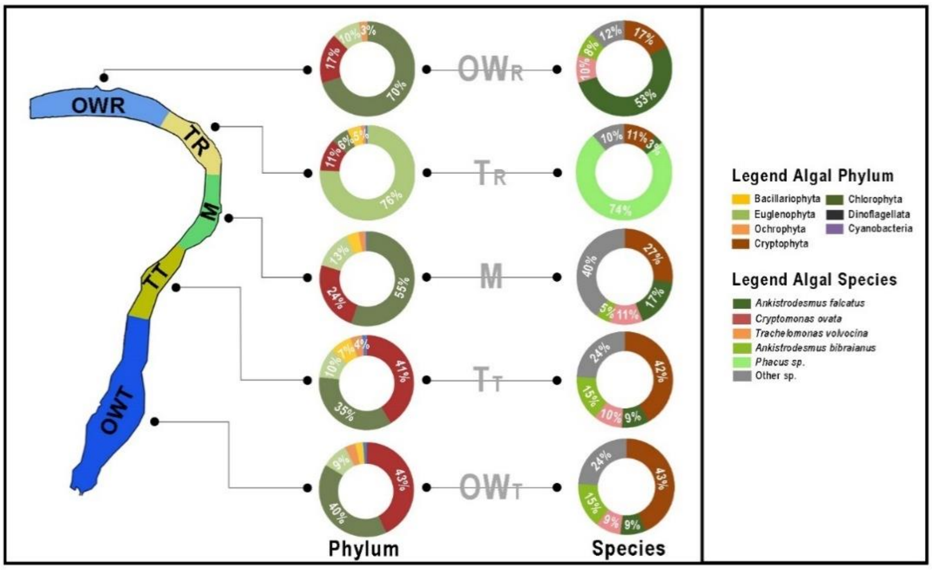


Figure 23: Phytoplankton abundance during autumn sampling at the oxbow zones.

4.1.2.3. PCA of phytoplankton in the oxbow lake

At apring sampling (Figure 24.A), it was observed that the OW_R, OW_T, and T_T zones were differs from T_R and M zones based on the results of the principal component analysis (PCA) shown in (Figure 4.16.A). The PC1 expressed 46.9% and PC2 was 29.1% of the total variance. Notably, the species *Tetraedron triangulare* and *Pediastrum duplex* exhibited high abundance in zone OW_R. *Cyclotella* sp. and *Dinobryon sertularia* were also found to have high abundance in Groups I and II, while the species of *T. triangulare* was highest abundance in M and T_R zones. Additionally, *Oscillatoria* sp. exhibited high abundance in T_R, M, T_T, and OW_T zones. Furthermore, the *Cyclotella* sp. have a significant positive correlation with conductivity ($r = 0.5$, $p \leq 0.05$), TDS ($r = 0.5$, $p \leq 0.05$), and humic acid ($r = 0.5$, $p \leq 0.05$). More information about significant correlation between phytoplankton species and physical-chemical variables can be found in (Appendix 1).

In early summer sampling (Figure 24.B), the various sampling points across the five zones were subjected to principal component analysis (PCA), whereas zones OW_R and T_R differs from M, T_T, and OW_T zones, as demonstrated in (Figure 4.16.B). The PC1 expressed 61.8% and PC2 was 23.3% of the total variance. Notably, *Cosmarium* sp. exhibited high abundance in both OW_R and T_R zones, whereas *P. duplex* was observed to have a high abundance in the same two groups. Furthermore, zone OW_R charactrised by high aboundance of *D. sertularia*. *Cyclotella* sp. and *Coelastrum microsporum*, on the other hand, were found to be most abundant in T_R zone. Finally, *Oscillatoria* sp. exhibited high abundance in M, T_T, and OW_T zones, thus indicating that the three groups were distinguished by the presence of certain algal species with varying levels of abundance. Furthermore, the *Oscillatoria* sp. significantly correlated with PO_4^{3-} ($r = 0.5$, $p = 0.02$), conductivity ($r = 0.4$, $p \leq 0.05$), and NO_3-N ($r = 0.4$, $p \leq 0.05$). More information about significant correlation between phytoplankton species and physical-chemical variables can be found in (Appendix 2).

During late summer sampling (Figure 24.C), the zones OW_R and T_R separated from the OW_T zone based on the principal component analysis (PCA) as presented in (Figure 4.16.C). The PC1 expressed 64.6% and PC2 was 35.4% of the total variance. The highest abundance of *Staurastrum paradoxum* was observed in OW_R zone, while T_R zone exhibited the highest abundance of *Monactinus simplex*. Finally, zone OW_T was characterized by the highest abundance of *Phacus* sp., *Aulacoseira granulata*, *Peridinium cinctum*, and *Nostoc* sp. thus indicating that the three groups were differentiated based on the presence of specific phytoplankton species with varying abundances. Furthermore, the *Nostoc* sp. have a significant negative correlation with conductivity ($r = -0.6$, $p \leq 0.05$) and TDS ($r = -0.6$, $p \leq 0.05$), and *P. cinctum* correlated significantly with humic acid ($r = 0.61$, $p = 0.02$). More information about significant correlation between phytoplankton species and physical-chemical variables can be found in (Appendix 3).

At autumn sampling (Figure 24.D), the zones OW_R distinctly separated from other zones, and T_R zone also separated signifigantly from other zones based the principal component analysis (PCA), as represented in (Figure 4.16.D). The PC1 expressed 41.8% and PC2 was 35.4% of the total variance. Zone OW_R was found to have the highest abundance of *Ankistrodesmus falcatus* and *Kephyrion littorale*, while M, T_T, and OW_T zones had a high abundance of *Asterionella formosa*, *Oscillatoria* sp., and *Lemmermannia triangularis*.

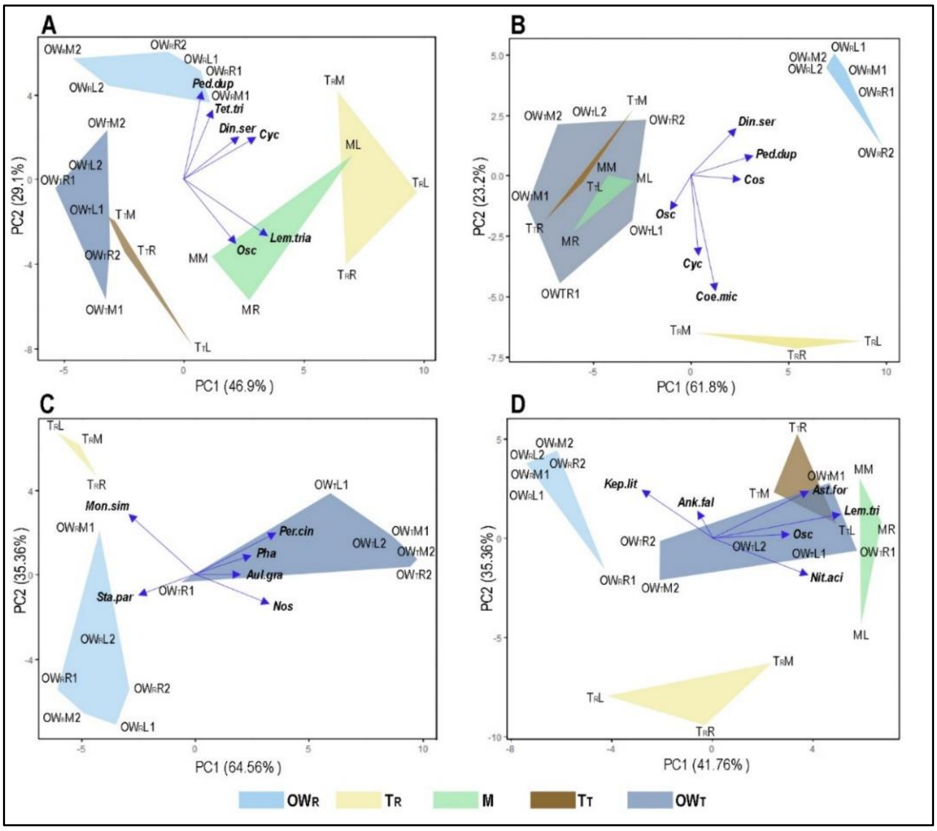


Figure 24: Principal component analysis PCA of the phytoplankton during the study period. Graph (**A**): spring, Graph (**B**): Early summer, Graph (**C**): Late summer, Graph (**D**): autumn. Phytoplankton name acronym, Ped.dup: *Pediastrum duplex*; Tet.tri: *Tetrastrum triangulare*; Din.ser: *Dinobryon 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*.

Additionally, the aboundance of *Nizschia acicularis* was observed to be at the maximum in all zones except OW_R zone, indicating that these three groups were differentiated based on the presence of specific phytoplankton species with varying abundances. Moreover, the *L. triangulare* have a significant negative correlation with DO ($r = -0.5$, $p \leq$

0.05). More information about significant correlation between phytoplankton species and physical-chemical variables can be found in (Appendix 4).

4.1.3. Land use/cover in the studied area

The land use in the Nagy-Morotva oxbow shallow lake was used for different activities which has an impact on the water quality (Figure 25.).

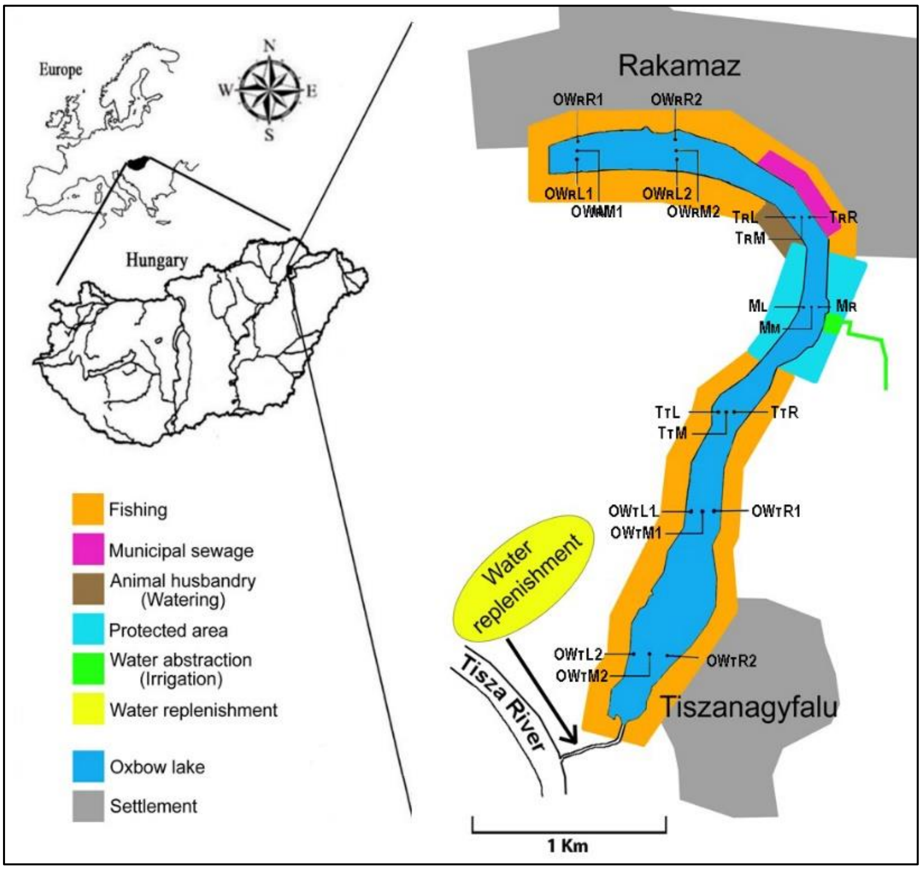


Figure 25: Land use in the studied area of the Nagy Morova oxbow lake.

The open water zone in Rakamaz OW_R included the OW_RR1, OW_RM1, OW_RL1, OW_RR2, OW_RM2, and OW_RL2 sampling points, and the open water zone in Tiszanagyfalu OW_T have the sampling points of OW_TR1, OW_TM1, OW_TL1, OW_TR2, OW_TM2, and OW_TL2 which are used for fishing activities.

The transitional zone in Rakamaz T_R consisted of T_RR, T_RM, and T_RL was highly 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. While the Middle zone M included M_R, M_M, and M_L were a protected area and covered with macrophytes (mostly with submerged vegetation and water soldier) and the water inside that zone used for irrigation activities.

4.1.4. Canonical correspondence analysis CCA of the seasons

Canonical correspondence analysis revealed a great different between the four-sampling seasons based on the algal species and environmental variables Figure 26. The CCA1 explained 49% and CCA2 explained 19% of total variance.

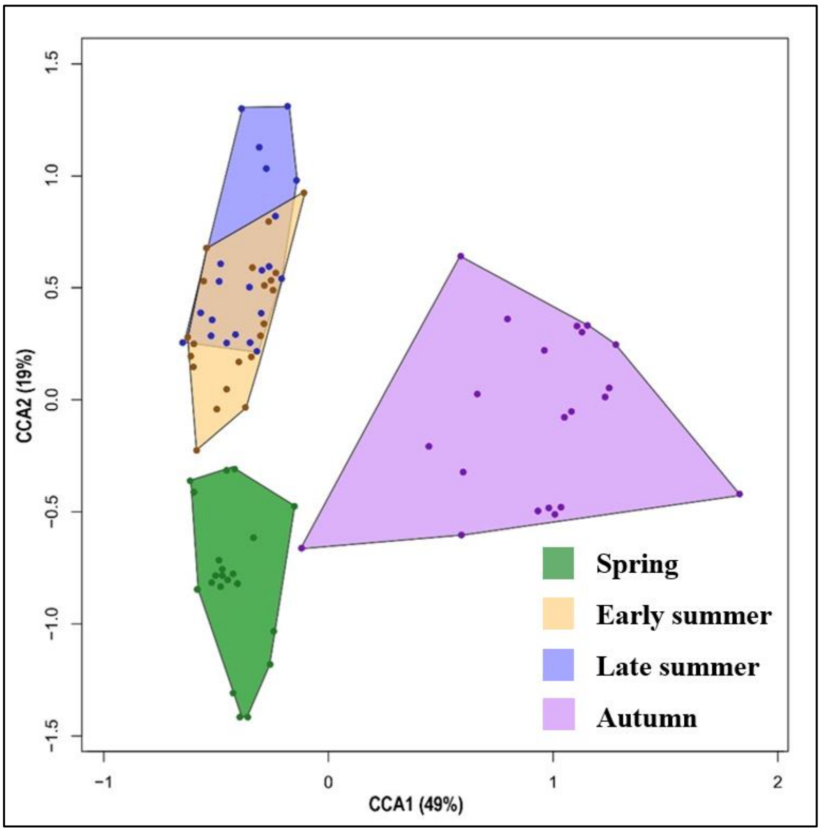


Figure 26: Canonical correspondence analysis CCA graph showing the differences between the four sampling times based on algal composition and physical-chemical variables.

According to the CCA graph, autumn sampling was highly separated from the other sampling periods. However, early and late summer sampling periods characteristics was more similar to each other than other sampling seasons.

4.2.1. Physical-chemical characterization of the Tigris River

4.2.1.1. Physical-chemical variation during the study period

The physical-chemical variables change throughout the investigation times (Figure 27).

Table 4: Minimum, maximum, and median values of the physical-chemical variables during the investigation in the Tigris River within Mosul city.

Variables	**Spring**	**Summer**	**Autumn**	**Winter**
	Min-Max Median±SD	**Min-Max Median ±SD**	**Min-Max Median ±SD**	**Min-Max Median ±SD**
BOD_5 (mg/l)	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)	0.21-0.65 0.4	0.1-0.5 0.1	0.5-1.5 0.8	0.2-0.8 0.4
Cl^- (mg/l)	28-40 33	30.5-41.9 38	38.1-40 38	14.5-29.1 22
COD_{sMn} (mg/l)	1.9-7.8 2.7	2.6-4.4 3.6	2.4-6.1 3.1	2.8-4.7 3.5
DO (mg/l)	3.4-5.9 4.2	ND-2 0.0	4.2-12 5.6	4.5-9.8 6.9
HCO_3^- (mg/l)	172-246 222	170.8-195.2 171	195.2-244 220	110.9-244 155
NH_4-N (mg/l)	ND-0.056 0.009	ND-0.055 0.012	0.017-0.059 0.026	0.002-0.011 0.005
NO_2-N (mg/l)	0.004-0.018 0.006	ND-0.0022 0.0	ND-0.0065 0.002	ND-0.0042 0.002
NO_3-N (mg/l)	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)	0.001-0.06 0.0014	0.004-0.026 0.009	ND-0.003 0.0	0.001-0.007 0.004
TDS (mg/l)	334-357 346	280-330 295	295-338 325	340-369 350

TSS (mg/l)	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
Water temperature (^0C)	15-16.7 15.5	18.5-20.6 19.28	16.18.6 17	11.7-12.8 12.4

ND, no detection (below detection limit).

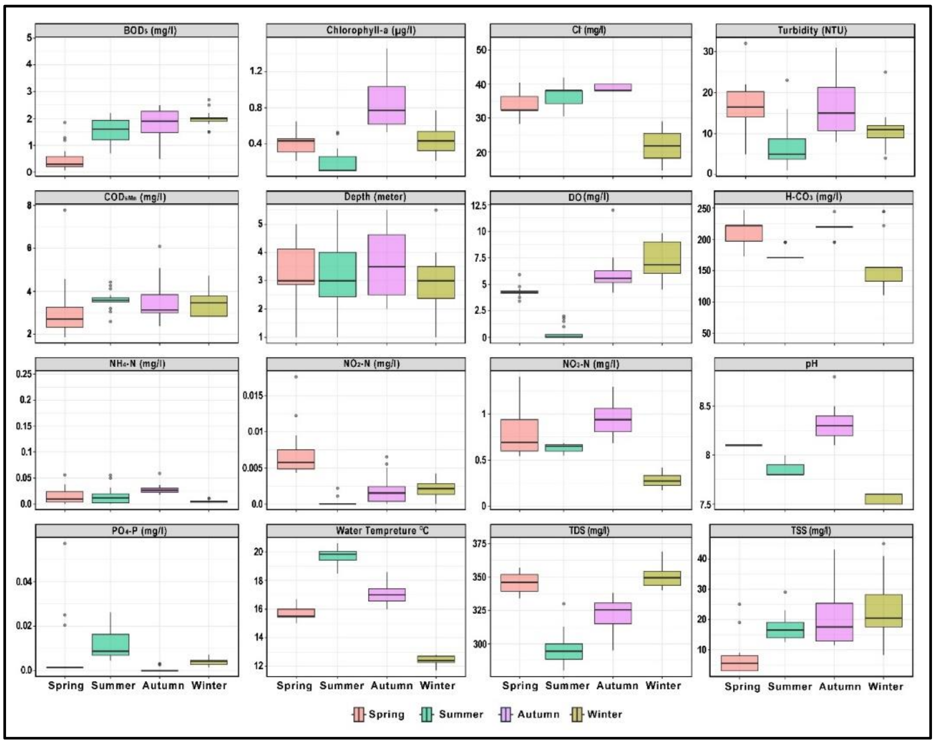


Figure 27: Physical-chemical variables in the Tigris River in Mosul during the sampling time.

4.2.1.2. Physical-chemical variables results

4.2.1.2.1. Spring season

Physical-chemical variables varied among the zones in the Tigris River (Figure 28).

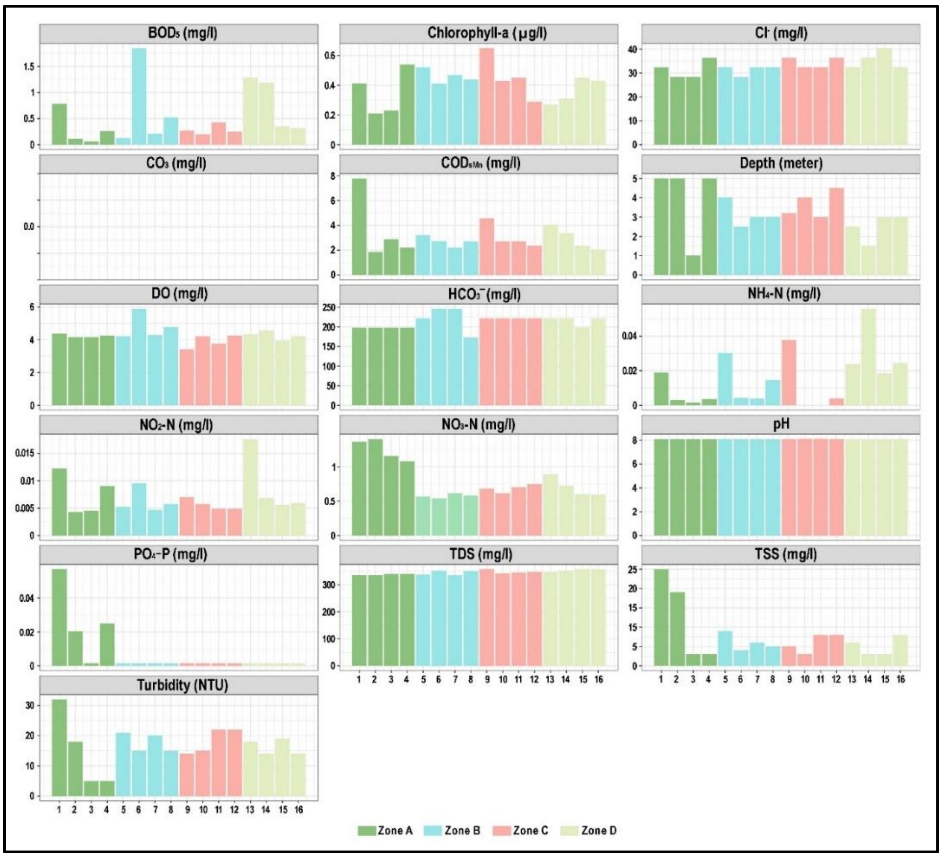


Figure 28: Physicochemical variables of oxbow lake in each sampling point at spring.

During spring, whereas Zone A characterized by the maximum concentration of TSS (25 mg/l), turbidity (32 mg/l), PO_4-P (0.06 mg/l), COD_{sMn} (7.8 mg/l), and NO_3-N (1.4 mg/l), while NH_4-N (0.056 mg/l) was at the lowest concentration in this zone. PO_4-P was below detection limit in the other zone. Zone B have higher concentration of HCO_3^- (246 mg/l), TDS (352 mg/l), and DO (5.9 mg/l). Zone C characterized by maximum concentration of chlorophyll-a (0.65 µg/l) while NO_2-N (0.005 mg/l) was at the lowest. Zone D characterized by the maximum concentration of TDS (357 mg/l), Cl^- (40 mg/l), NH_4-N (0.056 mg/l), NO_2-N (0.018 mg/l), while TSS (3 mg/l) was at the lowest.

4.2.1.2.2. Summer season

Physicochemical variables varied among the zones in the Tigris River during summer investigation (Figure 29), whereas Zone A characterized by the maximum concentration of HCO_3^- (195 mg/l), NH_4-N (0.05 mg/l), NO_3-N (0.69 mg/l), and pH (8). Furthermore, DO concentration was (2 mg/l) in zone A while was below detection limit in the other zones.

Figure 29: Physicochemical variables of oxbow lake in each sampling point at summer.

Zone B have higher concentration of pH (8), NO_3-N (0.69 mg/l), NH_4-N (0.055 mg/l), PO_4-P (0.022 mg/l), HCO_3^- (195 mg/l), and chlorophyll-a (0.53 µg/l). TSS (29 mg/l), turbidity (23 mg/l), TDS (330 mg/l), BOD_5 (2.2 mg/l), Cl^- (42 mg/l), and COD_{sMn} (4.4 mg/l) was at maximum in Zone C, while NH4-N (0.01 mg/l) was at the lowest concentration. While Zone D characterized by a concentration of TDS (313 mg/l), BOD_5 (2 mg/l), chlorophyll-a (0.51 µg/l), and PO_4-P (0.026 mg/l). Furthermore, NO_2-N was (0.002 mg/l) in the zone D, and below detection limit in the other zones.

Figure 30: Physicochemical variables of oxbow lake in each sampling point at autumn.

4.2.1.2.3. Autumn season

Physicochemical variables varied among the zones in the Tigris River during autumn sampling investigation (Figure 30), whereas Zone A characterized by the maximum concentration of TSS (41 mg/l), turbidity (29 mg/l), HCO_3^- (244 mg/l), COD_{sMn} (5.1 mg/l), NH_4-N (0.06 mg/l), pH (8.2), and DO (12 mg/l). Zone B have higher concentration of Cl^- (38 mg/l), NO_3-N (1.29 mg/l), and pH (8.2).

Figure 31: Physicochemical variables of oxbow lake in each sampling point at winter.

Zone C have high concentration of BOD_5 (2.5 mg/l), turbidity (31 mg/l), TSS (43 mg/l), TDS (335 mg/l), Cl^- (40 mg/l), chlorophyll-a (1.46 µg/l), COD_{sMn} (6.1 mg/l), while NO_2-N (0.001 mg/l) was at the lowest. Furthermore, PO_4-P was (0.003 mg/l) in the zone C while was below detection limit in the other zones. While Zone D characterized by a high concentration of TDS (338 mg/l), BOD_5 (2.5 mg/l), Cl^- (40 mg/l), NO_2-N (0.006 mg/l), and NO_3-N (1.26 mg/l), while TSS (11 mg/l) and turbidity (9 NTU) was at the lowest concentration.

4.2.1.2.4. Winter season

Physicochemical variables varied among the zones in the Tigris River during winter sampling investigation (Figure 31). Zone A characterized by the maximum concentration of chlorophyll-a (0.77 µg/l), Cl^- (29.1 mg/l), COD_{sMn} (4.7 mg/l), DO (9.8 mg/l), HCO_3^- (244 mg/l), NH_4-N (0.01 mg/l), NO_3-N (0.42 mg/l), and PO_4-P (0.007 mg/l). The zone B characterized by high concentration of PO_4-P (0.007 mg/l), TDS (369 mg/l), TSS (45 mg/l), and turbidity (25 NTU). Zone C characterized by high concentration of HCO_3^- (244 mg/l), while NO_2-N (0.001 mg/l), TSS (10 mg/l), and PO_4-P (0.03 mg/l) was at the lowest. And zone D characterized by high concentration of BOD_5 (2.7 mg/l), NH_4-N (0.011 mg/l), and NO_2-N (0.004 mg/l).

4.2.1.3. LDA of physical-chemical variables in the Tigris River

According to the physical-chemical properties (Figure 32.a) in spring, zone A differed strongly from the other three zones. The LDA1 expressed 96.7 % and LDA2 was 2.17% of the total variance. During spring, zone A exhibited elevated levels of NO_3-N and PO_4^{3-}-P. The zones D, C, and B characterized with high level of turbidity, NH_4-N, TSS, and NO_2-N.

During the summer season, the graph of LDA (Figure 32.b) showed that zone A and B are similar, but zone C and D differed from each other and from zone A and B zones based on the physical-chemical properties. The LDA1 expressed 64.74 % and LDA2 was 24.2 % of the total variance. Zone C have a high level of TSS and COD_{sMn}. Zone D characterized by maximum level of NO_2-N, PO_4-P, and chlorophyll-a. Zones B and A have a high level of NH_4-N.

During the season of autumn, the LDA graph (Figure 32.c). According to the physical-chemical properties indicates that zones A and B differed from the C and D zones. The C and D zones also differed from each other. The LDA1 expressed 74.3 % and LDA2 was 23.5 % of the total variance. At zones B and A, the concentrations of NO_3-N and NH_4-N was the maximum level. Zone C have the maximum level of COD_{sMn} and TSS. While, zone D has a maximum level of NO_2-N.

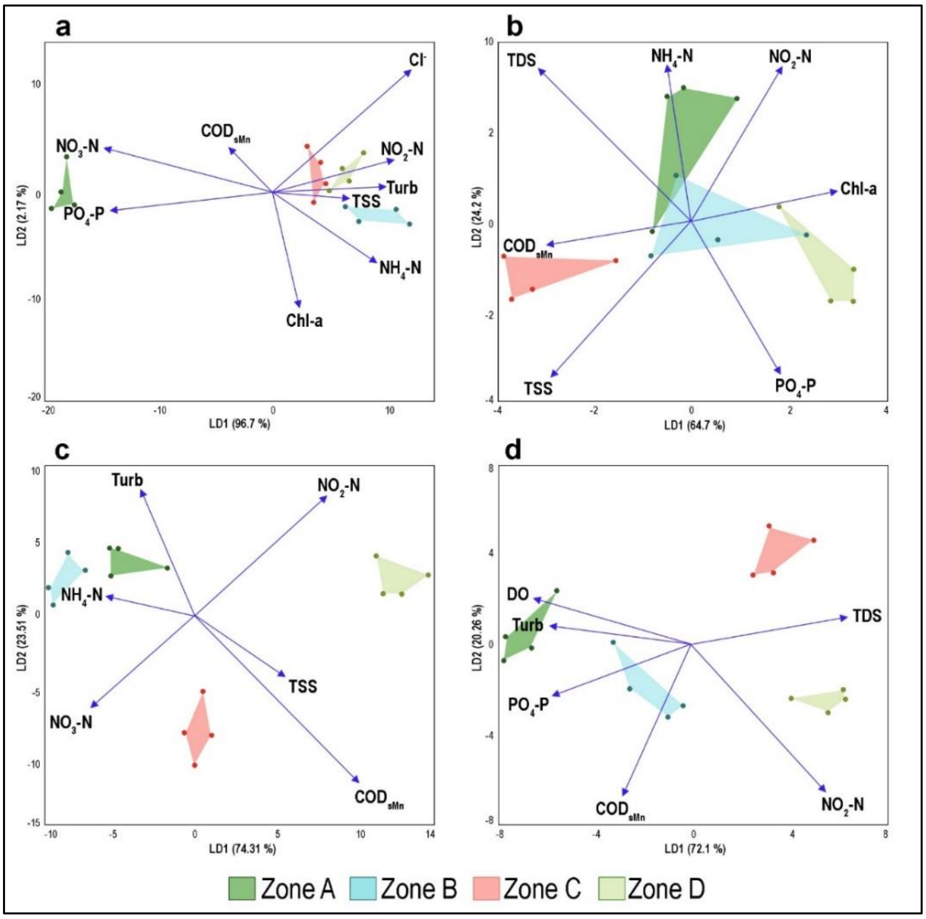


Figure 32: Linear discriminant analysis (LDA) based on the physical-chemical variables during the investigated four seasons. Graph (a): spring; (b): summer; Graph (c): autumn; Graph (d): winter. Cl^-: Chloride; TSS: Total suspended solids; COD_{sMn}: Chemical oxidation demand; TDS: Total dissolved solids; NH_4-N: ammonium nitrogen; PO_4-P: Orthophosphate; NO_3-N: Nitrate nitrogen; NO_2-N: Nitrite nitrogen; Chl-a: Chlorophyll-a; DO: Dissolved oxygen; and Turb: Turbidity. Zone A: upstream river affected by agricultural activities, Zone B: forest and agricultural area, Zone C: urban area, Zone D: affected by livestock and agricultural.

According to the LDA graph in the winter season (Figure 32.d) every zone differed from each other. The LDA1 expressed 72.1 % and LDA2 was 20.26 % of the total variance. Zone A have the maximum level of turbidity and DO. Zone B charactrized by maximum level of TDS and

PO_4-P. Zone C have the maximum level of TDS, and NO_2-N was at maximum at zone D.

4.2.2. Algal composition in the Tigris River

4.2.2.1. Algal composition during the investigation

Algal phylum

The Bacillariophyta dominated the algal community in the Tigris River inside Mosul city during the sampling periods by 79.9% of the total algal abundance (Figure 33). This was followed by the Cryptophyta phylum 10.9%, the Chlorophyta phylum 4.1%, the Cyanobacteria 3.6%, the Euglenophyta 1% and the Dinoflagellata 0.4%.

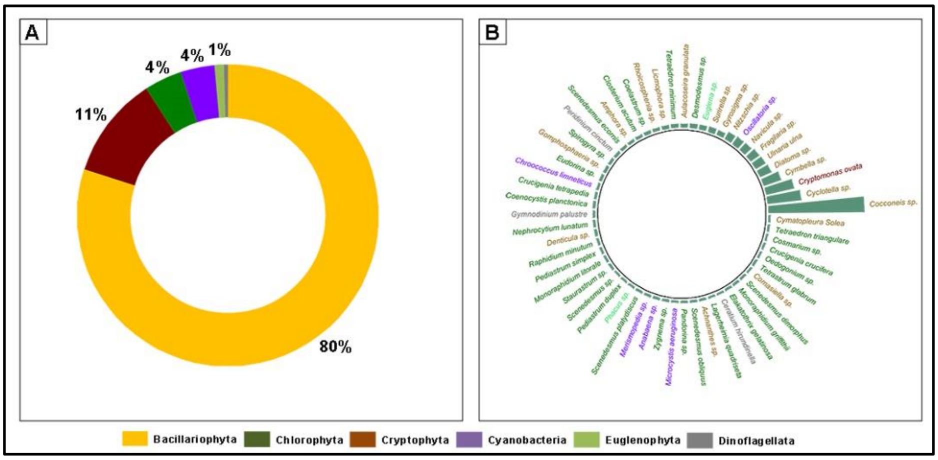


Figure 33: Figure showing the algal community in the Tigris River in Mosul city during the investigation. (A) figure showing algal phylum during the study period. (B) figure showing the algal species during the investigation whereas the bar length indicating the abundance.

However, the maximum abundance of Bacillariophyta was 65,772 Ind. L^{-1} during autumn sampling period, while the minimum was 12,456 Ind. L^{-1} at summer. Cryptophyta have the maximum abundance 8,363 Ind. L^{-1} at autumn while the minimum was 3950 Ind. L^{-1} at spring. The highest abundance of Chlorophyta was 5,167 Ind. L^{-1} in autumn while the lowest was 434 Ind. L^{-1} during spring. Cyanobacteria have the maximum abundance 2,369 Ind. L^{-1} during summer while the minimum was 29,871 Ind. L^{-1} in winter. Euglenophyta have the maximum abundance 1,209 Ind. L^{-1} at spring while the minimum was 73 Ind. L^{-1} at winter. And the maximum abundance of Dinoflagellata was 511 Ind. L^{-1} during autumn sampling period, while there was appearance at winter.

Algal species abundance

During the sample periods Figure 33, *Cocconeis* sp. was the most abundant species at 39%, followed by *Cyclotella* sp. (13%), *Cryptomonas ovata* (11%), *Cymbella* sp. (7%), *Diatoma* sp. (4%), *Ulnaria ulna* (4%), *Fragillaria* sp. (4%), *Navicula* sp. (3%) and *Oscillatoria* sp. (3%).

Furthermore, within the Bacillariophyta, *Cocconeis* sp. represented 48% of the characterized genius, followed by *Cyclotella* sp. (16%), *Cymbella* sp. (8%), *Ulnaria ulna* (5%), *Fragillaria* sp. (4%), *Navicula* sp. (3%), *Nitzschia* sp. (3%), *Gyrosigma* sp. (2%) and *Surirella* sp. (1%) species. *Aulacoseira granulata* (1%). Within the Cryptophyta phylum, only *Cryptomonas ovata* was found. While the phylum of Chlorophyta characterized by the highest abundance of *Desmodesmus* sp. was 22%, *Tetraëdron minimum* was 14%, *Coelostrum* sp. was 10%, *Closterium acutum* was 8%, *Scenedesmus ecornis* was 8%, was *Spyrogera* sp. was 6% of the total Chlorophyta species. *Desmodesmus* sp. contributed 22% of all Chlorophyta species, followed by *Tetradron minimum* (14%), *Coelastrum* sp. (10%), *Closterium acutum* (8%), *Scenedesmus ecornis* (8%), and *Spyrogera* sp. (6%). The genus Oscillatoria sp. stands for 86% of all Cyanobacteria, followed by *Chroococcus limneticus* (7%), *Gomphosphaeria* sp. (5%), *Microcystis aeruginosa* (1%), *Merismopedia* sp. (1%), and *Anabena* sp. (1%). About (95%) of the Euglenophyta phylum was made up of *Euglena* sp., whereas only (5%) was *Phacus* sp. *Peridinium cinctum*, *Gymnodinium palustre*, and *Ceratium hirundinella* made up (67%), (28%), and (5%), respectively, of the total Dinoflagellata species.

4.2.2.2. Algal composition during different seasons

4.2.2.2.1. Spring season

Phytoplankton phylum

The Bacillariophyta species was the most abundant phylum with an 80% (25,743 - 43,960 Ind. L^{-1}) of total algal abundance in the Tigris River within Mosul city during Spring sampling period, then the second highest phylum was Cryptophyta with a 11% (1,129 - 8,779 Ind. L^{-1}) of total algal abundance, the third highest phylum was Chlorophyta with a 4% (0 - 1,820 Ind. L^{-1}) of total abundance. However, the Cyanobacteria was 3% (0 -

3,705 Ind. L^{-1}), Euglenophyta was 1% (0 - 2,800 Ind. L^{-1}), and Dinoflagellata was 0.4% (0 - 557 Ind. L^{-1}) of total phylum abundance (Figure 34).

Phytoplankton species abundance

Cocconeis sp. was 50.82% (15,525 - 28,055 Ind. L^{-1}), *Cryptomonas ovata* was 9.13% (1,129 - 8,779 Ind. L^{-1}), and *Cymbella* sp. was 7.75% (1,901 - 5,094 Ind. L^{-1}) of total algal species in spring investigation abundance (Figure 34.D-F).

Algal composition in the zones during spring investigation

- Zone A – Agricultural area

  Bacillariophyta was 87.23%, Cryptophyta was 5.43%, Cyanobacteria was 5.24%, Chlorophyta was 1.26%, Euglenophyta was 0.62%, and Dinoflagellata was 0.22%.

  The most abundance species in the zone, *Cocconeis* sp. was 50.98%, *Cymbella* sp. was 10.35%, *Cryptomonas ovata* was 5.43%, and *Oscillatoria* sp. was 5.11% of total species abundance in the zone during the investigation (Figure 35).
- Zone B – Forest and Agricultural area

  Bacillariophyta was 83.63%, Cryptophyta was 8.01%, Cyanobacteria was 4.76%, Euglenophyta was 2.91%, Chlorophyta was 0.45%, and Dinoflagellata was 0.25%.

  The most abundance species in the zone, *Cocconeis* sp. was 54.41%, *Cryptomonas ovata* was 8.01%, *Cymbella* sp. was 7.38%, *Diatoma* sp. was 4.05%, and *Oscillatoria* sp. was 4.76% of total species abundance in the zone during the investigation (Figure 35).
- Zone C – Urban area

  Bacillariophyta was 81.05%, Cryptophyta was 10.33%, Euglenophyta was 3.4%, Cyanobacteria was 3.31%, Chlorophyta was 1.66%, and Dinoflagellata was 0.25%.

  The most abundance species in the zone, *Cocconeis* sp. was 50.21%, *Cryptomonas ovata* was 10.33%, *Cymbella* sp. was 6.7% of total species abundance in the zone during the investigation (Figure 35).

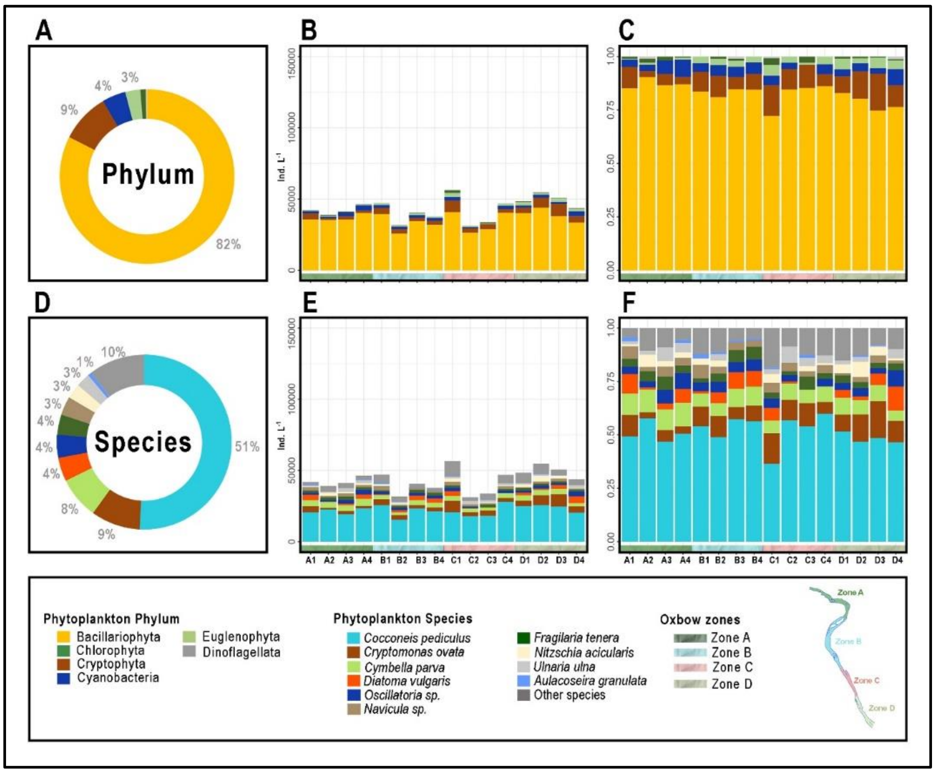


Figure 34: Phytoplankton abundance during early spring sampling at each sampling point in Tigris River. (A, B, and C) graphs representing the phylum abundance level of the phytoplankton. (D, E, and F) graphs representing the species abundance level of the phytoplankton.

- Zone D – Agricultural and livestock farming zone

  Bacillariophyta was 78%, Cryptophyta was 12.16%, Cyanobacteria was 4.18%, Euglenophyta was 4.04%, Chlorophyta was 0.68%, and Dinoflagellata was 0.28%.

  The most abundance species in the zone, *Cocconeis* sp. was 48.34%, *Cryptomonas ovata* was 12.16%, *Cymbella* sp. was 6.73%, and *Diatom* sp. was 5.27% of total species abundance in the zone during the investigation (Figure 35).

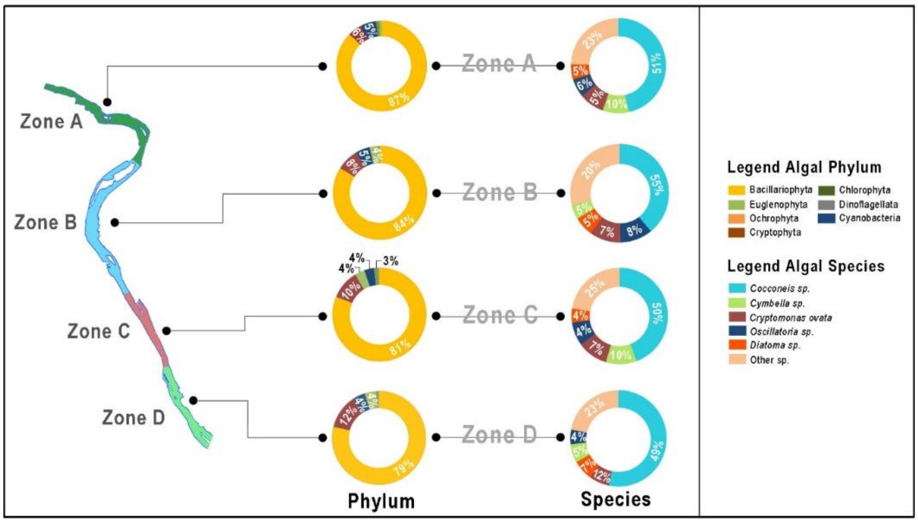


Figure 35: Phytoplankton abundance during early spring sampling in the Tigris River zones.

4.2.2.2.3. Summer season

Algal phylum

The Bacillariophyta species was the most abundant phylum with a 56.37% (241 - 24,747 Ind. L^{-1}) of total algal abundance in the Tigris River within Mosul city during summer sampling period.

The second highest phylum was Cryptophyta with a 23.4% (48 - 10,664 Ind. L^{-1}) of total algal abundance, the third highest phylum was Cyanobacteria with a 10.37% (24 - 6,836 Ind. L^{-1}) of total abundance.

However, the Chlorophyta was 7.57% (72 - 3,718 Ind. L^{-1}), Euglenophyta was 2.12% (4,111 – 0 Ind. L^{-1}), and Dinoflagellata was 0.18% (0 - 282 Ind. L^{-1}) of total phylum abundance (Figure *36*.A-C).

Algal species abundance

Cocconeis sp. 25.90% (144 - 12627 Ind. L^{-1}), *Cryptomonas ovata* was 23.40% (48 - 10,664 Ind. L^{-1}), *Oscillatoria* sp. was 9.85% (24 - 6,286 Ind. L^{-1}), *Cyclotella* sp. was 6.92% (72 - 3,334 Ind. L^{-1}), and *Cymbella* sp. was 5.39% (0 - 3,705 Ind. L^{-1}) of total species abundance during summer investigation (Figure 36.D-F).

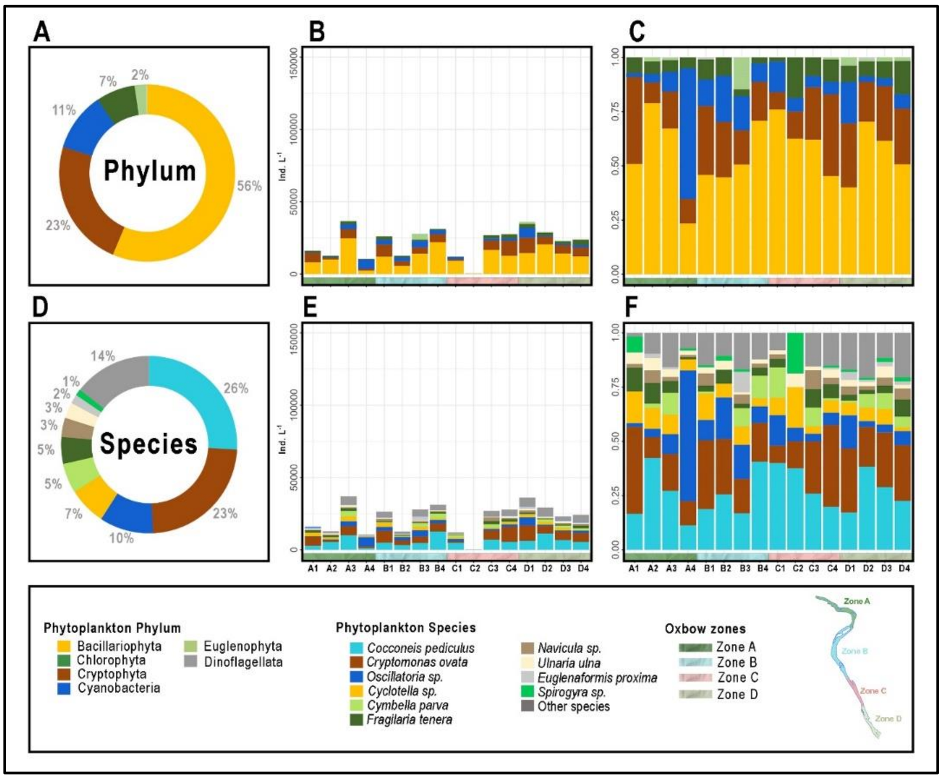


Figure 36: Phytoplankton abundance during summer sampling at each sampling point in Tigris River. (A, B, and C) graphs representing the phylum abundance level of the phytoplankton. (D, E, and F) graphs representing the species abundance level of the phytoplankton.

Algal composition in the zones during summer investigation

- Zone A – Agricultural area

  Bacillariophyta was 59.66.8%, Cryptophyta was 19.9%, Cyanobacteria was 13.63%, Chlorophyta was 5.88%, Euglenophyta was 0.81%, and Dinoflagellata was 0.12%.

  The most abundance species in the zone, *Cocconeis* sp. was 25.25%, *Cryptomonas ovata* was 19.10%, *Oscillatoria* sp. was 13.63%, *Cyclotella* sp. was 9.77%, *Fragillaria* sp. was 6.74%, and *Cymbella* sp. was 5.18% of total species abundance in the zone during the sampling (Figure 37).

- Zone B – Forest and Agricultural area
  Bacillariophyta was 54.96%, Cryptophyta was 22.02%, Cyanobacteria was 12.34%, Chlorophyta was 6.23%, Euglenophyta was 4.25%, and Dinoflagellata was 0.25%.
  The most abundance species in the zone, *Cocconeis* sp. was 26.01%, *Cryptomonas ovata* was 22.02%, *Oscillatoria* sp. was 11.84%, *Cyclotella* sp. was 7.69%, and *Cymbella* sp. was 5.95% of total species abundance in the zone during the sampling (Figure 37).
- Zone C – Urban area
  Bacillariophyta was 57.63%, Cryptophyta was 26.8%, Chlorophyta was 8.28%, Cyanobacteria was 6.28%, and Euglenophyta was 0.39%.
  The most abundance species in the zone, *Cryptomonas ovata* was 26.8%, *Cocconeis* sp. was 25.96%, *Fragillaria* sp. was 6.91%, *Cymbella* sp. was 6.36%, *Oscillatoria* sp. was 6.28%, *Cyclotella* sp. was 5.27%, and *Navicula* sp. was 4.99% of total species abundance in the zone during the sampling (Figure 37).

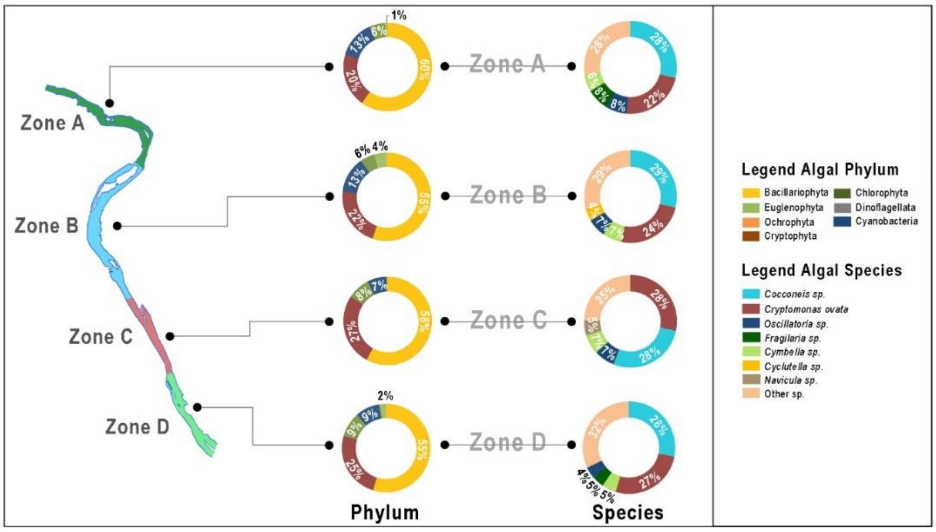


Figure 37: Phytoplankton abundance during summer sampling in the Tigris River zones.

- Zone D – Agricultural and livestock farming zone
  Bacillariophyta was 54.62%, Cryptophyta was 24.93%, Chlorophyta was 9.09%, Cyanobacteria was 8.87%, Euglenophyta was 2.24%, and Dinoflagellata was 0.25%.
  The most abundance species in the zone, *Cocconeis* sp. was 26.21%, *Cryptomonas ovata* was 24.93%, *Oscillatoria* sp. was 7.69%, and *Cyclotella* sp. was 5.31% of total species abundance in the zone during the sampling (Figure 37).

4.2.2.2.4. Autumn season
Phytoplankton phylum

The Bacillariophyta species was the most abundant phylum with an 79.96% (25,175 - 175,889 Ind. L^{-1}) of total algal abundance in the Tigris River within Mosul city during autumn sampling period, then the Cryptophyta has the second highest total algal abundance with a 10.17% (1,329 - 20,939 Ind. L^{-1}), the third highest phylum was Chlorophyta with a 6.54% (1,376 - 10,470 Ind. L^{-1}) of total abundance. However, the Cyanobacteria was 2.36% (262 - 8,568 Ind. L^{-1}), Euglenophyta was 0.62% (0 - 1,047 Ind. L^{-1}), and Dinoflagellata was 0.35% (0 - 2,114 Ind. L^{-1}) of total phylum abundance (Figure 38.A-C).

Phytoplankton species abundance

Cyclotella sp. was 30.80% (0 - 82,710 Ind. L^{-1}), *Cocconeis* sp. was 26.33% (11,099 - 48,160 Ind. L^{-1}), *Cryptomonas ovata* was 10.17% (1329 - 20939 Ind. L^{-1}), *Diatoma* sp. was 6.18% (0 - 12,852 Ind. L^{-1}), and *Cymbella* sp. was 6.05% (235 - 15,704 Ind. L^{-1}) of total species abundance during autumn sampling (Figure 38.D-F).

Algal composition in the zones during autumn investigation

- Zone A – Agricultural area
  Bacillariophyta was 76.94%, Cryptophyta was 10.62%, Chlorophyta was 7.1%, Cyanobacteria was 4.14%, Dinoflagellata was 0.91%, and Euglenophyta was 0.29%.
  The most abundance species in the zone, *Cyclotella* sp. was 35.27%, *Cocconeis* sp. was 14.55%, *Cryptomonas ovata* was 10.62%, *Diatoma* sp. was 4.95%, and *Cymbella* sp. was 5.17% of

total species abundance in the zone during the sampling (Figure 39).

- Zone B – Forest and Agricultural area
  Bacillariophyta was 84.89%, Chlorophyta was 6.36%, Cryptophyta was 5.42%, Cyanobacteria was 2.55%, Euglenophyta was 0.57%, and Dinoflagellata was 0.21%.
  The most abundance species in the zone, *Cocconeis* sp. was 33.79%, *Cyclotella* sp. was 28.9%, *Cymbella* sp. was 6.91%, and *Cryptomonas ovata* was 5.42% of total species abundance in the zone during the sampling (Figure 39).

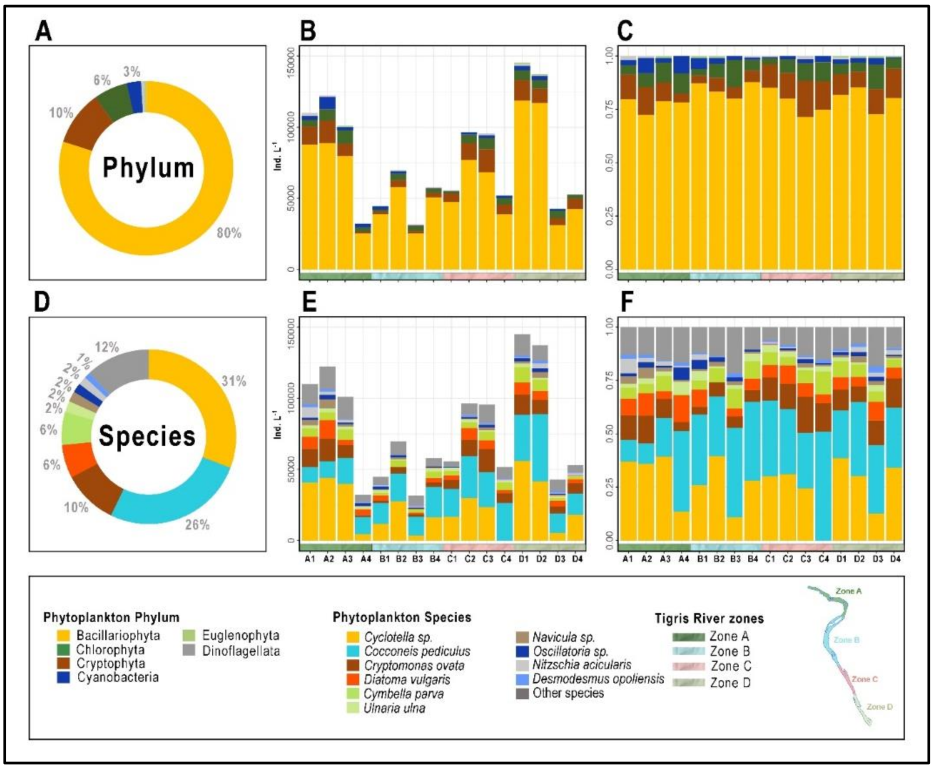


Figure 38: Phytoplankton abundance during autumn sampling at each sampling point in Tigris River. (A, B, and C) graphs representing the phylum abundance level of the phytoplankton. (D, E, and F) graphs representing the species abundance level of the phytoplankton.

- Zone C – Urban area
  Bacillariophyta was 77.33%, Cryptophyta was 13.59%, Chlorophyta was 7.24%, Cyanobacteria was 1.28%, and Dinoflagellata was 0.56%.
  The most abundance species in the zone, *Cocconeis* sp. was 33.51%, *Cyclotella* sp. was 23.37%, *Cryptomonas ovata* was 13.59%, *Diatoma* sp. was 6.54%, and *Cymbella* sp. was 6.24% of total species abundance in the zone during the sampling (Figure 39).

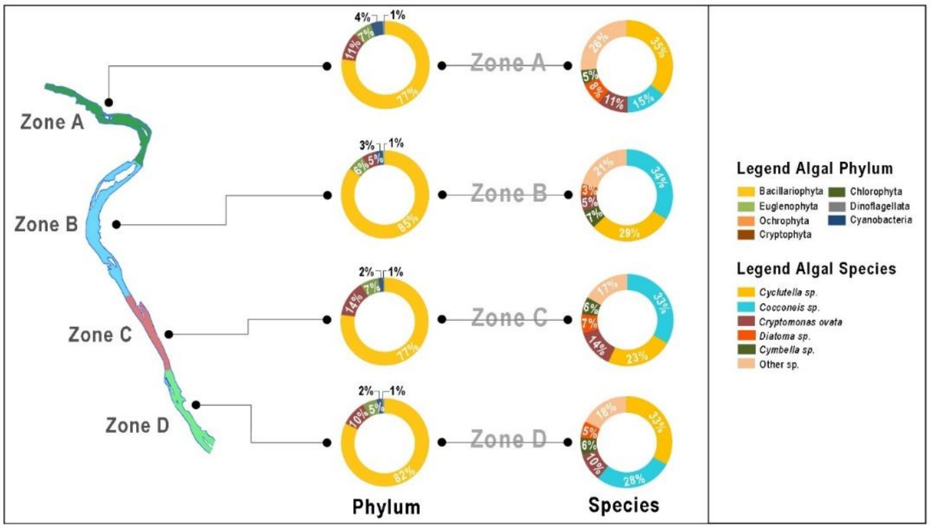


Figure 39: Phytoplankton abundance during autumn sampling in the Tigris River zones.

- Zone D – Agricultural and livestock farming zone
  Bacillariophyta was 81.92%, Cryptophyta was 9.67%, Chlorophyta was 5.71%, Cyanobacteria was 1.54%, Dinoflagellata was 0.62%, and Euglenophyta was 0.53%.
  The most abundance species in the zone, *Cyclotella* sp. was 32.99%, *Cocconeis* sp. was 27.77%, *Cryptomonas ovata* was 9.67%, *Cymbella* sp. was 6.23%, and *Diatoma* sp. was 5.57% of total species abundance in the zone during the sampling (Figure 39).

4.2.2.2.5. Winter season

Algal phylum

The Bacillariophyta species was the most abundant phylum with an 78.44% (13,364 - 41,850 Ind. L^{-1}) of total algal abundance in the Tigris River within Mosul city during winter sampling period, then the Cryptophyta has the second highest total algal abundance with a 11.97% (301 - 18,060 Ind. L^{-1}), the third highest phylum was Chlorophyta with a 7.43% (502 - 4,515 Ind. L^{-1}) of total abundance. However, the Cyanobacteria was 1.96% (0 - 2,207 Ind. L^{-1}), and Euglenophyta was 0.2% (0 - 401 Ind. L^{-1}) of total phylum abundance (Figure 40.A-C).

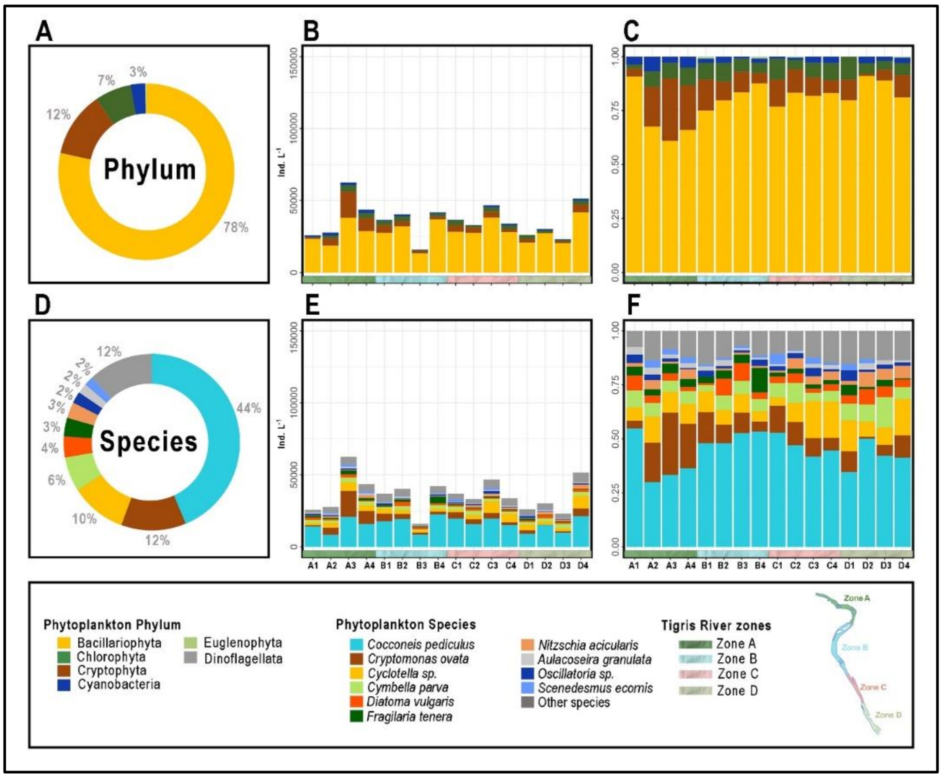


Figure 40: Phytoplankton abundance during winter sampling at each sampling point in Tigris River. (A, B, and C) graphs representing the phylum abundance level of the phytoplankton. (D, E, and F) graphs representing the species abundance level of the phytoplankton.

Algal species abundance

Cocconeis sp. was 43.67% (8294 - 22475 Ind. L^{-1}), *Cryptomonas ovata* was 11.97% (301 - 18060 Ind. L^{-1}), *Cyclotella* sp. was 10.25% (1365 - 8710 Ind. L^{-1}), and *Cymbella* sp. was 6.32% (1003 - 3311 Ind. L^{-1}) of total species abundance during winter sampling (Figure *40*.D-F).

Algal composition in the zones during winter investigation

- Zone A – Agricultural area

  Bacillariophyta was 68.32%, Cryptophyta was 20.74%, Chlorophyta was 8.21%, and Cyanobacteria was 2.73%.

  The most abundance species in the zone, *Cocconeis* sp. was 36.97%, *Cryptomonas ovata* was 20.74%, *Cyclotella* sp. was 9.36%, and *Cymbella* sp. was 6.09% of total species abundance in the zone during the sampling (Figure 41).

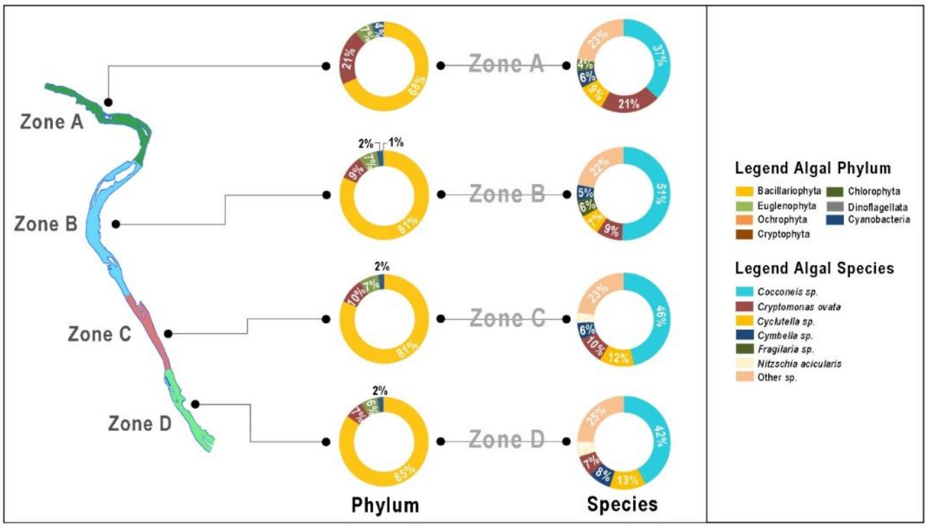


Figure 41: Phytoplankton abundance during winter sampling in the Tigris River zones.

- Zone B – Forest and Agricultural area

  Bacillariophyta was 81.36%, Cryptophyta was 9.12%, Chlorophyta was 6.87%, Cyanobacteria was 2.10%, and Euglenophyta was 0.56%.

The most abundance species in the zone, *Cocconeis* sp. was 50.2%, *Cryptomonas ovata* was 9.12%, *Cyclotella* sp. was 7.12%, *Fragillaria* sp. was 5.97%, and *Cymbella* sp. was 5.31% of total species abundance in the zone during the sampling (Figure *41*).

- Zone C – Urban area

  Bacillariophyta was 81.26%, Cryptophyta was 9.43%, Chlorophyta was 7.71%, Cyanobacteria was 1.49%, and Euglenophyta was 0.11%.

  The most abundance species in the zone, *Cocconeis* sp. was 46.27%, *Cyclotella* sp. was 12%, *Cryptomonas ovata* was 9.43%, and *Cymbella* sp. was 6% of total species abundance in the zone during the sampling (Figure *41*).
- Zone D – Agricultural and livestock farming zone

  Bacillariophyta was 84.51%, Cryptophyta was 7.15%, Chlorophyta was 6.71%, Cyanobacteria was 1.44%, and Euglenophyta was 0.2%.

  The most abundance species in the zone, *Cocconeis* sp. was 42.1%, *Cyclotella* sp. was 12.56%, *Cymbella* sp. was 8.01%, *Cryptomonas ovata* was 7.15%, and *Nitzschia* sp. was 5.23 of total species abundance in the zone during the sampling (Figure *41*).

4.2.2.3. Linear discriminant analysis LDA of phytoplankton in the Tigris River

According to the phytoplankton taxa abundance at spring season (Figure *42*.a), zone A differed from other three zones. The LDA1 expressed 68.5% and LDA2 was 26.9% of the total variance.In spring, zone D had the greatest abundance of phytoplankton. *Cymbella* sp., *Oscillatoria* sp., *Diatoma* sp., and *Fragillaria* sp. are all quite common in Zone A. High abundance of *Euglena* sp. were found in Zone B. However, zone C contains a high abundance of *Fragillaria* sp. and *Euglena* sp. but a low abundance of *Diatoma* sp. species. Moreover, zone D has a greater abundance of *Cryptomonas ovata*, *Oscillatoria* sp., *Diatoma* sp., and *Euglena* sp. species. Furthermore, the *Cryptomonas ovata* have a significant positive correlation with NH_4-N ($r = 0.7$, $p \leq 0.05$), TDS ($r = 0.7$, $p \leq 0.05$), and chloride ($r = 0.5$, $p \leq 0.05$). More information about significant correlation between phytoplankton species and physical-chemical variables can be found in (Appendix 5).

In the summer sampling period, the LDA (Figure *42*.b) showed that zone D differed from the other three zones based on the phytoplankton taxa. The LDA1 expressed 80.7 % and LDA2 was 15.5 % of the total variance. The LDA (Fig.4.b) performed during the summer sampling time demonstrated that zone D was distinct from the other zones with respect to phytoplankton taxa. The zone A is distinguished by an abundance of *Oscillatoria* sp. and *Cocconeis* sp. species. In contrast, a large number of *Cryptomonas ovata*, *Oscillatoria* sp., and *Cocconeis* sp. species have been observed in zone B. Meanwhile, species of *Navicula* sp. and *Fragillaria* sp. have been found in zone C. While the largest abundance of *Cryptomonas ovata* and *Cocconeis* sp. are found in Zone D. Furthermore, the *Oscillatoria* sp. have a significant negative correlation with turbidity (r= -0.6, p = <0.05), TSS (r= -0.7, p= <0.05), and TDS (r= -0.6, p= <0.05). More information about significant correlation between phytoplankton species and physical-chemical variables can be found in (Appendix 6).

During the autumn sampling, the LDA graph (Figure 42.c) indicated that according to the abundance of phytoplankton taxa, zones A and C differed from the B and D zones. The LDA1 expressed 61.3% and LDA2 was 26.5% of the total variance. Zone A is distinguished by its high abundance of *Oscillatoria* sp., *Cryptomonas ovata*, *Ulnaria ulna*, and *Surirella* sp. species. In zone B, the species *Oscillatoria* sp. are most abundant. Zone C was characterized by a high abundance of *Fragillaria* sp. and *Navicula* sp., whereas zone D is characterized by a high abundance of *Cocconeis* sp., *Surirella* sp., *Fragillaria* sp., and *Cryptomonas ovata*. Furthermore, the *Cryptomonas ovata* have a significant correlation with chlorophyll-a (r= 0.6, p = <0.05), COD_{sMn} (r= 0.5, p= <0.05), and DO (r= 0.6, p= <0.05), while negativly correlated with NO_3-N (r= -0.5, p= <0.05). More information about significant correlation between phytoplankton species and physical-chemical variables can be found in (Appendix 7).

According to the LDA graph in the winter season (Figure 42.d) and based on the abundance of phytoplankton taxa, zone A differed from the other zones. The LDA1 expressed 93.9% and LDA2 was 4.5% of the total variance. Zone A is distinguished by an abundance of *Cryptomonas ovata*, *Oscillatoria* sp., and *Scenedesmus ecornis*. In Zone B, *Cocconeis* sp. are the most common, along with *Oscillatoria* sp. and *Fragilaria* sp.. Zone C is distinguished by an abundance of *S. ecornis* and *Cyclotella* sp. species. While both *Cyclotella* sp. and *Cocconeis* sp. are more abundant in abundance Zone D. Furthermore, the *Oscillatoria* sp. have a significant correlation with DO (r= 0.5, p= <0.05) and negativly correlated with NH_4-

N (r= -0.6, p= <0.05). More information about significant correlation between phytoplankton species and physical-chemical variables can be found in (Appendix 8).

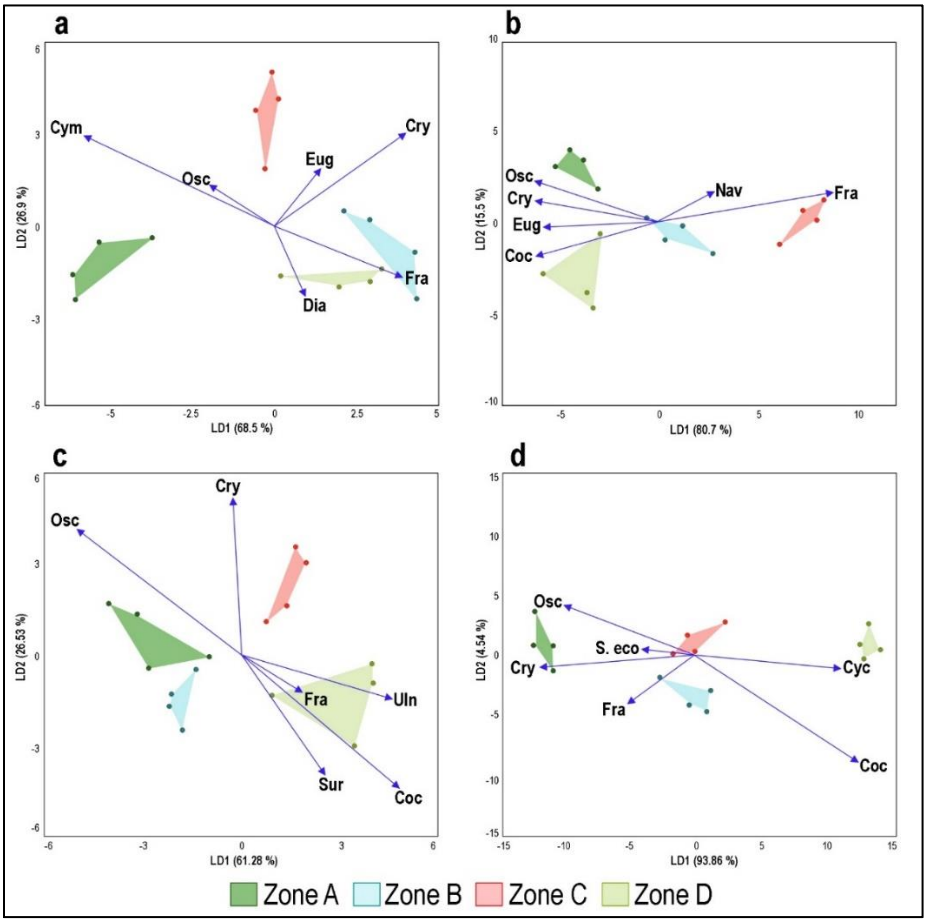


Figure 42**:** Graphs representing linear discriminant analysis (LDA) based on the phytoplankton taxa. (a): spring; (b): summer; Graphs (c): autumn; Graphs (d): winter. Whereas Eug: *Euglena* sp.; Sur: *Surirella* sp.; Spi: *Spirogyra* sp.; S. eco: *Scenedesmus ecornis*; Cyc: *Cyclotella* sp.; sp.; *Desmodesmus* sp.; Fra: *Fragilaria* sp.; Cym: *Cymbla* sp.; Osc: *Oscillatoria* sp.; Cry: *Cryptomonas ovata*; Dia: *Diatoma* sp.; Uln: *Ulnaria ulna*; and Coc: *Cocconeis* sp. Species. A zone: upstream river affected by agricultural activities, B zone: forest and agricultural area, C zone: urban area, D zone: downstream river affected by livestock farming and agricultural.

4.2.3. Land use/cover in the studied area

The area of the Tigris River (600 m around the river in Mosul city) was characterized by 3 main characterizations (Urban area, Agriculture area, and Forest area). The study area covered by 29% of agriculture and the urban area covered about 62% mainly in the Rakamaz zone, while the forest covered around 9%. However, the zones A and D characterized by the maximum coverage of agricultural areas 82% and 40% respectively while the zone C affected mostly by the urban activities including the effect of Al-Khosar River on the Tigris River quality, but the zone B characterized by the forest 37% and agricultural 48% areas (Figure 43).

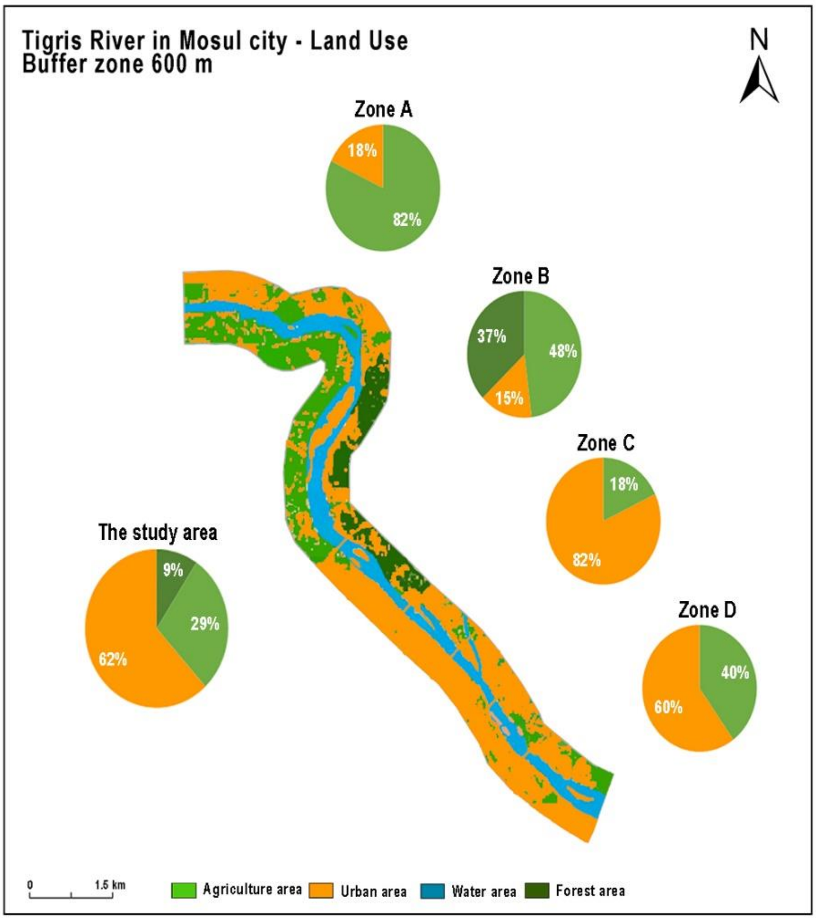


Figure 43: Figure showing the land/cover use percentage in the studied area of the Tigris River within Mosul city.

4.2.4. Canonical correspondence analysis CCA of the seasons

Canonical correspondence analysis revealed a great different between the four-sampling seasons. Whereas summer season greatly separated from other sampling seasons. The first axis (CCA1) explained 57.5% of the total variance, while the second axis (CCA2) explained 20.1%.

According to the CCA (Figure 44), the sampling during spring and summer was highly differed from autumn and winter sampling seasons.

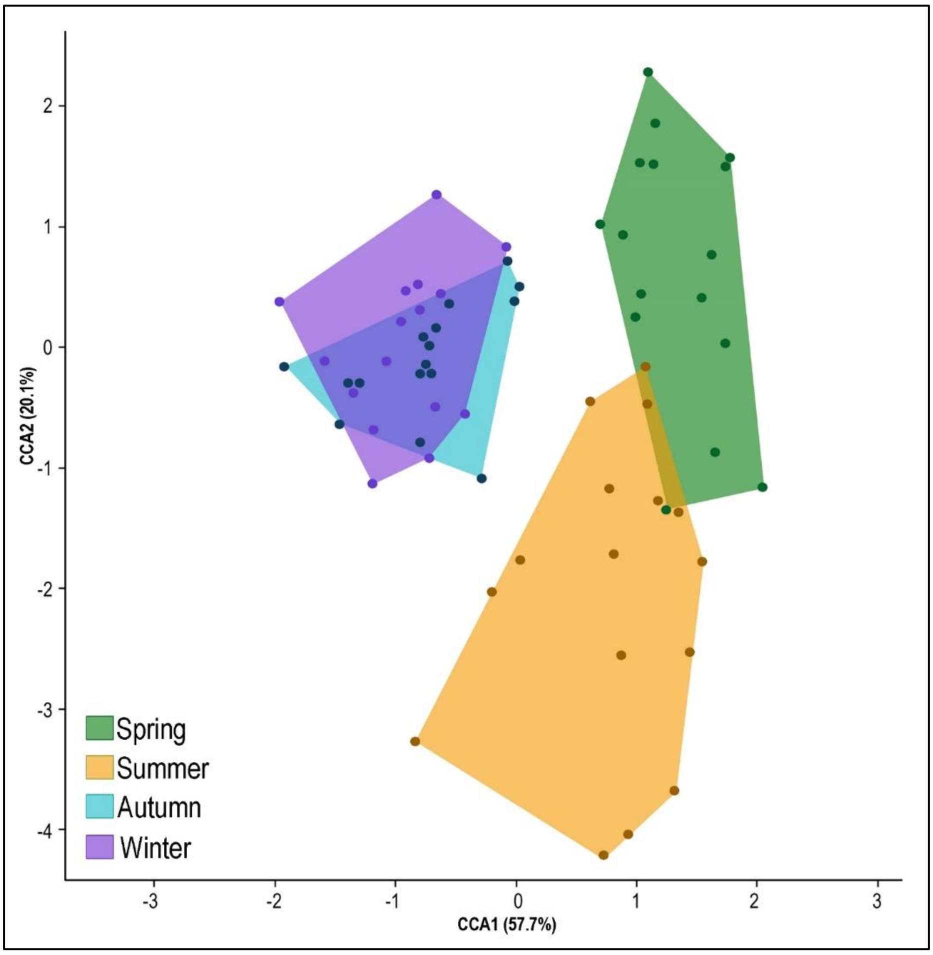


Figure 44: Canonical correspondence analysis CCA graph showing the separation of the four sampling times based on phytoplankton composition and physical-chemical variables.

5. DISCUSSION

During in the investigation in 2019 at Nagy-Morotva oxbow shallow lake in the four periods at 21 sites, a total of 44 phytoplankton species was identified, whereas Chlorophyta was the most dominated phylum with 21 species, 8 species of Bacillariophyta, 6 species of Cyanobacteria, 4 species of Euglenophyta, 2 species of Ochrophyta, and one species for each of the Cryptophyta and Dinoflagellata. At the Tigris River within Mosul city during the investigation of the 4 seasons in 2021 at 16 sites, a total of 61 phytoplankton species was identified, whereas Bacillariophyta was the most dominated phylum with 19 species, 30 species of Chlorophyta, 6 species of Cyanobacteria, 3 species of Dinoflagellata, 2 species of Euglenophyta, and one species of Cryptophyta. Our study found that the Nagy-Morotva oxbow was dominated by Chlorophyta while the Tigris River was characterized by the dominating of Bacillariophyta phytoplankton species.

5.1. Nagy-Morotva oxbow shallow lake

During the spring sampling time, the three zones of oxbow lake can be categorized into two groups, depending on both phytoplankton taxa and physical-chemical variables. The zones OW_T and OW_R (open water zones), were distinctly differentiated from each other, as well as from the middle zone. Usually, the water in the OW_R zone is less flowing compared to the OW_T zone, which has the ability to receive water from the Tisza River for replenishment. In spring, the most abundant algal group was the Chlorophyceae, green algae, which made up 40% of the total phytoplankton abundance. Phytoplankton colonies appeared in the OW_R zone represented by *P. duplex* and *T. triangular*. The Chlorophyceae taxonomic group exhibited a negative relationship with NO_3-N, a phenomenon previously documented in Lake Glebokie, Poland (Oyvind Hammer et al., 2001). During spring sampling period, *P. duplex* was identified taxa in the OW_R zone in the group I. While *P. duplex* is a cosmopolitan species, it exhibits a preference for eutrophic and mesotrophic water bodies (Kozak et al., 2017; Sigee et al., 2002). According to Ramezanpoor's investigation (Lenarczyk, 2015), the phytoplankton species of *T. triangulare* prefers water bodies with low concentration of dissolved oxygen; but, based on other study, this species is more likely to present in relatively nutrient-poor (mesotrophic and oligotrophic) water environments with a normal pH between 6.5-8.5 (Ramezanpoor et al., 2015), while a different investigation indicated that *T. triangulare* appeared with high abundant in water bodies that have a vegetation coverage (Willén, 1992).

Our study findings indicate that the physical-chemical components observed in the T_R zone are similar to those in the OW_R zone. Both zones exhibited elevated levels of TP, Kjeldahl-N concentrations, and COD, indicating a more enriched water trophic level. Moreover, the conductivity level in the T_R and OW_R zones was relatively high in spring. Most of urban water bodies can be affected by the urban leach outs, including sewage (Ray, 2022), in case of our investigated lake there was a source of sewage in the zone T_R which can explain the elevated concentration of conductivity, TP, and Kjeldahl-N. *Oscillatoria* sp. was a characterized species in the area that affected by sewage at T_R zone during spring sampling period, which can be used as an indicator of organic pollution (Das & Panda, 2010). Moreover, *Cyclotella* sp. was another characterized species in the zone T_R. The nutrient conditions of the aqueous system influence the growth diatom species such as *Cyclotella* sp. is the indicator of the high nutrient conditions (Arumugham, 2023). Furthermore, aquatic plants including *S. aloides*, *Nymphaea alba L.*, and *C. demersum* were presented at the onset of the yearly vegetation period.

Phytoplankton members of *Cyclotella* sp. and *Dinobryon* sp. appeared with high abundance in mesotrophic and oligotrophic water systems in the temperate zone (Celewicz et al., 2008). The *Dinobryon* genus tends to thrive in waters near estuaries (Pappas, 2010) and with comparatively high conductivity (Armstrong, 1985). The phytoplankton species found in the T_R zone are comparable to those in the M (Middle) zone, aside from their physical-chemical variables. In spring, the M zone of the oxbow lake had a limited concentration of nutrient resources. During spring, the M zone in the PCA (Figure 14), was identified by low concentrations of DO and NO_2-N. The *Oscillatoria* genus is a notable taxonomic group that proliferates significantly in aqueous environments that are utilized for irrigation (Celewicz-Gołdyn, 2005; Mohamed, 2002a). The primary function of the studied oxbow lake is irrigation, and the water is extracted from the M zone. Most of the macrophyte coverage in the zone M (*S. aloides*, *N. alba.*, and *C. demersum*) consisted of remnants from the previous vegetation period, which are located underwater, resulting in varied habitats and conditions for the phytoplankton community. The findings of our research suggest that the presence of macrophytes, a characteristic attribute of the M zone, exerts a significant influence during the spring season, and extends towards the OW_R zone which is an open water. Furthermore, during spring sampling period, OW_T (open water-Tiszanagyfalu) and T_T (transitional zone-Tiszanagyfalu) zones characterized by highest concentration of PO_4^{3-}, sulphate ion, NO_3-N, and transparency concentrations.

At early summer time, a three groups was distinguished in the the oxbow lake, distinguished by the PCA of phytoplankton taxa and physical-chemical variables (Figure 24, Figure 14). The OW_R zone represented the first group. This zone have a high concentration of conductivity, TDS, humic acid, TSS, BOD_5, NH_4-N, chlorophyll-a, and DO. The zone OW_R was characterized by the presence of a high abundance of *Dinobryon* sp., *P. duplex*, and *Cosmarium* sp. as determined by the PCA analysis of phytoplankton species (Figure 24). Both zones OW_T and OW_R (open water zones), were distinctly segregated from each other in the early summer period, based on both phytoplankton species and physical-chemical variables. However, the OW_R zone was significantly separated from the other regions, both in terms of phytoplankton species and physical-chemical variables. *Dinobryon* is a genus within Group I (OW_R) that is often found in waters with a high conductivity (Brittain et al., 2000). Group I was also characterized by the abundance of *Cosmarium* taxa during early summer; which are widely distributed throughout Europe but favour eutrophic environments (Tas et al., 2010). Another species in the OW_R zone was *P. duplex* which is a characterized species in eutrophic, mesotrophic, and warmer water bodies (Stamenković & Cvijan, 2008). The occurrence of high concentrations of NH_4-N and BOD_5 in early summer suggest a potential for eutrophication, while the increased TSS, conductivity, and TDS concentrations suggest that the water in the oxbow lake became more concentrated during the onset of irrigation and warm weather periods.

The zones of M and T_R characterized by high concentration of Kjl-N, sulphate, and TP. The phytoplankton species of *Oscillatoria* sp. and *Cyclotella* sp. was also characterized maily in the T_R zone that affected by sewage, which was the indicator of the high nutrient and pollution conditions (Das & Panda, 2010; Arumugham, 2023).

At the start of summer, a significant amount of macrophyte growth is observed both on the surface of the water (*Nuphar lutea, N. alba, Trapa natans, S. aloides, Lemna minor*) and within the water column (*Ceratophyllum demersum*). These macrophytes create distinct diverse habitats and environmental conditions for the phytoplankton communities, which may impact their composition through various factors like variations in light availability, competition for resources, and allelopathy (Ozimek et al., 1990; Zamaloa & Tell, 2005). Additionally, the vegetation covering the water surface can create a barrier that limits the exchange of oxygen from the atmosphere, potentially reducing oxygen dissolution in the water column below (Fonseca & Bicudo, 2010). The substantial growth of macrophytes on the water surface in the T_R zone occurred at the start of summer, leading to the creation of anaerobic conditions. This suggests that the dense macrophyte coverage in the T_T, T_R, and M zones had a notable impact by early summer, extending towards the open water region (OW_R) of an oxbow lake. Regardless the physical-chemical properties, the zone M is comparable to the OW_T and T_T zones in terms of phytoplankton taxa composition. In early summer, *Cyclotella* sp. is a characteristic species of T_R zone and exhibits a preference for water bodies that contain high concentration of TP (Stansbury et al., 2008). Another taxonomic feature of T_R zone is *C. microporum*, that thrives in eutrophic water bodies (Wunsam et al., 1995). *C. microporum* is well adapted to low-light, heterotrophic, and warm environments and can efficiently utilize various forms of carbon from organic substances. As a result, *C. microporum* is often observed in high abundances in these environments (Bouterfas et al., 2006). During early summer sampling period, the OW_T and T_T zones characterized by the highest concentration of humic acid, COD_{cr}, NO_2-N, NO_3-N, PO_4^{3-}, in addition to high transparency. Furthermore, in early summer sampling, the genus of *Oscillatoria* significantly correlated with PO_4^{3-} which is a potential factor affecting cyanobacterial growth (Lynch et al., 1967). The presence of *Oscillatoria* in irrigation waters is commonly observed in high quantities and its ability to generate a substantial biomass through vegetative reproduction is noteworthy. This utilization of the oxbow lake significantly impacts the variety of phytoplankton species present (Fatima et al., 2022a; Mohamed, 2002b).

In the late summer sampling period, the open water regions (OW_T and OW_R) were distinct and separate from each other based on the PCA of phytoplankton species and physical-chemical variables, as they were in the previous season. The OW_R zone had high concentrations of TDS, CO_3^{2-}, TSS, DO, conductivity, chlorophyll-a, and depth. A characterized species of OW_R zone is the abundant of *S. paradoxum*. During late summer, the water level reduced which led to an increased conductivity in OW_R zone.

The impact of water replenishment is comparatively minimal here, as compared to OW_T zone. *Staurastrum paradoxum* was the characteristic phytoplankton species in OW_R zone. As per a study conducted in Serbia, 50% of the *S. paradoxum* species are characterized in water bodies that are eutrophic and mesotrophic (Chang et al., 2012).

In summer, the T_R zone transect formed the second group. T_R zone was distinguished by an exceptionally elevated concentration of COD_{sMn}, indicating a significant quantity of organic matter present in the waterbody. The area also exhibited high levels of nutrient concentrations, including pH and Kjl-N, along with high levels of NO_3-N and NH_4-N. These features are indicative of extended durations of anaerobic conditions, particularly in areas close to the sediment. This group is distinguished by a significant presence of *M. simplex*, which is capable of producing large quantities of biomass by the conclusion of summer from an unlimited nutritional supply (Fužinato et al., 2011).

The open water region which included the zone OW_T have a highest amount of BOD_5, NO_2-N, humic acid, and sulphate concentration during summer sampling period. However, OW_T zone characterized by the abundance of *Phacus* sp., *Nostoc* sp., *A. granulata,* and *P. cinctum*. These phytoplankton species belong to a species that has been seen in flooded rice fields under anaerobic conditions (Duangjan et al., 2014). Nonetheless, this group has a strong preference for high concentrations of organic matter. Another significant taxon found in this zone is the *Nostoc* genus, which has the ability to fix nitrogen from the atmosphere. Regardless of their substantial population, they do not decrease the nitrogen level in the body of water. Additionally, *Nostoc* sp. was correlated negatively with conductivity, and studies have demonstrated that cyanobacteria, such as Nostocales, are more commonly found in low conductivity shallow lakes (Kokociński & Soininen, 2019). The phytoplankton species of *A. granulata* occurred mostly in the vegetation time in the summer (Wang et al., 2009) which was a characterised species in OW_T zone. *P. cinctum* was another taxon characterised in the OW_T zone, which in many studies has been reported in the meso-eutrophic or eutrophic standing waters (Grigorszky et al., 2006; Schweikert & Meyer, 2001), abundance of *P. cinctum* has a significant positive correlation with humic acid during the late summer. The growth of Dinoflagellata is greatly influenced by a substantial concentration of humic acid, according to a study conducted by Prakash and Rashid (Prakash & Rashid, 1968). This particular species thrives in warm temperatures and waters rich in organic substances and nitrogen. The oxbow lake is commonly utilized for fishing, which involves the addition of organic matter to the water in the form of ground bait. Furthermore, the lake is also used for irrigating the nearby agricultural fields during summers, leading to decreased water levels, heightened temperatures, and more evaporation.

Oxbow Lake can be divided into three separate groups during the autumn sample according to the PCA analysis of physical-chemical characteristics and algal species. Likewise, in the summer sample period, the two open water zones, OW_T and OW_R, were completely separated from one another.

The zone OW_R was in group I during autumn, which highly characterized by elevated levels of BOD_5, humic acid, NO_3-N, TSS, TP, DO, and COD_{cr}, in addition to the high abundance of *A. falcatus* and *K. littorale*.

According to research by (Patil, 1991), *A. falcatus* is an extremely efficient phytoplankton species that can eliminate ammonium nitrogen from the body of water. Ammonium ions concentration which builds up during the warmer months, could well be reduced by this species *A. falcatus*. As per Jones' and Meyer's study (Jones, 1983; Meyer, 1971), *K. littorale* is widespread in water bodies in the northern region, particularly in lakes characterized as mesotrophic and oligotrophic. This suggests that the zone of OW_R during the autumn sampling also had mesotrophic features.

The T_R zone, is known for its high concentrations of chlorophyll-a and PO_4^{3-}. Phytoplankton species tend to thrive in the presence of easily accessible nutrients such as PO_4^{3-}, leading to competition within the community. As a result, it is difficult to distinguish a distinct group based on phytoplankton abundances through PCA analysis. The sections of the T_R zone have a low number of species. Our research in autumn indicates that the physical-chemical variables of the M, T_T, and T_R, zones are similar.

In autumn, oxbow lake was categorized into three groups based on the abundance of phytoplankton, as determined by the PCA of physical-chemical variables and phytoplankton species. Group III consisted of transects within the OW_T zone, which were notable for their elevated levels of TDS, Kjehldahl-N, SO_4^{2-}, EC, NO_2-N, NH_4^+, and transparency. The OW_T, T_T, and, M zones was distinguished by a high prevalence of *N. acicularis*, *L. triangulare*, *Oscillatoria* sp., and *A. formosa*.

During the summer period, the presence of anaerobic conditions in the water body led to the retention of elevated levels of NO_2-N and PO_4^{3-}. The presence of PO_4^{3-} and N in the water promoted the proliferation of a dominant phytoplankton taxon (Kling et al., 2001). High concentrations of PO_4^{3-} and different N forms are typical of eutrophic waters and can facilitate the dominance of *N. acicularis*. Phytoplankton growth can be constrained by the scarcity of phosphorus. *A. formosa* is a characteristic species of T_T zone, and is commonly found in eutrophic and mesotrophic lakes (Lund, 1950). The presence of diverse nitrogen forms suggests that organic matter decomposition occurred under prolonged anaerobic conditions, creating conditions facilitative to eutrophication. The prevalence of the *Oscillatoria* genus indicates water abstraction for irrigation, water scarcity, and low water levels. In autumn, *L. triangulare* was observed in the M zone, which had also been previously identified in spring. Additionally, a separate study has indicated that this species is associated with macrovegetation coverage (Celewicz et al., 2008). A previous study of 21 stationary water bodies within the Araguaia River basin found that *T. triangulare* thrives in waters that have high levels of transparency and are oxygen-deficient (Nabout et al., 2006). Our study also noted the influence of macrovegetation coverage, which was dense in autumn but less so than in late summer in the T_T, M, and T_R zones.

Our results (based on phytoplankton and physical-chemical analyses) indicated a condition of meso-eutrophic in the OW_R zone in spring (Figure 45, Figure 14, Figure 24), as evidenced by high conductivityand low concentrations of DO. Conversely, higher trophic conditions were observed in the T_R zone, which exhibited high nutrient abundances. On the other hand, a study conducted in India on a high mountain lake (Altaf & Saltanat, 2014) indicated that Chlorophyceae species was only the second most abundant group, contrary to our study where we found that Chlorophyceae species were the highest abundant group. Our study also revealed meso-oligotrophic conditions in the M zone, characterized by a low number of phytoplankton species and low nutrient concentrations. Anaerobic conditions were indicated by an increase in the amount of PO_4^{3-}, while the accumulation of NO_3-N suggested an external nutrient load, which is typically found in aerobic, oxygenated waters. The water supply of the oxbow lake is solely derived from the Tisza River at the OW_T zone, where the OW_T and T_T zones are deeper compared to other zones, resulting in greater transparency. During the spring season, anaerobic conditions near the sediment were indicated by a high concentration of PO_4^{3-}.

The observation of raised levels of nutrients during the early summer implies the incidence of eutrophication which led to a rise in trophic states. According to Welch (Welch et al., 1992), adding low-nutrient water can slow down the process of eutrophication. The dominance of *Oscillatoria* sp. during early summer indicates eutrophic and meso-eutrophic conditions in both transitional and open water zones zones. A characteristic environmental variable during early summer was high conductivity, which was caused by evaporative loss due to higher temperatures at the beginning of the irrigation season. The findings of our study imply that there is an elevated quantity of organic materials, which resulted from the significant macrovegetational nutrient source and their decomposition. The identification of distinctive species in the M zone is indicative of the presence of eutrophic environmental conditions. During the summer season, there was a substantial increase in the macrophyte population, resulting in a significant expansion of their coverage area. The floating vegetation was transported towards the open water areas as a result of the currents produced by the discharge of irrigation water and summer precipitation.

In the late summer sampling period, a significant accumulation of nutrients, especially readily available nitrogen forms, was observed in the OW_R zone. The trophic conditions in the oxbow area experienced a minor reduction during the autumn season, which caused a shift towards a mesotrophic state. The extent of this transition was contingent upon the particular species inhabiting the area. During the summer season, there was a significant discharge of PO_4^{3-} from the sediment of the T_R zone, which was caused by extended periods of anaerobic conditions. The existence of the dominant species indicates the manifestation of eutrophic circumstances, denoting the conclusion of phosphate insufficiency and instigating rivalry among phytoplankton taxa regarding the latter phase of the vegetation cycle. The presence of diatom species *Nitzschia acicularis* is an indicator of the high nutrient conditions in the water bodies (Arumugham, 2023), which was a characterized species in the zone T_R.

The proliferation of macrophytic vegetation in the M zone impeded the oxygen diffusion process within the water column and resulted in a reduction in photosynthetic activity. Additionally, the prevalence of specific types of algae such as *Oscillatoria* sp. during the latter part of summer suggests a eutrophic-mesotrophic-eutrophic correlation within the OW_T and T_T regions.

During the autumn season, there was a slight decrease in the trophic level, resulting in a meso-eutrophic state. However, the dominant phytoplankton taxa indicated a trophic level that was still relatively high. Even though nutrient concentrations were decreasing, the OW_R zone remained in a mesotrophic state. The OW_T and T_T zones, which were both stagnant and nutrient-rich with anaerobic conditions, exhibited similar physical-chemical conditions throughout the entire investigation period. Moreover, both zones were classified in the same group in terms of specific species present.

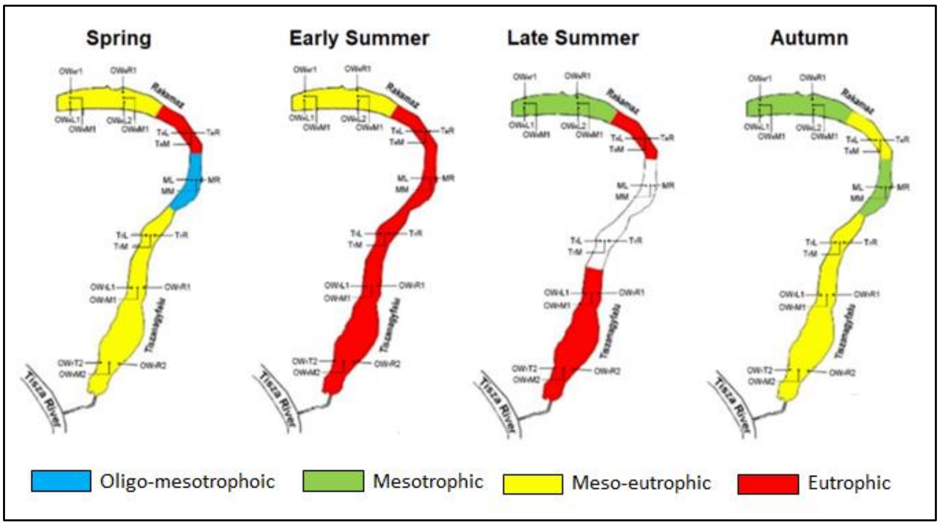


Figure 45: Trophic levels in various zones at Nagy-Morotva oxbow shallow lake. The scale color depicts different trophic levels: red indicates eutrophic, orange indicates meso-eutrophic, blue indicates oligotrophic, yellow indicates mesotrophic, and white indicates areas where sampling was not feasible.

Our research demonstrates with high certainty that the physical-chemical parameters have a significant impact on the both zones of T_T and OW_T. These zones have a deeper riverbed, which increases their transparency. Senthilkumar & Sivakumar, (2008) research also shows that phytoplankton composition closely correlates with hydrography seasonality. The OW_T and OW_R zones were both in a meso-eutrophic condition throughout the spring, with plenty of nutrients for primary producers. Moreover, the OW_T zone went through major anaerobic states close to the sediment, which resulted in the release of food supplies.

During the summer, the open water zones (OW_R and OW_T) continued to exhibit eutrophic and meso-eutrophic conditions, while the OW_R zone showed mesotrophic conditions in the fall. The annual buildup of macrophyte biomass within the M zone had a significant impact on the nutrient concentrations present in the aquatic environment. The alterations in transitional zones were significantly influenced by the extent of macrovegetation coverage and the reduction in water levels resulting from irrigation practices. During the autumn season, it was observed that both zones exhibited meso-eutrophic conditions. The spring phytoplankton abundances suggested the presence of meso-oligotrophic conditions. However, during the summer season, there was a notable increase in the trophic level of the water, as evidenced by the appearance of characteristic species indicative of eutrophic relationships. According to Jargal et al., (2021), common water quality issues include nutrient enrichment, water level fluctuations, and large macrophyte coverage. As fall approached, the trophic conditions in the oxbow lake decreased to a mesotrophic level once again. Zone M exhibited the most significant alteration in its trophic level among the investigated areas, as evidenced by the dominant phytoplankton taxa.

When examining a smaller body of water, the composition of phytoplankton and physical-chemical properties are sampled only at a few locations and infrequently. Changes in factors such as land use, macrovegetation coverage, seasonal variations, and water supplements significantly impact various aspects of the water, resulting in notable fluctuations in the abundance and dominance of phytoplankton. Our research indicates that even in a small body of water like the Nagy-Morotva oxbow lake, considerable variations exist in both physical-chemical parameters and phytoplankton taxa. As a result, open waters (OW_T and OW_R) and water covered vegetation (M) are differentiated from one another and from other transitional zones (T_R and T_T).

5.2. Tigris River in Mosul city

The urbanization process can bring about alterations to the composition of living organisms in both running and stagnant bodies of water within a community (Grimm et al., 2008; Paul & Meyer, 2001). Diverse pollution sources, including both non-point and point sources like domestic wastewater and agricultural runoff, can have a significant impact on the environmental conditions of water, which can increase the nutrient and pollutant levels in the water, leading to adverse effects (Kaye et al., 2006; Peng et al., 2020). Phytoplankton is commonly used as a bioindicator in river ecosystems because of their sensitivity to long-term ecosystem alterations, such as climate change and land use (Yang et al., 2021). Phytoplankton is an essential part of ecological systems, and monitoring how their abundance and composition fluctuate may provide important information about the state of the ecosystem as a whole (Gökçe, 2016; Khalil et al., 2021). Previous studies have shown that it is important to study how nutrients change with the seasons, especially how phosphorus and nitrogen forms are affected by river flow and weather, in order to understand how they affect the composition and abundance of phytoplankton (Casartelli & Ferragut, 2015; Cózar & Echevarría, 2005; Seguro et al., 2015; Stevenson et al., 2012; Yadav et al., 2018).

Based on the environmental variables and phytoplankton community represented in (Figure 44), the CCA graph suggests that the water quality of Tigris River during the winter and autumn sampling periods shared certain environmental characteristics, as indicated by the overlap. However, there was no overlap observed between the spring and summer sampling periods, indicating a significant difference in their respective environmental characteristics. However, the spring season was marked by a relatively low water temperature of 15.6 ^{0}C and rainy weather, which is reflected in the phytoplankton structure as the second-highest peak of phytoplankton abundance during the study period. This may suggest that phytoplankton possess more adaptive mechanisms for growth under low-temperature conditions than they do under high-temperature condition (Du et al., 2017; Ruiz et al., 2006). According to our findings, the summer season showed the least abundance of phytoplankton, whereas the autumn season had the highest. The decrease in phytoplankton was linked to high temperatures (29 ^{0}C) and low water flow, which also led to extremely low concentrations of DO (<2 mg/l) across all sampling locations in summer. Organic matter and plant nutrients from various sources are among the main factors responsible for the reduction in DO, causing hypoxia and posing a threat to the aquatic ecosystem by consuming significant amounts of DO (Basant et al., 2010; Mallin et al., 2006; Whitehead et al., 2009b; Xu & Xu, 2015). Despite the minimum chlorophyll-a concentration occurring in summer, phytoplankton populations remain a crucial factor in the DO budget of rivers and play a vital role in maintaining DO levels (Carpenter et al., 2013). During autumn, the water temperature dropped to (17 ^{0}C) with low water discharge, creating suitable conditions for maximizing the abundance of phytoplankton. This observation is consistent with (Al-Shahri et al., 2016) findings, which show that phytoplankton species reach their highest abundance during the seasons of spring and autumn. As the winter season approached, rainfall increased, causing a drop in water temperature (11◦C) and an apparent impact on river water quality due to the runoff of nutrients from nearby agricultural areas.

Studies have demonstrated a clear relationship between the quality of water in freshwater ecosystems and the surrounding land use (Dzinomwa & Ndagurwa, 2017; Jordan et al., 2018; Marmen et al., 2020). In our study, we observed that both the LDA (Figure 32, Figure 42) yielded identical for phytoplankton and physical-chemical variables across all seasons. Additionally, throughout the investigation time, zone A's water quality was significantly impacted by the agricultural area. Both the LDA graph of physical-chemical characteristics (Figure 32) and the LDA of algal species (Figure 42), which showed a substantial separation of the agricultural region in zone A from other zones across the Tigris River in the city of Mosul, clearly showed this impact. In Zone A, the spring sampling time is marked by elevated levels of PO_4-P, NO_3-N, and COD_{sMn}. The high-water discharge rate during this season, which directly affects the nutrient inputs coming from the agricultural areas upstream, can be attributed to the rise in nutrient content. One of the most important markers of nutrient loading is the discharge rate (Amano & Kazama, 2012; Le Tien et al., 2020). The quality of water in urban streams can be impacted by the discharge rates and diffuse sources of nutrients that originate from the runoff of the surrounding agricultural areas (Arreghini, 2005; Karlsen et al., 2019). The elevated levels of COD_{sMn} found in the agricultural area may be linked to the organic content, which could be a result of the remains of phytoplankton and their dissolved organic matter (Zhang et al., 2008). The agricultural zones (A and B zones) consistently exhibited high levels of various forms of orthophosphate and nitrogen ions throughout the study period. The concentration of orthophosphate can rapidly fluctuate in areas where autotrophic organisms are present. However, according to the minimum law of Liebig, it can be considered a crucial factor for stimulating eutrophication (Smith, 2009; Somlyai et al., 2019b). The presence of high concentrations of PO_4-P and different nitrogen forms in the agricultural region suggests that fertilizers have been employed along the river's course prior to entering zone A.

The species of *Oscillatoria* sp., *Cymbella parva,* and *Cryptomonas ovata* (Figure 42) were the most distinctive species observed in the agricultural region. This finding is in line with other researches, which has consistently reported the prevalence of Oscillatoria sp. in water sources utilized for irrigation in agricultural areas (Fatima et al., 2022b; Mohamed, 2002c; Ren et al., 2022; Yaqoob et al., 2021b). *Oscillatoria* is a genus commonly found in conditions of low water discharge (Espinosa et al., 2020). Surface water bodies can experience significant water quality problems related to cyanobacteria (Smith et al., 2002; Wang et al., 2005). There is contradictory evidence regarding whether cyanobacteria can dominate over other types of phytoplankton in turbid water systems (Dzialowski et al., 2011; Smith, 1990a); Some studies indicate that they are capable of doing so (Burkholder et al., 1998; Scheffer et al., 1997), while others suggest that their abundance decreases in the areas of high levels of non-algal turbidity (Cuker et al., 1990; Smith, 1990b).

During the winter season in Zone A's agricultural area, *Cryptomonas ovata* was identified as the second notable species. *Cryptomonas ovata* thrives in a nutrient-rich environment, and higher concentrations level of NO_3-N and NH_4-N may enhance Cryptomonas growth (Capo et al., 2017; Y. Liu et al., 2020). *Cymbella parva* is another noteworthy taxon found in this zone, detected during the spring season in the agricultural region. *C. parva* has been observed in rivers that pass through agricultural areas (Sinco & Tampus, 2020).

Zone B was primarily characterized by forestry and agricultural land use. During the winter season, this zone experienced higher concentrations of PO_4-P and COD_{sMn}, which may have been washed off by rainfall from the adjacent agricultural areas (Siksnane & Lagzdins, 2021). Throughout the year, various forms of nitrogen are prevalent in this area. During the summer sampling season in Zone B, *Oscillatoria* sp. was a commonly occurring taxon. This could be attributed to the nutrient availability, which may originate from Zone A, as well as the suitable temperature for the proliferation of *Oscillatoria* sp. in this zone during summer. Another distinctive species found in Zone B was *Fragilaria tenera* (Figure 42), which is known as an indicator in bodies of water that have a high nutrient concentration (Desianti et al., 2017).

Due to the influence of the urban region, zone C of the Tigris River within the city had much poorer water quality than other zones. This is because urbanization can cause significant changes in the hydrology, leading to disruptions in the structure and function of aquatic communities (Isabwe et al., 2018). Water quality could be negatively affected by human activity along rivers, which may cause changes in nutrient types, proportions, and physical-chemical factors (Yang et al., 2017). Which was illustrated in the LDA figures of phytoplankton species (Figure 42) and physical-chemical variables (Figure 32). Urban areas at small scales have a stronger association with degraded water quality than at larger scales (Shi et al., 2017).

According to our research findings, the occurrence of *Oscillatoria* sp. was found to be minimal in zone C of the urban setting, likely due to the direct impact of pollution discharge in that area. Prior research has suggested that the discharge of harmful substances such as endocrine-disrupting chemicals, pharmaceuticals, and disinfectants may have detrimental effects on the biochemical processes and physiological characteristics of phytoplankton, resulting in inhibited enzymatic systems and hindered growth (Liu et al., 2019; Wang et al., 2017; Zhang et al., 2018b). While other studies has indicated that the presence of submerged vegetation can efficiently absorb and eliminate phosphorus and nitrogen from the water, which also inhibits the growth of phytoplankton by releasing allelochemicals (Mohamed, 2017; Sun et al., 2022). The most characteristic species in the urban area (zone C) were *Fragilaria tenera, Euglenaformis proxima, Cryptomonas ovata*, and *Navicula sp* (Figure 42). During the spring season in zone C, there was a greater abundance of *Euglenaformis proxima*. This could be attributed to the rainfall, which leads to higher organic matter content and greater nutrient loading (Conceição et al., 2021). Previous studies have highlighted the significance of Euglenophyceae species, as they serve as indicators of organic contamination in water bodies (Al-Thahaibawi et al., 2021; Laskar & Gupta, 2009). During the summer season, *Navicula* sp. and *F. tenera* were identified as distinctive species in the urban region. *F. tenera* is a prevalent species in urban environments and is commonly found in areas with high nutrient concentrations (Jüttner et al., 2012; Klimaszyk et al., 2022). *Cyclotella* sp. was identified as another distinctive diatom species in the urban region, which is a typical species in urban areas (Cira et al., 2016), *Cyclotella* sp. was indicated during winter sampling time in the urban area at zone C. In addition, *Scenedesmus economic* was also observed during winter sampling in the urban area. Previous research has reported that *Scenedesmus* sp. are often found in urban rivers contaminated with untreated sewage (Venkatesan et al., 2020; Xia et al., 2020b).

Zone D is situated downstream of the Tigris River and is predominantly utilized for agricultural purposes, including animal husbandry which contributes to the presence of animal feces. In spring, this area experiences a high level of ammonium concentration in the water. The elevated concentration of ammonium in surface water is commonly linked to anthropogenic sources such as untreated sewage and the use of fertilizers in agricultural practices (Du et al., 2017). The largest concentration of NO_2-N is found in Zone D in the fall, most likely as a result of agricultural activity on the river's right bank and the occurrence of animal waste. Additionally, the presence of anaerobic microorganisms that encourage nitrite synthesis through the denitrification mechanism is indicated by the elevated levels of nitrite found in this area (Ruiz et al., 2006). In the zone D, *Oscillatoria* sp., *E. proxima*, and *Cryptomonas ovata* were the most distinct species. LDA analysis during summer and spring revealed that *E. proxima* dominated in zone D (Figure 42). The high dominance of *E. proxima* could be attributed to the influx of nutrients and agricultural activities into zone C. The increase in organic matter and nutrient load may create a favorable environment for Euglenophyceae, whose structure is dependent on various biotic and abiotic factors (Al-Thahaibawi et al., 2021; Haque et al., 2020).

6. SIGNIFICANT RESULTS OF THE STUDY

6.1. 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?*

The composition of the algae and physical-chemical variables differed at each zone during the sampling time in different seasons. OW_R Zone during spring sampling characterized by maximum concentration of TSS, TDS, conductivity, BOD_5, Cl^-, CO_3, HCO_3^-, COD_{Cr}, COD_{sMn}, humic acid, Kjl-N, NO_2-N, pH, SO_4^{2-}, and TP. In early summer sampling time, the highest concentration was ORP, TSS, TDS, conductivity, Cl^-, chlorophyll-a, CO_3, and NH_4-N. while late summer sampling characterised by maximum concentration of TSS, TDS, conductivity, Cl^-, chlorophyll-a, CO_3, HCO_3^-, Kjl-N, NH_4-N, NO_2-N, DO, and pH. And in autumn sampling time, ORP, TSS, TDS, conductivity, HCO_3^-, COD_{Cr}, humic acid, NO_3-N, DO, TP, and pH was at the maximum concentration. Furthermore, *Ankistrodesmus falcatus* characterized in spring sampling time, *Trachelomonas volvocina* was in early summer sampling, while *Oscillatoria* sp. characterized in late summer, and in autumn A*nkistrodesmus falcatus* return to dominate again. T_R Zone in spring sampling time characterized by higher concentration of TDS, conductivity, chlorophyll-a, HCO_3^-, COD_{Cr}, COD_{sMn}, humic acid, and TP. In early summer sampling time, the highest concentration was TSS, TDS, conductivity, Cl^-, HCO_3^-, Kjl-N, pH, and TP. while late summer sampling characterised by maximum concentration of TDS, conductivity, Cl^-, chlorophyll-a, HCO_3^-, COD_{Cr}, COD_{sMn}, Kjl-N, and NH_4-N. And in autumn sampling time, chlorophyll-a and pH was at the maximum concentration. Furthermore, *Ankistrodesmus falcatus* characterized in spring sampling time, while *Oscillatoria* sp. dominate during early and late summer time, And *Phacus* sp. was a characterized species in autumn sampling time. M zone during spring sampling time characterized with maximum concentration of CO_3, COD_{sMn}, and humic acid. In early summer sampling time, the maximum was transparency, HCO_3^-, Kjl-N, and DO. while late summer sampling was fully covered with macrophytes, and for that we couldn't collect the water samples. And in autumn sampling time, CO_3, PO_4^{3-}, and pH was at the maximum concentration. Moreover, *Ankistrodesmus falcatus* characterized in spring sampling time, while *Cryptomonas ov*ata characterized in both early summer and autumn time. T_T zone in spring sampling time characterized with maximum transparency, ORP, BOD_5, HCO_3^-, PO_4^{3-}, NO_2-N, DO, and SO_4^{2-}. In early summer sampling time, the transparency, COD_{Cr}, COD_{sMn}, PO_4^{3-}, humic acid, NO_2-N, DO, pH, NO_3-N, and SO_4^{2-} was at maximum. while late summer sampling was fully covered with macrophytes, and for that we couldn't collect the water samples. And in autumn sampling time, transparency, ORP, TDS, conductivity, Cl^-, COD_{Cr}, humic acid, NH_4-N, NO_2-N, DO, pH, and SO_4^{2-} was the maximum. Furthermore, *Trachelomonas volvocina* characterized in spring sampling time, *Oscillatoria* sp. was in early summer, while *Cryptomonas ovata* characterized in autumn sampling time. OW_T Zone during spring sampling characterized by maximum transparency, ORP, BOD_5, HCO_3^-, PO_4^{3-}, NO_2-N, DO, and SO_4^{2-}. In early summer sampling time, the transparency, COD_{Cr}, COD_{sMn}, PO_4^{3-}, humic acid, NO_2-N, DO, pH, NO_3-N, and SO_4^{2-}. while late summer sampling characterised by maximum transparency, ORP, BOD_5, COD_{Cr}, COD_{sMn}, PO_4^{3-}, humic acid, NO_2-N, DO, pH, NO_3-N, and TP. And in autumn sampling time, the transparency, ORP, TDS, conductivity, Cl^-, COD_{Cr}, humic acid, NH_4-N, NO_2-N, DO, pH, and SO_4^{2-} was at the maximum. Moreover, *Trachelomonas volvocina* characterized in spring sampling time, *Oscillatoria* sp. characterized during early summer sampling, while *Cryptomonas ov*ata characterized in both late summer and autumn time.

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. 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 noteworthy during the spring season in the direction of the open water zone OW_R, as indicated by the abundance of algae and physical-chemical parameters. Whereas, *Oscillatoria* sp. and *Lemmermannia triangularis* was a distigused speices in the macrophyte region (zone M), and the T_R zone characterized by *Oscillatoria* sp., *Dinobryon sertularia*, and *Cyclotella* sp. in the transitional area. While the open water region (OW_R and OW_T zones) dominated mainly by green algae species (eg. *Pediastrum duplex* and *Tetraëdron triangulare*).

At the onset of summer, a substantial amount of macrophytic vegetation had developed on the surface of the water and within the water column. The presence of macrophytes creates distinct environmental conditions and varied habitats for the algal plankton population. This may have an impact on the composition of algal plankton due to factors such as resource competition, allelopathy, and variations in light exposure. During the summer season, a substantial growth of macrophytes was observed on the water surface in the zones of T_T, M, and T_R zones. This growth led to the occurrence of anaerobic conditions, indicating a significant impact of macrophyte coverage on OW_R during this time. During summer sampling, a notable appearance of *Oscillatoria* sp. and *Cyclotella* sp. was recorded in the macrophyte region (zone M). While the transitional area in (T_R zone) dominated by *Oscillatoria* sp., *Cyclotella* sp., and *Coelastrum microporum*. The open water region characterized by *Pediastrum duplex*, *Dinobryon sertularia*, *Cosmarium* sp., and *Staurastrum paradoxum* in the OW_R zone, while the zone OW_T have more divered species (eg. *Oscillatoria* sp., *Nostoc* sp., *Aulacoseira granulata*, *Peridinium cinctum*, and *Phacus* sp.).

During the autumn season, *Oscillatoria* sp., *Nitzschia acicularis*, and *Lemmermannia triangularis* charactrized in the macrophyte region (zone M) during aurumn sampling. The transitional area in the (T_R zone) dominated by *Oscillatoria* sp. and *Nitzschia acicularis*, while the (T_T zone) characterized by *Oscillatoria* sp. and *Asterionella Formosa*. The open water region characterized mainly by Kephyrion littorale and *Ankistrodesmus falcatus* in the OW_R zone.

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 parameters indicated the presence of meso-eutrophic conditions, characterized by elevated conductivityand reduced dissolved oxygen levels, within the OW_R zone. Conversely, the TR zone exhibited a higher trophic condition, as evidenced by the abundant nutrient levels. Elevated nutrient levels during the initial phase of summer are indicative of the phenomenon of eutrophication and consequent escalation in trophic states. The prevalence of certain species during the initial phase of summer is indicative of eutrophic and meso-eutrophic environmental conditions in both the open water and transitional zones. At the onset of the irrigation season, a rise in temperature led to an evaporative loss, resulting in an increase in conductivity which became a notable environmental feature. During the end of the summer season, a considerable quantity of nutrients, particularly nitrogen forms that were easily accessible, were present in the zone of OWR. This resulted in a minor decrease in the trophic condition by the onset of the fall. This area of the oxbow changed into a mesotrophic state, depending on the species present. 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 OWR region.

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 OW_R and T_R are affected by the urban area of Rakamaz and the T_R zone mainly affected by the municipal sewage and animal husbandry pollutants, 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, while the OW_R zone affected by the land use of the Tiszanagyfalu.

The T_R zone which affected by sewage was characterized mainly by the aboundance of *Oscillatoria* sp. and *Cyclotella* sp. which are used as indicator of organic pollution, 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. Furthermore, *Oscillatoria* sp. was distinctive taxon in the middle area of the oxbow lake (M zone), which thrives abundantly in water bodies utilized for irrigation purposes during spring, summer, and autumn seasons. This zone characterized by high concentration of Kjl-N, Chl-a, PO_4^{3-}. The open water zones (OW_R and OW_T) which utilized for fishing characterized by diverse algae species such as *Pediastrum duplex*, *Tetraëdron triangulare*, *Kephyrion littorale*, and *Ankistrodesmus falcatus*, *Dinobryon sertularia*, and *Staurastrum paradoxum*.

6.2. 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?*

The composition of the algae and physical-chemical variables differed at each zone during the sampling time in different seasons. Zone A during spring sampling characterized by maximum concentration of TSS, turbidity, PO_4-P, COD_{sMn}, and NO_3-N. In summer sampling time, the highest concentration was HCO_3^-, NH_4-N, NO_3-N, and pH. while autumn sampling characterised by maximum concentration of TSS, turbidity, HCO_3^-, COD_{sMn}, NH_4-N, pH, and DO. And in winter sampling time, chlorophyll-a, Cl^-, COD_{sMn}, DO, HCO_3^-, NH_4-N, NO_3-N, and PO_4-P was at the maximum concentration. Furthermore, *Cocconeis* sp., *Cryptomonas ovata*, *Cymbella* sp., and *Oscillatoria* sp. was a characterized species in both spring and summer sampling time, in autumn characterized by *Cyclotella* sp., *Cocconeis* sp., and *Cryptomonas ovata*, while in winter sampling *Cocconeis* sp., *Cryptomonas ovata*, and *Cyclotella* sp. was at highest. Zone B during spring sampling characterized by elevated concentration of HCO_3^-, TDS, and DO. In summer sampling time, the pH, NO_3-N, NH_4-N, PO_4-P, HCO_3^-, and chlorophyll-a. while autumn sampling characterised by maximum Cl^-, NO_3-N, and pH. And in winter sampling time, the PO_4-P, TDS, TSS, and turbidity was at the maximum. Furthermore, *Cocconeis* sp., *Cryptomonas ovata*, *Cymbella* sp., and *Oscillatoria* sp. was a characterized species in spring sampling time, summer characterized by *Cocconeis* sp., *Cryptomonas ovata*, and *Oscillatoria* sp., while autumn characterized by *Cocconeis* sp., *Cyclotella* sp., and *Cymbella* sp. was at the highest, and *Cocconeis* sp., *Cryptomonas ovata*, and *Cyclotella* sp. was the dominated species during winter sampling time. Zone C during spring sampling characterized by high chlorophyll-a. In summer sampling time, the highest concentration was TSS, turbidity, TDS, BOD_5, Cl^-, and COD_{sMn}. while autumn sampling characterised by maximum concentration of BOD_5, turbidity, TSS, TDS, Cl^-, chlorophyll-a, COD_{sMn}. And in winter sampling time, HCO_3^-, while NO_2-N, TSS, and PO_4-P was at the maximum concentration. Furthermore, *Cocconeis* sp., *Cryptomonas ovata*, and *Cymbella* sp. was a characterized species in spring sampling time, summer characterized by *Cryptomonas ovata*, *Cocconeis* sp., *Fragilaria* sp., while autumn characterized by *Cocconeis* sp., *Cyclotella* sp., *Cryptomonas ovata* characterized during both autumn and winter sampling time. Zone D during spring sampling characterized by elevated concentration of TDS, Cl^-, NH_4-N, NO_2-N. In summer sampling time, the TDS, BOD_5, chlorophyll-a, and PO_4-P. while autumn sampling characterised by maximum TDS, BOD_5, Cl^-, NO_2-N, and NO_3-N. And in winter sampling time, the BOD_5, NH_4-N, and NO_2-N was at the maximum. Furthermore, *Cocconeis* sp., *Cryptomonas ovata*, and *Cymbella* sp. was a characterized species in spring sampling time, summer characterized by *Cocconeis* sp., *Cryptomonas ovata*, and *Oscillatoria* sp., while autumn characterized by *Cyclotella* sp., *Cocconeis* sp., *Cryptomonas ovata* was at the highest, and *Cocconeis* sp., *Cyclotella* sp., *Cymbella* sp. was the dominated species during winter sampling time.

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. 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 unfavourable 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.

7. 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.

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8. SUMMARY

The aim of this work is to examine the effects of land use and seasonal change on the physical-chemical variables and phytoplankton composition in the fresh water bodies. Two water bodies were investigated during the study, Nagy-Morotva oxbow shallow lake in Hungary and the Tigris River within Mosul city in Iraq.

In the Nagy-Morotva oxbow shallow lake, the study aimed to examine whether differences exist among the various zones of an oxbow lake with different land uses based on physical-chemical variables and dominant of phytoplankton species. This oxbow lake consists of two ends bordered by settlements and open water areas used primarily for fishing, with a protected area featuring large aquatic plant coverage and two transition zones towards the open water areas. The lake receives periodic water replenishment only at one end from one of the open water areas, and the water is also used for irrigation during summer. Our research was conducted within a vegetation time of spring, early summer, late summer, and autumn, which revealed significant differences in physical and chemical properties of the water and the characteristic algal species among the various zones of the lake in different sampling times. *Oscillatoria* sp. was a characterized species in the zones that effected by municipal sewage and irrigation.

Our study findings suggest that the ecological classification of smaller water bodies requires regular and extensive studies on the physical- chemical variables of the water and the composition of the phytoplankton, which can be influenced by seasonal changes, vegetation coverage, land use, and water replenishment. Phytoplankton can act as a bio-indicator of water quality, responding quickly and sensitively to changes in the environment. Land use, including agricultural and urban activities, has a significant impact on the dominant phytoplankton species and physical-chemical variables in water bodies, and can lead to pollution and negative effects on the aquatic ecosystem. Our research highlights the importance of ongoing monitoring and management of water bodies to ensure the preservation and maintenance of water quality and aquatic biodiversity.

During the investigation in the Tigris River within Mosul city, we investigated the impact of land use on the phytoplankton community and physical-chemical variables in the different zones of the river. Agricultural

and urban activities were found to have a significant impact on the water quality of the river, with point and non-point source pollutants affecting the river from upstream through agricultural activities and by urban activities in the middle section of the city, respectively from both banks. Our research was conducted by examining phytoplankton species and physical-chemical variables at 16 sites during each vegetation time, spring, summer, autumn, and winter. The observed a clear connection between pollution caused by different land uses and the effects on the algal community and physical-chemical variables in different zones and seasons of the year. Whereas *Oscillatoria* sp. was a characterized species in the agricultural zone.

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. The observed alterations can be attributed to varying land uses: Nutrients released from agricultural regions entered zone A; zone B displayed not only agricultural nutrient influx but also prevalent high levels of COD_{sMn} and TSS; zone C experienced elevated COD_{sMn} and TDS due to diffuse and point-source pollution from urban areas; and the urban influence in zone D resulted in the presence of reduced nitrogen forms (with a notable concentration of nitrate-nitrogen) alongside elevated values of TSS, TDS, and PO_4-P.

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11. APPENDIX

Appendix 1: Table shoing pearson correlation coefficients among phytoplankton species and physical-chemical variables during spring sampling time in Nagy-Morotva oxbow shallow lake in Hungary.

	BOD_5	Cl-	Chl-a	CO3	COD_{Cr}	COD_{sMn}	PO_4^{3-}	HCO_3^-	Humic	Kjl-N	NO_2-N	NO_3-N	pH	SO_4^{2-}	TDS	TP	TSS
Euglena acus	0.1	0.7^{***}	0.6^{**}	0.3	0.6^{**}	0.8^{***}	-0.2	0.2	0.7^{**}	0.3	0.1	-0.7^{***}	0.1	-0.5^{*}	0.8^{***}	0.4	0.2
Ankistrodesmus falcatus	0.1	0.6^{**}	0.6^{**}	0.2	0.5^{*}	0.7^{***}	-0.16	0.4	0.6^{**}	0.3	-0.2	-0.3	0.13	-0.6^{**}	0.7^{***}	0.2	0.2
Closterium acutum	-0.1	0.1	0.1	-0.2	0.2	0.1	-0.1	0.2	0.3	-0.2	0.5^{*}	-0.4	-0.4	-0.02	0.071	0.4	-0.1
Cryptomonas ovata	-0.3	-0.4	0.1	-0.1	-0.4	-0.2	0.186	-0.1	-0.3	-0.7^{**}	0.2	-0.1	-0.6^{**}	0.2	-0.4	0.3	-0.3
Cyclotella sp.	0.1	0.5^{*}	0.2	0.1	0.4	0.5^{*}	-0.2	0.4	0.52^{*}	0.3	0.1	-0.34	0.2	-0.4	0.5^{*}	0.4	0.2
Desmodesmus sp.	0.3	0.2	0.2	-0.1	0.4	0.5^{*}	0.1	0.2	0.7^{***}	0.1	0.1	-0.2	-0.1	-0.4	0.3	0.2	0
Dinobryon sp.	-0.2	0.5^{*}	0.4^{*}	0.2	0.4	0.4	-0.45^{*}	0.2	0.2	0.2	0.1	-0.4^{*}	0.1	-0.2	0.5^{*}	0.3	0.3
Fragilaria sp.	0.1	0.2	0.5^{*}	0.1	0.2	0.3	-0.2	0.1	0.3	0.1	-0.1	-0.1	0.2	-0.2	0.2	0.2	-0.1
Lagerheimia quadriseta	0.5^{**}	0.2	-0.2	0.2	0.4	0.2	0.3	-0.1	0.2	0.4^{*}	-0.3	0.1	0.7^{***}	-0.1	0.2	-0.3	0.4
Navicula sp.	0.5^{*}	0.1	-0.5^{*}	0.2	0.4	0.1	0.1	0.03	0.2	0.4	0.1	0.1	0.51^{*}	0.2	0.101	-0.1	0.3
Nitzschia acicularis	0.1	-0.2	-0.2	-0.2	0.1	-0.1	0.1	0.1	0.1	-0.1	0.1	0.2	0.1	0.1	-0.2	-0.1	-0.1
Pediastrum boryanum	-0.2	-0.2	0.1	0.1	-0.2	-0.3	-0.1	-0.01	-0.6^{**}	-0.1	-0.1	0.2	-0.1	0.1	-0.2	0.1	-0.1
Pediastrum duplex	0.3	0.4^{*}	0.1	0.2	0.5^{*}	0.4	-0.3	0.3	0.2	0.4	0.1	-0.3	0.55^{*}	-0.2	0.4^{*}	0.2	0.5^{*}
Pediastrum simplex	0.1	0.4	0.5^{*}	0.2	0.4	0.3	-0.4	0.2	0.4	0.2	0.2	-0.2	-0.1	-0.1	0.4	0.4^{*}	0.1
Phacus sp.	0.2	0.1	0.5^{*}	0.3	0.1	0.4	0.24	-0.1	0.2	-0.3	-0.4	-0.1	0.2	0.1	0.1	-0.2	0.1
Scenedesmus dimorphus	0.2	0.6^{**}	0.5^{*}	0.2	0.4	0.6^{**}	-0.5^{*}	0.1	0.4	0.2	0.1	-0.5^{*}	0.11	-0.3	0.6^{**}	0.4	0.3
Staurastrum sp.	-0.2	0.4	0.1	0	0.4	0.4	-0.24	0.1	0.4	0.2	0.1	-0.5^{*}	0.1	-0.4	0.4^{*}	0.2	0.4
Tetraëdron triangulare	0.5^{*}	0.4	0.3	0.3	0.4^{*}	0.6^{**}	-0.1	0.3	0.2	0.3	-0.2	-0.3	0.6^{**}	-0.1	0.5^{*}	0.3	0.4
Tetrastrum glabrum	-0.1	0.2	0.6^{**}	-0.3	-0.1	0.2	-0.34	0.5^{*}	0.3	-0.3	0.16	-0.1	-0.5^{*}	-0.4	0.2	0.4	-0.2
Tetrastrum triangulare	-0.3	0.1	0.5^{*}	0.1	-0.2	0.2	-0.2	0.3	0.4	-0.5^{*}	-0.2	-0.1	-0.3	-0.15	0.4	-0.1	-0.2
Trachelomonas volvocina	0.1	0.5^{*}	0.7^{***}	0.45^{*}	0.4	0.5^{*}	-0.06	0.1	0.5^{*}	-0.4	-0.2	-0.2	0.1	-0.4^{*}	0.5^{*}	0.2	-0.1

A small starlike symbol (*) representing the signifigant lever of correlation. (***) denotes significant at 0.001 level,(**) denotes significant at 0.01 level, and (*) denotes significant at 0.05 level. Chl-a: Chlorophyll-a; Cond.: Conductivity; Dpt.: Depth; Humic: Humic acid; Kjl-N: Kjeldahl-N.

Appendix 2: Table shoing pearson correlation coefficients among phytoplankton species and physical-chemical variables during early summer sampling time in Nagy-Morotva oxbow shallow lake in Hungary.

	BOD_5	Cl-	Chl-a	CO_3	COD_{Cr}	COD_{sMn}	PO_4^{3-}	HCO_3^-	Humic	NO_3-N	DO	pH	SO_4^{2-}	TDS	TP	Trans.	TSS
Euglena acus	0.1	0	0.6^{**}	-0.4	0.1	0.1	0	0.5^{*}	-0.1	0	-0.3	-0.4	0.2	0	-0.1	0	-0.1
Ankistrodesmus falcatus	0	0.5^{*}	0.5^{*}	0.3	-0.4	-0.6^{**}	-0.6^{**}	0.4	-0.4	-0.6^{**}	0.4^{*}	-0.3	0.2	0.5^{*}	0.1	-0.5^{*}	0.5^{*}
Closterium acutum	0.2	0.2	0.5^{*}	0.2	-0.3	-0.2	-0.5^{*}	0.2	-0.2	-0.4	0.2	-0.3	0.3	0.3	-0.2	-0.5^{*}	0.4
Coelastrum sp.	-0.2	0.1	-0.5^{*}	0.4	-0.1	-0.1	-0.1	-0.3	0	-0.1	0.3	0.4	-0.1	0	0.4	-0.1	0.3
Cosmarium sp.	0.4	0.5^{*}	0.5^{*}	0.7^{**}	-0.3	-0.4	-0.7^{***}	0	-0.4	-0.6^{**}	0.5^{*}	-0.1	0.2	0.5^{*}	0.2	-0.7^{***}	0.4
Crucigenia tetrapedia	0.1	0.8^{***}	0.45^{*}	0.5^{*}	-0.6^{**}	-0.7^{***}	-0.7^{***}	0.3	-0.6^{**}	-0.6^{**}	0.2	-0.5^{*}	0	0.9^{***}	0.2	-0.5^{*}	0.7^{***}
Crucigenia crucifera	0.2	0.6^{**}	0.2	0.1	-0.5	-0.4	-0.6^{**}	0.4	-0.3	-0.3	-0.1	-0.3	0.2	0.6^{**}	0	-0.3	0.5^{*}
Cryptomonas ovata	-0.1	0.1	0.2	-0.4	-0.2	0	0.2	0.5^{*}	0	-0.1	-0.3	-0.1	0.1	0	-0.1	0.3	-0.5^{*}
Cyclotella sp.	0	0.2	-0.1	0	-0.4	-0.3	-0.2	0.3	0.1	-0.1	0	0.4	0	0.2	0.3	-0.1	0.3
Desmodesmus sp.	0.5^{*}	0.6^{**}	0.3	0.7^{***}	-0.3	-0.5^{*}	-0.6^{**}	0.1	-0.4	-0.5^{*}	0.8^{***}	-0.2	0	0.6^{**}	0.1	-0.3	0.2
Dinobryon sp.	0.4	0.6^{**}	0.6^{**}	0.4	-0.3	-0.3	-0.5^{*}	0.4	-0.5^{*}	-0.5^{*}	0.3	-0.5^{*}	0.2	0.6^{**}	0.2	-0.6^{**}	0.5^{*}
Hydrococcus sp.	0.3	0	0.1	-0.2	0.2	0.2	0.2	0	0.1	0	0.1	-0.6^{**}	-0.1	0	-0.4	-0.1	-0.1
Kephyrion littorale	0.3	0.7^{***}	0.4	0.4	-0.5^{*}	-0.5^{*}	-0.6^{**}	0.2	-0.5^{*}	-0.7^{***}	0.3	-0.4	0.3	0.7^{***}	0	-0.7^{***}	0.4
Lagerheimia quadriseta	-0.1	-0.3	-0.5	0.2	0.2	0.3	0.1	-0.5^{*}	0.4	0.3	0.3	0.2	-0.2	-0.3	-0.2	0.1	0
Merismopedia sp.	0.1	0	-0.1	-0.3	0.2	0.3	0.4	0.1	0.2	0	0.1	0	0.3	-0.1	0.3	0.1	-0.5^{*}
Navicula sp.	0.3	-0.1	-0.2	0.5^{*}	0.1	0.1	-0.2	-0.5^{*}	0.1	-0.1	0.3	0.3	0.2	-0.1	0.1	-0.1	0
Oscillatoria sp.	-0.3	-0.4	-0.4	-0.2	0.3	0.4	0.5^{*}	-0.2	0.1	0.4^{*}	-0.2	0.4	0.2	-0.4	0.3	0.2	-0.2
Pandorina morum	0	0.5^{*}	0.2	0.4^{*}	-0.2	-0.5^{*}	-0.5^{*}	0.3	-0.4	-0.5^{*}	0.3	-0.3	-0.2	0.6^{**}	0.1	-0.3	0.4
Pediastrum duplex	0.4	0.5^{*}	0.6^{**}	0.6^{**}	-0.3	-0.4	-0.7^{***}	0.1	-0.3	-0.4	0.3	-0.3	0.1	0.6^{**}	0.1	-0.7^{***}	0.7^{***}
Pediastrum simplex	0.4	0.6^{**}	0.7^{**}	0.5^{*}	-0.4	-0.5^{*}	-0.7^{***}	0.2	-0.5^{*}	-0.6^{**}	0.3	-0.8^{***}	-0.1	0.7^{***}	-0.3	-0.7^{***}	0.6^{**}
*Phacus*sp.	0.4	0	0.2	0.1	0.1	0.2	-0.3	0	0.2	0.1	0.4^{*}	-0.1	0	0	-0.1	-0.3	0.1
Scenedesmus dimorphus	0.2	0.6^{**}	0.6^{**}	0.5^{*}	-0.4	-0.6^{**}	-0.7^{***}	0.3	-0.7^{***}	-0.8^{***}	0.4	-0.3	0.4^{*}	0.6^{**}	0.1	-0.5^{*}	0.4
Staurastrum sp.	0.2	0.5^{*}	0.4	0.5^{*}	-0.5	-0.4^{*}	-0.7^{***}	0.1	-0.4	-0.4	0.4	-0.1	0.1	0.6^{**}	0	-0.5^{*}	0.7^{***}
Tetraëdron triangulare	0	0.45^{*}	0.2	0.3	-0.3	-0.3	-0.6^{**}	0.3	-0.4	-0.5^{*}	0.3	-0.2	0.1	0.5^{*}	0.1	-0.2	0.3
Tetrastrum glabrum	0.4	0.6^{**}	0.5^{*}	0.5^{*}	-0.4	-0.6^{**}	-0.6^{**}	0.3	-0.5^{*}	-0.6^{**}	0.5^{*}	-0.4	-0.1	0.7^{***}	0.2	-0.6^{**}	0.5^{*}
Tetrastrum triangulare	0.1	0.3	0.5^{*}	0.1	-0.1	-0.4	-0.2	0.3	-0.3	-0.4	0.3	-0.6^{**}	-0.2	0.4	-0.1	-0.3	0.3
Trachelomonas volvocina	-0.1	0.2	0.4	0.4	-0.2	-0.4	-0.6^{**}	0.1	-0.4	-0.2	0.1	-0.2	-0.3	0.3	-0.2	-0.3	0.6^{**}
Ulnaria ulna	0	0.2	0	0.2	0.1	-0.1	-0.2	0.3	-0.2	-0.1	0.2	0.1	0.2	0.2	0.5^{*}	-0.1	0.4

A small starlike symbol (*) representing the signifigant lever of correlation. (***) denotes significant at 0.001 level,(**) denotes significant at 0.01 level, and (*) denotes significant at 0.05 level. Chl-a: Chlorophyll-a; Cond.: Conductivity; Dpt.: Depth; Humic: Humic acid; Kjl-N: Kjeldahl-N.

Appendix 3: Table shoing pearson correlation coefficients among phytoplankton species and physical-chemical variables during late summer sampling time in Nagy-Morotva oxbow shallow lake in Hungary.

	BOD_5	Cl-	Chl-a	CO3	COD_{Cr}	PO_4^{3-}	HCO_3^-	Humic	NH_4-N	NO_3-N	DO	pH	SO_4^{2-}	TDS	TP	Trans.	TSS
Euglena acus	0.6*	-0.3	0.1	0.2	0.1	-0.3	-0.4	0.2	0.5*	-0.2	0.2	0.4	-0.2	-0.3	0.1	0.1	-0.2
anabaena	-0.5*	-0.4	-0.6**	-0.7**	0.1	0.4	0.1	-0.1	-0.2	0.9***	-0.3	-0.8***	0.1	-0.4	0.2	0.2	-0.1
Ankistrodesmus falcatus	0.2	-0.4	-0.3	-0.4	0.6*	0	-0.2	0.4	-0.1	0.3	-0.3	-0.3	0.2	-0.4	0.1	0.1	-0.3
Asterionella formosa	0.4	-0.5*	-0.3	-0.5*	0.4	0.4	-0.3	0.5	-0.3	0.3	0.1	-0.4	0.6*	-0.6**	0.4	0.3	-0.4
Cosmarium sp.	0.1	-0.2	-0.1	-0.4	0.4	0.2	0.2	0.4	0.1	0.3	-0.5*	-0.3	0.1	-0.2	0.2	-0.2	-0.5
Crucigenia tetrapedia	0.3	0.7**	0.9***	0.4	-0.3	-0.1	0.6*	-0.3	0.1	-0.7**	0.2	0.5*	0.1	0.7**	-0.3	-0.5	0.2
Crucigenia crucifera	0.4	-0.6**	-0.4	-0.6*	0.5	0.4	-0.4	0.4	-0.4	0.3	0.1	-0.5	0.6*	-0.8***	0.4	0.4	-0.3
Cryptomonas ovata	0.2	-0.2	-0.1	-0.3	0.2	0.1	0.1	0.2	0.1	0.1	-0.2	0.1	0.1	-0.2	0.6*	0.1	-0.7**
Cyclotella sp.	0.5*	-0.1	0.1	0.2	0.1	-0.1	-0.3	0.4	0.1	-0.5	0.3	0.4	0.3	-0.2	0.2	0.1	-0.1
Desmodesmus sp.	-0.1	0	-0.1	-0.3	0.1	0.2	0.2	-0.2	0.1	0.5*	-0.3	-0.4	0.1	-0.1	0.1	0.1	-0.2
Dinobryon sp.	0.2	0.4	0.5	0.1	-0.3	0.1	0.6*	-0.4	0.4	-0.2	0.2	0.2	-0.4	0.5	0.1	-0.4	0.1
Fragilaria sp.	0.1	0.2	0.2	0.3	0.1	0.1	0.2	0.1	0.5*	-0.2	-0.4	0.4	-0.4	0.3	0.1	-0.4	-0.2
Gloeocapsa sp.	0	-0.2	-0.3	0.1	0.4	-0.7**	-0.3	0.3	0.4	0.1	-0.3	0.2	-0.3	-0.1	0.2	-0.1	-0.2
Gryosigma sp.	-0.2	0.2	0.2	0.1	0.3	-0.6*	0.2	0.1	0.5	0.1	-0.4	0.2	-0.3	0.2	0.2	-0.6*	-0.1
Kephyrion littorale	0.6*	-0.1	0.2	-0.1	0.1	-0.1	0.1	0.3	0.2	-0.2	0.2	0.2	0.1	-0.1	0.1	-0.2	-0.2
Lagerheimia quadriseta	0.7**	-0.4	0.1	-0.2	0.3	0.2	-0.3	0.3	-0.2	-0.3	0.4	0.1	0.5	-0.5	0.3	0.4	-0.3
Navicula sp.	-0.2	-0.2	-0.4	-0.3	0.6*	0.3	0.1	0.3	-0.1	0.3	-0.7**	-0.3	0.1	-0.2	0.5*	-0.1	-0.5
Nitzschia acicularis	-0.4	0.1	-0.1	-0.5*	0.2	-0.2	0.4	-0.2	-0.1	0.4	-0.4	-0.5	-0.3	0.1	0.1	-0.2	-0.2
Nostoc sp.	0.4	-0.5	-0.2	-0.5	0.3	0.2	-0.2	0.1	-0.2	0.3	0.3	-0.4	0.3	-0.6*	0.1	0.4	-0.1
Pediastrum duplex	-0.1	0.1	0.1	-0.3	0.2	0.2	0.4	0.3	-0.1	0.3	-0.4	-0.4	0.2	0.1	0.1	-0.6*	0.3
Pediastrum simplex	-0.2	0.5	0.4	0.2	-0.1	-0.3	0.6*	-0.2	0.4	-0.1	-0.4	0.2	-0.4	0.5*	-0.2	-0.6*	-0.1
Peridinium cinctum	0.3	-0.8***	-0.5*	-0.5	0.7**	0.1	-0.6*	0.6*	-0.2	0.3	-0.1	-0.3	0.4	-0.8***	0.5*	0.3	-0.4
Phacus sp.	0.6*	-0.5*	-0.2	-0.1	0.7**	-0.1	-0.6*	0.6*	-0.1	-0.3	0.1	0.2	0.3	-0.6**	0.4	0.3	-0.4
Scenedesmus dimorphus	-0.1	-0.5	-0.4	-0.5*	0.2	0.2	-0.1	0.3	-0.1	0.3	-0.2	-0.3	0.1	-0.4	0.1	0.2	-0.5*
Staurastrum sp.	-0.2	0.4	0.3	0.4	-0.5	-0.5	0.3	-0.4	0.5*	-0.1	0.2	0.2	-0.6*	0.5*	-0.4	-0.4	0.3
Trachelomonas volvocina	0.5*	-0.6*	-0.3	-0.3	0.4	-0.1	-0.5	0.3	-0.3	0.1	0.4	-0.2	0.4	-0.6**	0.1	0.4	-0.1

A small starlike symbol (*) representing the signifigant lever of correlation. (***) denotes significant at 0.001 level,(**) denotes significant at 0.01 level, and (*) denotes significant at 0.05 level. Chl-a: Chlorophyll-a; Cond.: Conductivity; Dpt.: Depth; Humic: Humic acid; Kjl-N: Kjeldahl-N.

Appendix 4: Table shoing pearson correlation coefficients among phytoplankton species and physical-chemical variables during autumn sampling time in Nagy-Morotva oxbow shallow lake in Hungary.

	BOD$_5$	Cl-	Chl-a	CO$_3$	COD$_{sMn}$	Cond.	HCO_3^-	Humic	Kjl-N	NH$_4$-N	DO	pH	SO_4^{2-}	TDS	TP	Trans.	TSS
Ankistrodesmus bibraianus	-0.1	0.3	0.1	-0.2	-0.2	0.2	-0.1	0.1	0.4*	0.1	0.3	0.1	0.2	0.2	0.2	0.4	0.1
Ankistrodesmus falcatus	0.2	-0.4	0.1	0.1	0.4	-0.1	0.5*	0.4	0.1	-0.3	0.5*	-0.3	-0.5*	-0.2	0.2	-0.3	0.4*
Ankistrodesmus spiralis	0.1	0.2	0.1	-0.2	-0.1	0.3	0.1	0.1	0.5	0.1	0.4	0.1	0.1	0.2	0.1	0.3	0.1
Asterionella formosa	0.1	0	0.2	-0.4	-0.1	-0.4	-0.4	-0.3	0.1	0.2	-0.3	-0.2	0.2	-0.4*	0.1	0.5*	-0.4
Closterium acutum	0.1	-0.2	-0.1	0.1	0.1	-0.1	-0.1	0.5*	0.1	0.1	-0.2	0.1	-0.2	-0.1	0.1	-0.2	0.1
Cosmarium sp.	0.5*	-0.2	-0.2	-0.6**	0.4*	-0.2	0.1	-0.2	0.3	0.1	-0.3	0.1	0.1	-0.2	-0.2	0.4	-0.3
Crucigenia tetrapedia	0.1	-0.4	0.1	-0.2	0.2	-0.5*	0.1	0.2	0.2	0.1	-0.2	-0.4	-0.2	-0.5*	0.1	0.1	0.1
Crucigenia crucifera	-0.4	0.2	0.4*	0.1	-0.2	0.1	-0.2	-0.2	-0.2	0.3	-0.1	-0.1	0.2	0.1	-0.1	0.1	-0.3
Cryptomonas ovata	-0.1	0.1	0.5*	-0.2	-0.1	-0.1	-0.1	-0.3	0.1	-0.1	0.4	-0.5*	0.1	-0.2	0.2	0.4*	0.1
Cyclotella sp.	-0.5	0.2	-0.4	0.1	-0.4	0.1	-0.2	-0.1	-0.1	0.1	-0.3	0.1	0.2	0.1	-0.3	-0.1	0.1
Desmodesmus sp.	-0.4	0.3	0.1	-0.2	-0.4	0.1	-0.5	-0.3	0.1	0.4	0.1	-0.1	0.5*	0.1	-0.1	0.6**	0.1
Dinobryon sp.	-0.3	0.2	0.1	-0.1	-0.4	-0.1	-0.6	-0.6**	-0.1	0.3	-0.5*	0.1	0.5*	-0.1	-0.5*	0.4	-0.6**
Kephyrion littorale	0.1	0.1	-0.1	-0.4	0.3	0.1	0.6**	0.3	0.4	0.1	0.1	-0.1	-0.2	0.1	0.5*	-0.2	0.2
Merismopedia sp.	-0.2	0.2	0.1	0.1	-0.2	0.1	-0.3	0.4	0.2	0.5*	-0.2	0.1	0.2	0.1	-0.1	0.3	-0.3
Monoraphidium contortum	-0.6**	0.5*	-0.3	0.3	-0.6**	0.2	-0.6**	-0.2	-0.1	0.6**	-0.2	0.2	0.6**	0.2	-0.3	0.3	0.1
Navicula sp.	-0.2	0.3	-0.5*	0.2	-0.3	0.3	-0.3	0.2	0.2	0.1	-0.1	0.4	0.3	0.4	-0.3	0.1	-0.4
Nitzschia acicularis	0.1	-0.2	0.1	-0.2	0.1	-0.6**	-0.4	-0.1	-0.1	0.4*	-0.6**	-0.1	0.2	-0.6**	-0.2	0.3	-0.2
Oscillatoria sp.	-0.3	0.3	0.1	-0.2	-0.3	-0.1	-0.6	-0.4*	0.1	0.4	-0.4	0.1	0.4	-0.1	-0.2	0.6**	-0.4
Pandorina morum	-0.3	-0.2	0.1	0.1	-0.1	-0.3	-0.1	-0.1	-0.2	0.1	-0.1	-0.4*	0.1	-0.3	-0.1	0.2	0.1
Pediastrum duplex	0.1	0.2	-0.1	-0.5	-0.1	-0.1	-0.3	-0.2	0.3	0.3	-0.3	-0.2	0.2	-0.1	-0.2	0.4	-0.4
Pediastrum simplex	0.3	-0.1	0.1	0.1	0.2	-0.1	0.3	0.3	0.2	-0.2	0.4	-0.1	-0.3	-0.1	0.4	-0.1	0.6**
Phacus sp.	0.3	-0.3	0.1	0.2	0.2	-0.5*	-0.1	0.1	-0.4*	0.1	-0.5*	0.2	-0.1	-0.4	0.1	-0.2	0.1
Staurastrum sp.	0.1	-0.1	-0.2	0.1	0.2	0.1	0.5*	0	0	-0.2	0.1	0.1	-0.4	0.1	-0.1	-0.2	-0.1
Tetraëdron triangulare	0.4	-0.2	0	-0.1	0.3	-0.1	0.2	0.2	0.2	-0.3	0.3	-0.2	-0.4*	-0.1	0.1	-0.1	0.2
Tetrastrum glabrum	0.1	-0.2	0	0.2	-0.1	-0.3	-0.5*	0.1	-0.1	0.1	-0.1	0.1	0	-0.3	-0.3	0.2	-0.3
Tetrastrum triangulare	-0.4	0.1	0.1	-0.3	-0.3	-0.3	-0.5*	-0.3	0.1	0.4	-0.5*	-0.3	0.4	-0.4	-0.3	0.3	-0.3
Trachelomonas volvocina	0	-0.2	0.2	-0.2	0.2	-0.1	0.3	0.1	0.1	-0.1	0.4	-0.7	-0.2	-0.2	0.3	0.2	0.3

A small starlike symbol (*) representing the signifigant lever of correlation. (***) denotes significant at 0.001 level,(**) denotes significant at 0.01 level, and (*) denotes significant at 0.05 level. Chl-a: Chlorophyll-a; Cond.: Conductivity; Dpt.: Depth; Humic: Humic acid; Kjl-N: Kjeldahl-N.

Appendix 5: Table shoing pearson correlation coefficients among phytoplankton species and physical-chemical variables during spring sampling time in Tigris River in Mosul city in Iraq.

	BOD_5	Chl-a	Cl^-	DO	HCO_3^-	NH_4-N	NO_3-N	TDS	TSS	Turb.
Amphora sp.	-0.3	-0.1	-0.1	-0.1	-0.3	-0.3	0.6^{*}	-0.4	0.2	-0.4
Aulacoseira granulata	0.2	0.6^{**}	0.3	0.1	0.01	0.3	-0.2	0.01	0.01	0.2
Ceratium hirundinella	-0.1	0.5^{*}	0.3	-0.5^{*}	0.1	0.4	-0.1	0.4	-0.1	-0.1
Cocconeis sp.	-0.2	-0.2	0.6^{*}	-0.3	-0.1	0.4	0.1	-0.1	0.1	0.2
Cryptomonas ovata	0.3	0.4	0.6^{*}	-0.2	0.2	0.7^{**}	-0.5	0.7^{**}	-0.2	0.3
Cymatopleura solea	0.6^{**}	0.01	-0.4	0.8^{***}	0.4	-0.2	-0.3	0.2	-0.2	0.01
Cymbella sp.	-0.2	-0.2	0.3	-0.3	-0.5^{*}	0.1	0.7^{**}	-0.4	0.1	-0.3
Denticula sp.	-0.1	0.5^{*}	0.3	-0.5^{*}	0.1	0.4	-0.1	0.4	-0.1	-0.1
Desmodesmus sp.	-0.1	0.5^{*}	0.2	-0.4	-0.1	0.1	0.2	0.1	0.3	0.01
Euglena sp.	0.3	0.4	0.5^{*}	0.01	0.3	0.4	-0.5^{*}	0.4	0.01	0.5^{*}
Gyrosigma sp.	0.01	-0.2	-0.5^{*}	0.1	0.2	0.01	0.2	-0.4	0.3	-0.1
Licmophora sp.	-0.1	0.1	-0.1	-0.3	-0.1	0.2	0.4	0.1	0.6^{**}	0.2
Microcystis aeruginosa	-0.1	0.3	0.3	0.01	-0.2	-0.2	0.3	-0.2	-0.3	-0.6^{**}
Pediastrum simplex	-0.1	0.1	0.5^{*}	-0.2	-0.2	0.1	-0.2	0.4	-0.3	0.1
Spyrogera sp.	-0.1	0.5	0.6^{*}	-0.5^{*}	-0.1	0.3	-0.2	0.5^{*}	-0.2	0.01
Surirella sp.	0.4	-0.2	0.2	0.1	0.2	0.5^{*}	0.1	0.2	0.3	0.4

A small starlike symbol (*) representing the signifigant lever of correlation. (***) denotes significant at 0.001 level,(**) denotes significant at 0.01 level, and (*) denotes significant at 0.05 level. Chl-a: Chlorophyll-a; Cond.: Conductivity; Dpt.: Depth; Humic: Humic acid; Kjl-N: Kjeldahl-N.

Appendix 6: Table shoing pearson correlation coefficients among phytoplankton species and physical-chemical variables during summer sampling time in Tigris River in Mosul city in Iraq.

	Chl-a	Cl^-	Dpt.	DO	HCO_3^-	NH_4-N	NH_2-N	NH_3-N	pH	PO_4-P	TDS	TSS	Turb.
Ceratium hirundinella	-0.3	-0.1	0.1	-0.2	0.3	-0.2	0.6^{*}	0.3	0	0.2	-0.2	-0.2	0.1
Closterium acutum	-0.2	-0.2	0.2	-0.5	-0.2	0.1	0.3	-0.2	-0.6^{*}	0.5	-0.1	0	0.1
Cocconeis sp.	0.1	0.4	-0.4	-0.1	0.1	0	0.3	0.1	0.1	0.1	-0.6^{*}	-0.4	-0.5^{*}
Coenocystis planctonica	-0.2	0.1	0	-0.1	-0.1	0	0.9^{***}	0.1	-0.2	0.5^{*}	-0.1	0.1	-0.1
Cosmarium sp.	0	-0.7^{**}	0.4	0.3	-0.1	0.5^{*}	-0.1	-0.4	-0.2	0.1	-0.1	-0.2	0.1
Cryptomonas ovata	0.2	0.2	-0.3	-0.1	0.2	-0.1	0.1	0	0.1	0	-0.5^{*}	-0.4	-0.4
Cyclotella sp.	0.2	0.2	-0.4	0.2	0.3	-0.1	0.2	0.5	0.4	-0.3	-0.7^{**}	-0.5^{*}	-0.6^{*}
Desmodesmus sp.	0.1	0.2	-0.5^{*}	-0.3	0.3	-0.1	0.2	-0.1	0.2	0	-0.5	-0.4	-0.4
Diatoma sp.	0	0.2	-0.4	-0.5^{*}	0	-0.1	0.3	0.2	-0.3	0.3	-0.1	-0.1	-0.3
Euglena sp.	0.6	0.3	-0.5^{*}	0	-0.2	-0.1	0.3	0.3	0	0.1	0	-0.3	-0.5*
Eudorina sp.	0.5^{*}	0.2	0	-0.2	-0.2	0	-0.1	-0.3	-0.3	0.3	0.3	0.1	0.1
Fragilaria sp.	0.2	0.4	-0.4	0.1	0.1	-0.1	0	0	0.2	-0.1	-0.6^{*}	-0.4	-0.4
Gyrosigma sp.	0.1	0.1	-0.3	-0.3	0.2	0.1	0.1	-0.1	0.1	0	-0.6^{*}	-0.6^{*}	-0.5^{*}
Merismopedia sp.	0.5^{*}	0.1	0	-0.1	-0.1	0	-0.1	0	-0.2	-0.1	0	0.1	-0.1
Odugonium sp.	0.3	0.1	-0.1	0.5^{*}	-0.1	0.2	-0.1	0.3	0.2	-0.3	-0.4	-0.1	0.1
Oscillatoria sp.	0.3	-0.1	-0.1	-0.1	0.3	0.2	-0.1	-0.2	0.2	-0.1	-0.6^{*}	-0.7^{**}	-0.6^{*}
Pediastrum duplex	0	0.2	0	-0.2	-0.2	0	0.6	-0.2	-0.3	0.7	0.2	0.1	0.2
Pediastrum simplex	-0.2	-0.3	0.1	-0.1	0.5^{*}	-0.2	-0.1	0.3	0.2	-0.2	-0.3	-0.3	0.1
Peridinium cinctum	0	-0.3	-0.4	0.4	0.5^{*}	0.2	-0.1	0.1	0.5^{*}	-0.2	-0.1	-0.2	-0.2
Phacus sp.	0.6^{*}	0.1	-0.6^{*}	-0.1	-0.1	-0.2	-0.1	0.2	0.2	-0.2	0	-0.3	-0.5
Rhoicosphenia sp.	-0.2	0.1	0	-0.1	-0.1	0	0.9^{***}	0.1	-0.2	0.5^{*}	-0.1	0.1	-0.1
Scenedesmus dimorphus	0.2	0.1	0	-0.1	-0.1	0	-0.1	-0.4	-0.2	0.5^{*}	0.4	0	0.3
Scenedesmus ecornis	-0.2	-0.5^{*}	0	0.2	0.5^{*}	0.3	0.3	0.1	0.2	0.1	-0.3	-0.4	-0.1
Scenedesmus arcuatus	0.1	0.3	0	-0.4	-0.3	-0.2	0.5^{*}	0	-0.5	0.5^{*}	0.2	0	-0.1
Surirella sp.	0.4	0.1	-0.6^{*}	0.3	0.1	0.1	0.4	0.4	0.4	-0.1	-0.3	-0.3	-0.4
Tetraëdron triangulare	0	-0.7^{*}	0.4	0.3	-0.1	0.5^{*}	-0.1	-0.4	-0.2	0.1	-0.1	-0.2	0
Tetrastrum glabrum	-0.2	0.1	0	-0.1	0.5^{*}	-0.2	-0.1	-0.5^{*}	0.5	-0.2	-0.3	-0.3	-0.3
Ulnaria ulna	0.1	0.2	-0.3	0.2	0.3	0	0.2	0.2	0.3	-0.2	-0.6^{*}	-0.5	-0.5

A small starlike symbol (*) representing the signifigant lever of correlation. (***) denotes significant at 0.001 level,(**) denotes significant at 0.01 level, and (*) denotes significant at 0.05 level.

Appendix 7: Table shoing pearson correlation coefficients among phytoplankton species and physical-chemical variables during autumn sampling time in Tigris River in Mosul city in Iraq.

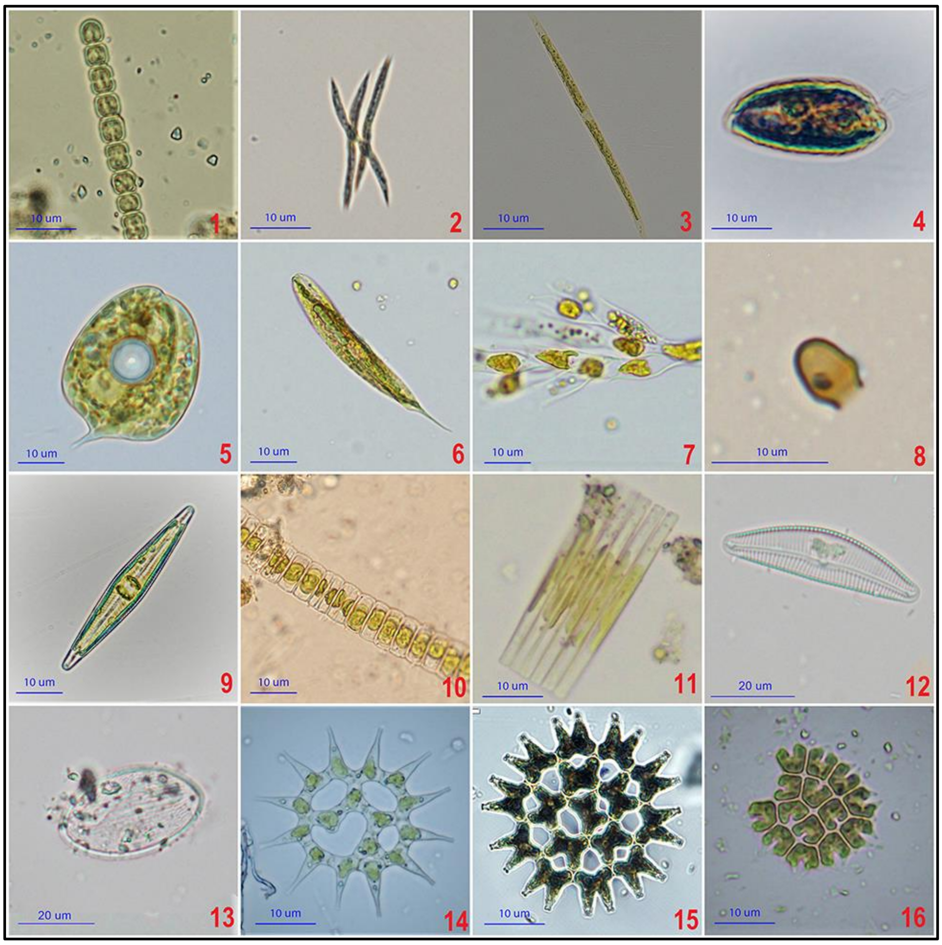
	BOD_5	Chl-a	COD_{sMn}	Dpt.	DO	HCO_3^-	NH_4-N	NO_2-N	NO_3-N	pH	PO_4-P	TDS	TSS	Turb.
Achnanthes sp.	-0.1	-0.3	0.4	-0.1	0.8^{***}	0.6^{*}	0.8^{***}	-0.1	-0.2	0.2	-0.1	-0.6^{*}	0.01	-0.1
Amphora sp.	-0.6^{*}	-0.1	-0.2	0.01	-0.3	-0.3	0.1	0.2	0.01	0.01	-0.2	-0.1	-0.3	-0.1
Closterium acutum	0.1	0.1	0.4	0.1	0.3	0.1	0.2	0.01	-0.1	-0.1	0.6^{**}	0.1	0.1	0.3
Cocconeis sp.	0.5^{*}	0.6^{**}	0.2	0.6^{*}	-0.2	-0.5	-0.5	0.2	-0.3	-0.1	0.5^{*}	0.5^{*}	0.1	0.2
Coelastrum sp.	0.01	0.2	-0.1	0.1	-0.2	-0.5^{*}	-0.5	-0.1	0.01	0.01	0.01	0.3	-0.3	0.2
Crucigenia tetrapedia	-0.5	0.2	-0.1	-0.3	0.01	-0.2	-0.1	-0.3	-0.3	0.4	0.1	-0.3	0.6^{**}	0.5
Cryptomonas ovata	0.3	0.6^{*}	0.5^{*}	0.2	0.6^{*}	0.01	0.2	0.1	-0.5^{*}	-0.3	0.4	0.01	0.4	0.1
Denticula sp.	0.01	0.2	-0.1	0.2	0.01	-0.6^{*}	-0.4	-0.1	-0.1	0.1	0.5	0.1	0.1	0.1
Diatoma sp.	0.7^{**}	0.01	0.1	0.2	0.3	0.5^{*}	0.01	0.01	-0.3	-0.3	0.2	0.2	0.1	0.01
Eudorina sp.	0.2	0.2	0.5	0.1	0.5^{*}	0.01	0.4	0.3	-0.3	0.01	0.2	-0.2	-0.3	-0.1
Euglena sp.	-0.1	0.01	0.1	-0.4	-0.3	-0.5^{*}	0.01	0.6^{**}	0.01	-0.1	-0.1	0.2	-0.1	-0.3
Gomphonema sp.	-0.1	-0.3	0.4	-0.1	0.8^{***}	0.6^{*}	0.8^{***}	-0.1	-0.2	0.2	-0.1	-0.7^{**}	0.01	-0.1
Gymnodinium palustre	-0.1	0.01	0.5	0.01	0.5^{*}	0.4	0.5^{*}	-0.3	-0.3	-0.2	0.1	-0.5	0.1	0.3
Gyrosigma sp.	-0.2	-0.1	0.01	-0.2	-0.6^{*}	-0.5^{*}	-0.4	0.3	0.1	-0.1	0.2	0.4	-0.1	0.2
Lagerheimia quadriseta	-0.1	-0.3	0.4	-0.1	0.8^{***}	0.6^{*}	0.8^{***}	-0.1	-0.2	0.2	-0.1	-0.7^{**}	0.01	-0.1
Licmophora sp.	0.4	0.7^{**}	0.3	0.4	0.01	-0.2	-0.3	0.1	-0.3	-0.2	0.4	0.2	0.3	0.2
Merismopedia sp.	-0.5^{*}	-0.1	0.3	-0.2	0.5^{*}	0.01	0.6^{**}	-0.1	0.01	0.3	-0.2	-0.7^{**}	0.01	-0.1
Microcystis aeruginosa	-0.2	-0.5^{*}	0.01	-0.3	0.2	0.4	0.3	-0.2	0.01	0.2	-0.3	-0.6^{*}	0.2	0.01
Monoraphidium litorale	0.2	0.2	0.4	0.5	-0.2	0.1	-0.2	-0.2	0.1	-0.2	0.8^{***}	0.3	0.6^{*}	0.5^{*}
Navicula sp.	-0.3	0.4	0.5^{*}	-0.2	0.6^{*}	0.01	0.5^{*}	0.2	-0.5	-0.1	0.1	-0.4	0.2	0.1
Nitzschia sp.	0.3	0.01	0.4	-0.1	0.4	0.3	0.4	0.4	-0.2	-0.5^{*}	-0.1	-0.1	0.1	-0.5
Pediastrum duplex	0.1	-0.3	0.01	0.2	-0.3	0.1	0.01	0.01	0.3	-0.5^{*}	0.1	0.2	0.01	-0.2
Pediastrum simplex	-0.1	0.1	-0.4	0.1	-0.1	0.1	-0.4	-0.5	0.01	0.6^{*}	0.01	0.01	0.3	0.4
Peridinium cinctum	0.4	0.1	0.7^{**}	0.3	0.5^{*}	0.01	0.3	0.1	-0.2	-0.3	0.4	0.01	-0.1	0.01
Rhoicosphenia sp.	-0.3	0.1	0.3	-0.1	0.5^{*}	-0.4	0.3	0.1	-0.2	0.1	0.2	-0.5	-0.2	0.01
Scenedesmus dimorphus	0.3	0.01	0.4	0.2	-0.3	0.1	0.01	0.4	0.1	-0.4	0.5^{*}	0.6^{*}	0.3	0.1
Scenedesmus ecornis	0.01	0.01	-0.1	-0.1	-0.1	0.1	-0.2	-0.3	-0.3	0.5	0.3	0.1	0.7^{**}	0.6^{*}
Surirella sp.	0.1	0.1	0.3	-0.1	0.3	0.01	0.1	-0.1	-0.6^{*}	0.01	0.2	-0.2	0.1	0.3
Ulnaria ulna	0.2	0.3	-0.2	0.3	0.4	0.01	-0.1	-0.4	-0.7^{**}	-0.1	0.1	-0.3	0.3	0.2

A small starlike symbol (*) representing the signifigant lever of correlation. (***) denotes significant at 0.001 level,(**) denotes significant at 0.01 level, and (*) denotes significant at 0.05 level

Appendix 8: Table shoing pearson correlation coefficients among phytoplankton species and physical-chemical variables during winter sampling time in Tigris River in Mosul city in Iraq.

	BOD_5	Chl-a	COD_{sMn}	Dpt.	DO	HCO_3^-	NH_4-N	NO_3-N	pH	TDS	TSS
Chroococcus limneticus	0.01	0.4	0.01	0.1	0.4	0.3	-0.4	0.2	-0.2	-0.5	0.4
Closterium acutum	0.1	0.5*	0.01	0.5*	0.01	0.1	-0.3	0.1	0.3	-0.2	-0.1
Cocconeis sp.	-0.2	0.7**	-0.3	0.4	0.01	-0.3	-0.5*	0.01	0.1	-0.3	-0.2
Coelastrum sp.	0.5*	0.2	0.2	-0.1	0.01	-0.1	-0.1	0.3	-0.1	-0.3	-0.2
Coenocystis planctonica	-0.1	0.01	-0.3	0.3	-0.3	0.5*	-0.3	-0.2	0.2	-0.2	-0.1
Crucigenia tetrapedia	0.01	0.01	0.1	-0.4	0.1	-0.5	0.01	-0.1	-0.5*	-0.2	0.2
Cryptomonas ovata	0.01	0.6**	-0.2	-0.1	0.5*	-0.2	-0.4	0.1	-0.5*	-0.4	0.2
Cyclotella sp.	0.2	0.3	-0.2	0.01	0.01	0.1	-0.2	0.4	0.01	-0.4	0.3
Desmodesmus sp.	-0.1	0.2	-0.6*	-0.1	-0.2	-0.4	-0.7**	-0.4	-0.2	0.01	0.2
Gyrosigma sp.	-0.1	0.1	-0.7**	-0.1	-0.4	-0.5	-0.6*	-0.5	-0.1	0.1	0.1
Navicula sp.	-0.3	0.3	0.1	0.4	0.3	0.3	-0.2	0.1	0.01	-0.6*	0.2
Oscillatoria sp.	-0.5	0.4	-0.1	0.5	0.5*	0.1	-0.6*	-0.2	-0.3	-0.3	-0.1
Rhoicosphenia sp.	-0.2	-0.1	-0.4	0.01	-0.6*	0.2	-0.1	-0.1	0.6**	0.1	0.1
Scenedesmus dimorphus	-0.2	0.01	-0.3	0.1	0.1	-0.2	-0.2	-0.2	-0.3	-0.2	-0.5*
Staurastrum	0.5*	-0.3	0.1	-0.4	-0.5	0.01	0.6*	0.3	0.2	0.1	0.01
Ulnaria ulna	-0.1	0.1	0.1	-0.2	0.2	-0.5*	0.1	0.2	-0.1	0.2	0.01

A small starlike symbol (*) representing the signifigant lever of correlation. (***) denotes significant at 0.001 level,(**) denotes significant at 0.01 level, and (*) denotes significant at 0.05 level



Appendix 9: 1. *Anabaena* sp. 2. *Ankistrodesmus falcatus* 3. *Closterium acutum* 4. *Cryptomonas ovata* 5. *Phacus pleuronectes* 6. *Euglena spirogyra* 7. *Dynobryon* sp. 8. *Kephyrion littorale* 9. *Navicula* sp. 10. *Hyalotheca dissilensis* 11. *Fragillaria sp.* 12. *Cymbella* sp. 13. *Cocconeis* sp. 14. *Pediastrum simplex* 15. *Pediastrum duplex* 16. *Pediastrum boryanum*

Appendix 10: 1. *Desmodesmus sp.* 2. *Hyalotheca dissilensis* 3. *Scenedesmus* sp. 4. *Staurastrum* sp. 5. *Gyrosigma* sp. 6. *Trachelomonas* sp. 7. *Zygnema* sp. 8. *Oscillatoria* sp. 9. *Nitzshia acicularis sp.* 10. *Cyclotella sp.* 11. *Tetraedron triangulare* 12. *Dinophyta sp.* 13. *Diatoms species* 14. *Closterium sp.* 15. *Koliella* sp. 16. *Crucigenia tetrapedia* sp.

12. PUBLICATIONS

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Subject: PhD Publication List

Candidate: Majd Muwafaq Yaqoob
Doctoral School: Pál Juhász-Nagy Doctoral School of Biology and Environmental Sciences
MTMT ID: 10089616

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
   IF: 3.53

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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.
   Limnetica. 38 (1), 41-53, 2019. ISSN: 0213-8409.
   DOI: http://dx.doi.org/10.23818/limn.38.11
   IF: 0.918

Total IF of journals (all publications): 7,848
Total IF of journals (publications related to the dissertation): 6,93

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of the Journal Citation Report (Impact Factor) database.

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