

# **Trophic States of Freshwater Lakes and their Relationship with Algae and Macrophytes**

**A Summary Submitted to the  
Babasaheb Bhimrao Ambedkar University, Lucknow  
in fulfilment of Requirement for the Award of Degree of**

**Doctor of Philosophy**  
**in**  
**Environmental Science**



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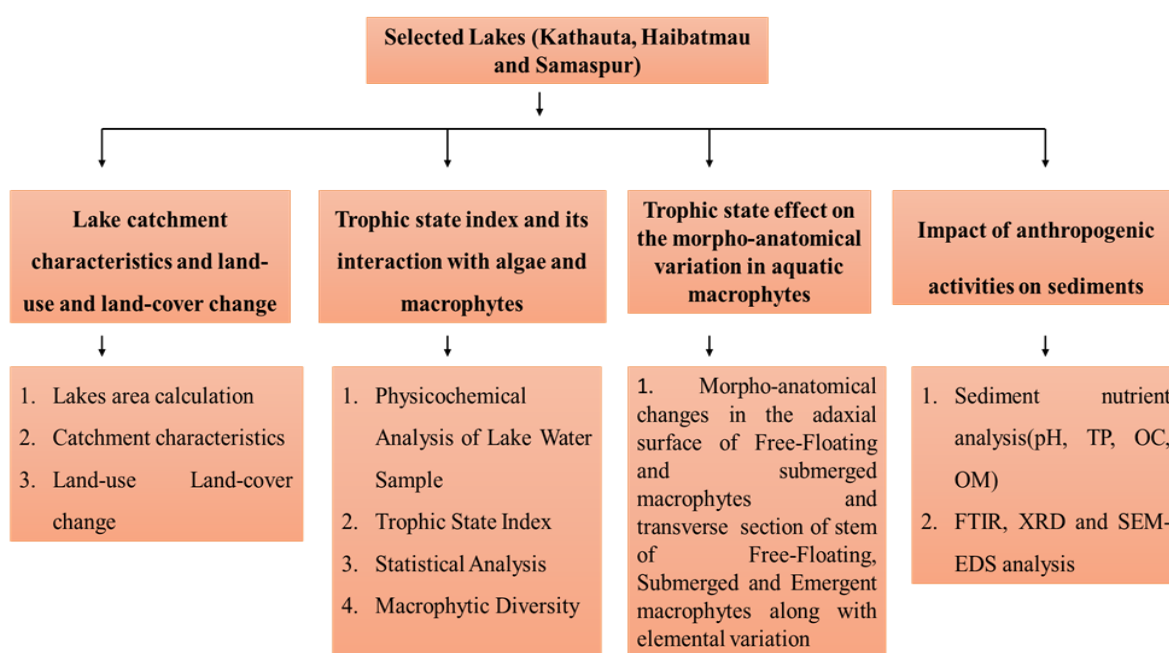
**DEPARTMENT OF ENVIRONMENTAL SCIENCE  
SCHOOL FOR ENVIRONMENTAL SCIENCES  
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**2024**

## 6. Summary and Conclusion

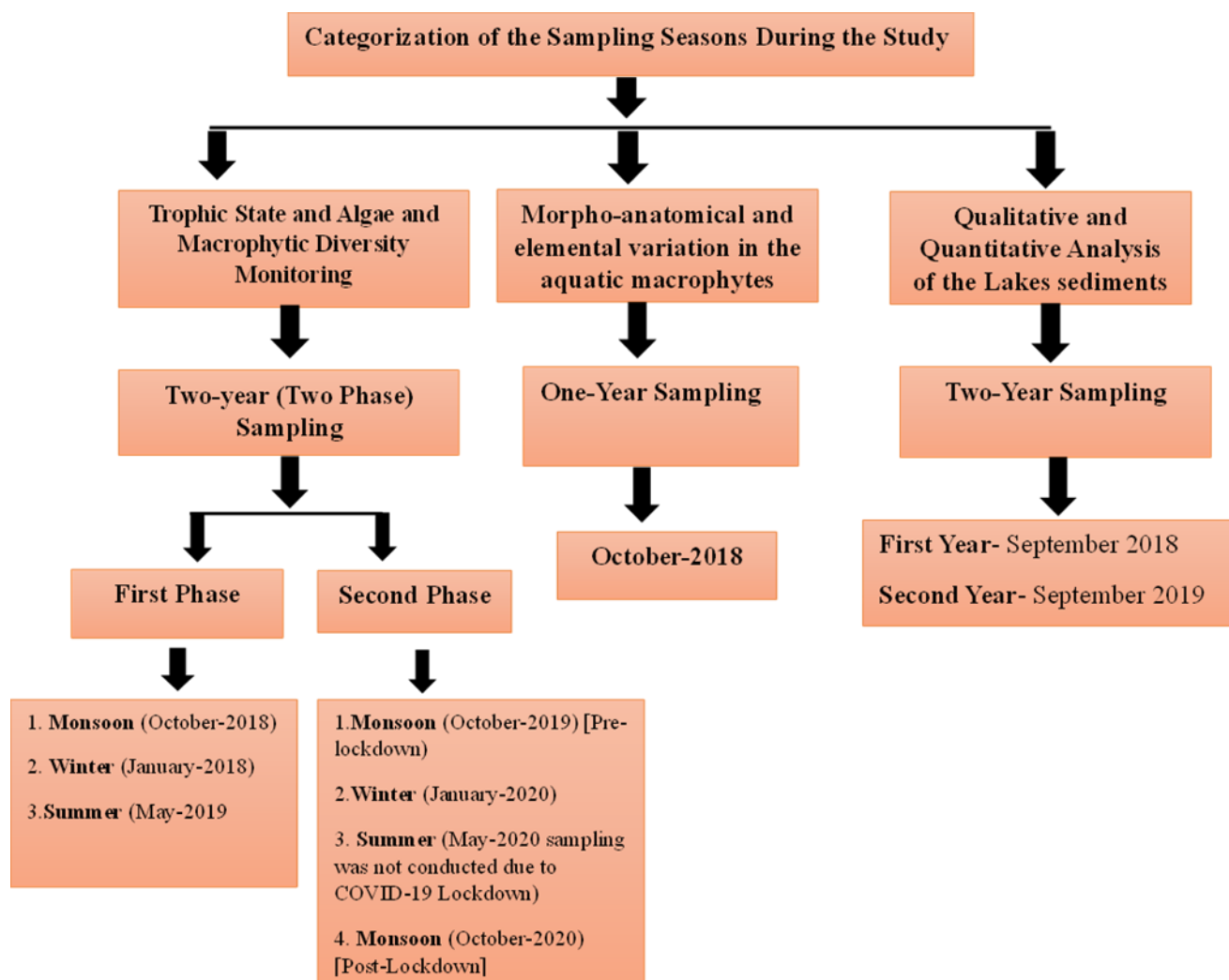
Freshwater lakes are currently facing numerous stressors, predominantly caused by human activities, particularly land use and land cover changes resulting from rapid urbanization and human interventions. These factors contribute to the degradation and loss of freshwater ecosystems, affecting both urban and rural catchments and leading to their eventual degradation and extinction.

The main purpose of this study is to analyze how the change in the trophic state affects the algal and macrophytic diversity of freshwater lakes. Three lakes are selected for the study, two are from urban catchments in highly disturbed and stressful conditions and the third is a Ramsar site, in the rural catchment, which is under the protection of the Forest Department and is comparatively less disturbed. The field study was conducted for the duration of two years, from October 2018 to October 2020. Changes in the land use and land cover in the selected lakes for the last three decades were also studied. The overall study revolves around the effects of changing trophic state and eutrophication on algal and macrophytic diversity, and how both algae and macrophytes interact with each other. Morpho-anatomical and elemental changes in the aquatic macrophytes are also studied along with the effect of anthropogenic activities on the qualitative and quantitative characteristics of the lake. The study details the interaction and changes in the biotic community (algae and macrophytes) with the trophic state in freshwater lakes.



**Figure 6.1:** Flow chart showing the overall methodology selected for the study

The seasonal categorization of the sampling during the study is shown in Figure 6.2.



**Figure 6.2:** Flow chart showing the categorization of the sampling seasons

### **Factors Responsible for the Trophic State Change of the Freshwater Lakes**

The trophic state of the freshwater lake is a variable component. Various natural and anthropogenic factors are responsible for the changes in the trophic state. During this study, various factors were considered which resulted in the changes in the trophic state of the lake of which the major factor with regards to the tropical country is the seasonal change. Seasons in tropical countries are mainly categorized into summer, winter, and monsoon. In the summer season lakes under study were mainly found to be in the mesotrophic to eutrophic conditions, the same scenario was also seen in the winter season as in this season flourishing growth of the algae was reported resulting in the increased trophic state of the lake. Whereas during the monsoon season lake was mainly found in the oligotrophic condition due to the dilution prospects caused by increased

water level in the lake from the rainfall. Anthropogenic interferences like pollution discharge and aquaculture activities also resulted in the increased trophic state of the lake. As in aquaculture activities, feed for the fish has been additionally added as well as excreta of the fishes in the lake resulting in an increase in the trophic state of the lake. Cultural eutrophication mainly from the point and non-point sources, mainly discharge in the lake from the nearby settlements resulted in the increased trophic state of the lakes. Floristic invasion in freshwater lakes also causes an increase in the trophic state of the lake as during the death and decaying stage of the macrophytes additional nutrients are added to the lake. Hence, changes in the trophic state of the lakes continuously vary based on seasonal changes and anthropogenic interferences.

### **Effect of Intensive Aquaculture Activities on the Trophic State and Floristic Diversity of the Lake**

Freshwater ecosystems play a vital role in the biosphere, yet they are progressively undergoing alterations to facilitate economic growth as seen in this study, especially for Kathauta Lake. A significant threat faced by freshwater lakes is land use change, fragmentation, cultural eutrophication, and biotic shift, stemming from the influx of nutrients. Changes in the richness and diversity of aquatic biota caused by aquaculture operations have been linked to a decline in the lake's native species diversity. Furthermore, fish-rearing aquaculture activities in lakes induce transformation in the algae and macrophytic diversity.

The results of this study show that nutrient enrichment in the lake is primarily due to anthropogenic activities such as clothes washing by local washermen, which increases the phosphorous loading in the lake, and fragmentation of the lake. The other reason is the unrestricted discharge of sewage from the surrounding residential areas into the lake. This lake has suffered severe anthropogenic stress in the catchment and open area in the last four decades. This anthropogenic stress resulted in the polluted water in the lake leading to the mesotrophic condition of the lake having numerous species of littoral grasses, herbaceous plants, and sedges, as well as free-floating, submerged, and emergent macrophytes, documented during the study period. Aquaculture activities increased the lake's organic pollution which adversely affects the diversity and evenness of the algae and macrophytes in the lake. The proliferation of cyanophyceae due to aquaculture activities further exacerbates eutrophication, which changes the

species composition and overall floristic diversity. It is seen that when macrophytes were manually uprooted, planktonic algae took over the lake environment due to the aquaculture activities. The high dominance of diatoms during winter can be interpreted as a net growth of phytoplankton that is possibly favoured by low predation and high nutrient availability. Consequently, changes in the biodiversity composition of the lake environment were reported and shifts in the algae and macrophytic diversity caused due to anthropogenic aquaculture activities.

Increasing human dependence on the lake's natural ecosystem for subsistence may be detrimental to the natural ecological functioning of the lake ecosystem as it adversely affects the aquatic food chain and biotic composition thereby affecting the normal functioning of the lacustrine ecosystem. This research helps us to understand the effect of human interference on the floristic biotic composition of the lake ecosystem and how they get adversely affected by this. Many native and vulnerable aquatic species might go extinct if aquaculture was pursued intensively in the lake for an extended period. Therefore, appropriate regulatory measures should be developed to strictly supervise the activities thereby contributing to the economic growth without compromising the native aquatic biodiversity of the lake ecosystem. Overall, the study is important for understanding the impact of human activities on fragile aquatic ecosystems and for promoting sustainable development practices in urban areas while preserving the native freshwater biodiversity.

### **Increased Trophic Level Favours the Floristic Invasion in Freshwater Lakes**

The major state of concern in the protected Ramsar wetland i.e. Samaspur wetland selected for the study was the floristic invasion which directly or indirectly affected the biotic heterogeneity in the lake. Excessive growth of free-floating invasive macrophytes affects the normal growth and function of the submerged flora and fauna in the lake. In the 40 years of catchment study, there has been a slight decrease in the proportion of the lake catchment area. Changes in the water quality and trophic state of the lake were significantly due to the seasonal variation as no major anthropogenic impacts were observed for this lake. Water quality and trophic state decrease in the monsoon season mainly because of heavy rainfall which causes dilution of pollutants and nutrients in the lake, whereas in other seasons trophic state increases due to a decrease in the water level causing degradation in the water quality resulting in

increased trophic state of lake. The invasive macrophytes were present in all the phases of the sampling. Floristic invasion can displace non-invasive native vegetation and tolerate a wide range of water depths, disrupting natural cycles of vegetation replacement in the fragile non-invasive native macrophyte communities of lakes. It is crucial to prioritize the management of lakes that have higher densities of invasive alien species. This is because these species can significantly alter the structure and diversity of native species in the area, which can ultimately lead to a decrease in the function and services provided by the ecosystem. Therefore, it is important to implement effective management methods to mitigate the negative impact of invasive alien species on the ecosystem.

The invasion of non-native species into aquatic habitats is a global environmental challenge with serious ecological, social, and economic consequences. Floristic invasion can alter the sediment and water chemistry, nutrient cycling, hydrology, and disturbance regime of the ecosystem they infest. Additionally, they affect seedling recruitment by blocking seed dispersal through their thick mat growth of stem, root, and rhizome. As a result, native plant species are often outcompeted, leading to the establishment of a monotypic community. It has been observed that the presence of dominant non-native macrophytes can cause significant changes in the food web structure of invaded ecosystems. Additionally, the impact of a constantly changing trophic state on the macrophyte-phytoplankton productivity balance is not straightforward and can complicate the lake's ecological functioning. Ecosystem damage, impact on human livelihood, and disruption of human activities must be quantified. Conducting comprehensive research and developing implementable models can provide policymakers with tools to reduce the impact on infested lakes and prevent invasive species from spreading to other freshwater lakes.

Biological invasions can have significant impacts on ecosystems, the services provided by them, and the associated economies and conservation efforts. In the context of protected lakes, the invasion of flora can be particularly harmful, as it can negatively impact the ecosystem services that are essential for human well-being. The pattern and dynamics of the aquatic flora are seriously affected by the floristic invasion. Hence it is strongly recommended to do continuous vegetation monitoring to predict the extent of invasion in the lake along with the prohibition of unsustainable activities in the selected protected lakes. Other negative consequences may include reduced natural

beauty, loss of biodiversity, and obstruction of recreational boating, which can discourage tourism. Our research shows that the widespread floristic invasion can severely affect ecosystem services, with alarming consequences for the associated economic and recreational value of the Ramsar site. Therefore, it is crucial to have proper management of selected lakes to address this issue. The overall conclusion drawn from the study is that despite being in the protected areas along with the designation of the Ramsar site, this lake complex is facing floristic invasion which affects the normal growth and functioning of the other non-invasive aquatic flora in the lake. Hence, there is an urgent need to check the growth of invasive macrophytes in these freshwater lakes of international importance and to conserve the biotic heterogeneity of the non-invasive aquatic biota.

### **Effects of Land Use Change on the Trophic State and Floristic Habitat Shift of the Freshwater Lake**

The main contributors to cultural eutrophication are the rapid land development and encroachment activities on the lake catchment as seen in the selected Haibatmau Lake. The dynamics of the floristic cover appeared to be influenced more by seasonal monsoon-related variables in the urban lake along with the variations in the nutrient loads discharged into the lake from wastewater. According to our study, the spread of macrophyte cover is highly dynamic and has significant seasonal competition effects on algal populations. This could hurt the important ecological responsibilities that the lake flora plays, such as the system's overall nutrient intake and modifications to the physico-chemical characteristics of lakes.

According to the study's findings, the macrophytes in the lakes were increasing annually, whereas the trophic state remained constant in Haibatmau Lake. The macrophytes and algae had a persistent negative correlation, which was stronger seen at the selected lake. However, because of increased nutrients from numerous human activities in the surrounding areas, the lake is nutrient-rich and contaminated with water hyacinth and alligator weed. Nevertheless, the available literature has not specifically addressed the quantity of pollution, the levels of water quality, or the health hazards associated with the toxins in these lakes.

Numerous factors influenced how the macrophytic cover of the selected lake changed over time. Climate, light levels, precipitation, seasonal winds, pest infestation intensity,

human weeding and harvesting of fodder, inflow, and outflow of volatile waste and stormwater loads, duration of water residence, lake depth, and water changes flow through the sediments and macrophytes are important factors influencing macrophytes and algae. Comprehensive ecological statements are limited by these multi-causal interactions. It was difficult to cover all these factors in the present study; however, some broad conclusions concerning the evident connections between environmental effects and the evolution of lake cover can be made.

The current policies and procedures for preventing contamination should be strengthened to stop the practices that could negatively affect the ecosystem, such as limiting the amount of nutrients that can be released into the environment, monitoring septic systems, reducing the amount of household waste that is discharged, and controlling runoff. In general, this study suggests controlling the floristic invasion in the lake and locating the sources of pollution while also keeping an eye on the water quality. Consequently, this will aid the investigator in analyzing information and carrying out remediation measures to safeguard the lake water's quality against contaminants. To stop the ecosystem of the lake from further deterioration, immediate action is required to minimize the amount of municipal wastewater entering the lake and remove the nutrients using appropriate waste treatment procedures.

### **Native Macrophytes are Becoming Invasive in Tropical Freshwater Lakes due to Anthropogenic and Climatic Factors**

Anthropogenic activities like aquaculture and climate change may pose a challenge to the current definition of invasive species irrespective of the origin as seen in the selected lakes. Formerly non-invasive species can turn invasive and certain invasive species to become less so. There will be changes in the geographic distribution of both native and non-native species, and the boundaries of their natural ranges will need to be adjusted.

Presently changing climatic conditions and anthropogenic activities mainly aquaculture activities resulted in the invasion of the native macrophytes in the lakes. As in the present scenario floristic invasion in the freshwater ecosystem is mainly governed by climate change and anthropogenic interferences. The macrophytic invasion involves various mechanisms such as competition, evolution of increased competitive ability, enemy release, allelopathy, naturalization of related species, mutualisms, phenotypic plasticity, empty niche, and fluctuating resources. Species traits and ecological

characteristics have been recognized as aspects that regulate the invasion potential. Certain invasive species may become less invasive, while previously non-invasive species may become more invasive due to anthropogenic impacts and climate change. These changing ecological and anthropogenic conditions are resulting in the invasion of native macrophytes in the tropical freshwater lakes which needs to be addressed through proper lake management actions.

Our study found that the traits linked to growth and reproduction along with the climatic and anthropogenic interference is mostly correlated with invasive success among the various groups of traits in the macrophytes. With the exception of response traits, it has been found that nearly every trait category of invasive macrophytes is more correlated with their invasiveness than those of non-invasive macrophytes. Additionally, whether they are native or exotic, macrophytes with a wider variety of environmental tolerances have a higher chance of successfully colonizing new areas. The high incidence of invasive features that are associated with the aquatic macrophytes' likelihood of success in new aquatic settings is the primary factor in their successful invasion.

Plant invasion success is often attributed to certain traits such as the short life cycle, rapid growth rate, ability of vegetative reproduction, fast germination rates, high seed production, and the production of allelopathic chemicals. Some non-invasive plants lack certain characteristics that invasive plants possess. By comparing the characters or traits of non-invasive and invasive macrophytes, we can gain insight into this subject, while variations in the functional characteristics of native communities may have an impact on an invasion's success. Therefore, it is of urgent importance that the invasiveness of the macrophytes is considered a separate concept, as the origin of the macrophytes does not affect the invasive capacity in this Anthropocene era. Proper management action and policies are urgently needed in developing countries like India, to protect our freshwater ecosystem from the adverse effects of the invasion.

### **Effects of Changing Trophic State on the Morpho-anatomical and Elemental Variations in the Aquatic Macrophytes**

This study shows that within the Central Gangetic Plain, the Trophic State Index (TSI) provides a comprehensive tool for the water quality assessment of freshwater lakes. Furthermore, the study has shown how the increasing trophic state and deteriorating

water quality affect the anatomy of macrophyte leaf surfaces through the biomineralization on their adaxial surfaces. Anatomical changes in macrophytes shown in this study include effects on the leaf surface, changes in stomatal structure, and depositions around it. It is clear from the study that within mesotrophic lakes such as L2 (Kathauta) and L3 (Haibatmau), nutrient enrichment and pollution stresses affect the leaves of the macrophytes through the accumulation of biogenic materials, whereas in oligotrophic lakes L1 (Samaspur), macrophytes show normal morphology with proper stomatal structures.

The anatomies of the rhizome of free-floating *Eichhornia crassipes* in lakes L2 (Kathauta) and L3 (Haibatmau) were found to be normal despite being in mesotrophic conditions and polluted states of the lake. In contrast within the oligotrophic L1 (Samaspur), the presence of calcium oxalates and carbonate crystals was noted within macrophytes. Environmental and genetic factors are the main factors responsible for biomineralization within aquatic macrophytes. The water quality of an oligotrophic Samaspur lake (L1) shows high pH and low alkalinity. Biomineralization and calcification in *Eichhornia*, therefore, appear to be mainly brought about by achieving supersaturation of the lacustrine ecosystem, which increases carbonate ion activities by shifting the inorganic carbonate ion equilibrium. The main function of calcium oxalate and calcium carbonate crystals in aquatic ecosystems is regulating cytoplasmic free calcium levels in the macrophytes. They also help in the biogeochemical cycling of carbon, calcium, and silicon and the sequestration of atmospheric CO<sub>2</sub>, alleviating both salt and temperature stresses. It has also been reported that they regulate ion balance (e.g., sodium and potassium), detoxify oxalic acid, and reduce alkalinity generated by nitrate assimilation.

The study has also shown that the trace elemental concentration within aquatic macrophytes varies with changes in trophic state from samples collected from different lakes. Macrophytes of the mesotrophic lakes contain higher trace elemental activities compared with the macrophytes within the oligotrophic lake. The study shows that the trace elemental concentrations in floating macrophytes are higher than in submerged and emergent macrophytes. It seems, therefore, that the trophic state and water quality are the principal determinants of the elemental variation in aquatic macrophytes.

### **Impact of Anthropogenic Activities on the Sediments of the Selected Lakes**

Lake sediment particles are derived from rock, soil, and biotic compounds of aquatic organisms along with anthropogenic or human-influenced inputs. The main constituents of lake sediments include quartz, clay, calcium carbonate, and various silicate minerals. The basic structural unit of lake sediment is alumina silicate and silicate. The properties of lake sediment are mainly governed by its mineral composition, sorption capacity for pollutants, percentage of organic matter, particle size distribution, and porosity. The properties of the lake sediments decide the pollutant concentration in the sediment. The sediment mineral analysis is a noticeable area of the research on environmental pollution. Sediment analysis gives useful information on the natural weathering process, geochemical constituents, environmental changes, and anthropogenic impacts that affect sediment composition. Identification of physicochemical attributes, particle size, morphologic, mineralogy, functional groups, and metallic contents provides useful information regarding the mineralogy and geochemistry of the lake's sediments.

Laboratory analysis of the lake sediments reveals fewer variations in the pH, organic matter, organic carbon, and total phosphorous of the L2 (Haibatmau) and L3 (Samaspur) lakes during the years 2018 and 2019 whereas major variations in pH, organic matter, organic carbon, and total phosphorous were reported in the L1 (Kathauta) during the year 2019 when compared with 2018. One of the major reasons could be the fish rearing in the lake during the year 2019. This result correlated with the analytical chemical analysis of the lake's sediments.

The qualitative identification of lacustrine sediments of the selected three lakes was conducted by FTIR, XRD, and SEM-EDS techniques. This provides a rich insight into the sediment characteristics and mineralogy. The FTIR and XRD results showed that the dominant minerals in studied samples are quartz, clay, and calcite and sediments contain significant amounts of organic matter. Various minerals identified by FTIR analysis were confirmed in the XRD analysis of the sediments. The infrared study of sediment samples from four different locations of the selected three lakes indicates the presence of quartz, calcite, kaolinite, and montmorillonite. In comparison to other minerals, quartz is present in all the lake's sediment samples. The recurrent occurrence of quartz in lake sediments is mainly due to its hardness as well as chemical structure which make it unwitherable and difficult to erode. Therefore, it is considered to be the

main component of the sediment samples. Feldspar is also reported in different compositions i.e., albite was reported in XRD analysis but was absent in FTIR analysis mainly due to its crystalline nature. XRD analyses show the presence of albite, quartz, olivine, and calcite. Among all other minerals, the lake's quartz showed major peaks in the diffractogram obtained from XRD. The witnessed XRD patterns indicate quartz and kaolinite as the key or major constituents and other minerals as the minor constituents. This shows that quartz is the most plentiful mineral in the sediment samples and is supported by our infrared studies. The combined study using FTIR and XRD indicated that it is a helpful technique for sediments mineral analysis especially for lacustrine sediments profiling.

Major minerals like quartz, kaolinite, montmorillonite, calcite, biogenic silica, as well as humic compounds, minerogenic, organic compounds, and biogenic silica, are common among all three selected lakes as they share the same geological evolution (Central Gangetic Plain of Uttar Pradesh, India). In Lake L3 (Samaspur) additional components of cellulose, hemicellulose, and lignin compounds are reported in the year 2019. This may be due to the degradation of the uprooted aquatic macrophytes on the littoral area of the lake. The mineralogic constituent of the selected lakes shows negligible variations between the sampling period of the two years during 2018 and 2019.

Elemental analysis of the lake sediments for the years 2018 and 2019 correlates with the minerals reported in the FTIR and XRD analysis of minerals. No major elemental changes in the L2 (Haibatmau) and L3 (Samaspur) lakes were reported between 2018 and 2019 whereas in lake L1 (Kathauta) increase in elemental constituent was reported during 2019 along with an increase in carbon content which matches with our laboratory analysis major reason being the fishing rearing activities. Hence anthropogenic activities in the lake ecosystem change the elemental constituents in the sediments.

The study reveals a marked variation in the surface morphological patterns of the selected lakes' sediments. The SEM images were taken at 100X and 500 X resolutions from the selected three lakes in the year 2018 and 2019. Morphological variations were reported in terms of shape, size, and amorphous nature among the three lakes, the reason may be due to the different catchment characteristics and levels of anthropogenic stressors. However negligible variation was reported in the lakes between the years

2018 and 2019. Anthropogenic activity (aquaculture) in Lake L1 (Kathauta) does not result in major changes in the morphology of the sediments as reported in the SEM images.

From this study, it is concluded that the spectroscopic route of analysis for the qualitative assessment of the lacustrine sediment is a highly reliable and accurate method. No element or mineral is left unidentified, and results correlate with the laboratory analysis. The lake situated in the agriculture catchment has a clear influence or contribution from the decomposition of aquatic plants which showed the presence of cellulose, hemicellulose, and lignin. At the same time, the lake in the urban catchment under the influence of aquaculture shows an increase in organic matter, further conferred by EDS analysis.

The minor variation in the minerals during the years 2018 and 2019 is due to the constant input of terrigenous materials in the lakes. In Lake L1 (Kathauta) aquaculture activity during the year 2019 increased pH, organic carbon, organic matter, and total phosphorous. Hence, sediment characteristics of the lakes get affected by anthropogenic stress or interference which includes the aquaculture activities in the lake ecosystem.

Anthropogenic activities such as mining, dredging, changes in land use, wastewater discharge, and aquaculture operations have a significant impact on the mineral and elemental composition of lake sediments. The primary objective of this paper is to identify and analyze the key physicochemical parameters as well as the mineral and elemental compositions of freshwater lake sediments and establish potential connections between sediment mineralogy, ecological conditions, and catchment characteristics. The results of the elemental study revealed the heterogeneous composition of the lake sediments with distinct signatures of elemental constituents. The mineral composition suggests that the lake sediment generally inherits the geogenic terrigenous mineral composition that enters the lake with run-off water from the lake catchment. The recurrent occurrence of the most plentiful quartz mineral in lake sediments is mainly because of its hardness and chemical structure which make it difficult to weathering and erosion. Therefore, it is the main component of the sediment samples. The occurrence of the geogenic minerals reported in the XRD analysis of the sediment samples is confirmed by the FTIR analysis.

Lake sediment composition is influenced by in-lake and shoreline vegetation cover as the degradation of dead and decaying plant biomass is a major source of organic matter and biogenic minerals in the sediment. Anthropogenic activities affect the physicochemical parameters, biogenic minerals, and elemental concentration in the lakes whereas the morphology of the lake sediment remains largely unaffected by these disturbances. Geogenic minerals remain constant in the temporal analysis of the lake whereas the biogenic minerals are dependent on the in-lake processes.

The elevated nutrient levels in the lakes promote excessive growth of aquatic biota, ultimately resulting in higher organic content within the sediment. The buildup of organic material within the lake is closely tied to several factors, including the lake's size, local hydrological characteristics, geomorphological features, and the scale of aquaculture operations.

Mineral in lake sediments reported in the study are mainly of allochthonous origin and therefore contain more quartz, feldspar, and mica than fine mud, which is composed mainly of carbonate minerals and clays. Biogenic silica and carbonate or calcite formation in the lake is an important process linking geogenic and biogenic minerals in freshwater ecosystems as redeposition of the sediment mineral is controlled by the hydrodynamical characteristics of the lakes.

The distribution of minerals in the lake is impacted by in-lake particle dynamics, including episodic biogenic silica whose main sources are diatoms and planktons, production events, calcium carbonate (CaCO<sub>3</sub>) precipitation events, and nutrient and elemental concentration in lakes. Concentrating sediment has a considerable impact on the distribution of nutrients and elements within lakes, which are related to organic matter, silica content, and carbonate matter. This cycle involves the whole geosystem of the lacustrine environments including biotic, abiotic, and anthropic factors, which directly influence the formation and alterations of the minerals in the lake sediment.

Depending on the biotic species and environmental factors, the types of minerals and concentration of the nutrients vary. This bio-deposition may play a crucial role in controlling the water and sediment column processes of the various lacustrine components. Sediment minerals play key roles in nutrient cycling in lakes. The geological allochthonous and autochthonous minerals contributing to the mineral budget of the sediment are less well-known. Wind-blown dust (air deposition), biogenic

organic matter, biogenic silica, and carbonates are the chief elements of lake sediments and the precursor of the lake biogenic cycle.

The results emphasize the significance of studying annual fluctuations and spatial variations in mineral particle fluxes. These investigations offer valuable insights into the yearly dynamics of minerals within lakes, contributing to a more comprehensive understanding of their behaviour and distribution. Furthermore, it is concluded that in-lake mixing processes are insufficient in homogenizing spatial variations in the concentration of geological minerals within the lake.

### **Overall Conclusion of the Study**

Overall, this study concludes that freshwater lakes in the urban and to some extent in the rural catchments are under severe threat, mainly due to irrational anthropogenic activities. During the last three decades, severe loss in freshwater lakes in the Central Gangetic Plain of Uttar Pradesh was mainly due to urbanization and encroachment of the lacustrine area.

The major factor which determines the trophic state and aquatic diversity of the lake are catchment characteristics; land use and land cover change, aquaculture activity, and pollution sources. Aquaculture activities cause a shift in the macrophytic and algal diversity due to human interference. Aquaculture activities lead to the invasion of the native macrophytes in the lakes as reported during the time of the study. Excessive pollution and encroachment activities along with wastewater discharge favour the growth and proliferation of invasive macrophytes. As many species of macrophytes have an antagonistic relationship with algae, hence the excessive growth of invasive macrophytes should be checked for the proper survival of another biotic organism in the lake. Lakes in less stressed conditions support healthy and diverse species of algae and macrophytes and provide various ecological and economic services. Aquaculture activities also result in overall change in all the components of the freshwater lake, as it disturbs the normal distribution of algae and macrophytes in the lakes. Hence aquaculture activities should be under proper regulatory policies, which regulate the kinds of fertilizers, pesticides, and fish feed to be added in the lakes as they will be helpful for the proper functioning and survival of the aquatic floristic diversity.

Changes in the algae and macrophytes' diversity are mainly governed by three factors, firstly by any changes in the nutrient concentration and trophic state of the lakes, secondly by the seasonal changes that result in the change in the algae and macrophytes diversity in the lakes, and third by the presence of the macrophytic species in the lake itself that affects the presence of algal species in the lakes as sometimes they show antagonistic and sometimes the mutual relationship between them. Hence any change in the trophic state of the freshwater lake affects the algae and macrophytic diversity present in the lake, and alters the morpho-anatomical and elemental variation in the free-floating, submerged, and emergent macrophytes of the freshwater lakes. Anthropogenic aquaculture activities along with the trophic state alteration in the freshwater lakes affect the sediment qualitative and quantitative characteristics of the lake.

Floristic invasion is the major problem reported in this study. It can displace non-invasive native vegetation and tolerate a wide range of water depths, disrupting natural cycles of vegetation replacement in the fragile non-invasive native macrophytic communities of lakes. It is crucial to prioritize the management of lakes that have higher densities of invasive alien species. This is because these species can significantly alter the structure and diversity of native species in the area, which can ultimately lead to a decrease in the function and services provided by the ecosystem. Therefore, it is important to implement effective management methods to mitigate the negative impact of invasive alien species on the ecosystem.

The invasion of non-native species into aquatic habitats is a global environmental challenge with serious ecological, social, and economic consequences. Floristic invasion can alter the sediment and water chemistry, nutrient cycling, hydrology, and disturbance regime of the ecosystem they infest. Additionally, they affect seedling recruitment by blocking seed dispersal through their thick mat growth of stem, root, and rhizome. As a result, native plant species are often outcompeted, leading to the establishment of a monotypic community. It has been observed that the presence of dominant non-native macrophytes can cause significant changes in the food web structure of invaded ecosystems. Additionally, the impact of a constantly changing trophic state on the macrophyte-phytoplankton productivity balance is not straightforward and can complicate the lake's ecological functioning. Ecosystem damage, impact on human livelihood, and disruption of human activities must be

quantified. Conducting comprehensive research and developing implementable models can provide policymakers with tools to reduce the impact on infested lakes and prevent invasive species from spreading to other freshwater lakes.

Hence, an increase in pollution in the lakes by various factors affects each component of the freshwater lakes starting from water to biotic components and sediments of the lake. Therefore, proper monitoring, pollution control, and strict regulation of the encroachment and aquaculture activities in the lakes are urgently required. This would also improve water quality and healthy biotic diversity for supporting the normal functioning of the freshwater lakes.