BIODIVERSITY CHALLENGES

A Way Forward

Shashikanth Majagi

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Biodiversity Challenges

— *A Way Forward* —

THE EDITOR

Dr. Shashikanth H. Majagi did his M. Sc. and Ph. D. in Zoology from Gulbarga University, Kalaburagi, Karnataka. He started his carrier as Assistant professor in Government First Grade College, Chikkballapur and Government College (Autonomous) Kalaburagi. He has published 45 research papers and book articles. He has attended and presented 50 research papers in national/international conferences/symposia and 06 books to his credit. He is a reviewer/editorial board member for many journals of international acclaim. He is the life member for many academic bodies. He has given radio talks and Doordarshan programmes as well . Received prestigious Award for Research Paper (ARP) award from VGST, Government of Karnataka and IOSRD Life time award and Novel Research Academy Award of Excellence in Research. He has successfully organized two national Conference and Workshops. Successfully completed research projects funded by is UGC. Successfully Guided 02 Ph. D. students and 03 are working. He has worked as Special officer for NAAC, Department of Collegiate Education, Regional Joint Director Office, Kalaburagi. Currently he is teaching Environmental biology, Biodiversity and Limnology to Master degree Students. His research interests are on Limnology, Water quality studies and biodiversity. Currently working as Associate Professor and Chairman, Department of Zoology, Deputy Registrar (DPAR) and Nodal officer for Youth Red Cross.

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— *A Way Forward* —

– Editor –

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— *Dedicated to* —

My Beloved Sister

Late Smt. Manjula R.

Acknowledgements

I wish to express my deep sense of gratitude to all the research paper contributors who were very generous for sending their original book chapters.

I am thankful to Dr. Vijaykumar Malashetty, Professor, Department of Zoology, Vijayanagar Sri Krishnadevaraya University, Ballari for writing foreword to this book.

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My sincere thanks to Doddappa Sri Manikappa Majagi and Doddamma Smt. Sukumari and my parents Sri. Hanmantappa Majagi and Shakuntala Laxmibai, Wife Dr. Anita S. Majagi and daughters Miss. Sinchana and Miss. Saanidhya.

Shashikanth Majagi

Foreword

The book before you offers an overall view of this biological diversity and carries the urgent warning that we are rapidly altering and destroying the environment, its challenges and how to way forward to protect. Thus it gives me a great pleasure to contribute this foreword.

As I read the book prior to writing this Foreword, I was impressed by many unique features that I would like to share with you. Biodiversity is life! The diversity of life forms, so numerous that we have yet to identify most of them, is the greatest wonder of this planet. The biosphere is an intricate tapestry of interwoven life forms. The major threats to biodiversity that result from human activity are habitat loss, fragmentation and degradation, over exploitation of species for human use, introduction of exotic species and possibility of spread of disease. This leads to threats to the threatened species and result in the extinction of such species. Typically these threats develop so rapidly and on such a large scale that species are not able to adopt genetically to the changes or disperse to more hospitable location. The rapid and visible changes in environmental variables within few weeks of the lockdown due to COVID-19 were surprising even for experts which should create an optimistic attitude towards biodiversity conservation. The scientific community has to lead from the front, in creating solutions and in steering the socio-political will required to implement these solutions for a more long lasting process of environmental conservation. Besides there is an urgent need to create awareness among rural and urban population to highlight the importance of conserving biodiversity.

Today, the issues and challenges relating to wildlife and biodiversity conservation are embedded in understanding the human dimension with its social, cultural, political, economic and legal complexities. An interdisciplinary approach to challenges like that of human–wildlife conflict, will help scientists to arrive at better solutions that might ensure conservation of nature in the longer run.

Biodiversity Challenges – A Way Forward is a edited book, Many scientists have generously contributed in this endeavour, an updating of many of the principal issues in conservation biology and resource management. It also documents a new alliance between scientific, governmental, and commercial forces—one that can be expected to reshape the international conservation movement for decades to come. This book also accumulated enough data on deforestation, species extinction, and tropical biology to bring global problems into sharper focus and warrant broader public exposure. It also a handy resource for the local conservationist community consisting of policy makers, academicians, scientists, environmentalists, students and gross root level conservationists. It also provides an invaluable toolkit for a large and under-resourced audience of students in developing nations and addresses the key issues in conservation biology, clearly stating the challenges but also offering solutions.

Dr. Shashikanth H. Majagi is currently Associate Professor of Zoology at Vijayanagara Sri Krishnadevaraya University, Ballari and one of the leading Environmental Biologist of the country. "Dream is not what you see while sleeping. Dream is something that doesn't let you sleep" – rightly quoted by Dr. A.P.J. Abdul Kalam. His broad research interests in the field of biodiversity, strong determination and dedication made him to bought this edited book. I know that you will soon have a much larger audience for your work.

Congratulations!

Dr. Vijaykumar B. Malashetty, Ph.D

Professor,
Department of Studies in Zoology,
Vijayanagara Sri Krishnadevaraya University, Ballari

Preface

The present book provides an information about biodiversity, how its rise, about its distribution, importance and how to maintain it, representing its point of view into the literature on biological diversity. Biodiversity continues to decline, and the main drivers of biodiversity loss continue to increase. The unsustainable use of natural resources has led to an alarming rate of habitat loss. Climate change, invasive species, and pollution pose additional threats to global species richness. The present book neither complies of a technical research reports or the complete action plans and nor the detailed documentation on biodiversity importance or the issues for the loss of biodiversity. Instead, various recent research articles, here represents the relevant ideas and goals in the critical importance to sustainable development and a conservation measures on biodiversity. The biodiversity loss or crisis is one of the major global concerns and every country or community has vital role in the challenges ahead. The chapters in the book has its own impact on values, distributions and maintenance of biodiversity as of which we tried to draw out the major problems and reveal the ground reports with actual examples. This book might form a relevant source for the readers and hope to be a useful resource in exploring the main stream themes at greater levels and details.

Shashikanth Majagi

Contents

Chapter 10

Diversity of Phytoplankton in Lakes of Bangalore, Karnataka, India

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Phytoplanktons are an essential component in the ecosystem as they provide food (primary producer) to higher trophic levels through the process of photosynthesis with the release of oxygen as a by-product. They act as an indicator of variations in water quality and helps in nutrient removal in lakes. The diversity, density, and distribution of phytoplankton in a water body are dependent on the quality of the habitat (water quality). The present study deals with the assessment of physico-chemical parameters and phytoplankton diversity of lakes in Bangalore. A total of 58 genera of phytoplankton were recorded in Bangalore lakes. The phytoplankton in the studied lakes was represented by five major groups, i.e., Chlorophyta, Bacillariophyta, Cyanobacteria, Charophyta, and Euglenozoa. Cyanobacteriais the most dominant that suppresses the growth of other phytoplankton groups. The primary production evident from the composition of phytoplankton in the lakes depends on the environmental parameters. Canonical Correspondence Analysis (CCA) of the water quality parameters and phytoplankton genera indicated the influence of water quality on phytoplankton composition *in monitored lakes of Bangalore. A reduction in phytoplankton diversity is attributed to a decline in the water quality of lakes with increased water pollution. The phytoplankton serves as excellent bioindicators as it responds to environmental stress. Hence, phytoplanktons are being used in the biomonitoring programs of lakes.*

***Keywords**: Phytoplankton, Lakes, Water quality, Cyanophyceae, Biomonitoring.*

Introduction

Wetlands play a vital role in providing food and fiber, microclimate regulation, water purification, groundwater recharge, flood protection, erosion prevention, biodiversity conservation, recreation, *etc.* (Ramachandra *et al.,* 2020a; Li *et al.,* 2020). Sustaining these services entails maintaining the ecological integrity of wetlands through regular monitoring of wetlands, which involves assessing the physical, chemical, and biological characteristics (Alves *et al.,* 2018). The spatial and temporal variations in the water quality of freshwater ecosystems are associated with several natural factors and anthropogenic factors (Varol, 2020; Shil *et al.,* 2019). The land use land cover [LULC] of a region influences water quality (Chen and Lu, 2014; Xu *et al.,* 2019). Anthropogenic activities cause water quality deterioration and render the water unfit for drinking, domestic purpose, irrigation, industrial and recreational use. Unplanned rapid urbanization and the consequent disposal of untreated or partially treated wastewater have been deteriorating water resources (Ramachandra *et al.,* 2020b).

Phytoplankton (microalgae) are ubiquitous photosynthetic organisms that occur in water bodies. Phytoplanktons as producers play a key role in nutrient cycling and transformations and the productivity of aquatic ecosystems. Phytoplanktons consist of both eukaryotic (green algae, diatoms, *etc.*) and prokaryotic forms (cyanobacteria). Algae provide food (energy transfer) and dissolved oxygen for consumers at higher trophic levels in an aquatic ecosystem. Phytoplankton has a plethora of applications such as pharmaceuticals, nutraceuticals, feed, and aid in bioremediation. For the past few decades, microalgae have been explored for biofuel production, electricity generation, wastewater treatment, greenhouse gas mitigation, and CO_2 removal (Das *et al.,* 2021; Qu *et al.,* 2019; Xu *et al.,* 2015). The influence of physico-chemical characteristics of water on the phytoplankton density and diversity is demonstrated in numerous studies (Kozak *et al.,* 2020; Afonina and Tashlykova, 2018; Sharma *et al.,* 2016). The distribution and composition of phytoplankton in lakes or wetlands are influenced by factors such as temperature, light, nutrients, water level, and grazing pressure. Land use and land cover (LULC) changesin the wetland catchment altered the physical,chemical, and biological parameters (Ramachandra *et al.,* 2013).Water level fluctuations and turbulence induce disturbances in the physical environment and concentration of nutrients (Adamczuk *et al.,* 2020), altering phytoplankton communities structure (Ji *et al.,* 2017; Yang *et al.,* 2016; Zhao *et al.,* 2020). The sustained inflow of untreated wastewater to waterbodies enhances the nutrient concentration in water leading to eutrophication, which increases the phytoplankton biomass, and it reduces the nutritional value, affecting higher trophic level organisms (Taipale *et al.,* 2019).Multivariate analyses using canonical correspondence analysis (CCA)have established the relationships between phytoplankton taxa and environmental variables (Fetahi *et al.,* 2014; Abd El-Karim, 2014, Tian *et al.,* 2012).

Phytoplankton serves as a valuable bioindicator of water quality changes as they have a short lifespan and respond quickly to environmental changes and pollutants (El-Kassas and Gharib, 2016; Kireta *et al.,* 2012; Lavoie *et al.,* 2012). The species number and cell density of phytoplankton serve as bioindicators of water quality. Monitoring these bioindicators and the physical and chemical factors help in overall water quality assessment (Jiang *et al.,* 2014).Objectives of this study are to (i) assess the water quality of lakes in Vrishabhavathi valley in Greater Bangalore, Karnataka;(ii) record the phytoplankton composition of lakes; (iii) evaluate the role of environmental variables in phytoplankton community structure using multivariate statistical analysis (canonical correspondence analysis, CCA) and (iv) biomonitoring of lakes by determining the Palmer algal genera pollution index.

Materials and Methods

Study Area: Select Lakes in Vrishabhavathi Valley (V Valley), Greater Bangalore

Greater Bangalore (12°49’5’’N to 13°08’32”N latitude and 77°27’29”E to 77°47’2”E longitude), covers an area of 741 square kilometers. The district is located at an altitude of 920 m above mean sea level, delineating three watersheds, namely Koramangala and Challaghatta Valley (K and C Valley), Vrishabhavathi Valley (V Valley), and Hebbal Valley (H Valley). Due to the undulating terrain, a large number of tanks were created by the earlier rulers in Bangalore that provide water for various uses like drinking, irrigation, washing,fishing, *etc.* The mean annual rainfall in Bangalore is 880 mm, with 60 rainy days a year over a decade. The summer temperature ranges from 18°C - 38°C while the winter temperature ranges from 12°C - 25°C (Ramachandra and Aithal, 2015).Vrishabhavathi valley has a catchment area of ~170 square kilometers that covers 97 wards of Bengaluru. Vrishabhavathi river had numerous interconnected lake systems such as Kempambudilake in Basavanagudi, Sankey lake in Sadashivnagar, Yediyurkerein Yediyur, *etc.* (Ramachandra *et al.,* 2017). The present study involves field survey, physico-chemical analysis, and recording phytoplankton diversity of 15lakes in Vrishabhavathi Valley (V Valley) of Greater Bangalore (Figure 10.1).

Water Quality Analyses of Lakes

Water samples were collected from 15 lakes in Vrishabhavathi valley for physico-chemical analysis during 2017 - 2018. The physico-chemical parameters analyzed include water temperature (WT), total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), pH, chloride (Cl), total alkalinity (TA),total

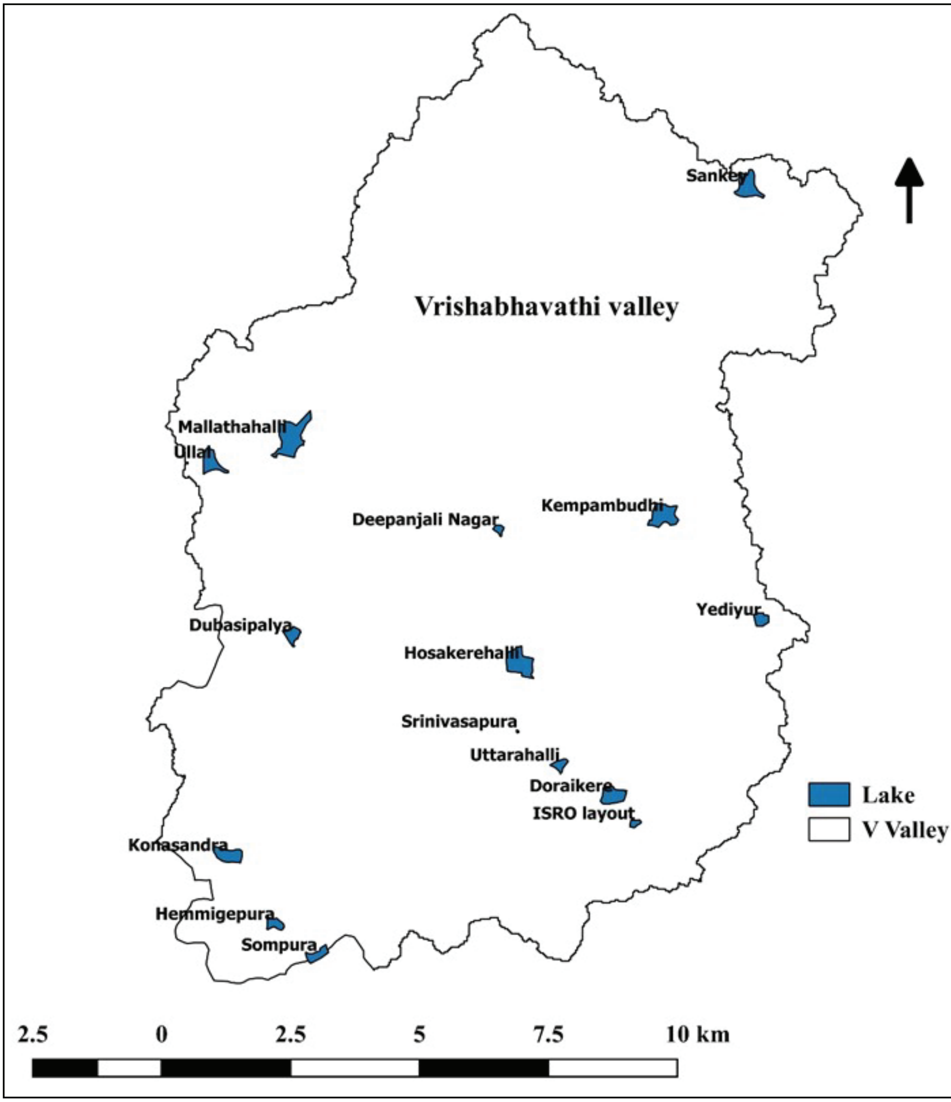

Figure 10.1: Lakes of Vrishabhavathi Valley, Greater Bangalore, Karnataka, India.

hardness (TH), calcium (Ca), magnesium (Mg), biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate (N) and ortho-phosphate (OP). The on site parameters include water temperature, pH, dissolved oxygen, total dissolved solids, and electrical conductivity measured using a portable meter (Extech). The turbidity was measured with a hand-held Turbidometer (Hach). The water samples collected from monitored lakes in clean and sterile polypropylene bottles were transported to the laboratory for further chemical and nutrient analysis using standard methods (APHA, 2005), and experiments were carried out in triplicates.

QGIS open-source GIS software was used for generating maps of various physico-chemical parameters of 15 lakes in the Vrishabhavathi valley of Greater Bangalore.

Phytoplankton Sampling and Analyses

Planktons were collected by filtering 50 liters of water from the lake surface using a plankton net. Phytoplankton samples were fixed with 4 per cent Lugol iodine solution and concentrated to 50 mL. Then, the samples were stored in labeled plastic bottles and transported to the laboratory for taxonomic analysis. Phytoplankton samples were identified according to the standard keys (Desikachary, 1959; Prescott, 1970; AlgaeBase, 2021)and enumerated with an optical microscope at 10 X and 40 X magnifications. Generally, three subsamples were counted for each lake sample. The maps depicting phytoplankton diversity of 15 lakes in Vrishabhavathi valley were created using QGIS open-source GIS software.

Data Analysis

Statistical analyses were carried out using PAST3 software. Pearson correlation analysis was carried out to evaluate the correlation between phytoplankton abundance and water quality parameters. Then, multivariate statistical analysis of the water quality data set and phytoplankton was performed through (CCA) to understand the relationship between water quality parameters and phytoplankton distribution as well as the composition of the monitored lakes. In this study, the Shannon-Wiener index, Simpson index, Pielou Evenness index, Berger and Parker index, Margalef Diversity index, and Menhinick index were used to evaluate the phytoplankton structure lakes. Various diversity measures such as the Shannon–Wiener index (H´), Evenness (J´), Simpson index (Ds), richness (S), and Berger and Parker index (Db) can be used to estimate the phytoplankton diversity (Zhang *et al.,* 2016).

Results and Discussion

Variations in Physico-chemical Parameters of Lakes

The lakes monitored in this study varied in their physico-chemical characteristics as these lakes receive untreated sewage or pollutants. An alteration of the physical, chemical, and biological properties of water happens due to pollution with the sustained inflow of untreated or partially treated wastewater from domestic and industrial sources (Udhayakumar *et al.,* 2016). The changes in water quality can alter phytoplankton community structure and distribution in lakes. The discussions on physico-chemical parameters analyzed are elaborated below:

Water Temperature and pH

Temperature strongly influences the chemical composition of cells, uptake of nutrients, uptake of carbon-dioxide, and growth rate of phytoplankton (Singh and Singh, 2015; Brönmark and Hansson, 2002). Water temperature varied between

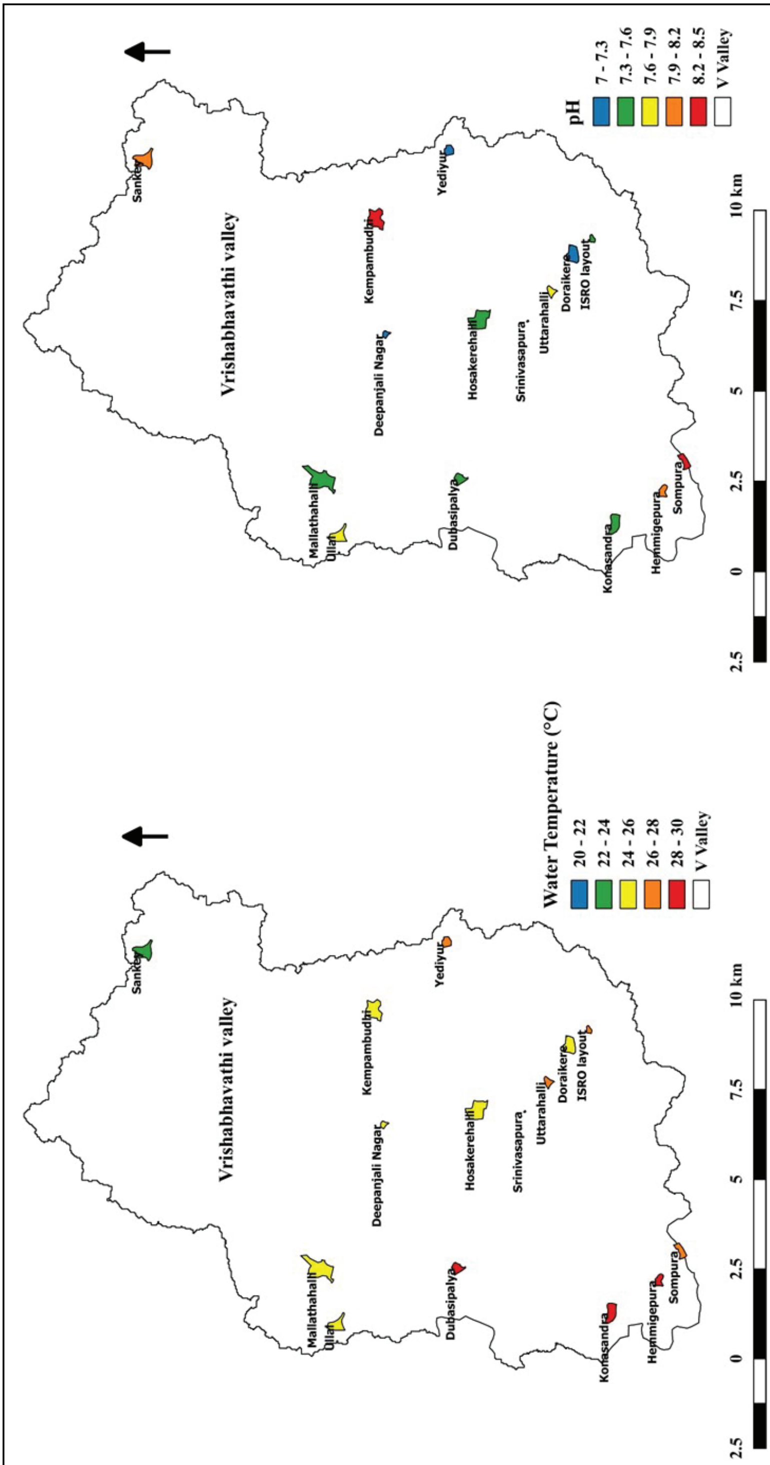

Figure 10.2: Variation of Water Temperature and pH in Lakes of Bangalore.

23.9 °C to 29.7 °C in monitored lakes during the current study (Figure 10.2). pH indicates hydrogen ion concentration in lake water (Kumar and Mahajan, 2020) and is generally governed by the equilibrium between carbon-dioxide, carbonate, and bicarbonate ions. Here, alkaline conditions prevailed in lakes, which ranged from 7.01 – 8.5. This range of pH is suitable for phytoplankton growth. During photosynthetic activity by phytoplankton, pH increases due to the consumption of carbon-dioxide.

Total Dissolved Solids (TDS) and Electrical Conductivity (EC)

The total dissolved solids (TDS) include inorganic salts and small amounts of organic matter in water. The concentration of total dissolved solids ranged from 152.5 mg/L to 883.42 mg/L in lakes (Figure 10.3). The variations in TDS occur naturally from rocks and soil as well as from anthropogenic sources through sewage, industrial effluent discharges, and urban run-off (Ntengwe, 2006). The conductivity is a measure of the capacity of water to conduct an electric current. The value of electrical conductivity ranged from 306.67 µS/cm to 1303.67 µS/cm (Figure 10.3). EC depends on the type, quantity, and ionic state of dissolved substances (electrolytes), thus, indicates the mineral content of water (Le *et al.,* 2017). Mallathahalli lake had the highest level of TDS and EC, hence shows ionic pollution.

Total Hardness, Calcium, and Magnesium

Hard water is not suitable for domestic and industrial purposes. The cations that impart total hardness to water are calcium, magnesium, iron, strontium, and manganese. The total hardness, calcium, and magnesium varied among sampled lakes and ranged from 78.67 mg/L- 463.5 mg/L, 23.51 mg/L - 117.9 mg/L, and 4.85 mg/L - 41.09 mg/L,respectively (Figure 10.4). Mallathahalli lake had the highest levels of total hardness, calcium, and magnesium, which indicates ionic pollution.

Total Alkalinity and Chloride

Total alkalinity is determined by the concentration of hydroxide, carbonate, and bicarbonate in water. Thus, total alkalinity influences the composition and abundance of phytoplankton (Bose *et al.,* 2019).

Mallathahalli lake receives a lot of untreated domestic and industrial sewage, so profuse growth of phytoplankton was observed that increased the alkalinity of lake water. In addition, the discharge of domestic and industrial wastes increases chloride levels in lake water. The concentration of total alkalinity and chloride in lakes ranged from 81.33 mg/L - 684.33mg/L and 26.74 mg/L - 305.89 mg/L, respectively (Figure 10.5).

Turbidity and Dissolved Oxygen (DO)

Turbidity in water occurs mainly due to particles of clay, silt, organic particles, inorganic matter, micro-organisms, and algae bloom. The range of turbidity in monitored lakes was found as 5.77 NTU - 103.51 NTU (Figure 10.6). Under

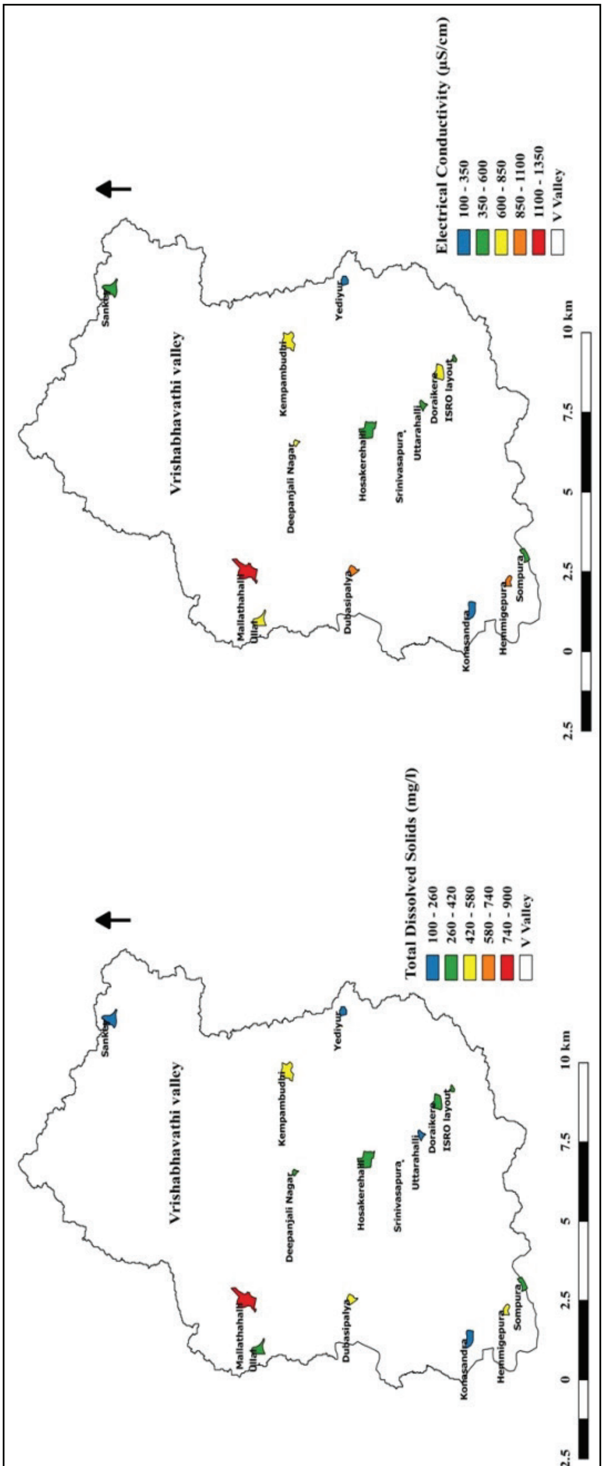

Figure 10.3: Level of Total Dissolved Solids and Electrical Conductivity in Lakes.

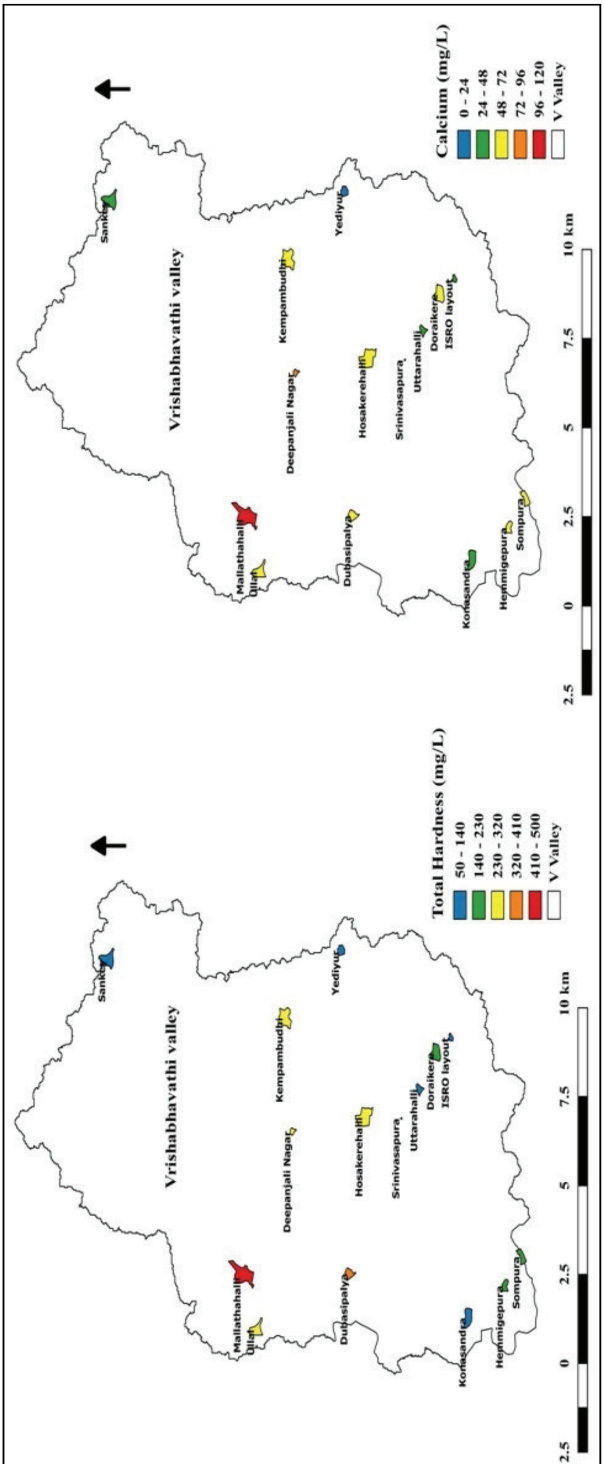

Figure 10.4: Concentration of Total Hardness and Calciumin Lakes.

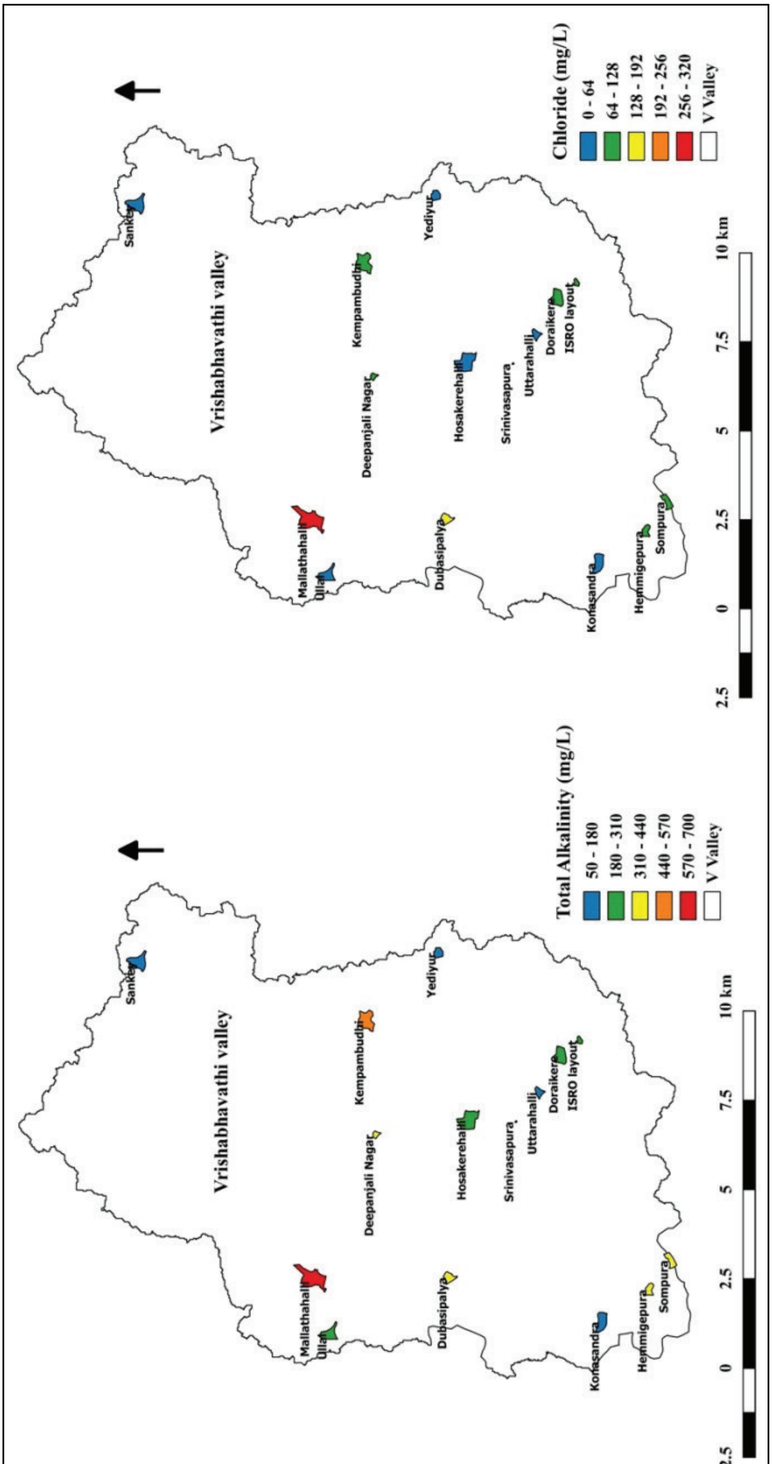

Figure 10.5: Concentration of Total Alkalinity and Chloride in Lakes.

turbid conditions, only less light can penetrate through the water column to the lake bottom. This results in inhibition of the growth of phytoplankton and lower photosynthetic activity (Yang *et al.,* 2012). This may, in turn, decrease the dissolved oxygen level in lake water. The dissolved oxygen levels in lakes ranged from 0.81 mg/L - 9.84 mg/L (Figure 10.6). Dissolved oxygen affects the various physico-chemical attributes and biological processes in lake water (Ramachandra *et al.,* 2014).

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

Biochemical oxygen demand (BOD) determines the amount of oxygen required by aerobic micro-organisms to stabilize the organic matter (Avvannavar and Shrihari, 2008). High COD concentrations indicate pollution related to untreated domestic sewage and industrial effluents. The BOD and COD of monitored lakes ranged between 12.2 mg/L - 60.97 mg/L and 21.33 mg/L - 128 mg/L, respectively (Figure 10.7). The higher levels of BOD and COD show the level of pollution, which will increase the oxygen demand in lakes. Among the sampled lakes, Kempambudhi lake had more elevated BOD and COD, indicating organic pollution.

Nitrate and Ortho-phosphate

Nutrients such as nitrogen and phosphorus are the limiting factors for phytoplankton growth. In the present study, nitrate and ortho-phosphate ranged between 0.01 mg/L - 3.1 mg/L and 0.077 mg/L - 3.701 mg/L, respectively (Figure 10.8). The excessive amount of nitrogen and phosphorus can stimulate eutrophic conditions (He *et al.,* 2011). The discharge of phosphorus into aquatic ecosystems results in eutrophication, whichhas enhanced the overgrowth of algae and macrophytes (Çelekli and Sahin, 2021). Kempambudhi lake was found to be rich in nitrate and ortho-phosphate (OP), which indicates nutrient pollution.

The study reveals that (i) Mallathahalli lake had higher levels of TDS, EC, total hardness, calcium, magnesium, chloride, total alkalinity, (ii) Kempambudhi lake with high pH, BOD, COD, and OP show organic and nutrient pollution, and (iii)Yediyur lake had less ionic contents such as TDS, total hardness, calcium, magnesium, and COD. Thus, the monitored lakes are polluted as they receive untreated domestic waste, agricultural residues, and industrial effluents. This may threaten biodiversity, reduce the aesthetic and recreational value of lakes.

Phytoplankton Community in Lakes

The present study covers 15 lakes in Vrishabhavathi valley of Bangalore, which recorded a total of 58 genera of phytoplankton belonging to 5 phyla, 9 class, 24 orders, and 41 families were identified (Figure 10.9). The fifty-eight species of phytoplankton were represented by five major groups, namely, Chlorophyta (25 species), Bacillariophyta (12 species), Cyanobacteria (12 species), Charophyta (5 species), and Euglenozoa (4 species).

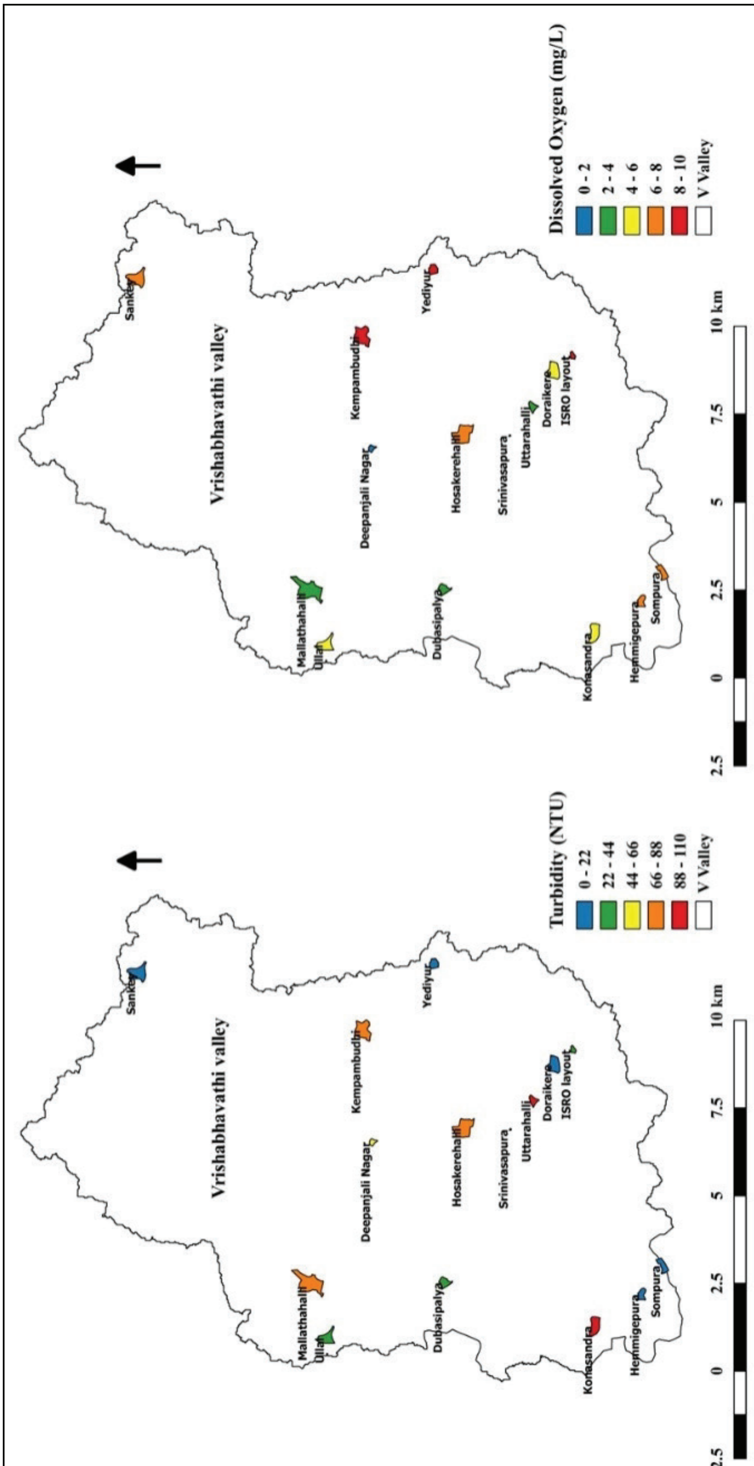

Figure 10.6: Turbidity and Dissolved Oxygen Levels in Lakes.

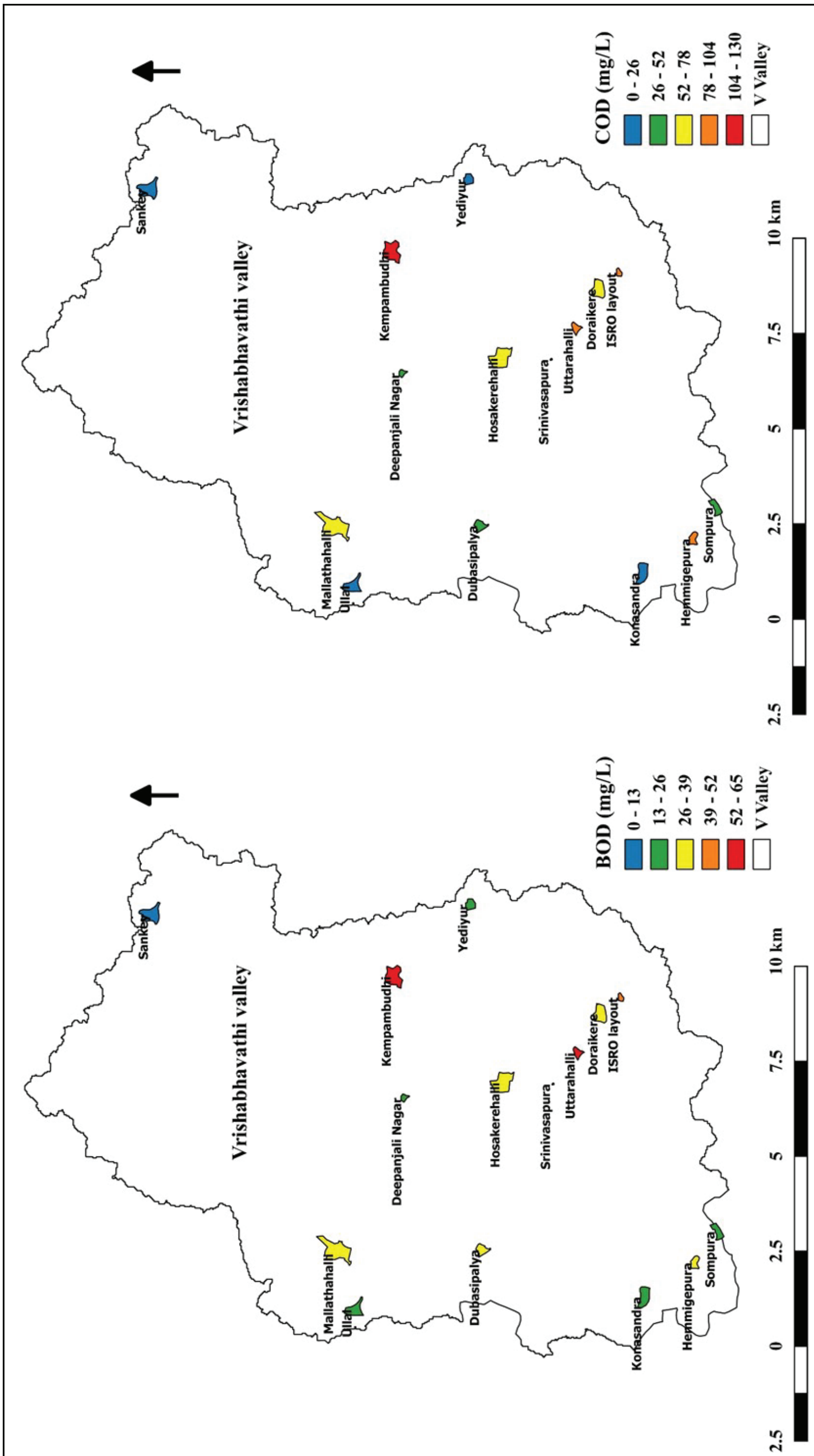

Figure 10.7: Variation of BOD and COD in Lakes.

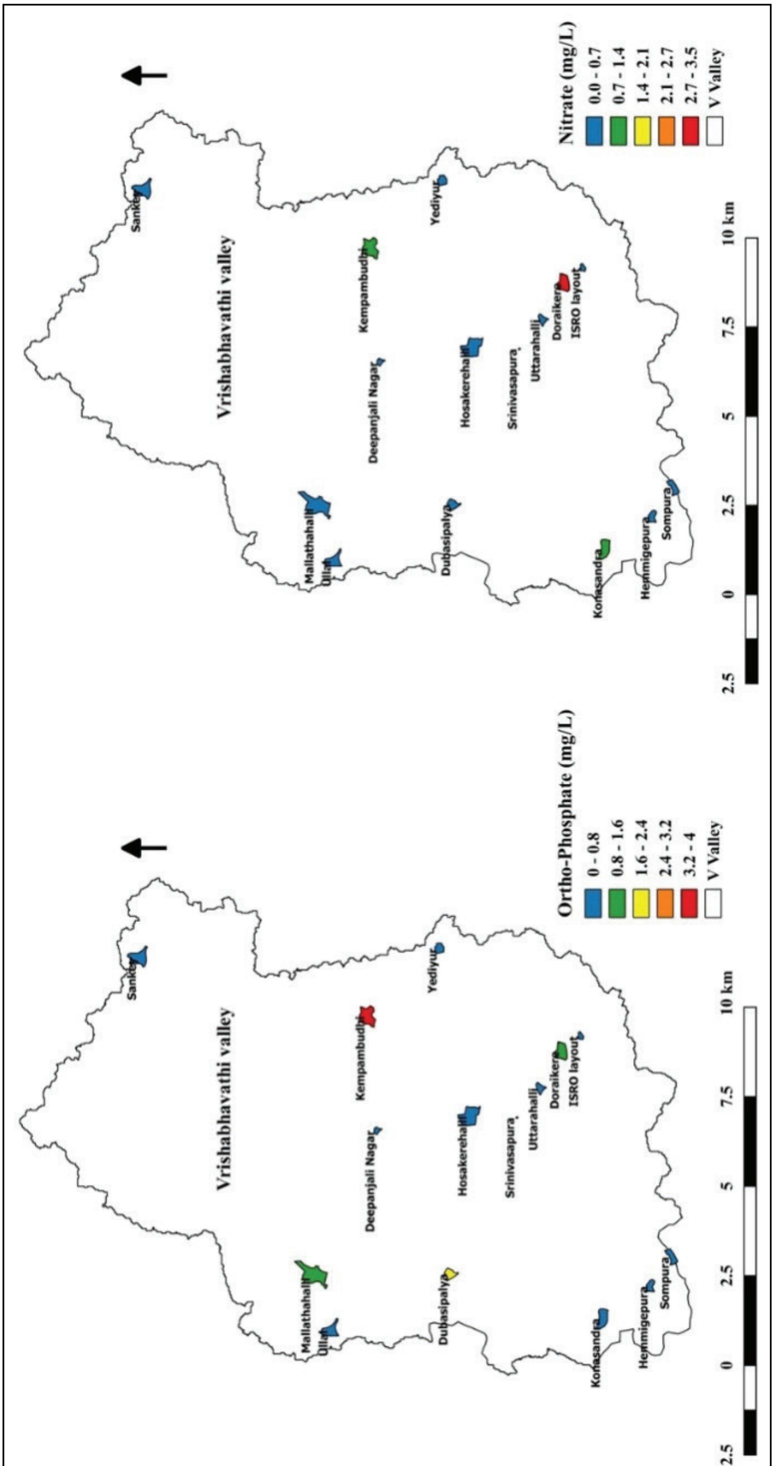

Figure 10.8: Concentration of Nitrate and Ortho-phosphate in Lakes.

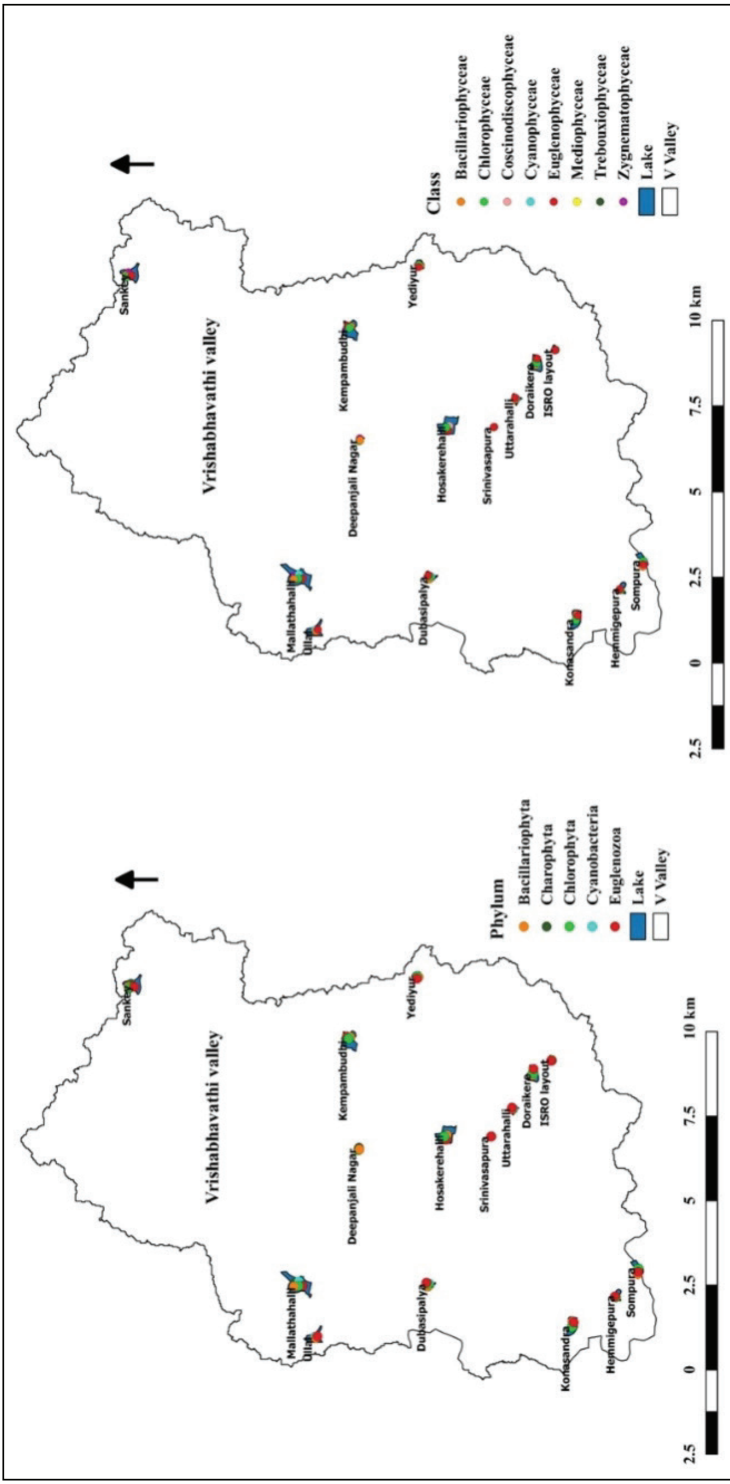

Figure 10.9: Phytoplankton Composition (Phylum and Class) in Lakes of Bangalore.

Cyanobacteria, commonly known as blue-green algae, are photosynthetic prokaryotes that form algal blooms in water (Elliott, 2012). Cyanobacteria are represented by species such as *Anabaena* sp., *Aphanocapsa* sp., *Chroococcus* sp., *Coelosphaerium* sp., *Cylindrospermopsis* sp., *Gloeocapsa* sp., *Merismopedia* sp., *Microcystis* sp., *Oscillatoria* sp., *Phormidium* sp., *Planktothrix* sp. and *Spirulina* sp. Cyanobacteria, mainly *Microcystis* sp.was dominant and formed surface blooms in Doraikere, Uttarahalli, ISRO layout, and Yediyur lakes in Vrishabhavathi valley, Greater Bangalore, Karnataka (Figure 10.10). A total of 25 species of Chlorophyta was recorded in this study, such as *Actinastrum* sp., *Ankistrodesmus* sp., *Asterococcus* sp., *Botryococcus* sp., *Chlamydomonas* sp., *Chlorella* sp., *Chlorococcum* sp., *Coelastrum* sp., *Crucigenia* sp., *Desmodesmus* sp., *Dictyosphaerium* sp., *Golenkinia* sp., *Kirchneriella* sp., *Micractinium* sp., *Monoraphidium* sp., *Oocystis* sp., *Pandorina* sp., *Pediastrum* sp., *Scenedesmus* spp., *Schroederia* sp., *Stichococcus* sp., *Stigeoclonium* sp., *Tetraedron* sp. and *Tetrastrum* sp. Both pennate and centric forms of Bacillariophyta (or diatoms) are present lakes inVrishabhavathi valley, Bangalore.*Achnanthes* sp., *Amphora* sp., *Cyclotella* sp., *Fragilaria* sp., *Gomphonema* sp., *Melosira* sp., *Navicula* sp., *Nitzschia* sp., *Pinnularia* sp., *Stauroneis* sp., *Surirella* sp. and *Synedra* sp. belonging to Bacillariophyta was recorded.

A total of four species under Charophyta were recorded, such as *Closterium* sp., *Cosmarium* sp., *Euastrum* sp., *Spirogyra* sp. and *Staurastrum* sp. in the present investigation. Euglenozoa is represented by species such as *Euglena* spp., *Lepocinclis* sp., *Phacus* sp. and *Trachelomonas* sp. *Euglena* sp. is mixotrophic algae, which can grow faster in wastewater because they can utilize organic matter as an energy source (Mahapatra *et al.,* 2013).

Diversity Indices

Various diversity measures were used to estimate the phytoplankton diversity of lakes in Vrishabhavathi valley, Bangalore. Shannon-Wiener index ranged from 0.16 -2.54. Shannon and Wiener index value of 0.0-1.0 indicates heavy pollution, 1.0-2.0 indicates moderate pollution, 2.0-3.0 indicates light pollution, and 3.0-4.5 indicates slight pollution. The species diversity indices decrease in polluted waters (Shanthala *et al.,* 2009). Thus, Doraikere (2.54) is heavily polluted with less species diversity. Simpson index ranged from 0.045 (Doraikere) -0.882 (Sompura, Mallathahalli). Pielou evenness index reveals an even distribution of individuals among varied species (Miao *et al.,* 2019). The evenness index ranges from near 0 (low evenness) to 1 (dominance). Evenness index ranged from 0.07 (Uttarahalli) – 0.80 (Deepanjali Nagar, Srinivasapura). Menhinick index ranged from 0.26 (Doraikere) – 1.59 (Hemmigepura) in this study. Margalef species richness index measures the number of different species in each sample (Ray *et al.,* 2021). Margalef index ranged from 0.72 – 4.77 as Dubasipalya lake has the highest taxa whereas Srinivasapura has the lowest taxa and individuals. A high value of richness index indicates healthy status, while a low value indicates the unhealthy and contaminated status (Hussien and Zaghloul, 2017). The Berger-Parker index gives the measure

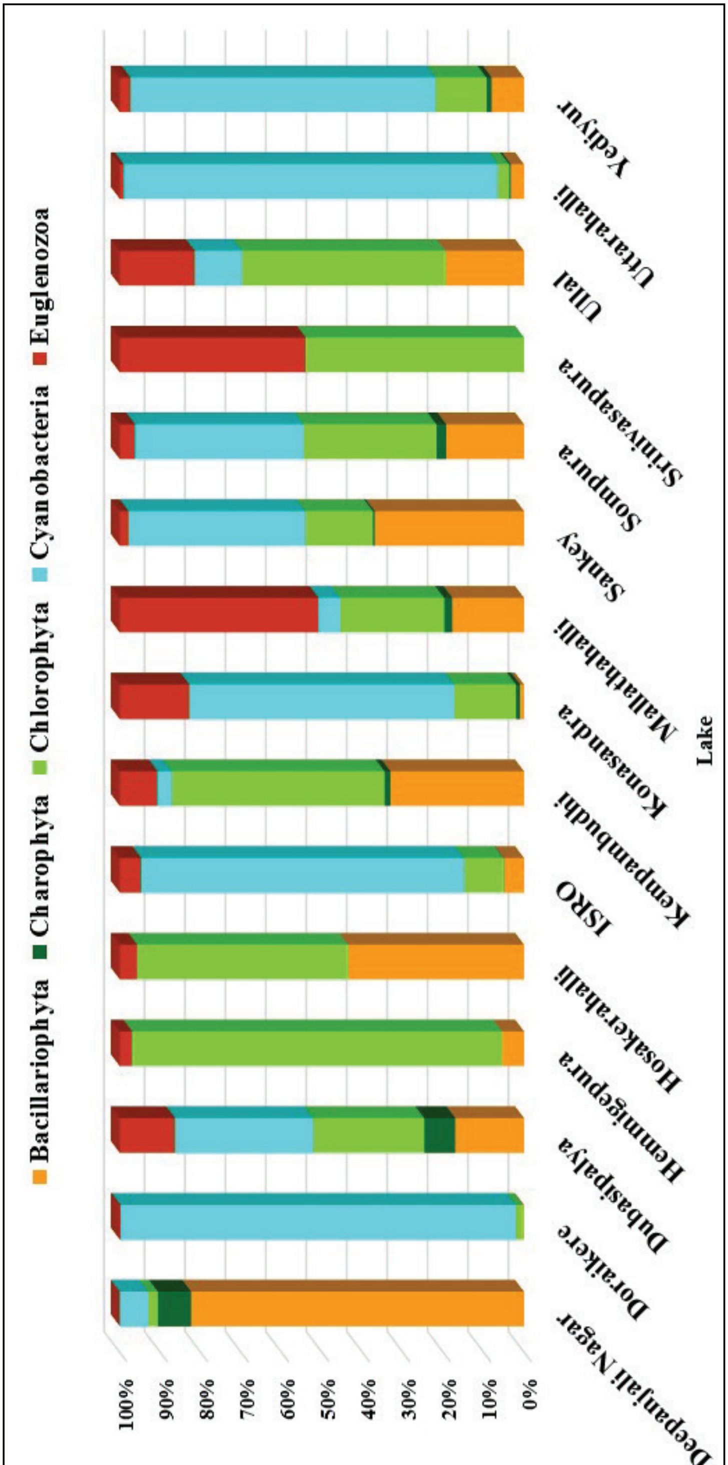

Figure 10.10: Phytoplankton Composition in Lakes of Bangalore.

of the most abundant species (Berger and Parker, 1970). Berger-Parker index in this study ranged from 0.21 (Deepanjali Nagar) -0.98 (Doraikere).

Correlation between Water Quality Parameters and Phytoplankton

Pearson correlation analysis is used to measure the interrelation and extent of associations among the water quality parameters and algal phyla. Bacillariophyta negatively correlated with BOD (r = -0.31) and COD (r = -0.38). Bacillariophyta responds rapidly to organic and nutrient contamination (Saxena *et al.,* 2020). Charophyta positively correlated with water temperature (r = 0.41), electrical conductivity (r = 0.36), magnesium (r = 0.40), ortho-phosphate (r = 0.31) and Bacillariophyta (r = 0.57). Chlorophyta positively correlated with water temperature (r = 0.38), Charophyta (r = 0.68) and Bacillariophyta (r = 0.90). A positive correlation was found between temperature and phytoplankton such as Charophyta and Chlorophyta (Gogoi *et al.,* 2019) as temperature plays an important role in growth and reproduction of phytoplankton. Cyanobacteria negatively correlated with pH (r = -0.45), total hardness (r = -0.44), calcium (r = -0.39), magnesium (r= -0.46), total alkalinity (r = -0.49) and positively correlated with nitrate (r = 0.63). A similar pattern of positive correlation recorded between Cyanophytes with nitrate, and inverse correlation with alkalinity, pH, total hardness, calcium and magnesium (Mishra *et al.,* 2019). In Baiyangdian lake, Cyanophyta and Chlorophyta became dominant because of increased organic matter from industrial wastewater and domestic sewage (Wang *et al.,* 2013). Euglenozoa positively correlated with TDS (r = 0.49), EC (r = 0.59), total hardness (r = 0.49), calcium (r = 0.36), magnesium (r = 0.61), chloride (r = 0.58), total alkalinity (r = 0.43), ortho-phosphate (r = 0.31), Bacillariophyta (r = 0.39), Charophyta (r = 0.79), Chlorophyta (r = 0.72) and negatively correlated with DO (r = -0.30). The dominance of Euglenophyta indicates organic pollution, water pollution, and eutrophic condition of water body (Shams and Shamsabadi, 2019).

Relationship between Phytoplankton Community and Physico-chemical Factors

Canonical correspondence analysis (CCA) was computed with phytoplankton composition data (58 genera), 15 physico-chemical parameters across 15 lakes during the study period to evaluate the role of environmental variables in structuring phytoplankton communities. For CCA, 15 physico-chemical parameters, namely: water temperature, pH, conductivity, total alkalinity, dissolved oxygen, nitrate, ortho-phosphate, turbidity, TDS, BOD, COD, chloride, calcium, magnesium, and total hardness,were selected. Different species of phytoplankton showed varied responses to physico-chemical parameters. The length of the arrow in CCA ordination indicates the relative importance of environmental variables. Eigenvalues of the first two axes are 0.58 and 0.48,which explain 34.97 per cent of the variance of phytoplankton and environmental data. Axis 1 has strong positive loadings of turbidity. Thus, *Spirulina* sp., *Actinastrum* sp., *Asterococcus* sp., *Micractinium* sp. and *Phacus* sp. are positively correlated with the turbidity. Turbidity of freshwater lakes increases due to the influx of urban run-off, silt, sand, and organic matter (Nandigam *et al.,* 2016). This decreases the phytoplankton diversity and increases the dominance of *Spirulina* sp. as in Konasandra lake.

Axis 2 has strong positive loadings of total hardness, calcium, magnesium, and total alkalinity. Total hardness, calcium, magnesium, and total alkalinity are found in lakes such as Deepanjali Nagar, Hemmigepura, Sompura, Kempambudhi, Srinivasapura, Ullal, Doraikere, Dubasipalya, Hosakerehalli, and Uttarahalli. Therefore, the growth of species such as *Anabaena* sp., *Chroococcus* sp., *Cymbella* sp., *Fragilaria* sp., *Gomphonema* sp., *Lepocinclis* sp., *Monoraphidium* sp., *Navicula* sp., *Oscillatoria* sp., *Pandorina* sp., *Phormidium* sp., *Pinnularia* sp., *Spirogyra* sp., *Stauroneis* sp., *Stichococcus* sp. and *Surirella* sp. are positively dependent on the parameters like total hardness, calcium, magnesium, and total alkalinity. Magnesium is crucial for chlorophyll synthesis and serves as a limiting factor for phytoplankton growth and reproduction (Narchonai *et al.,* 2019). The remaining species did not show a relation with the selected variables. Phytoplankton species such as *Amphora* sp., *Aphanocapsa* sp., *Botryococcus* sp., *Chlorococcum* sp., *Desmodesmus* sp., *Dictyosphaerium* sp., *Euastrum* sp., *Golenkinia* sp., *Kirchneriella* sp., *Melosira* sp., *Microcystis* sp., *Pediastrum* sp., *Planktothrix* sp., *Scenedesmus* spp., *Schroederia* sp., *Staurastrum* sp., *Stigeoclonium* sp., *Tetraedron* sp., *Tetrastrum* sp. and *Trachelomonas* sp. found nearer to the center of CCA ordination has a broad range of tolerance to the variations in physico-chemical parameters in lakes. *Anabaena* sp., *Merismopedia* sp., *Microcystis* sp. and *Oscillatoria* sp. indicate eutrophic lake conditions (Yilmaz *et al.,* 2018).

Palmer Index

The phytoplankton community composition alters quickly due to changes in the physico-chemical characteristics of water. For example, the presence of varied species of phytoplankton can indicate the quality of water. For example, Oscillatoria and Euglena are indicators of dirty water, while Pediastrum indicates clean water (Kantachote *et al.,* 2009). Thus,phytoplankton communities serve as indicators of pollution in an aquatic ecosystem. The Palmer index is a rapid, efficient, and cost-effective tool that reveals the water quality status or water pollution in freshwater bodies (Salem *et al.,* 2017). Palmer prepared a list of algal genera and species that are tolerant to varying levels of organic pollution (Vishal and Meeta, 2020). Palmer index accounts for the abundant pollution tolerant phytoplankton taxa and categorizes water bodies based on the pollution status. The palmer index value of 20 or more confirms high organic pollution. A value of 15-20 indicates probable organic pollution. The values between 10-15 and 0-10 show moderate pollution and lack of organic pollution, respectively (Jose and Kumar, 2011).

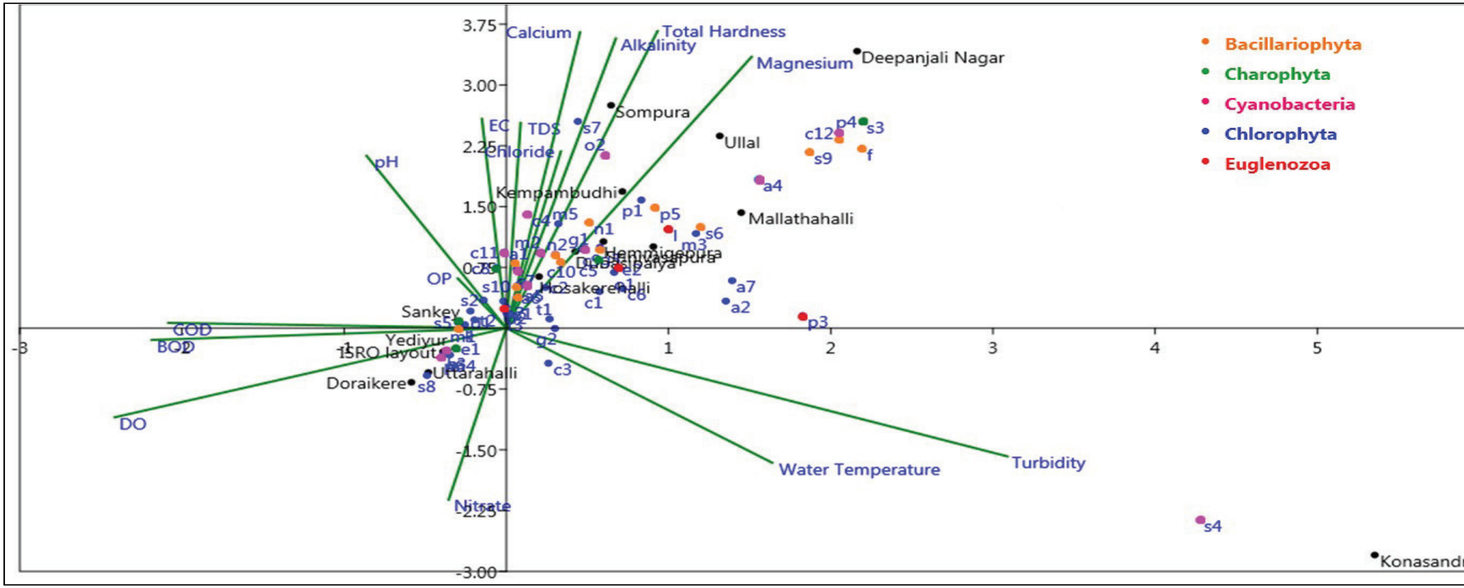

Figure 10.11: Canonical Correspondence Analysis (CCA) Ordination Diagram Showing Scatter Plot for Phytoplankton, Lakes and Physico-chemical Parameters (Arrows)

(Abbreviations: a1: *Achnanthes* sp.; a2: *Actinastrum* sp.; a3: *Amphora* sp.; a4: *Anabaena* sp.; a5: *Ankistrodesmus* sp.; a6: *Aphanocapsa* sp.; a7: *Asterococcus* sp.; b: *Botryococcus* sp.; c1: *Chlamydomonas* sp.; c2: *Chlorella* sp.; c3: *Chlorococcum* sp.; c4: *Chroococcus* sp.; c5: *Closterium* sp.; c6: *Coelastrum* sp.; c7: *Coelosphaerium* sp.; c8: *Cosmarium* sp.; c9: *Crucigenia* sp.; c10: *Cyclotella* sp.; c11: *Cylindrospermopsis* sp.; c12: *Cymbella* sp.; d1: *Desmodesmus* sp.; d2: *Dictyosphaerium* sp.; e1: *Euastrum* sp.; e2: *Euglena* spp.; f-*Fragilaria* sp.; g1: *Gloeocapsa* sp.; g2: *Golenkinia* sp.; g3: *Gomphonema* sp.; k: *Kirchneriella* sp.; l: *Lepocinclis* sp.; m1: *Melosira* sp.; m2: *Merismopedia* sp.; m3: *Micractinium* sp.; m4: *Microcystis* sp.; m5: *Monoraphidium* sp.; n1: *Navicula* sp.; n2: *Nitzschia* sp.; o1: *Oocystis* sp.; o2: *Oscillatoria* sp.;p1: *Pandorina* sp.; p2: *Pediastrum* sp.; p3: *Phacus* sp.; p4: *Phormidium* sp.; p5: *Pinnularia* sp.; p6: *Planktothrix* sp.; s1: *Scenedesmus* spp.; s2: *Schroederia* sp.; s3: *Spirogyra* sp.; s4: *Spirulina* sp.; s5: *Staurastrum* sp.; s6: *Stauroneis* sp.; s7: *Stichococcus*sp.; s8: *Stigeoclonium* sp.; s9: *Surirella* sp.; s10- *Synedra* sp.; t1: *Tetraedron* sp.; t2: *Tetrastrum* sp. and t3: *Trachelomonas* sp.).

According to Palmer index (Table 10.1), Doraikere, Deepanjali Nagar, Srinivasapura, Hosakerahalli lakes had moderate pollution as the Palmer index for these lakes was 10 -15.On the other hand, lakes such as ISRO Layout, Uttarahalli, Sankey, Yediyur, Sompura, Ullal, Hemmigepura, Konasandra, Dubasipalya, Mallathahalli, and Kempambudhi had high organic pollution (with Palmer index of 20 or more) in the present study. The dominance of species such as Chlorella, Oscillatoria, Pediastrum, Scenedesmus, Nitzschia, Melosira, Gomphonema, Navicula, Euglena, *etc.*, indicates of organic pollution in water bodies (Kshirsagar, 2013; Parvez *et al.,* 2019). The Palmer algal genera pollution index was in the range of 15 -24 in Vaigai river in Madurai (Noel and Rajan, 2015), while 5 - 28.6 in Chulband River in Maharashtra,which indicate organic pollution (Shahare, 2017). Palmer pollution index revealed that Sidi Abderrahmane is an oligotrophic or mesotrophic reservoir (Belokda *et al.,* 2019). Any alteration in the water quality of the aquatic ecosystem will alter the phytoplankton community structure. Only pollution tolerant species can thrive well in polluted waters, whereas sensitive species disappear, as they cannot survive in polluted water. Thus, phytoplankton serves as a bioindicator for assessing the extent of pollution of water bodies (Abdulwahid, 2016).

Table 10.1: Palmer Pollution Index of Lakes Based on algal genus

Lake	*Index Level*	*Remark*
ISRO	21	High organic pollution
Uttarahalli	27	High organic pollution
Sankey	25	High organic pollution
Yediyur	20	High organic pollution
Doraikere	14	Moderate pollution
Sompura	35	High organic pollution
Ullal	35	High organic pollution
Hemmigepura	26	High organic pollution
Konasandra	30	High organic pollution
Dubasipalya	39	High organic pollution
Mallathahalli	23	High organic pollution
Deepanjali Nagar	10	Moderate pollution
Srinivasapura	10	Moderate pollution
Hosakerehalli	12	Moderate pollution
Kempambudhi	25	High organic pollution

The physico-chemical parameters are the major factors controlling the structure and composition of phytoplankton in freshwater ecosystems. Phytoplanktons are an important component of an aquatic ecosystem and are responsible for primary productivity. The development of phytoplankton was favored by higher concentrations of nutrients and organic matter (Devercelli and

O'Farrell, 2013). Water quality parameters such as temperature, pH, DO, EC, BOD, COD, phosphate, and nitrate influenced phytoplankton species composition and distribution (Cheraghpour *et al.,* 2013). Phytoplankton grows well in nutrient-rich water and removes BOD, COD, and nutrients while providing oxygen to other aquatic organisms (Kiran *et al.,* 2016). The abundance of *Chlamydomonas* sp., *Cyclotella* sp. and Euglenophyta indicates the excessive availability of N and P as these species are organic-tolerant (Ghobara and Salem, 2017). Domestic sewage rich in sodium triphosphate (a component in synthetic detergents) can stimulate the growth and proliferation of *Chlorella vulgaris* (Marchello *et al.,* 2015). *Cyclotella meneghiniana*is an indicator of organic pollution (Krupa *et al.,* 2016). *Euglena* sp. is a biological indicator of high organic pollution (Mahapatra *et al.,* 2011). A shift in phytoplankton composition towards bloom-forming cyanobacteria occurs due to excess phosphorus loading (Lv *et al.,* 2011).

Cyanobacteria were found to be dominant in lakes of Vrishabhavathi valley, Bangalore. *Microcystis* sp. belonging to Cyanobacteria formed surface blooms in Doraikere, Uttarahalli, ISRO layout, and Yediyur lakes. Microcystis can tolerate high temperatures and hence survive well in warm, shallow, and eutrophic environments (Ke *et al.,* 2008). They form blooms in water bodies due to the buoyant nature imparted by the gas vacuoles (Muthukumar *et al.,* 2007). The surface blooms of *Microcystis* sp. will decrease the water transparency as well as light irradiation to bottom layers, which in turn inhibits the growth of benthic algae (Su *et al.,* 2014; Teta *et al.,* 2017). Harmful algal blooms (HABs) forms surface scum, induce hypoxia, alter the food web, and produce toxins thus, threatens ecosystem and human health (Fang *et al.,* 2019; Lu *et al.,* 2013; Catherine *et al.,* 2013). Excessive phytoplankton growth eventually causes depletion of dissolved oxygen (DO) and kills fish as well as other aquatic life. Cyanobacteria produce toxic secondary metabolites called cyanotoxins, such as hepatotoxins, dermatotoxins, neurotoxins, and cytotoxins (Du *et al.,* 2019; Beaver *et al.,* 2018). These cyanotoxins differ in their chemical structure and toxicology (Merel *et al.,* 2013). The hepatotoxic microcystins (MCs) produced by *Microcystis* sp. blooms at higher water temperature, pH, and dissolved oxygen (Wu *et al.,* 2014). Generally, species under Cyanophyceae are resistant to inorganic pollution, organic pollution, untreated effluents, and anaerobiosis (Marchello *et al.,* 2015). In Dongping lake, temperature and chemical oxygen demand (COD) are the main drivers of the cyanobacterial community composition (Lu *et al.,* 2013). Cyanobacteria biomass increased with a rise in total phosphorus concentration (Yang *et al.,* 2016). *Microcystis aeruginosa*, *Spirulina* sp., and *Oscillatoria* sp. are bioindicators of eutrophic conditions (Wijeyaratne and Nanayakkara, 2020). The cyanobacterial dominance was influenced by rainfall, flow, water temperature, EC, DO, pH, total nitrogen, nitrate, ammonia, total phosphorus, ortho-phosphate, chlorophyll–a, BOD, COD, total organic carbon, iron, and silicon dioxide content (Kim *et al.,* 2019). Cyanophyta grows faster under conditions such as increased temperature, salinity, and light intensity with less water turbulence (Kouhanestani *et al.,* 2019).

Water quality monitoring and management of lakes at regular time intervals are compulsory to control water pollution and deterioration of freshwater ecosystems. The integration of wastewater treatment plants with constructed wetlands and algal pond helps in efficient nutrient removal from urban lakes (Ramachandra *et al.,* 2018). The periodic monitoring of lakes will also aid in bloom management. It is necessary to control the levels of nutrients, dissolved oxygen, and organic matter content of water bodies to prevent algal blooms (Chen *et al.,* 2018). Aeration of water bodies will increase the dissolved oxygen levels and reduce bloom formation tendency (Ramachandra *et al.,* 2015). A ban on the use of phosphate-containing detergents and improved wastewater treatment can reduce the phosphorus (P) loads in lakes. Reductions in nutrient (N and P) input are requisite for effective long-term control of cyanobacterial algal blooms (Paerl *et al.,* 2011). The increasing water pollution and harmful cyanobacterial algal blooms due to nutrient enrichment in lakes pose a severe threat to freshwater resources and biodiversity.

Conclusion

The water quality parameters play a decisive role in the structure and composition of phytoplankton in aquatic ecosystems. The water quality and phytoplankton community structure varied among the monitored 15 lakes of Vrishabhavathi valley, Greater Bangalore, Karnataka. Mallathahalli lake had higher levels of ionic pollution, while Kempambudhi lake showed higher levels of organic and nutrient pollution. A total of 58 genera of phytoplankton belonging to 5 phyla such as Chlorophyta, Bacillariophyta, Cyanobacteria, Charophyta, and Euglenozoa were recorded in the monitored 15 lakes. Cyanobacteria formed blooms in Doraikere Uttarahalli, ISRO layout, and Yediyur lakes in Vrishabhavathi valley, threatening aquatic life. CCA results revealed that turbidity, total hardness, calcium, magnesium, and alkalinity influences phytoplankton community structure and composition. Palmer index revealed that Doraikere, Deepanjali Nagar, Srinivasapura, and Hosakerehalli lakes had moderate pollution. In contrast, ISRO, Uttarahalli, Sankey, Yediyur, Sompura, Ullal, Hemmigepura, Konasandra, Dubasipalya, Mallathahalli, and Kempambudhi lakes had high organic pollution. Hence, phytoplanktons are helpful as bioindicators of water quality and aid asa low-cost tool for monitoring lakes. This study will serve as a baseline for wetland protection and biodiversity conservation and help various stakeholders decide to control pollution from domestic and industrial sources.

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BIODIVERSITY CHALLENGES

A Way Forward

The present book explores the new ideas, overall up-to-date overview of the biological diversity, and outcome of Biodiversity challenges and measures comprising many interesting chapters focusing on the different aspects of biodiversity. The Most chapters compile the findings of investigations and observations on biodiversity, while a few chapters relay on statistically and theoretically derived information. It is a comprehensive review across the recently emerged research endeavors in areas of biodiversity as it is highly interdisciplinary, predicated as it is on the basis that biodiversity and the health of the planet are related indistinguishably. It generates adequate knowledge on the existence, organization and classification of flora and fauna with environmental estimates from a wide variety of interesting terrestrial and aquatic habitats. With 16 engrossing and detailed chapters, Biodiversity and Conservation deals with general to specific aspects of the discipline in its own way. Conservation of the biodiversity is necessarily an umbrella term for traditional species, linkage to human health, ecosystem conservation and the need to manage the human use of the species and ecosystems in a sustainable way. The book gives detailed information, it is hoped that this book will serve the purpose of students whose curricula include biodiversity and its conversation, it forms an ideal source of scientific information to the advanced students, junior researchers, scientists related to this field. I would recommend biodiversity and conservation students to read this book because it shows how our understanding of the complexities and interaction of the natural world help us to live better life naturally.

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