FRESHWATER ALGAL STUDIES IN WAYANAD DISTRICT

Thesis Submitted to the University of Calicut

in partial fulfilment of the requirements

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DOCTOR OF PHILOSOPHY

in

BOTANY

under the faculty of Science

by

DHANYA JOSE

under the guidance of

Dr. Ignatius Antony (Guide)

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RESEARCH AND POSTGRADUATE

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This is to certify that this is the revised version of the thesis entitled "FRESHWATER ALGAL STUDIES IN WAYANAD DISTRICT" submitted by **Ms. Dhanya Jose** under my guidance after incorporating the necessary corrections or suggestions made by the adjudicators. The content of the CD is the same as in the hard copy.

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DECLARATION

I hereby declare that the work presented in the thesis entitled **"FRESHWATER ALGAL STUDIES IN WAYANAD DISTRICT"** is based on the original work done by me under the guidance of Dr. Ignatius Antony, Principal & Associate professor (Retd.), Department of Botany, St. Thomas College (Autonomous), Thrissur and the Co-guidance of Dr. Anto P. V, Associate professor, Department of Botany, St. Thomas College (Autonomous), Thrissur and has not been included in any other thesis submitted previously for the award of any degree. The contents of the thesis are undergone plagiarism check using iThenticate software at C.H.M.K. Library, University of Calicut, and the similarity index found within permissible limit. I also declare that the thesis is free from AI generated contents.

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Dedicated to my beloved parents

PREFACE

Freshwater serves as blood of society and freshwater bodies should be preserved and prevented from contamination as this resource have excess demand and scarce supply. Even though, freshwater bodies are easily getting polluted and degraded because of inadequate monitoring and maintenance. Eventually, freshwater species are becoming more threatened than those in other biomes. Biodiversity hotspot like Western Ghats possess unique freshwater bodies with rich and endemic species. Idukki and Wayanad are the two districts that are at high altitude and are part of Western Ghats in Kerala. They have suitable climate and have enormous plant wealth. Regardless of this expected diversity, algae of Wayanad are not yet explored. Most of the area of the district is under forest and is the last remaining true wilderness of nature. The district is prone to landslides and floods due to its steep slopes. The fragile ecosystem of Wayanad demands more attention to safeguard its distinctiveness. Lower forms like algae are often neglected in the assessment of plant diversity and seen deficient in data. The documentation of this diverse and highly sensitive organisms helps in understanding our waterbodies. Numerous applications of algae have made their taxonomical studies inevitable to prevent misidentification and improper usage. Algae can portray the nature of a waterbody as they are susceptible to slightest change in water chemistry. Thus, they are unique and vary with different seasons and sites. Algae is used for biomonitoring pollution because of this aspect.

This study is an exploration of freshwater algae of Wayanad district of Kerala which is part of Western Ghats. The taxonomy and diversity of algae is discussed along with physicochemical parameters that influence their growth. Admitting their specificity, seasonal and spatial variation of algae in study area is examined. The pollution status of waterbodies was also assessed using algae.

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LIST OF ABBREVIATIONS USED

˚C	Degree Celsius
˚N	Degree North
˚E	Degree East
%	Percentage
µm	Micrometre
m	Metre
mm	Millimetre
cm	Centimetre
Sq.km.	Square kilometers
msl	Mean sea level
mg/l	Milligram per litre
µmhos/cm	Microsiemens per centimetre
ppm	Parts per million
pH	Potential of Hydrogen
EC	Electrical Conductivity
TDS	Total Dissolved Solids
DO	Dissolved Oxygen
L	Length
W	Width
I	Isthmus
T	Thickness
D	Diameter
ssp	Without spines
csp	With spines
spr	Without processes
cpr	With processes
SP	Spine
ANOVA	Analysis of Variation
WGEEP	Western Ghats Ecology Expert Panel
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNEP	United Nations Environment Programme
IUCN	International Union for Conservation of Nature

APHA	American Public Health Association
KeralaWRIS	Kerala Water Resource Information System
WHO	World Health Organization
PHAs	Polyhydroxyalkanoates
ISI	Indian Standards Institute
COVID-19	Corona virus Disease-19
Govt.	Government
Dept.	Department
HCA	Hierarchical Cluster Analysis
NMDS	Non-metric multidimensional scaling
CCA	Canonical Correspondence Analysis
NPI	Nutrient Pollution Index
p.	Page
Pl.	Plate
fig.	Figure
sp.	Species
PRE1	Pre-monsoon of first year
PRE2	Pre-monsoon of second year
MO1	Monsoon of first year
MO2	Monsoon of second year
PO1	Post-monsoon of first year
PO2	Post-monsoon of second year
S1	Pookode Lake
S2	Banasurasagar Dam
S3	Kuruva Islands
S4	Heart Lake
S5	Karapuzha Dam
S6	Papanasini River

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Chapter 1

Introduction

Every living thing on our planet relies on water and most species including us require freshwater which is of scarce supply and is polluted easily. Out of 3% of Earth's freshwater, 2.5% is trapped in glaciers, polar ice caps, atmosphere, and soil, leaving only 0.5% as accessible freshwater. In addition to this low availability, increase in population and pollution, calls for regular monitoring and conservation of freshwater resources. Unquestionably, only continuous monitoring can maintain water quality. According to the UN Environment Programme, by 2030 our requirement for water will be 40% greater than our freshwater supplies (UNEP, 2016). Even now, climate changes and the increasing intensity and frequency of natural calamities like floods, droughts, etc. affect the freshwater supply. The 'Thelineerozhukum Navakeralam' campaign by the Government of Kerala reports that 79% of the water bodies of Kerala are contaminated (Suresh, 2022). Continuous and unrelenting stress on water bodies in the name of development and tourism is worsening the situation of water bodies. Ecosystems that are being disrupted or degraded will eventually lose their functionality and self-sustainability. The ability of many freshwater resources to supply clean water and to support the freshwater species in it is now being questioned.

Depletion of freshwater is undoubtedly a serious peril to all living organisms. One of the grave consequences of pollution of these vital resources is the threat posed to the freshwater species present in the ecosystem. The freshwater biodiversity is declining unpredictably. According to the IUCN, freshwater species are threatened and declining more than the species in the marine and terrestrial ecosystems (IUCN, 2024). Out of all freshwater taxa assessed, 7.2% are threatened with extinction and 31.3% are assessed as Data Deficient (Molur, 2011). This highlights the urge for taxonomical and distribution studies of freshwater ecosystems to narrow the gap of data deficiency. Industrial development and rapid urbanisation are taking a toll on the freshwater species in the biodiversity hotspots like the Western Ghats which support unique freshwater biome with endemic organisms. The term "biodiversity hotspot" refers to 25 areas worldwide that are rich in biodiversity but have lost at least 70% of their original habitat. India has three biodiversity hotspot regions and Western Ghats is one among them. The species in the hotspots are less resilient to the changes in the equilibrium of the ecosystem and are easily vulnerable. Unfortunately, in contrast, the areas with high endemic species instead of being conserved are becoming areas with more threatened species.

The Western Ghats is a mountain range stretching along the western side of India, characterized by the most diverse freshwater ecosystems. The Western Ghats include various hill ranges such as the Cardamom Hills, Nilgiris, Anamalai Hills, and Western Ghats. High level of rainfall makes the geographically unique area, biologically rich. The Western Ghats are renowned for their extraordinary biological diversity and high levels of endemism, earning recognition from UNESCO as one of the world's eight "hottest hotspots" of biodiversity. In 2011, the Western Ghats Ecology Expert Panel classified the entire Western Ghats as an Ecologically Sensitive Area (WGEEP, 2011). In 2012, UNESCO declared thirty-nine sites in the Western Ghats region as World Heritage Site (UNESCO, 2012). Twenty-eight per cent of the total plants found in the Western Ghats are endemic to the area, which elevates the importance of conservation. A biodiversity assessment by the IUCN on the Western Ghats found that the Kerala region of the Western Ghats ecoregion is the richest in endemic species and the most diverse part of the entire range. In contrast, the Southern Western Ghats Hotspot contains the highest number of threatened species, with key biodiversity areas identified in this region (Molur, 2011). This report communicates the need for the protection of species in the Kerala part of the Western Ghats region. The absence of baseline data on the distribution and ecological needs of freshwater species can worsen the extent of biodiversity loss. Documenting and biomonitoring of algae becomes important to assess the immense wealth of water bodies. IUCN recommends a comprehensive taxonomic review and ongoing monitoring of all freshwater groups in the Western Ghats as a part of their first biodiversity assessment in Western Ghats. Such investigation will support and assist in maintaining the status and condition of water bodies.

Algae are the primary producers of water bodies which has prime influence over the food web in the water body. Knowing algal composition will determine the status of water bodies. Taxonomical studies which advise the potential applications of algae in the right direction are important. Especially in a biodiversity hotspot like the Western Ghats with the presence of highly endemic organisms, exploring the less studied lower plant groups like algae is much needed.

Areas with high altitudes are highly diverse and have algae abundantly in response to their special ecology. This diversity owes to factors like temperature, sunlight, rainfall, and pH of the area. According to the WGEEP, the four districts such as Kodagu in Karnataka, Nilgiris in Tamil Nadu, and Wayanad and Idukki in Kerala are entirely located within the Western Ghats region. The water resources of peninsular India depend on the high ranges of the Western Ghats (WGEEP, 2011). Considering this prime area of diversity, Nasser and Sureshkumar (2013) studied periphytic microalgae of selected areas of Western Ghats. The study concentrated on the Anamalai part of Western Ghats founding 242 species of microalgae. Idukki and Wayanad districts of Western Ghats were excluded from the study. Idukki and Wayanad are the two districts in Kerala that have tropical evergreen forests with plenty of freshwater resources. They encompass most areas of the Western Ghats in Kerala. Idukki district lies almost within the Western Ghats Mountain range followed by Wayanad district. The algal resources of Idukki have been investigated and rich flora with 494 taxa were documented John (2008). Nevertheless, Wayanad remains unexplored.

Wayanad is a high-altitude district in the Southern Western Ghats of Kerala and an integral part of the Western Ghats. In Wayanad, 74.2% of the district is covered by forests, including tropical dry forests and moist deciduous forests, fostering a distinctive diversity of endemic and endangered plant and animal species (Kerala State Planning Board, 2024). The district still occupies 30% of its total area as virgin forests (Forest Watch, 2024). Undoubtedly, it is one of the last remaining pristine wildernesses of India. Wayanad is a part of Nilgiri Biosphere Reserve and has an inseparable connection with tiger reserves and wildlife sanctuaries of Bandipur, Mudumalai, Nagarholai, Biligiriranga Hills, Sathyamangalam and Silent Valley of neighbouring states. Being home to a large tribal population and wide forest area, tribal land encroachment problems and human-animal conflicts are common cases. The fast mushrooming of unregulated and illegal tourism in the district threatens the fragile landscape and ecosystem of Wayanad. Additionally, the threat of natural catastrophes is a pressing issue affecting people and biodiversity. Deforestation, unsustainable land use and unscientific development projects hamper the pristine environment. Deforestation of forest for timber and conversion of grasslands to plantations have interfered with the diversity of forests. Converting paddy fields to other crops can destroy the efficiency of soil. The construction of dams has destroyed the ecosystem of the area.

Wayanad has steep slopes and is prone to landslides during the rainy season. According to the Geological Survey of India, the district is in seismic zone 3 of the

ISI classification. After the disaster floods of 1924, Wayanad experienced the worst flood during the heavy South-West monsoon of 2018. A chain of landslides triggered by heavy monsoon rains happened in 2019, 2021, 2022 and 2024. After extensive damage caused by the 2018 flood and landslide, it is the recent 2024 landslide which took a toll on human lives and nature. As per the Wayanad District Soil Conservation Office records, forty-seven landslides, one hundred and fifty-five landslips and forty-five instances of land subsidence were reported in Wayanad excluding those incidences in forests during 2018. The landslide hazard map warns that 25.97% area of the district is in a high-risk zone. A biodiversity loss for 376 angiosperms and 21 pteridophytes was estimated as post-disaster impact as a part of the survey. (Sivadas et al., 2019). Poor monitoring and water resource management is observed in Wayanad (Sohn, 2024). Groundwater quality assessment in the block Sulthan Bathery of Wayanad revealed that majority of samples are polluted with phosphate and nitrate beyond permissible limits (Richard et al., 2016). A water quality study in Kabini states the presence of industrial pollution and faecal contamination in several areas of the basin where Banasurasagar reservoir is also detected with faecal contamination and Kuruva islands with organic pollution (Mavukkandy et al., 2014). Hence, Wayanad and its fragile water ecosystems need urgent attention and monitoring.

A total of 2034 species and 903 genera were reported from the Wayanad district as part of the floristic study (Ratheesh Narayanan, 2009). This forms nearly half of the flora of the Kerala state. Out of these 2034 taxa, 29% are endemic and 138 taxa belong to different threat categories (Ratheesh Narayanan, 2009). Mini (2015) conducted pteridophyte studies in Wayanad district finding rich pteridophyte flora with 163 species among which 19 are endemic and 27 are threatened. Two among three indigenous gymnosperms reported from Kerala were found in Wayanad (Ratheesh Narayanan, 2009). A rich biodiversity of bryophytes is observed from Wayanad in the study by Nair and Madhusoodanan (2003). Thirteen plant taxa have the district's name as a specific epithet, usually *wynaadensis* or *wynaadica*. All these studies prove Wayanad is a biodiversity pocket and promises a considerable algal diversity too. This notion led us to explore and study the algal flora of the district. The algal collections were made from lakes, rivers, dams, islands, ponds, streams, puddles, temple ponds and rock crevices to comprise the flora. This exploration will be a contribution to the algal biodiversity of Kerala and the Western Ghats. The rich vegetation of Wayanad offers us hope for a very diverse algal flora in Wayanad.

Knowing the species in an area is the first step to understanding the biodiversity of the area. The lack of algal studies in Wayanad adds to the importance of our investigation. We also aim to quantify the diversity of algae using different diversity indices which help to compare the diversity in future inspections. Perception of the diversity and species richness of an area enhances its attempt at conservation and protection. As a botanist, we must study and document unexplored diverse areas like Wayanad.

Besides the diversity of algae, the factors which influence algal growth are also a subject that needs discussion. Not only the identification of algal diversity but also identifying the physicochemical properties of their ecosystem is essential to correlate and distinguish the requirements of the algae. This learning helps to comprehend the ecology of algae and for culturing the desirable ones in labs. Therefore, we plan to correlate physicochemical parameters and algae as a part of this research. As a result, how phytoplankton dynamics and different parameters are related is determined. Temperature, altitude, nitrate, phosphate, silicate, dissolved oxygen, pH, total dissolved solids, and electrical conductivity of water are the major parameters that affect algal growth. The result will reveal how these parameters and algal communities are related.

Any slight variation in the parameters of water will have a massive effect drifting community structure of algae. As algae are easily subjected to change, comprehension of the community structure of algae in an area becomes significant. The dominant group of algae thus changes according to the changes in the ecosystem. So, an interesting seasonal variation of the algal community is suspected in the study. Six permanent collection sites Pookode Lake, Heart Lake, Banasurasagar Dam, Karapuzha Dam, Papanasini River, and Kuruva Islands are selected based on their ecological importance for the study. Seasonal changes such as rainfall and sunlight affect algal growth. Normally, the seasons of a year are pre-monsoon, monsoon, and post-monsoon. Comparatively, post-monsoon is usually observed with more algae, possibly because of less precipitation and concentrated nutrients that are introduced in monsoon. But nowadays a strict separation between seasons is difficult due to climate change. Late monsoon rains have now become a common phenomenon. Floods and landslides also affect water parameters and algal composition.

Studying the algal community structure of a water body can disclose the trophic state of the water body. There are pollution indices to evaluate the pollution in the water body by assessing pollution-tolerant algae in the system. Looking more into the dominant algal community in a water body will reveal its nature. Taxonomic composition of algae can be used to assess the biotic integrity and can diagnose direct and indirect causes of problems in an aquatic environment (Stevenson, 1998). Many scientists have developed different pollution indices using pollution-tolerant algal species. These algae can thrive in polluted water bodies. In Palmer's Algal Pollution Index, the twenty most pollution-tolerant algae were given a pollution index factor based on their tolerance, and a score is calculated by the presence of this alga in the water body. Based on the score we know how polluted the water body is. Algae can thus be helpful in biomonitoring water resources. Biomonitoring using algae is the best method than any other assessment because they are the most sensitive group of ecosystems.

It is biodiversity that can improve the water quality of a water body through niche partitioning (Cardinale, 2011). The coexistence of different species in an ecosystem makes the ecosystem dynamics functional. Each organism is interrelated through the food web and the loss of one of them makes it incomplete. So, the conservation of the biodiversity of species as well as the maintenance of environmental heterogeneity which allows species to coexist is important. This altogether maintains a healthy ecosystem. Anything which disturbs this coexistence is a risk. Apart from natural causes, anthropogenic activities also lead to the accumulation of nutrients in a system. Predominantly, it is the seepage of excess nutrients into water bodies that cause eutrophication and pollution. Excess nutrients from unscientific agricultural practices and improper waste disposal eventually reach water bodies and disrupt the freshwater ecosystem. Nitrate and phosphate from fertilizers and chemicals are the major nutrients that cause blooms and eutrophication. Untreated waste that is deposited near and into water bodies is hazardous to the living world in them. Plastic and toxic chemicals are released unruly and leach into water bodies.

Recent studies claim that algae can be a part of the solution to this problem. They are capable of filtering excess nutrients and even microfibres and microplastics from the water bodies through adsorption (Peller et al., 2021). They are now used in wastewater treatment plants. Algae are ubiquitous, aquatic, and photosynthetic organisms that can live in a variety of habitats. They can be found at different altitudes and habitats. The type of algae found at different altitudes will depend on several factors such as temperature, water availability, pH, and nutrient levels. Many types of algae are adapted to living in high altitudes and can be found in mountain ponds, streams, and lakes. These algae have unique adaptations that allow them to survive in harsh conditions such as low oxygen levels, intense sunlight, and extreme temperatures. Even a slight change in the water chemistry has a direct impact on the algal community which eventually affects the entire ecosystem. Furthermore, algae are the primary biomass producers in aquatic ecosystems on a global scale (Hader et al., 1998). In every ecosystem, producers are at the first level and provide energy to the entire system. The freshwater ecosystem is duly dependent on algae for its productivity as a primary producer. Here, where algae play a major role as a producer, its diversity and richness are a concern. Increased temperatures can also result in more frequent toxic algal blooms, as well as heightened toxicity to other organisms (Hallengraeff, 1993). Their growth and diversity can control the excess nutrient accumulation and productivity of the water body they are present. In this scenario, more studies on algal diversity and ecology are compelled to be done.

Moreover, the merit of algae is now undoubted due to its countless applications in various fields. Algae proved to have a remarkable contribution as a major primary producer and oxygen provider. As a bioindicator for pollution and for wastewater treatment, algae are gaining importance. They can reduce carbon dioxide emissions in power plants. The amount of organic carbon produced by algae is seven times more than that produced by higher plants (Batista et al., 2015). Their photosynthetic efficiency is ten times higher than terrestrial plants (Singh & Ahluwalia, 2013). The simple structure of algae requires less energy to maintain, which increases their efficiency. Microalgae are capable of adsorbing microfibers and even microplastics in water and can reduce nutrient levels to optimum. Algae are extensively used commercially as a food, nutrient supplement, biofuel, biofertilizer, dye, etc. The copious use and applications of diatomaceous earth produced by diatoms are immense. A field of study called forensic limnology is on the sake of diatoms. Diatoms are inexpensive and ubiquitous in nature, and their community changes seasonally which favours forensic investigations. As an animal feed, they can reduce harmful methane emissions from cattle. Being protein rich they are used as a protein supplement in space travel. They have excellent antibiotic properties as well. A recent study shows algae has anticancer properties that modulate cellular mechanisms and are used for making anticancer drugs (Khavari et al., 2021). Algae were found capable of inhibiting the replication of some viruses including COVID-19 which can help the medical community (Periera & Critchley, 2020). Aerosols originating from the phytoplankton are related to cloud formation which will eventually lead to precipitation (McCoy et al., 2015). Thus, algae can influence climate too. Algae can naturally produce polyhydroxyalkanoates (PHAs), when they are stressed. These PHAs are biodegradable thermoplastic polyesters. That is, they can biosynthesize biodegradable polyesters which can be utilised in textile industries (Banerjee et al., 2016). Algae are used for power generation in bacterio-algal microbial fuel cells (Saba et al., 2017). These countless applications of algae in different fields are an aid for sustainable development in future. Algae also have a bad side to the environment by causing blooms and contaminating water by eutrophication. Some algae are seen in parasitic associations and can produce algal toxins. Because of all these qualities, studies on algae are increasing and obtaining significance. Research to explore, identify and understand algae around us, thus becomes a requisite for a better future.

1.2 Significance of the present study

Documentation of the current biodiversity is essential to assess the biodiversity and to protect from its loss. Lower forms such as algae are often neglected in taxonomical studies but require special attention as they are very sensitive to their environment. This nature of algae gives us the advantage of comprehending the nature of water body they present. Numerous applications and bioprospecting studies of algae are gaining importance. In this situation, proper taxonomical studies become a pressing priority as they are the foundation for all application studies. They prevent misleading in the studies and thereby assure the proper and effective application studies.

The study attempts to discuss the taxonomy of algae of Wayanad district which is a part of Western Ghats. The study area has immense biodiversity and is less documented for algae. Moreover, the district is a major tourist area of the state and is subjected to unsustainable land uses and deforestation for the means of development and tourism. The area is subjected to a series of landslide disasters during 2018 to

2024. All these results in unrelenting stress on the environment and affect the diversity of the district. This increases the scope of the present research.

The study examines seasonal and spatial variations in algal diversity to understand the changes occurring in the water body. The physicochemical parameters influencing the algal diversity are recorded and their correlation is studied. These studies aim for a clear understanding of the factors contributing the algal diversity.

By revealing the diversity of algae, the pollution status was also determined. Algal pollution indices denote the biological pollution in an early stage which makes it more reasonable compared with other indices.

1.3 Objectives

1. To gather information regarding the taxonomy of freshwater algae in the Wayanad district.
2. To quantify the algal diversity of habitats, using diversity Indices.
3. To compare physicochemical aspects of water with algal diversity.
4. To compare the seasonal and spatial distribution of algae from the study area.
5. To assess the pollution of water bodies using algal pollution indices.

Chapter 2

Review of Literature

Wayanad district of Kerala, nested on Western Ghats is a hub of biodiversity with several endemic and undiscovered species. Numerous endemic and new species of plants (Sivu et al., 2014), orchids (Kumar et al., 2001), lichens (Haridas et al., 2023), bryophytes (Nair, 2005), fungi (Pillai et al., 2015), trees (Volga et al., 2013), spiders (Rajeevan et al., 2019), ants (Anu & Sabu, 2007), fishes (Augustine & Jose, 2012), amphibians (Vijayakumar et al., 2019) were discovered from the district. However, the algal diversity of Wayanad remains relatively hidden and unexplored.

2.1 Freshwater algal taxonomic studies in Wayanad

The district Wayanad was formed in 1980 as a twelfth district of Kerala, incorporating the taluks of North and South Wayanad (https://wayanad.gov.in/). The South Wayanad was part of Kozhikode district before the formation of district. In 1964, a comparative algological study in rice fields of the state was attempted by Aiyer. The study considered rice fields of seven districts including Kozhikode which incorporated South Wayanad at that time. Among nineteen blue-green algae recorded, twelve taxa were observed in Kozhikode. The very first phytoplankton enumeration in Wayanad was by Nirmala et al. in 1991 as limnological studies of Pookode Lake. This resulted in the identification of sixteen genera from the Lake. A comparative study by Divya et al. (2013) investigated the growth of phytoplankton in the surface water of six different water bodies including two species from the Iritty River which originated from Wayanad Pass. Babeesh et al. (2016) noted the spatial distribution of diatoms in Karlad Lake with twelve taxa. Genera such as *Aulacoseira*, *Navicula* and *Pinnularia* were dominant in the Lake. Philip (2020) researched on cyanobacterial diversity of forests in the Western Ghats of Kerala revealing high cyanobacterial diversity representing thirty taxa from Wayanad out of two hundred and four species of cyanobacteria. As a part of this study, Jose et al. (2022) discovered thirty-nine desmids from the Karapuzha Dam of the district with a new report to India and eight new reports to Kerala. Recently, Panikkar et al. (2024) assessed plankton diversity and physicochemical characteristics of the Karapuzha reservoir of Wayanad. Thirty-six genera of phytoplankton were identified from the area. The algae of Wayanad are still obscure and requires more attention to disclose the concealed diversity.

2.2 Freshwater algal taxonomic studies in Kerala

The rich biodiversity of Kerala is an appropriate space for taxonomical and systematic plant studies. As part of the Western Ghats, Kerala is home to many species that are both endemic and newly discovered in the plant world. Climate and topography keep up these highly diverse ecosystems. Lower groups such as algae, bryophytes, and fungi which were considered insignificant in past, now are explored widely in numerous applicable fields. Studies exploiting the potential of such groups are gaining importance. However, the taxonomy and baseline documentation of algae remains incomplete despite this trend. For use in various applicational fields, proper systematic studies become the need of the hour. Even now, documentation by Easa (2004) remains the only work which encompasses entire algae from Kerala reporting 834 species of algae. An extensive study on the algae of entire state remains unfulfilled.

The first one to publish papers in the algal taxonomy of Kerala is Erady who is regarded as the father of algology in Kerala. He has published new species of *Oedogonium* (Erady & Rajappan, 1958), *Vaucheria* (Erady, 1954), *Spirogyra* (Erady, 1962), and *Temnogametum* (Randhawa, 1959). Randhawa made a note on two freshwater algae from Kerala in 1962. Algae of Cranganore were described by Suxena et al. (1973). A comparative algological study in rice fields of the state was attempted, which considered rice fields of seven districts (Aiyer, 1964). Amma et al. (1966) studied the algal flora of Kuttanad soils and reported the presence of nineteen blue-green algae in the acidic soils of Kerala. In 1987, Anand and Hopper conducted a survey of blue-green algae in the rice fields of Kerala, documenting thirty taxa. Ten among them are recorded for the first time in a rice field. Later, they published one hundred and fifty-eight taxa on the distribution of blue-green algae from rice fields of Kerala (Anand & Hopper, 1995).

Panikkar who specialises in both freshwater and marine algae have given immense contributions to algal society through various paper publications, research projects and PhD theses. Thirty-five species of freshwater algae and nine species of marine algae were discovered by him. Several taxonomic studies with discoveries and new records were rendered by Panikkar (Panikkar & Ampili, 1988, 1990, 1991, 1992a, 1992b, 1993a, 1993b; Panikkar et al., 1989; Panikkar & Sindhu, 1993;

Panikkar et al., 1997; Panikkar & Sreeja, 2005, 2006, 2007; Panikkar et al., 2012). Ampili discovered and reported new algal taxa (Ampili et al., 1989; Ampili & Panikkar, 1989; Ampili & Panikkar, 1994). Sindhu, Devi, and Shaji also published works with Panikkar. Sindhu published works on *Chara* (Sindhu & Panikkar, 1991, 1992), desmids (Sindhu & Panikkar, 1994a, 1994d, 1994e, 1994f, 1995a, 1995b) and Chaetophorales (Sindhu & Panikkar, 1994b, 1994c). Devi published works on *Spirogyra* (Devi & Panikkar, 1991a, 1991b, 1993c, 1993d, 1993e, 1993f, 1993g, 1994a, 1994b), *Temnogametum* (Devi & Panikkar, 1991c), *Zygogonium* (Devi & Panikkar, 1992), *Mougeotia* (Devi & Panikkar, 1993a), *Sirocladium* (Devi & Panikkar, 1993b), Zygnemataceae of Kerala (Devi & Panikkar, 1993e), *Desmidium* (Devi & Panikkar, 1993h) and *Zygnema* (Devi & Panikkar, 1995). They also published about Oedogoniales of Kerala in three volumes (Devi & Panikkar, 1993i, 1993j, 1993k). Shaji worked on Cyanophyceae (Shaji & Panikkar, 1994, 1995), euglenoids (Shaji & Patel 1990; Shaji et al., 1995) and red algae *Audouinella* (Shaji & Panikkar 1996).

Twenty-nine new records of freshwater diatoms to Kerala were contributed by Jose and Patel (1989). Anew freshwater red algae *Caloglossa ogasawaraensis* were also reported by them (Jose & Patel, 1990). A systematic account with twenty taxa of Chlorococcales which were new to Kerala was also prepared (Jose & Patel, 1992). Maya et al. (2000) conducted a preliminary survey of the algal flora in temple tanks of Southern Kerala, identifying one hundred and eight species of algae.

Madhusoodanan and Dominic have done good research on Cyanophyceae (Madhusoodanan & Dominic, 1995, 1996). Their study in paddy fields of Alappuzha district gave an account of forty-two species of acid-tolerant cyanobacteria (Dominic & Madhusoodanan, 1999). Sankaran (2001) studied blue-green algae of the Anamalai Hills of Tamil Nadu and Kerala. A new record of *Anabaena flos-aquae* was reported by Teresa and Rekha (2002).

Water quality studies using algae are innovative and efficient methods as they respond to a slight change in the water quality. Harilal (2005) came across twenty-three genera of phytoplankton from Nayyar and twenty from Karamana River and studied the relation of aquatic nutrients present in them. Sheeba and Ramanujan (2005) described phytoplankton composition and distribution in the Ithikkara River of

Kollam district with one hundred and thirty-five taxa. Radhika (2005) researched on limnology of Vellayani Lake of Thiruvananthapuram considering the micro and macro flora present there. Thirty-six phytoplankton were reported from the study. Subramoni (2007) worked on the algal diversity of the Vamanapuram River of South Kerala concerning water quality parameters reporting one hundred and seven species. Sixty-one algal species from thirty-seven temple tanks of Palakkad and Thrissur were discussed by Arulmurugan et al. (2010).

John (2008) investigated the freshwater algal flora of the Idukki district. The high diversity of the area resulted in the recording of four hundred and ninety-four taxa. Out of these thirty-eight are new science reports. John and Francis (2010) observed thirty-four taxa from wetland resources of the Idukki region. Later, a well-illustrated algal flora of the Idukki district was prepared by them (John & Francis, 2013b). John and Francis (2013a) reported new additions to algae from Idukki. John et al. (2024) studied forty-three taxa of algae in the Malakkapara sholayar stream of Thrissur district with three new reports to Kerala.

Pollution and algal diversity are interrelated and are very much applicable to finding the status of a water body in an early stage of pollution. Jose et al. (2008) evaluated organic pollution in ten temple ponds of Ernakulam based on physicochemical characteristics and algae. Thirty species were noted, and half of the ponds were detected with *Microcystis* showing eutrophic nature. Four temple ponds of Mattanchery were tested for pollution by Jose and Kumar (2011) using Palmer’s Algal Pollution Index. The study revealed high organic pollution in these water bodies which was also supported by results of physicochemical water analysis. Alexander and Nayar (2014) investigated on seasonal plankton diversity of Sasthamkotta Lake and the status of the lake. Eighty-three phytoplankton were found, of which eight are pollution-tolerant species. Ajayan and Kumar (2015) carried out algal studies in a lake inside the zoological garden of Thiruvananthapuram identifying one hundred and two algal species. The pollution status of the lake was then assessed finding thirty pollution-tolerant genera and twenty-four pollution-tolerant species (Ajayan & Kumar, 2017). Gopinath and Kumar (2015) discussed euglenoid diversity in Vellayani Lake of Thiruvananthapuram and revealed the polluted nature of the Lake by observing sixteen species of euglenoids. The trophic state of the Aruvikkara reservoir was assessed using different algal indices such as the Chlorophyceae index, compound index and diatom index based on algal species (Krishnan & Kumar, 2015). The reservoir was found to be slightly eutrophic due to leaching of nutrients from agricultural fields and plantations. Ajayan et al. (2013) examined the phytoplankton population of Ananthapura Temple Lake of Kasargod recording thirty-eight species of algae. The diversity indices also showed lake has low pollution and high diversity. Sreenisha and Paul (2016) assessed the pollution levels and phytoplankton diversity in the Tirur River of Malappuram district, identifying fifty-seven taxa.

Identifying and detecting bloom-causing algae is essential to avoid bloom and its consequences. Dhanya et al. (2012) surveyed algal blooms in ponds of Pallipuram detecting nine species of algae responsible for the bloom. The potential risk of Achenkovil River pollution was pointed out by Binoy et al. (2020) by identifying outbreaks of harmful algal blooms in the river. *Euglena sanguinea* and *Lepocinclis wangi* were the dominant algae causing colour change and death of fishes in the river. Occurrences of potentially toxic cyanobacteria *Microcystis aeruginosa* were noted in two freshwater ponds of Kochi (Mohan et al., 2020). Toxicological studies were conducted showing that the bloom was hepatotoxic resulting in fish mortality. Ray performed extensive research on phytoplankton in eutrophic freshwater bodies that can cause bloom and reported two hundred and ninety-seven species of algae (Ray et al., 2021).

Nasser and Sureshkumar (2013) worked on ninety-four species of algae in the Peringalkuthu reservoir and on their interactions with environmental variables. They also checked the phytoplankton of the Parambikulam reservoir (Nasser & Sureshkumar, 2014). Sebastian and Thomas (2016) studied the temporal variation of phytoplankton in the Idukki reservoir, identifying thirty-seven species. Achankunju and Panikkar (2022) studied the spatial and temporal diversity of diatoms in Pathanamthitta district. The study revealed high diversity with the presence of ninety taxa.

Paul immensely contributed to the algae of Kerala through her various publications. Paul and Sreekumar (2013) and Tessy and Sreekumar (2008, 2009) studied algae in the Kole lands of Thrissur district. Algae from the Guruvayur temple pond were also identified by Paul and Anu (2016). Paul (2012) made an extensive study identifying five hundred and ninety-one taxa with forty-two new reports to India and two hundred and thirty-five new reports to Kerala as a part of doctoral studies on the algal flora of Kole lands in Thrissur. Several genera including *Micrasterias* (Tessy & Sreekumar, 2007), *Pleurotaenium* (Tessy & Sreekumar, 2011), *Scenedesmus* (Paul & Sreekumar, 2012), *Cosmarium* (Paul & Sreekumar, 2015) and order Chlorococcales (Paul & Sreekumar, 2018) were exclusively researched. Algae of Tirur River was enumerated by Paul and Sreenisha (2020).

Sixty-four species of blue-green algae were observed in the soil of Kuttanadu paddy wetlands by Vijayan and Ray (2015). Philip et al. (2016) described fifteen species of cyanobacteria from Nelliyampathy of Palakkad. Philip (2020) attempted an extensive study of cyanobacteria in the Western Ghat forests of Kerala. The study identified two hundred and four species with thirty-one species new to Kerala and eight new to India. Ram and Shamina (2017) studied cyanobacterial diversity from seven mangroves of Kerala reporting thirty-seven taxa. Ram and Paul (2020) presented ten species of the genus *Oscillatoria* from the mangroves of Kerala. Ram (2022) described the ecology and diversity of mangrove-associated cyanobacteria of Southern Kerala. Out of eighty-nine species recorded, forty-four were new to India and twenty-nine were new to Kerala. Arun and Tessy (2022) explored mangrove-associated *Nostoc* species resulting in nine new reports. Thilak et al. (2020) performed isolation and taxonomy of twelve species of *Nostoc* with five species from Kerala.

The flood of 2018 caused a drastic change in the vegetation of Kerala. The impact of massive floods on algal biodiversity is analysed by Jayalakshmi and John (2019). The study advocates a great decrease in biodiversity and a shift in algal assemblages because of floods. A new record of red algae *Caloglossa beccarii* was reported from the Periyar and Chalakkudy Rivers in Kerala by considering morphological and molecular evidence by West et al. (2015). Jayalakshmi and John (2020) noticed twenty-eight taxa of Scenedesmaceae members from the Periyar River of Kerala. Out of these, three taxa are new to Kerala. They reported red algae *Kumanoa chaugulei* (Jayalakshmi & John, 2021) and *Macrosporophycos sahyadricus* (Jayalakshmi & John, 2023) from Idukki based on morphology and molecular evidence. Jayalakshmi et al. (2022) reported *Kumanoa periyarensis* from Idukki.

The algal diversity of the Meenachil River was enumerated by Sebastian (2016). Seena et al. (2019) investigated the influence of phytoplankton diversity in the tributaries of the Bharathapuzha River, identifying eighty-one species of algae and twelve pollution-tolerant genera. Seena (2021) also rendered a comparative study on the freshwater algal community from the main rivers in Palakkad district contributing two hundred and fifty-seven taxa. The study provided a new report to India and fourteen new reports to Kerala.

Anjali et al. (2020) explored the algal flora of Cheruchakkichola identifying fifty-three species of algae. Jose and Xavier (2022) investigated the algae from freshwater bodies of Chimmony Wildlife Sanctuary by identifying sixty-one species of algae. Krishnan et al. (2023) explored the algal diversity of the Pandalam municipality of the Pathanamthitta district recording seventy-eight algal taxa. Devikrishna et al. (2023) investigated freshwater algal biodiversity in the Peechi Dam of Thrissur district, presenting forty-eight species with two new reports to Kerala. Thilak and Kishore (2024) identified sixty-four taxa from a wetland in Kozhikode. Praseetha et al. (2024) documented seventy-two taxa with three new reports to Kerala from the Thanikkudam River of Thrissur. Ammini et al. (2024) found seventy-three taxa and four new reports to Kerala from water bodies of Malabar Wildlife Sanctuary. Bibina et al. (2024) conducted a thorough exploration of desmids in the Thattekkad Bird Sanctuary, describing seventy-four taxa, of which five are new to India and five are new to Kerala.

2.3 Freshwater algal taxonomic studies in India

Turner (1892) explored the freshwater algae of East India, focusing primarily on desmids. He recorded twenty-two species of Myxophyceae, five hundred and fifty-two desmids and sixty species of Chlorophyceae. Fritsch, renowned as the father of phycology, delivered appreciable contributions to the phycological society. Fritsch studied on algal flora of tropical regions (Fritsch, 1907) and Ceylon (Fritsch, 1906). The genus *Anabaena* with species recorded from India was presented by Fritsch in 1949. Freshwater algae of Burma with two hundred and seventy-six species and seventy-one genera from Bengal and Madras were reported by West and West (1907).

Iyengar is regarded as the father of modern Indian phycology attributed to his pioneering contributions towards algae of India. Contributions of Iyengar despite the infrastructure and facilities at that time, in an untouched group of plants, are inexplicable. He made Madras, a centre for phycological research at that time. His algal research began with Volvocaceae of Madras (Iyengar, 1920, 1921). He discovered *Hydrodictyon indicum* (Iyengar, 1925), *Tetrasporidium* and *Ecballocystis* (Iyengar, 1932a), *Fritschiella* (Iyengar, 1932b), *Characiosiphon* (Iyengar, 1936), *Triplastrum* (Iyengar & Ramanathan, 1942), *Halicystis* (Iyengar & Ramanathan, 1954), *Gloeotilopsis planctonica* (Iyengar & Philipose, 1946), *Ecballocystopsis indica* (Iyengar, 1933), *Nitella terrestris* (Iyengar, 1958a), *Johannesbaptistia pellucida* (Iyengar & Desikachary, 1946a), *Mastigocladopsis jogensis* (Iyengar & Desikachary, 1946b) from South India. He also studied lateral conjugation in *Spirogyra* (Iyengar, 1958b), the sexual reproduction of *Dictyosphaerium* (Iyengar & Ramanathan, 1940), the reproduction of *Characiosiphon rivularis* (Iyengar, 1954) and on *Euglena* (Iyengar, 1962). He identified three new species of *Temnogametum* (Iyengar, 1958c). Algae of South India were exposed by Iyengar through his series of publications named 'Contributions to our knowledge of South Indian Algae' (Iyengar, 1971, 1974, 1975; Iyengar & Desikachary, 1976).

Biswas surveyed the algal flora of Salt Lake (Biswas, 1927) in Kolkata and Chilka Lake (Biswas, 1932) in Orissa. He made the pioneer study on Indian diatoms (Biswas, 1936). He studied freshwater algae of Assam (Biswas, 1930, 1934). Common freshwater and brackish water algae of India and Burma were recorded by Biswas in 1949.

Randhawa worked on the freshwater algae of North India (Randhawa, 1936a, 1936b, 1936c, 1938). He researched new algae from India (Randhawa, 1936, 1939a) and made observations on algae *Fritschiella tuberosa* (Randhawa, 1939b, 1946). He studied *Spirogyra* (Randhawa, 1936d), *Zygnemopsis* (Randhawa, 1937), Zygnemales (Randhawa, 1938), *Cylindrocapsa* (Randhawa, 1941c), *Vaucheria* (Randhawa, 1939c, 1942a, 1942b), Ulotrichales (Randhawa, 1948), and order Cladophorales (Randhawa & Venkataraman, 1961, 1962). Three new species of *Zygnema* (Randhawa, 1936e, 1940c), *Cylindrocapsa oedogonioides* (Randhawa, 1936), *Zygogonium kumaoensis* (Randhawa, 1940a), *Sirocladium* (Randhawa, 1941a, 1958) were contributed by him. Notes were made by him on three species of *Oedocladium* (Randhawa, 1941b) and conjugation in *Zygnema* (Randhawa, 1940b) from the Himalayas. In 1959, a monograph on Zygnemaceae was prepared by Randhawa.

Rao studied the distribution of algae in six small ponds in 1953. Rao produced a series of ecological studies on freshwater ponds of Hyderabad (Rao, 1971, 1972, 1975, 1977) revealing the ecology of phytoplankton diversity. Rao and Gupta (1997) studied freshwater algae of India except for red algae and brown algae, as a part of a Botanical survey of floristic diversity and conservational strategies in India.

The algal flora of Pathiala was examined by Sarma (Sarma & Kanta, 1978, 1979). Sarma and Khan (1980) enumerated four thousand two hundred and sixty-nine species of algae described from India. They reported new records of Chlorococcales from Punjab (Sarma et al., 1983).

Desikachary revived unpublished papers of Iyengar's series, 'Contributions to our knowledge of South Indian Algae'. His primary contributions include a monograph on Cyanophyta (Desikachary, 1959), Taxonomy and biology of blue-green algae (Desikachary, 1972), Taxonomy of algae (Desikachary & Rao, 1980), Volvocales (Desikachary & Iyengar, 1981), six volumes of Atlas of diatoms (Desikachary & Ranjitha Devi, 1986; Desikachary et al., 1987a; Desikachary et al., 1987b; Desikachary, 1988; Desikachary, 1989) and Rhodophyta (Desikachary et al., 1990; Desikachary et al., 1998). New genera *Rosiella* (Desikachary & Maheswari, 1958), *Neofragilaria* (Desikachary et al., 1989), *Quadrodiscus* (Prema & Desikachary, 1989), *Spinodiscus* (Desikachary & Ranjitha Devi, 1986) from Bacillariophyta, *Mantoniella* (Desikachary, 1972a), *Papenfussiomonas* (Desikachary, 1972b), *Schilleriomonas* (Desikachary & Iyengar, 1976) from Chlorophyta, *Camptylonemopsis* (Desikachary, 1948), *Iyengariella* (Desikachary, 1953) from Cyanophyta were described by him. He described several new species from Bacillariophyta, Cyanophyta, Chlorophyta and Rhodophyta.

Venkataraman provided a systematic account of South Indian diatoms describing ninety-eight taxa with three new species, six new varieties and six new forms (Venkataraman, 1939). He also published a monograph on Vaucheriaceae (Venkataraman, 1961). Krishnamurthy contributed to the diatom flora of South India (Krishnamurthy, 1954) and published on algae of India and neighbouring countries (Krishnamurthy, 2000). Gandhi made significant works on diatoms of Rajasthan (Gandhi, 1955), Mysore (Gandhi, 1957, 1958a, 1959a, 1960c), Kolhapur (Gandhi, 1956, 1958b, 1959b), Ahmedabad (Gandhi, 1960a, 1961) and Bombay and Salsette

(Gandhi, 1960b). Gonzalves along with Gandhi published three volumes on diatoms of Bombay and Salsette (Gonzalves & Gandhi, 1952, 1953, 1954).

A monograph on Ulotrichales was published by Ramanathan (1964). He observed some new algae from South India (Ramanathan, 1966). Another monograph was on Chlorococcales by Philipose (1967). He contributed to Indian Eugleninae through three series of publications (Philipose, 1982, 1984, 1988).

Agarkar contributed to the desmids of Madya Pradesh by studying the desmids of Gwalior (Agarkar, 1969, 1971), Jabalpur (Agarkar et al., 1983), and Bandhavgarh (Agarkar et al., 1979). Agarker and Agarkar (1977) also contributed to the algal flora by studying the desmids of Pachmarhi.

Prasad studied various groups of algae such as Cyanophyceae (Prasad, 1952; Prasad & Mehrotra, 1978, 1980; Prasad & Saxena, 1980; Prasad & Srivastava, 1984a, 1986; Prasad & Khanna, 1987), desmids (Prasad & Mehrotra, 1977a, 1977b; Prasad & Misra, 1984b, 1984c, 1985), diatoms (Prasad et al., 1981; Prasad & Srivastava, 1981, 1983, 1984b, 1985; Prasad & Singh, 1982; Prasad & Jaitly, 1985), filamentous green algae (Prasad & Misra, 1984a), and Euglenophyceae (Prasad & Chaudhary, 1986). In 1992, Prasad and Misra compiled the freshwater algal flora of the Andaman and Nicobar Islands, describing 587 algal taxa.

Chlorophyceae of Ahmedabad (Kamat, 1962) and algae of Kolhapur (Kamat, 1963) were examined by Kamat. Kamat explored the algae of Simla (Kamat, 1968a), Alibag (Kamat, 1968b) and Vidarbha (Kamat, 1975). Kamat noted diatoms of Nainital (Kamat & Aggarwal, 1975) and check-listed Euglenophyceae and Chlorophyceae of Nagpur (Kamat & Frietas, 1976). Frietas checklisted Chlorococcales (Frietas, 1980) and Desmidiaceae (Frietas & Kamat, 1979) of Nagpur in Maharashtra. Ashtekar worked on Euglenophyceae (Ashtekar, 1982) and Chlorococcales (Ashtekar & Kamat, 1980b) of Aurangabad in Maharashtra. Ashtekar and Kamat added desmids (Ashtekar & Kamat, 1979) and Nostocales (Ashtekar & Kamat, 1980a) to the algal flora of Marathwada. Bhosale et al. explored phytoplankton of Maharashtra (Bhosale et al., 2010a, 2010b, 2010c, 2010d).

Pandey (1982a) studied freshwater diatoms of Shahjahanpur of Uttar Pradesh. Chaturvedi (1985) recorded algal flora from the Rohilkhand division and Chaturvedi and Pandey (1976) listed blue-green algae and green algae. Pandey and Chaturvedi

(1979) explored the algae of Rohilkand division. Pandey (1982b) added more taxa from Cyanophyceae to the algal flora of the Rohilkand division. The first part of the desmids of Bareilly was prepared by Pandey et al. (1987) while Chaturvedi et al. (1987) prepared the second part. Euglenineae of sewage waters were examined by Pandey (1985). Pandey with Gangwar authored Chlorococcales of Bareilly (Pandey & Gangwar, 1986). Pandey & Pandey contributed to the algal flora of Allahabad (Pandey & Pandey, 1980, 1982, 1983). Pandey et al. enumerated diatom flora (1983a) and Chlorococcales (Pandey et al., 1983b) of Allahabad. Srivastava (2010) found freshwater diatoms from the Faizabad and Balrampur districts of Uttar Pradesh. Srivastava and Odhwani reported *Trachelomonas* (Srivastava & Odhwani, 1990a) and *Peridinium* (Srivastava & Odhwani, 1990c) from Rajasthan. They also advanced the flora of Chlorococcales of Rajasthan (Srivastava & Odhwani, 1990b). The algal flora of Jaipur was observed by Trivedy (1982). Shah et al. (1992) researched Xanthophyceae from Rajasthan. Chaudhary and Meena (2007) noted Euglenoids and Dinophyceae of Udaipur of Rajasthan. Makandar and Bhatnagar (2010) studied the biodiversity of microalgae and cyanobacteria in Jodhpur of Rajasthan.

Somashekar inquired algal flora of river Cauvery (Somashekar, 1983a, 1983b) and River Kapila (Somashekar, 1984a, 1984b) of Karnataka. Hosmani and Bharati (1983) identified the Euglenineae of polluted and unpolluted waters. Hosmani (2008) studied ecology of Euglenaceae from Dharwar of Karnataka. Hegde contributed to the knowledge of the algae of Karnataka. He reported new records of desmids from the state (Hegde, 1986). Hegde and Bharati studied zygospore formation in desmids (Hegde & Bharati, 1983b), algal flora of Bijapur (Hegde & Bharati, 1983a) and euglenoids in lakes of Dharwad (Hegde & Bharati, 1986). Hegde with Isaacs noted new desmids from Uttara Kannada (Hegde & Isaacs, 1988a, 1989). Hegde & Malammanavar noted rice field algae in Dharwad (Hegde & Malammanavar, 1988a). Hegde also produced freshwater algal flora of Karnataka (Hegde & Isaacs, 1988b; Hegde & Somanna, 1991). Bongale and Bharati (1980) examined the freshwater algal flora of Davanagere and Raichur of Karnataka. Bongale recorded new taxa of *Cosmarium* (Bongale, 1987, 1989a), *Staurastrum* (Bongale, 1989b), *Aulosira* (Bongale, 1986), *Scytonema* (Bongale, 1986), and *Calothrix* (Bongale, 1986). Bhongale et al. (1987) found new species of *Cylindospermum* from the state.

Suxena (1983) determined the algal flora of Kodaikanal Hills and discovered a new *Xanthidium* species (Suxena, 1979). Anand looked for the blue-green algae from rice fields in Tamil Nadu (Anand & Revathi, 1987). Later Anand (1998) published on Indian freshwater microalgae. Perumal and Anand studied the desmid diversity of Tiruchirappalli (Perumal & Anand, 2008a) and then prepared a manual on freshwater algae of Tamil Nadu (Perumal & Anand, 2008b). Thirugnanamoorthy and Selvaraju (2009) checked the diversity of temple ponds in Tamil Nadu resulting in the identification of fourteen genera of phytoplankton. The microalgal diversity of the Noyyal River was identified by Mohanapriya and Geetharamani (2014). Ramadosu and Sivakumar (2010) reported one hundred and thirty-six taxa from Perumal Lake in Tamil Nadu. Sivakumar (2016) studied the diversity of freshwater algae from Tamil Nadu. Sikkarayapuram quarries were checked for algae by Palanivel et al. (2018). Parambikulam-aliyar irrigation canals (Manickam et al., 2012) and two perennial lakes of Coimbatore (Manickam et al., 2020) were assessed for phytoplankton. Valankulam Lake of Coimbatore was also examined for phytoplankton diversity (Mohan et al., 2023). An intensive algal study was attempted in a manmade aquatic ecosystem of Tiruvallur (Subramanian et al., 2023). Arumugham et al. (2023) studied the diversity of diatoms in the ponds of Kanyakumari. The diversity of Hydrodictyaceae in the Kothandaramar Temple tank of Chennai is evaluated by Saravanan et al. (2024).

Asokakumar and Patel (1988, 1990a, 1990b) made a detailed account of the desmids of Gujarat in three volumes. Patel studied on desmids (Patel & Asokakumar, 1979), Chlorococcales (Patel & Isabella, 1977, 1984) and Euglenophyceae (Patel & Waghodekar, 1981) of Gujarat. He found new taxa of Chlorococcales in India (Patel & Daniel, 1990) and Western India (Patel & Isabella, 1980). A new variety of *Pediastrum* was also discovered by Patel and Isabella (1982). They also examined algae of fishponds in Gujarat (Patel et al., 1980).

The freshwater algae of Chattisgarh are examined by Roy and Sen (1985). Mahajan (2012) examined the diversity of Nostocaceae at Jalgaon. Patralekh (1991a, 1991b, 1991c, 1991d, 1993a, 1993b, 1994) enquired about algae in freshwater bodies of Bihar. Singh and Saha worked on Chlorococcales (Singh & Saha, 1982a) and diatoms (Singh & Saha, 1982b) of Bhagalpur in Bihar. Singh et al. (2011) studied on desmids of Chattigarh. Kargupta and Ahmad (1991) noted freshwater green algae of

North Bihar. Kargupta with Keshri (2006) recorded new *Oedogonium* taxa from West Bengal. Keshri made contributions to the freshwater green algae of West Bengal. He studied Chaetophorales (Keshri, 2009), Ulotrichales (Keshri, 2010a), and Coleochaetales (Keshri, 2010b) of West Bengal. In 2010, Chakraborty et al. (2010) explored the microalgal diversity of Kolkata. Sau and Gupta (2005) assessed the algal flora of the Indian Botanical Garden in West Bengal.

The distributional and seasonal abundance of algae in Chilka Lake was examined by Adhikary and Sahu (1992). Jnanendra et al. (2005) published a book on algal flora of Chilika Lake. Later in 2008, Rath and Adhikary assessed the biodiversity of algae in Chilika Lake. Chlorococcales of eastern and northeastern states were investigated by Jena et al. (2007). Padhi et al. (2010) investigated the algal flora of Mohuda in Orissa. Algal diversity of Ansupa Lake (Behera et al., 2020), and Tampara Lake (Dash et al., 2021) of Odisha were analysed. Bharadwaja (1963) explored the algal flora of Manipur. Jena and Adhikary (2011) noted the algal diversity of Loktak Lake of Manipur. In 2010, Das et al. explored the algae of Tripura. Das and Adhikary inspected the diversity of freshwater algae in Arunachal Pradesh (Das & Adhikary, 2012a), Nagaland (Das & Adhikary, 2012b), Cherapunjee and Mawsynram (Das & Adhikary, 2012c). Bhakta and Adhikary (2014) studied the algae of streams and waterfalls of eastern and northeastern regions. Algae in selected aquatic bodies of Bhubaneswar were noted by Roy et al. (2016).

Suxena and Venkateswarlu studied desmids of Kashmir (Suxena & Venkateswarlu, 1968) and Andhra Pradesh (Suxena & Venkateswarlu, 1966, 1970). Along with Jitendra, Anand noted the occurrence of the genus *Oedogonium* in the Shivalik Himalayas (Anand & Jitendra, 2006). Kant and Anand (1978) noted the phytoplankton and physical factors of Mansar Lake. With Gupta, Kant (Kant & Gupta, 1998) prepared algal flora of Ladakh reporting eight hundred and forty-eight species. Habib studied on desmids (Habib, 1995; Habib & Pandey, 1990a), Chlorococcales (Habib, 1996, 2002; Habib & Chaturvedi, 2001; Habib et al., 1998; Eugleninae (Habib & Pandey, 1990b) and Cyanophyceae (Habib et al., 1992a, 1992b). Gonzalves published a monograph on Oedogoniales (Gonzalves, 1981). Reddy et al. (1986) investigated blue-green algae in North-east India. Shukla and Shukla (1987) contributed to the algal flora of Kanpur. Shukla et al. studied Chlorococcales (Shukla et al., 2007) and desmids (Shukla et al., 2008) from the foothills of Western Himalaya. Bhakta et al. (2010) researched on algal flora of Sikkim. Yasmin et al. (2011) documented the planktonic desmid flora of the south-eastern Himalayas, while in 2015, they evaluated the aquatic algae of Kaziranga National Park in Assam. Pond ecosystems in southern-Assam were studied for algae by Sharma et al. (2019). Das and Keshri studied the desmids of Kechiperi Lake (Das & Keshri, 2013). They noted the diversity of *Scenedesmus* (Das & Keshri, 2015), Chlamydomonadales (Das & Keshri, 2017a) in the foothills of Eastern Himalayas. Later, the algal diversity in the foothills of the Eastern Himalayas were comprised by them in three volumes (Das & Keshri, 2017b, 2017c, 2017d). The occurrence of *Audouinella chalybea*, a rare red alga was reported by Keshri and Mal (2023) from Eastern Himalaya. Nautiyal et al. (2004) discovered significant taxonomic richness in the diatom flora of Himalayan streams. Nath and Baruah (2021) checklisted phytoplankton in the foothill of the Arunachal Himalayas. Lone et al. (2021) published freshwater algal flora of Dal Lake in Kashmir. Algae of Mandakini River of Garhwal Himalaya were observed by Kumar et al. (2020). Diatoms of the world's highest aquatic environments from Western Himalaya were explored by Pardhi et al. (2023).

Kerkar and Madkaiker (2003) in quested blue-green alga from Goa. Shetiya and Kerkar (2004) studied algal flora of rice fields from Tiswadi of Goa. Geeta and Kerakar (2009) documented the freshwater green algal flora of Parsem in Goa.

Misra recorded freshwater algae of Uttar Pradesh (Misra & Srivastava, 2005; Misra et al., 2008; Misra et al., 2009). He studied diatoms (Misra et al., 2007), planktonic algae (Misra et al., 2004), filamentous chlorophyte algae (Misra et al., 2005) and Cyanophyceae (Misra et al., 2010). Suseela surveyed Garuda tal, of the Bundelkhand region of Uttar Pradesh (Suseela & Dwivedi, 2001, 2002) and Changu Lake of Sikkim (Suseela & Toppo, 2004). Suseela with Toppo studied desmids (Suseela & Toppo, 2009, 2011) and red algae (Suseela & Toppo, 2015). Jargo reservoir of Uttar Pradesh which is along River Ganga Basin was assessed for phytoplankton (Kumar et al., 2020).

Kumaraswamy et al. (2013) reported algae from reservoirs of Warangal in Andhra Pradesh. The Riwada reservoir of Visakhapatnam was studied for algae by

Kaparapu and Geddada (2013). New records of algae were reported from the YSR Kadapa district by Mallikarjuna et al. (2019).

Algal diversity of twenty-nine species from Hadhinaru Lake of Karnataka with physicochemical parameter analysis was done by Basavarajappa et al. (2010). Tungabhadra River was analysed for phytoplankton by Suresh et al. (2013). Two lakes of Telangana were also assessed for phytoplankton (Srinivas & Aruna, 2018).

Andhale and Papdiwal (2010) discussed the Chlorococcales diversity of the Jayakwadi bird sanctuary. Jayabhaye et al. (2007) discussed the phytoplankton diversity of the Parola Dam of Maharashtra. Reddy (2021) investigated major rivers of Chandrapur district recording new freshwater algae from Maharashtra. Rena reservoir of Godavari River Basin is assessed for phytoplankton by Alapure et al. (2024). Mul Lake of Chandrapur district is inspected for phytoplankton diversity (Borkar, 2024).

Sabarmati River of Gujarat was assessed for phytoplankton diversity by Kumar et al. (2012a). In Himachal Pradesh, Thakur et al. (2013) evaluated the plankton diversity in three freshwater lakes of Mandi, while Jindal et al. (2014) studied the phytoplankton dynamics of Prashar Lake. Rudrasagar Lake in Tripura, a Ramsar site was evaluated for phytoplankton by Bharati et al. (2020). Diatoms from different rivers in Chattigarh were identified by Tandon et al. (2023). Phytoplankton of Kanwar Lake of Bihar was studied by Saroj et al. (2023). Phytoplankton dynamics in the high-altitude lake of Tawang of Arunachal Pradesh is achieved by Bushi and Nimasow (2024). Devi and Bhatnagar (2024) analysed phytoplankton in lentic water bodies of Haryana. Ottu reservoir of Haryana was also evaluated (Mehta et al., 2024). Mehta and Pandey (2024) inspected the plankton diversity of the Bluebird Lake of Haryana. Joshi and Joshi (2024) assessed phytoplankton diversity in the Baur reservoir of Uttarakhand. Kosi River of Uttarakhand is also examined for phytoplankton (Gehlot et al., 2024). Singh et al. (2024) identified phytoplankton in the Sai River of Uttar Pradesh.

Chapter 3

Materials and Methods

3.1 Study area

Our study area is Wayanad, a district set on the mountains of Western Ghats in Kerala with an altitudinal range of 700 and 2100 msl. The district is located at the southern end of the Deccan Plateau. It lies between 11.6994˚N and 76.0773˚E and shares its border with states Tamil Nadu and Karnataka. The district has an area of 2131 sq. km. which is 5.48 per cent of the state's total area (https://wayanad.gov.in/). When the state of Kerala was formed in 1956, Wayanad was part of the Cannannore district. Then in 1957, South Wayanad joined to Kozhikode district and North Wayanad remained in Cannnanore. It was in 1980, the district Wayanad came into existence through the amalgamation of North and South Wayanad. The district consists of three taluks: Vythiri, Sulthan Bathery, and Mananthavady, along with four blocks: Kalpetta, Mananthavady, Sulthan Bathery, and Panamaram. Kalpetta is the district headquarters and Sulthan Bathery, and Mananthavady are other cities in the district.

Seventy-four percent of Wayanad's total geographical area is covered by forests, which is the highest in the state (Kerala State Planning Board, 2023). Over 95% of the population in the district is rural, making it the least urbanized district compared to others. Agriculture and tourism are the chief support of the economy in the district. 51.4% of the total area of the district is cultivated land. (https://wayanad.gov.in/). Apart from being the chief producer of coffee and pepper, paddy is also seen cultivated in Wayanad. It is said that the district got its name from the word ‘Vayal Nadu’ which means paddy fields. But now paddy fields have been converted to cash crops like coffee, tea and spices. A decline in the area under the paddy of Wayanad compared to 2020–21 is reported in the Economic Review of 2022 (Kerala State Planning Board, 2023). Wayanad hosts the highest population of indigenous people, which is 17.43% of the population, including Paniyas, Adiyas, Kattunayakan and Kurichiyans.

The district enjoys a uniformly pleasant climate throughout the year. South-West and North-East monsoon supply ample rain in the district. The average rainfall is 2,300mm per year. Lakkidi, the place which gets the highest rainfall in Kerala is in Wayanad. A range of 28.9˚C to 36.2˚C is the maximum temperature range and 17˚C to 23.4˚C is the minimum temperature range. April is the hottest month, and July is the coolest month of the year. Due to climate change, unpredicted floods, landslides, and heat waves are happening in Wayanad. A series of landslides have been experienced by the district from 2018–2024. These disasters not only caused a death toll but affected the biodiversity of the area also. Through GIS and remote sensing, landslide-vulnerable zones of Wayanad have been identified. Results indicate study sites such as Chembra Peak and Hills of Banasurasagar Dam to be highly unstable land while Kuruva Islands and Thirunelly temple as moderately stable regions (Jishnu, 2013).

The entire Wayanad district is drained by the Kabini River and its three tributaries namely, Mananthavady River, Panamaram River, and Thirunelly River. The Wayanad Plateau, with an elevation above 700 msl, slopes towards the East, giving rise to the Kabini River, one of the three East-flowing rivers in Kerala. It is a significant tributary of the Cauvery River. One of the tributaries of Kabini, the Panamaram River originates in Lakkidi and reaches Panamaram and flows towards Mananthavady. Later it unites with Mananthavady Rivulet originated from Thodarmudi and became Kabani. When Kabani reaches Karnataka, it is known as Cauvery. The western part of Wayanad is drained by the rivers Valapattanam, Kuttiyadi, and Chaliyar. The district predominantly features four types of soil such as, laterite soil, brown hydromorphic soil, forest loam, and riverine alluvium. The rock types found in Wayanad include Archaean supra-crustal gneisses and charnockites, Proterozoic basic and acidic intrusives, sub-recent laterite, and recent alluvial deposits (Department of Mining & Geology, 2016).

Wayanad, a biodiversity hotspot and part of the Nilgiri Biosphere Reserve in Kerala, is a green paradise known for its unique and diverse flora and fauna. The Wayanad Wildlife Sanctuary, the second largest wildlife sanctuary in Kerala, is a UNESCO World Heritage site and home to the state's largest tiger population. The district features Muthanga Wildlife Sanctuary in the south and Tholpetty Wildlife Sanctuary in the north. Muthanga borders the Bandipur Tiger Reserve in Karnataka and Mudumalai National Park in Tamil Nadu, while Tholpetty is near Nagarhole National Park in Karnataka. The rich biodiversity of Wayanad highlights the need for comprehensive taxonomic and ecological research.

3.2 Methodology

Taxonomical and ecological studies of freshwater algae are planned in Wayanad. Algal samples were collected from various locations across the region, with the collection sites categorized into temporary and permanent sites. Sampling at temporary sites was random and not repeated, focusing solely on exploring taxonomical diversity. In contrast, samples from permanent sites were collected seasonally over two years for the purpose of ecological studies. The map of study area is represented in Figure 1. Red dots in Figure 1 represent collection sites and black circles denote permanent collection sites such as S1, S2, S3, S4, S5 and S6.

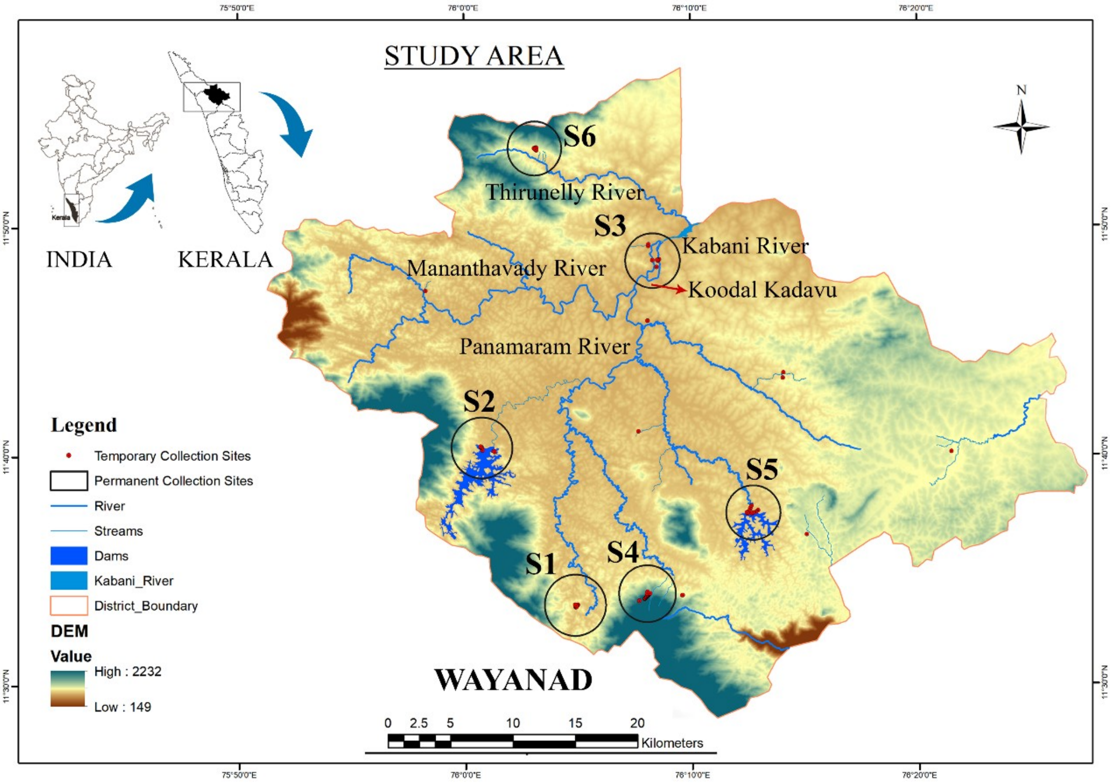


Figure 1. Map showing water bodies of Wayanad with collection sites

S1-Pookode Lake, **S2**-Banasurasagar Dam, **S3**-Kuruva islands, **S4**-Heart Lake, **S5**-Karapuzha Dam, **S6**-Papanasini River.

3.2.1. Taxonomical studies

To explore the algae of Wayanad, water samples were collected from various sites including lakes, rivers, dams, islands, puddles, paddy fields, ponds, streams, brooks, canals, temple ponds, quarries, tea plantations, and rock crevices (Plate 1). The samples were gathered randomly using a small cup, syringe, or by squeezing submerged plants, and preserved in 4% formalin (APHA, 1998). In the laboratory, the samples were allowed to settle and were examined under a microscope. Photomicrographs were captured using a MICAPS digital camera attached to a LABOMED LX 400 microscope. The images were then edited and arranged using Adobe Photoshop CS6. Species identification was carried out based on standard literature and scientific papers (Turner, 1892; West & West, 1904, 1905, 1907, 1908, 1912; Smith, 1920, 1924; Hustedt, 1930; Prescott, 1951; Korshikov, 1953; Desikachary, 1959; Scott & Prescott 1961; Ralfs, 1962; Philipose, 1967; Sarode & Kamat 1984; Prasad & Misra, 1992; Croasdale & Gronblad, 1964; Philipose, 1984, 1988; Wolowski, 1998, Wolowski et al., 2013; Coesel & Meesters, 2007). The online data repositories like the Biodiversity Heritage Library of New York Botanic Garden (https://www.biodiversitylibrary.org/), Algae Base (https://www.algaebase.org/), and Diatoms of North America (https://diatoms.org/), were used. Taxonomical descriptions were prepared by consulting various sources for the identification of taxa; however, only one reference that closely matched the species collected, was cited alongside the description. Among all recent classifications of algae, Fritsch's (1945) classification system was found to be the most authentic, widely accepted, and comprehensive, and it is used in this study. According to Fritsch, algae are classified into eleven classes, namely: Chlorophyceae, Xanthophyceae, Chrysophyceae, Bacillariophyceae, Cryptophyceae, Dinophyceae, Chloromonodineae, Euglenineae, Phaeophyceae, Rhodophyceae and Cyanophyceae (Myxophyceae) based upon pigments, flagella, and reserve food material. Systematic positions of algae were assigned under Prescott (1982). The systematic positions of members of Volvocales, Chlorococcales, Desmids, Bacillariophyceae, Euglenophyceae and Cyanophyceae were assigned based on Iyengar and Desikachary (1981), Philipose (1967), West and West (1904, 1905, 1907, 1908, 1912), Sarode and Kamat (1984), Wolowski (1998), and Desikachary (1959) respectively. The current name of each organism is noted using Algae Base (Guiry & Guiry, 2024). The water samples were kept in the Department of Botany, St. Thomas College, Thrissur, Kerala.

3.2.2. Ecological studies

For ecological studies of the algae, we selected six permanent sites for collection namely Pookode Lake, Banasurasagar Dam, Kuruva Islands, Heart Lake, Karapuzha Dam and Papanasini River, considering their ecological significance (Plate 2).

Plate 1 (Figs. A-O): Temporary collection sites of study area
A) Small stream **B)** Quarry land **C)** Brook **D)** Rock crevice **E)** Paddy field **F)** Temple Pond **G)** Tea plantation **H)** Puddle **I)** Canal **J)**, **K)** and **L)** Different algal collecting techniques from study areas **M)** *Cabomba furcata*, an invasive weed infestation in Pookode Lake **N)** Bana Hills surrounding Banasurasagar Dam **O)** Monsoon rain effect in Kuruva Islands.

Pookode Lake

Pookode Lake or Pookot Lake is the highest altitude freshwater Lake (770 msl) of Kerala and the only natural freshwater Lake of Wayanad. It is the smallest freshwater Lake in Kerala with 8.5 hectares area and 7m depth, surrounded by the beauty of Western Ghat forests near Kalpetta. It is the origin site of the Panamaram River which later joins with Kabini River. The Lake is a major tourist attraction of the district. One of the fascinating features is that the lake naturally has the shape of India in an aerial view. This perennial freshwater Lake is renowned for hosting unique flora and fauna. *Pethia pookodensis* is a fish which is endemic only to this Lake. The Lake has abundant blue waterlilies and fishes. Frogs are seen abundantly in the lake in the monsoon season. The lake is now dying due to various anthropogenic activities and eutrophication. Nutrient runoff from nearby farmlands makes the lake nutrient-rich. During our field visits, fast-growing invasive weeds like *Cabomba furcata*, *Lantana camara*, and *Eichornia* sp. were present at the site which may disrupt the Lake ecosystem. The lake banks are noted with numerous Indirana frogs in monsoons, which are endemic to Western Ghats. A total of 15.26% of the catchment area is agriculture and 10.46 % is forests. The water of the lake is used by the State Fisheries Dept. for aquaculture. Pedal boating is present as a recreational activity in the lake.

Banasurasagar Dam

Banasurasagar Dam is located on the Karamanathodu tributary of the Panamaram River in Padinjarathara village of Wayanad. It is built as a part of Indian Banasurasagar Project of 1979 to support Kakkkayam Hydroelectric power project. It is a dam at the foothills of Banasura Hills (2073 metres), a part of the Western Ghats. Banasura Hills is one of the highest peaks between Nilgiri Hills and the Himalayas after Chembra Peak. It is one of the major tourist spots and trekking areas. The dam has 38.5 m height and 685 m length. It is the largest earth dam in India and the second largest in Asia. The effect of quarrying started to affect the slope stability of Banasura Hills causing landslides in the area (Sajinkumar et al., 2014).

Kuruva Islands

Kuruva Islands or Kuruvadweep is a 950-acre protected river delta including scattered islands on the Kabini River. The area is uninhabited, pristine with unique biodiversity located in 700 msl. This virgin evergreen forest is home to several rare plants, birds, and animals. It is a haven for migratory birds and rare species of orchids. The entry is restricted by Vana Samrakshana Sena by the forest department of Kerala. It is one of the fragile and sensitive biodiversity hotspots in the Western Ghats. A study shows an increase in the number of vector mosquitoes in the area, which is a sign of human alteration of natural habitat (Aneesh et al., 2014). This rare highland riverine island forest needs ecotourism measures for its conservation.

Heart Lake

It is a small, never-drying, heart-shaped lake situated on the top of green meadows of Chembra Peak, at an altitude of 2100 msl. It is situated at Meppady, south of Kalpetta and belongs to the Wayanad Hills of Western Ghats. Chembra Peak is the highest peak in the district, joining Nilgiri Hills in Tamil Nadu and Vellarimala in Kozhikode of Kerala. A marvellous view of Wayanad can be seen from here after a trekking of 3 km. The trekking was subjected to restriction by the Forest Department. The hills and forest are so pristine and stunning. The lake is a source of water for elephants and other animals in the forest.

Karapuzha Dam

The Karapuzha Dam, built on the banks of the Karapuzha River, a tributary of the Kabini River. It was constructed for irrigation purposes in 1975. Located at 11.6223816˚N latitude and 76.170175˚E longitude, the dam sits within the Western Ghats. It is the second largest earth dam in India, with a height of 28 meters and a length of 625 meters. The reservoir has a gross storage capacity of 76.50 million cubic meters. The lush vegetation surrounding the dam attracts a variety of birds, making it a popular spot for bird watchers. The dam area has also become a notable tourist attraction in Wayanad.

Papanasini River

Papanasini is the mountain stream in Wayanad originating from Brahmagiri Hills and later joined with the Kabini River of Wayanad. It is on the premise of Thirunelly Temple and the pilgrims bathe in it believing the river resolves their sins. Cremation ashes are immersed here and considered sacred as a part of temple rituals. Studies reveal that these practices are now causing organic pollution affecting water quality (Mahadev et al., 2011). This can cause serious effects on the river ecosystem.

Plate 2 (Figs. A-F): Permanent Collection sites of the study area

A) Pookode Lake, **B)** Banasurasagar Dam, **C)** Kuruva Isands, **D)** Heart Lake, **E)** Karapuzha Dam, **F)** Papanasini River.

These six sites are permanent collection locations, evaluated seasonally over two years, from 2019–2021. The seasons were categorized into three such as Pre-monsoon (February-May), Monsoon (June-September), and Post-monsoon (October-January). The ecological studies of the study area encompass the analysis of physicochemical parameters, correlation analysis, quantitative analysis, community structure and diversity analysis, as well as pollution analysis at the six selected sites.

2.1. Physicochemical parameter analysis

Physicochemical parameters such as temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), and dissolved oxygen (DO) of water were measured using standard instruments on-site. Nutrients like nitrate, phosphate, and silicate were analysed in the laboratory following the guidelines of APHA (1998). These parameters were then compared against the permissible limits established by WHO (1999). Table 1 shows the parameters analysed in the study, their analytical method, instrument and unit.

Table 1. List of physicochemical parameters analysed in the study, their analytical method, instrument and unit

SL NO	PARAMETER	METHOD	INSTRUMENT	UNIT
1	Temperature	Electrometry	HM Digital pH / TEMP meter PH-80	˚C
2	pH	Electrometry	HM Digital PH-80 Hydrotester	–
3	Electrical Conductivity (EC)	Electrometry	HM Digital COM-80 EC/ TDS Hydrotester	µmho/ cm
4	Total dissolved solids (TDS)	Electrometry	HM Digital COM-80 EC/ TDS Hydrotester	ppm
5	Dissolved Oxygen (DO)	Electrometry	Lutron Digital DO meter PDO-519	mg/ L
6	Nitrate	Brucine method (Trivedi & Goel, 1984)	UV-Visible spectrophotometer	mg/ L
7	Phosphate	Stannous chloride method (APHA, 1998)	UV-Visible spectrophotometer	mg/ L
8	Silicate	Molybdosilicate method (APHA, 1998)	UV-Visible spectrophotometer	mg/ L

These eight physicochemical parameters were analysed for seasonal and spatial variation. Statistical tools and software such as Microsoft Excel Worksheet, SPSS and PAST 4.11 were used to analyse, comprehend, and interpret data conveniently. Univariate analyses like mean, range, standard deviation, and standard error of physicochemical parameters were calculated. To find out significant variations of parameters across seasons and sites, analysis of variance (One-way ANOVA) is performed at a 5% level. Pearson correlation coefficient is performed between parameters at a 5% level to statistically evaluate the interrelationship within the parameters and a correlation plot is prepared. The findings of the study are explained with monthly rainfall data obtained from the Kerala Water Resource Information System (KeralaWRIS).

3.2.2.2 Quantitative analysis

For ecological studies, three random samples are taken from each site. Each sample is of a litre and is meant for algal analysis. Such three samples are taken from a site. Algae were enumerated using the Sedgewick-Rafter cell method (Trivedy & Goel, 1984). Water samples were agitated and added drop by drop till the cavity of Sedgewick Rafter cell of 1 ml volume is filled. Then the algae were counted after proper sedimentation using a microscope. Colonial and filamentous forms are counted as a single unit.

$$\mathbf{N = nv / V}$$

Where, N = Average number of phytoplankton cells in 1 ml of sample, n = Total number of phytoplankton cells per litre of water, v = Volume of plankton concentrates and V = Total volume of water collected. In this study, 20 counts and 3 replicates were taken per each sample.

3.2.2.3 Community Structure and Diversity Analysis

Identifying frequent and dominant taxa of the community provides a clear community structure of the area. Calculating the Frequency index (Soyer, 1980) and quantitative dominance index (Bellan-Santini, 1969) will give the idea of structure of phytoplankton community.

The frequency index, $\mathbf{f\,\% = m / M \times 100}$

Where, m = number of samples where the species were found and M = number of all samples.

The quantitative dominance index, **DI % = d / D x 100**

Where, d = individual number of species in the samples and D = total individual number of all the species in samples.

According to Whittaker (1960) total species diversity, γ diversity is determined through α diversity and β diversity. Alpha diversity refers to the species diversity within a specific habitat or community, while beta diversity reflects the differences or similarities in species composition between different communities. Alpha diversity is quantified using diversity indices that assess species richness, evenness, and dominance. Common indices include Margalef's Richness Index, Pielou's Evenness Index, and Simpson's Dominance Index. Combined biodiversity index like Shannon-Wiener index is also calculated. Margalef's Richness index (Margalef, 1958) is a simple measure of species richness. Species richness denotes the number of species in the community.

Margalef's Richness index, $\mathbf{R = (S-1) / \ln N}$

where S = Total number of species in the community, ln = natural and N =Total number of individuals in the community

Species evenness is the fact that some species are common, and others are rare in the community. The Evenness Index measures how equally individuals are distributed among species in a community, and Pielou's Evenness Index (Pielou, 1966) specifically quantifies the similarity in abundance between different species.

Pielou's Evenness Index, $\mathbf{J' = H' / \ln S}$

where H' = Shannon and Wiener's diversity index, S = total number of species in the community and ln = natural logarithm.

Simpson's Dominance Index (Simpson, 1949) calculates the probability that two randomly selected individuals from a community will belong to different species, with the value decreasing as species richness and evenness increase.

Simpson's Dominance Index, $\mathbf{D = \sum (n_i / N)^2}$

where n_i = number of individuals of the i^{th} species and N = the total number of individuals for all species.

The Shannon-Wiener Index, on the other hand, considers both species richness and evenness, providing a more comprehensive measure of biodiversity. The Shannon-Wiener index (Shannon and Weaver, 1949) increases with richness and evenness and gives more emphasis on richness than on evenness. Seasonal and spatial variation in algal diversity will be revealed through these indices.

$$\text{Shannon-Wiener Index, } \mathbf{H = -\Sigma\, P_{\mathit{i}} \ln P_{\mathit{i}}}$$

where H = Shannon and Wiener's index, $Pi = n_i / N$ and is the proportion of individuals found in the i^{th} species, n_i = number of individuals of the i^{th} species, N = Total number of individuals of all the species in the sample and ln is the natural logarithm.

Beta diversity refers to the variation in species composition between two communities, indicating their similarity or dissimilarity. It can be measured using techniques like Hierarchical Cluster Analysis (HCA) and Non-metric Multidimensional Scaling (NMDS), both are based on the Bray-Curtis similarity index. HCA produces a dendrogram, grouping similar or dissimilar sites and seasons based on the algae observed in the study. NMDS, on the other hand, generates a 2D plot that arranges sites or seasons with similar species distributions close to each other. These analyses help visualize a multidimensional distance matrix in two dimensions, facilitating a clearer understanding of ecological patterns.

3.2.2.4 Correlation analysis

Different multivariate analyses help in solving the phytoplankton dynamics and parameter fluctuations across seasons and sites. To elucidate the relations between algae and parameters, multivariate analysis like Canonical Correspondence Analysis (CCA) is performed. This explains the niche of a particular taxa in an environment. CCA provides the correlation between phytoplankton dynamics and parameters across seasons and sites. An Indicator species or genus reflects the biotic or abiotic state of an environment. Indicator analysis identifies species or genus indicative of the environment (Dufrene & Legendre, 1997). This analysis helps in revealing the indicator taxa of each season and site. From the table of p values taxa whose $p \leq 0.05$ is considered a significant indicator.

3.2.2.5 Pollution analysis

3.2.2.5.1 Nutrient Pollution Index (NPI)

The Nutrient Pollution Index (NPI) assesses drinking water quality by evaluating the ratio of nitrate to phosphate concentrations in a water body (Isiuku and Enyoh, 2020). The formula for calculating NPI is:

$$\text{Nutrient Pollution Index, } \mathbf{NPI} = \frac{C_N}{M\,AC_N} + \frac{C_P}{M\,AC_P}$$

Where, $C_{N/P}$ = mean concentrations of nitrate and phosphate in the water body, respectively, $MAC_{N/P}$ = the permissible concentrations of nitrate and phosphate, with values of 50 mg/L and 5 mg/L, respectively as per WHO guidelines.

The interpretation of NPI is as follows:

- If NPI<1, there is no pollution.
- If 1≤NPI≤3, the water is moderately polluted.
- If 3<NPI≤6, the water is considerably polluted.
- If NPI>6, the water is very highly polluted.

3.2.2.5.2 Palmer’s Algal Pollution Index

Palmer’s Algal Genus Pollution Index was formulated by compiling reports of 165 authors by Mervin Palmer (Palmer, 1969). A pollution index factor was assigned to twenty genera of algae. The presence of pollution-tolerant algae is noted when the algae are more than 50 per ml of the sample. Thus, a score is calculated based on the genus present. If the value is 20 or more per ml, high organic pollution is present. If value is between 15 and 20 high organic pollution is suspected. A score between 10 and 15 is taken as probable organic pollution. If the values are lower, it means the water body is not polluted. Table 2 shows Palmer’s Algal pollution tolerant genera and their corresponding index.

Table 2. Palmer's Algal genus pollution index

Algal genera	Pollution index	Algal genera	Pollution index
Anacystis	1	*Micractinium*	1
Ankistrodesmus	2	*Navicula*	3
Chlamydomonas	4	*Nitzschia*	3
Chlorella	3	*Oscillatoria*	5
Closterium	1	*Pandorina*	1
Cyclotella	1	*Phacus*	2
Euglena	5	*Phormidium*	1
Gomphonema	1	*Scenedesmus*	4
Lepocinclis	1	*Stigeoclonium*	2
Melosira	1	*Synedra*	2

3.2.2.5.3 The diversity index of Boyd

Boyd's Diversity Index provides insight into the pollution level of a water body by assessing its diversity (Boyd, 1981). It is calculated using the formula:

$$\text{Boyd's diversity index, } \boldsymbol{H} = \frac{(S-1)}{\ln N}$$

Where, S = number of genera of phytoplankton, N = total number of phytoplankton, ln = natural logarithm.

The interpretation of Boyd's Diversity Index is as follows:

- Values greater than 4 indicate less pollution in the water.
- Values between 2 and 3 are characterized by moderate pollution.
- Values less than 1 are considered indicative of heavily polluted areas.

Chapter 4

Results

4.1 Taxonomical studies

Algal samples were collected from different sites to comprise the algal flora of Wayanad (Appendix 1). A total of 106 genera, 392 species and 442 taxa were identified from the study area between 2019–2021, belonging to 6 divisions, 7 classes, 16 orders, 43 families, and 106 genera. The taxa enumeration reveals 224 taxa in the Division Chlorophyta, 150 in Bacillariophyta, 38 in Euglenophyta, 22 in Cyanophyta, 4 in Pyrrhophyta and 4 in Chrysophyta. Class Chlorophyceae is represented by 224 taxa, Bacillariophyceae by 150 taxa, Euglenophyceae by 38 taxa, Cyanophyceae by 22 taxa, Dinophyceae by 4 taxa, Chrysophyceae by 3 taxa and Xanthophyceae by 1 taxon. Each identified alga is listed, with its presence across the study sites in Table 3. Algal species present in other sites than S1, S2, S3, S4, S5 and S6 are collected from temporary collection sites. The collection number of each alga from temporary site is denoted as suffix. Collection numbers denoting the habitat and location is provided in Appendix 1.

The classification of Fritsch (1945) was adopted for examination and the systematic positions of the algae are assigned according to Prescott (1982). The taxa are arranged in the following order.

Division I-Chlorophyta (Class-Chlorophyceae)

Division II-Chrysophyta (Class-Xanthophyceae and Chrysophyceae)

Division III-Bacillariophyta (Class-Bacillariophyceae)

Division IV-Euglenophyta (Class-Euglenophyceae)

Division V-Pyrrhophyta (Class-Dinophyceae)

Division VI-Cyanophyta (Class-Cyanophyceae)

Table 3. List of algae identified and their presence in study sites

Sl. No.		S1	S2	S3	S4	S5	S6	OTHERS
	Division: Chlorophyta							
	Class: Chlorophyceae							
	Order: Volvocales							
	Family: Volvocaceae							
1	*Pandorina cylindricum*	+						+[31]
	Family: Sphaerocystidaceae							

2	*Sphaerocystis schroeteri*		+			+		+[2]
	Order: Tetrasporales							
	Family: Palmellaceae							
3	*Gloeocystis planctonica*					+		
	Order: Chlorococcales							
	Family: Chlorococcaceae							
4	*Asterococcus limneticus*					+		
5	*Chlorococcum infusionum*	+		+				
	Family: Characeae							
6	*Schroederia* sp.1				+			
	Family: Micractiniaceae							
7	*Golenkinia paucispina*				+			
8	*Golenkiniopsis minutissima*				+			
9	*Trochiscia granulata*							+[31]
	Family: Hydrodictyaceae							
10	*Pediastrum biradiatum* var. *longicornutum*	+			+			
11	*P. duplex* var. *reticulatum*	+						
12	*P. duplex* var. *subgranulatum*	+						
13	*P. tetras*				+			+[33]
14	*P. tetras* var. *tetraodon*				+			
15	*Sorastrum americanum*	+						
16	*Tetraedron caudatum*				+			
17	*T. gracile*	+	+					
18	*T. lobulatum* var. *polyfurcatum*	+						
19	*T. regulare*	+						
20	*T. regulare* var. *torsum*	+	+					
21	*T. trigonum*	+		+				
22	*T. trigonum* var. *longispinum*		+					
23	*T. victoriae*		+					
	Family: Oocystaceae							
24	*Planktosphaeria gelatinosa*					+		+[31]
25	*Glaucocystis nostochinearum*					+		
26	*Glaucocystis* sp.1					+		
27	*Nephrocytium agardhianum*		+					
28	*N. allantoideum*		+					
29	*Oocystis lacustris*				+			
30	*O. pusilla*					+		
31	*O. solitaria*				+			
	Family: Botryococcaceae							
32	*Botryococcus braunii*					+		
	Family: Dictyosphaeriaceae							
33	*Dictyosphaerium ehrenbergianum*	+						

34	*D. pulchellum*	+			+			
35	*D. pulchellum* var. *ovatum*							
36	*Dimorphococcus lunatus*	+						
	Family: Radiococcaceae							
37	*Eutetramorus planctonicus*					+		
38	*E. polycoccus*	+				+		
39	*Coenocystis subcylindrica*					+		
40	*Radiococcus nimbatus*							+[3]
	Family: Selenastraceae							
41	*Ankistrodesmus densus*	+				+		
42	*A. falcatus*				+	+		
43	*A. falcatus* var. *acicularis*	+						
44	*A. falcatus* var. *mirabilis*	+						+[10, 33]
45	*A. falcatus* var. *spirilliformis*				+			+[33]
46	*A. spiralis*	+	+			+		
47	*Actinastrum aciculare* f. *minimum*				+			
48	*Elakatothrix lacustris*		+					
49	*Kirchneriella contorta*	+						
50	*K. lunaris*	+				+		
51	*K. obesa*		+					
52	*Selenastrum gracile*	+						
	Family: Coelastraceae							
53	*Coelastrum astroideum*			+				
54	*C. cambricum*			+				
55	*C. cambricum* var. *intermedium*	+						
56	*C. microporum*	+				+		
	Family: Scenedesmaceae							
57	*Scenedesmus acutiformis*	+						
58	*S. acuminatus*				+			
59	*S. armatus*			+				+[11]
60	*S. arthrodesmiformis*	+						
61	*S. bijugus* var. *irregularis*							+
62	*S. bijugatus*						+	+[33]
63	*S. bijugatus* f. *parvus*	+						+[33]
64	*S. dimorphus*			+	+			
65	*S. longus* var. *nagelii*			+				
66	*S. opoliensis*			+				
67	*S. quadricauda* var. *longispina*			+				
68	*S. quadricauda* var. *quadrispina*				+			
69	*S. serratus*			+				
70	*Crucigenia crucifera*			+				
71	*Tetrastrum heteracanthum*				+			
	Order: Chaetophorales							

	Family: Chaetophoraceae							
72	*Chaetosphaeridium globosum*					+		
	Family: Chaetophoraceae							
73	*Chaetophora pisiformis*						+	
	Family: Coleochaetaceae							
74	*Coleochaete* sp. 1					+		
	Order: Oedogoniales							
	Family: Oedogoniaceae							
75	*Bulbochaetae* sp. 1				+	+		+[2]
76	*Bulbochaete* sp. 2					+		
77	*Oedogonium* sp. 1							+[26]
78	*Oedogonium* sp. 2		+			+	+	+[25]
	Order: Trentipohliales					+		
	Family: Trentepohliaceae							
79	*Gongrosira debaryana*	+						
	Order: Ulotrichales							
	Family: Ulotrichaceae							
80	*Geminella* sp.1	+						
	Order: Zygnematales							
	Family: Zygnemataceae							
81	*Mougeotia* sp.1					+		
82	*Spirogyra* sp. 1					+		
83	*Spirogyra* sp. 2			+				
84	*Spirogyra* sp. 3						+	
	Family Mesotaeniaceae							
85	*Netrium digitus*					+		
86	*N. digitus* var. *lamellosum*		+					+[96]
	Family: Gonatozygaceae							
87	*Gonatozygon brebissonii*					+		
88	*G. monotaenium* var. *pilosellum*	+						
	Family: Desmidiaceae							
89	*Penium margaritaceum*					+		
90	*P. spirostriolatum*		+					
91	*Closterium abruptum*		+					+[25, 96]
92	*C. archerianum*	+						
93	*C. dianae* var. *minus*					+		
94	*C. infractum*	+						
95	*C. juncidum*			+				
96	*C. lanceolatum*					+		
97	*C. lineatum*						+	
98	*C. moniliferum*			+				
99	*C. navicula*	+						
100	*C. parvulum* var. *angustum*					+		

101	*C. porrectum* var. *angustatum*			+				
102	*C. submoniliferum* var. *malinvernianum*			+				
103	*C. ulna*				+			
104	*C. venus*	+						+[3]
105	*Pleurotaenium ehrenbergii*						+	
106	*P. ehrenbergii* var. *undulatum*		+					
107	*P. nodosum*		+					
108	*P. ovatum* var. *inerme*							+[3]
109	*P. trabecula*					+		
110	*P. trabecula* f. *clavatum*						+	
111	*P. verrucosum*				+			
112	*Triplastrum abbreviatum*					+		
113	*Euastrum acanthophorum* f. *minus*	+						
114	*E. ansatum*				+			
115	*E. denticulatum* f. *incisum*	+						
116	*E. distortum*		+					
117	*E. elegans* var. *pseudelegans*	+						
118	*E. luetkemuelleri*				+			
119	*E. spinulosum*					+		
120	*E. validum*					+		
121	*Micrasterias pinnatifida*	+				+		
122	*M. radians*	+						
123	*Actinotaenium cucurbitinum*				+			
124	*A. curtum*	+	+					
125	*A. diplosporum*					+		
126	*A. turgidum* var. *minus*	+						
127	*A. wollei*						+	
128	*Cosmarium auriculatum*					+		
129	*C. binum*					+		
130	*C. bioculatum* f. *depressum*					+		
131	*C. blyttii*						+	
132	*C. blyttii* var. *novaesylvae*						+	
133	*C. connatum*		+					
134	*C. contractum*					+		
135	*C. contractum* var. *ellipsoideum*					+		
136	*C. contractum* var. *incrassatum*		+					
137	*C. contractum* var. *minutum*	+						
138	*C. cucurbita*		+					
139	*C. cuneatum*	+						
140	*C. decoratum*				+		+	+[16, 3]
141	*C. difficile*					+		
142	*C. exiguum*		+					
143	*C. globosum* f. *minus*					+		

144	*C. granatum*					+		
145	*C. hammeri* var. *protuberans*						+	+[4]
146	*C. impressulum*	+						
147	*C. inornatum*	+						
148	*C. lundellii*	+				+		
149	*C. lundellii* var. *corruptum*					+		
150	*C. lundellii* var. *ellipticum*	+						
151	*C. mansangense*					+		
152	*C. margaritatum* f. *minus*					+		
153	*C. medioscrobiculatum* var. *egranulatum*					+		
154	*C. moniliforme* var. *punctatum*						+	
155	*C. norimbergense*	+						
156	*C. norimbergense* var. *depressum*	+						
157	*C. obtusatum*					+		
158	*C. obsoletum*	+				+		
159	*C. ocellatum*	+						
160	*C. ordinatum*	+						
161	*C. phaseolus* var. *elevatum*					+		
162	*C. porteanum*	+						
163	*C. porteanum* var. *nephroideum*					+		
164	*C. pseudobroomei*					+		
165	*C. pseudoconnatum*		+					
166	*C. pseudoconnatum* var. *ellipsoideum*			+				
167	*C. pseudoprotuberans*	+						
168	*C. pseudamoenum*					+		
169	*C. punctulatum* var. *subpunctulatum*						+	
170	*C. pyramidatum*					+		
171	*C. quadrum* var. *minus*		+					
172	*C. quadratulum*					+		
173	*C. regnesi* var. *montanum*					+		
174	*C. reniforme* var. *elevatum*					+		
175	*C. retusiforme*					+		
176	*C. scabrum*	+						
177	*C. sexangulare* f. *minimum*	+						
178	*C. sexnotatum* var. *tristriatum*	+						
179	*C. speciosum*		+					+[3]
180	*C. subspeciosum*						+	
181	*C. subturgidum* f. *minus*	+						
182	*C. tenue*	+						
183	*C. trachypleurum* var. *nordstedtii*					+		
184	*C. vitiosum* var. *orientale*			+				
185	*C. zonatum*	+						
186	*Arthrodesmus convergens*					+		

187	*A. convergens* f. *curtus*	+				+		
188	*A. octocornis*		+					
189	*A. triangularis*		+					
190	*Xanthidium acanthophorum* var. *raciborskii*	+						
191	*X. antilopaeum* var. *hebridarum*					+		
192	*X. ceylanicum*	+						
193	*X. spinosum*		+					
194	*Staurodesmus mucronatus* var. *subtriangularis*		+					
195	*Staurastrum bigibbum*		+					
196	*S. cerastes* var. *pulchrum*	+						
197	*S. corniculatum* var. *spinigerum*	+						
198	*S. crenulatum*					+		
199	*S. cuspidatum*		+					
200	*S. freemanii* var. *nudiceps*	+	+					
201	*S. gracile* var. *elongatum*	+						
202	*S. heimerlianum* var. *sumatranum*	+	+					
203	*S. indentatum* f. *minus*	+	+					
204	*S. limneticum* var. *burmense*	+	+					
205	*S. longipes*	+						
206	*S. orbiculare* var. *minus*	+						
207	*S. punctulatum*					+		
208	*S. sinense*					+		
209	*S. spiniceps* var. *trifidum*					+		
210	*S. tetracerum*	+	+					
211	*S. teliferum* var. *gladiosum*	+						
212	*S. tohopekaligense* f. *acuminatum*	+	+					
213	*S. tohopekaligense* f. *minus*	+						
214	*S. zonatum* var. *ceylanicum*		+					
215	*Staurastrum* sp. 1	+						
216	*Sphaerozosma excavatum*	+						
217	*S. granulatum*	+						
218	*Spondylosium moniliforme*					+		
219	*S. nitens* var. *triangulare fa javanicum*						+	
220	*S. planum*					+		
221	*Onychonema laeve* var. *micracanthum*	+						
222	*Groenbladia* sp. 1	+			+			
223	*Desmidium baileyi* f. *longiprocessum*		+					
	Division: Chrysophyta							
	Class: Xanthophyceae							
	Order: Heterococcales							
	Family: Centritractaceae							
224	*Centritractus belonophorus*	+						+^{10}

	Class: Chrysophyceae							
	Order: Chrysomonadales							
	Family: Ochromonadaceae							
225	*Dinobryon cylindricum*		+					
226	*D. divergens*	+						
227	*D. sertularia*	+						
	Division: Bacillariophyta							
	Class: Bacillariophyceae							
	Order: Centrales							
	Family: Coscinodiscaceae							
228	*Melosira granulata*		+		+			
229	*M. granulata* var. *angustissima*	+	+		+			
230	*Actinocyclus normanii*	+				+	+	
231	*Cyclotella* sp. 1		+					
	Family: Rhizosoleniaceae							
232	*Rhizosolenia eriensis*		+					
	Order: Pennales							
	Family: Fragilariaceae							
233	*Synedra acus*			+				
234	*S. acus* var. *acula*					+		
235	*S. acus* f. *radians*	+						$+^{4}$
236	*S. tabulata*				+		+	$+^{2}$
237	*S. ulna*			+			+	$+^{3}$
238	*S. ulna* var. *aequalis*			+				
239	*S. ulna* var. *amphirhynchus*						+	
240	*S. ulna* var. *danica*			+				
	Family: Eunotiaceae							
241	*Eunotia alpina*	+					+	
242	*E. arcus*	+						
243	*E. camelus* var. *gibbosa*	+						
244	*E. lunaris*						+	
245	*E. minor*				+			
246	*E. monodon*				+		+	
247	*E. pectinalis* var. *ventralis*						+	$+^{26}$
248	*E. valida*	+					+	
249	*E. zygodon*	+	+		+		+	
	Family: Achnanthaceae							
250	*Cocconeis placentula*	+					+	
251	*Achnanthes crenulata*						+	
252	*A. elata*						+	
253	*A. lanceolata*						+	$+^{1, 16}$
254	*A. lanceolata* var. *elliptica*						+	
255	*A. lanceolata* var. *rostrata*			+				

256	*A. microcephala*		+					+[4]
	Family: Naviculaceae							
257	*Frustulia rhomboides* var. *crassinervia*	+	+					
258	*F. krammeri*				+			+[96]
259	*F. saxonica*			+	+			
260	*Gyrosigma acuminatum*			+				
261	*G. kuetzingii*			+				
262	*Gyrosigma* sp.1			+				
263	*Caloneis silicula*		+					+[4]
264	*Neidium capitellatum*						+	
265	*N. dubium*							+
266	*N. globiceps* var. *biglobosum*				+			
267	*N. gracile*			+	+		+	
268	*N. grande*			+				
269	*N. iridis* f. *dhulense*				+			
270	*N. longiceps*				+			
271	*N. longiceps* var. *undulatum*					+		
272	*N. pseudogracile*				+			
273	*Diploneis elliptica*							+[16]
274	*Stauroneis obtusa* var. *nagpurensis*			+				
275	*S. phoenicenteron* var. *intermedia*				+			
276	*S. phoenicenteron* f. *producta*				+			
277	*Stauroneis* sp. 1			+				
278	*Navicula anglica*			+				
279	*N. cari* f. *indica*						+	
280	*N. cincta* var. *heufleri*			+				
281	*N. constans* var. *symmetrica*		+					
282	*N. cryptocephala*				+			
283	*N. cryptocephala* var. *exilis*				+			
284	*N. cryptocephala* var. *veneta*			+				
285	*N. cuspidata*	+						
286	*N. cuspidata* var. *ambigua*			+				
287	*N. densistriata*						+	
288	*N. disjuncta*			+	+			
289	*N. feuerbornii* f. *minor*			+				
290	*N. gregaria*			+			+	
291	*N. halophila* f. *robusta*			+				
292	*N. laterostrata*				+			
293	*N. mutica*	+						
294	*N. pupula* f. *capitata*			+				+[11]
295	*N. protracta*	+			+		+	
296	*N. pygmaea* var. *indica*			+				
297	*N. radiosa* var. *minutissima*							+[1]

298	*N. radiosa* var. *tenella*			+				
299	*N. rhynchocephala*						+	+[5, 16]
300	*N. rhynchocephala* var. *tenua*			+				
301	*N. salinarum* var. *intermedia*			+				+[4]
302	*N. subrhynchocephala*			+				
303	*N. viridula*							+[4, 5]
304	*Navicula* sp. 1		+					
305	*Pinnularia acrosphaeria* f. *minor*			+				
306	*P. acrosphaeria* f. *undulata*	+						
307	*P. braunii* var. *amphicephala*		+		+			
308	*Pinnularia braunii* f. *subconica*	+						
309	*P. brebissonii* var. *hybrida*						+	+[2]
310	*P. cardinaliculus*						+	
311	*P. conica*			+	+			
312	*P. gibba*	+						+[3]
313	*P. graciloides*	+	+					
314	*P. interrupta* f. *minutissima*				+		+	
315	*P. isostauron*			+				
316	*P. lundii*						+	
317	*P. major* var. *linearis*							+[5]
318	*P. neglecta*				+		+	+
319	*P. neomajor* var. *inflata*							
320	*P. panhalgarhensis*				+			
321	*P. pseudoluculenta*	+						
322	*P. subcapitata* var. *subrostrata*	+						
323	*P. subgibba* var. *undulata*	+						
324	*P. termes* var. *termitina*			+				+[3, 5]
325	*P. viridis*				+			
326	*P. viridis* var. *intermedia*						+	
327	*Amphora* sp.1					+		
328	*Cymbella affinis*			+				
329	*C. gracilis*				+			
330	*C. pseudocuspidata*				+			
331	*C. pusilla*			+				
332	*C. tumida*	+		+				
333	*C. tumidula*					+		
334	*C. turgidula*			+				
335	*C. ventricosa*	+			+			+[16, 96]
336	*C. ventricosa* var. *arcuata*			+				
	Family: Gomphonemaceae							
337	*Gomphonema abbreviatum*			+				
338	*G. gracile*	+					+	+
339	*G. gracile* var. *auritum*	+					+	+[16]

340	*G. gracile* var. *major*	+			+			+[10, 16]
341	*G. gracile* var. *naviculoides*						+	+[26]
342	*G. gracile* var. *subcapitatum*				+			
343	*G. hebridense*	+			+			
344	*G. intricatum* var. *fossile*					+		
345	*G. intricatum* var. *pumilum*			+				
346	*G. lacus-rankala*	+						+[1]
347	*G. lanceolatum*			+		+		
348	*G. olivaceum*						+	
349	*G. sphaerophorum*			+				
350	*G. spicula*	+			+	+		
351	*G. subtile*	+	+		+	+		+
	Family: Epithemiaceae							
352	*Epithemia zebra*						+	
353	*Epithemia* sp. 1					+		+[4]
354	*Rhopalodia gibba*			+		+	+	+[4]
355	*R. gibberula*					+		
	Family: Nitzschiaceae							
356	*Hantzschia amphioxys* f. *capitata*						+	
357	*Hantzschia* sp. 1					+		
358	*Nitzschia apiculata*			+				
359	*N. filiformis*			+				
360	*N. heufleriana*						+	+[5]
361	*N. ignorata*		+					+[96]
362	*N. intermedia*						+	
363	*N. obtusa*	+						
364	*N. lorenziana* var. *subtilis*	+						
365	*N. palea*			+				
366	*N. perminuta*			+				
367	*N. reversa*			+				+[10]
368	*N. sublinearis*						+	
369	*N. thermalis* var. *minor*			+				
370	*N. tryblionella* var. *victoriae*			+				+[16]
	Family: Surirellaceae							
371	*Surirella biseriata*							+[5]
372	*S. linearis*			+	+			+[5]
373	*S. ovata* var. *salina*		+					
374	*S. robusta* var. *splendida*						+	
375	*S. subsalsa*			+	+			
376	*S. tenera*				+			
377	*S. tenera* var. *nervosa*				+			
	Division: Euglenophyta							
	Class: Euglenophyceae							

	Order: Euglenales							
	Family: Astasiaceae							
378	*Astasia harrisii*				+			
	Family: Euglenaceae							
379	*Euglena acus*			+	+			+[31]
380	*E. agilis*				+			
381	*E. deses*				+			
382	*E. ehrenbergii*				+			
383	*E. oxyuris*	+						
384	*E. oxyuris* var. *major*				+			
385	*E. proxima*				+			
386	*E. splendens*		+		+			
387	*E. tripteris*				+			
388	*Euglena* sp.1				+			
389	*Phacus acuminatus*	+					+	+[3]
390	*P. longicauda*	+			+		+	
391	*P. pleuronectes*						+	
392	*P. splendens*				+			
393	*Lepocinclis acicularis*	+						+[2,3]
394	*L. constricta*	+						
395	*L. hispidula*	+						
396	*L. ovum*	+						+[10]
397	*L. ovum* var. *dimidio-minor*				+			+[3,5]
398	*L. ovum* var. *globulus*	+		+	+			
399	*L. playfairiana*				+			
400	*L. spirogyroides*			+				
401	*Trachelomonas abrupta*	+						
402	*T. armata*							+[31]
403	*T. curta*						+	
404	*T. cylindrica*	+					+	+[32]
405	*T. hispida*	+				+	+	
406	*T. hispida* var. *duplex*	+						
407	*T. intermedia*	+						+[2, 31]
408	*T. lacustris*	+						
409	*T. planctonica*	+						+[31]
410	*T. superba*	+						
411	*T. sculpta*	+						
412	*T. volvocina*	+						+[3, 10, 16, 25, 31, 33]
413	*T. volvocinopsis*				+			+
414	*T. woycickii*	+						+[10]
415	*Strombomonas* sp. 1			+				
	Division: Pyrrhophyta							

	Class: Dinophyceae							
	Order: Peridiniales							
	Family: Peridiniaceae							
416	*Peridinium cinctum*		+					
417	*P. inconspicuum*				+			
	Family: Ceratiaceae							
418	*Ceratium furcoides*		+					
419	*Triceratium* sp. 1		+					
	Division: Cyanophyta							
	Class: Cyanophyceae							
	Order: Chroococcales							
	Family: Chroococcaceae							
420	*Chroococcus minutus*					+		+[3]
421	*C. turgidus*					+		+[3]
422	*Aphanocapsa delicatissima*	+						
423	*A. elachista*	+						
424	*A. pulchra*	+						
425	*Aphanothece nidulans*					+		
426	*Coelosphaerium dubium*			+			+	
427	*C. kuetzingianum*							+[11, 33]
428	*Merismopedia minima*					+	+	+[10, 33]
	Order: Nostocales							
	Family: Oscillatoriaceae							
429	*Spirulina subtilissima*		+					
430	*Spirulina* sp. 1				+			
431	*Spirulina* sp. 2	+						
432	*Oscillatoria formosa*		+					
433	*O. limosa*					+		
434	*O. princeps*			+				
435	*O. subbrevis*			+				+[30]
436	*Oscillatoria* sp. 1					+		
	Family: Nostocaceae							
437	*Cylindrospermum muscicola* var. *longisporum*					+		
438	*Nostoc muscorum*					+		
439	*Nostoc* sp. 1					+		
440	*Anabaena* sp. 1			+				
441	*Pseudanabaena catenata*				+			
442	*Scytonema ocellatum*							+[25]

4.1.1 Systematic account

All measurements are in micrometres and the abbreviations used are following:

L = length; W = width; D = diameter, T = thickness; I = width of isthmus; SP = spine; ssp (*sine spinibus*) = without spines; csp (*cum spinibus*) = with spines; spr (*sine processibus*) = without processes; cpr (*cum processibus*) = with processes. Photomicrographs of algae is assembled in plates (Plate 3–32).

Class: Chlorophyceae

Order: Volvocales

Family: Volvocaceae

Genus: *Pandorina* Bory

1. ***Pandorina cylindricum*** M.O.P. Iyengar **(Pl. 3, Fig. A)**
   Iyengar and Desikachary, 1981. p. 420, pl. 245, Figs. 1–17; pl. 246, Figs. 1–12.
   L-17.8, W-13.8
   Cells pyramidal and compactly packed, surrounded by band of mucilage. Colony cylindrical with rounded ends.

Family: Sphaerocystidaceae

Genus: *Sphaerocystis* Chodat

2. ***Sphaerocystis schroeteri*** Chodat **(Pl. 3, Fig. B)**
   Prescott, 1982. p. 83, pl. 3, Figs. 6, 7.
   Cell W-4.9–6, Colony W-58
   Cells spherical in homogenous colonial mucilage. Colony also spherical in shape.

Order: Tetrasporales

Family: Palmellaceae

Genus: *Gloeocystis* Nageli

3. ***Gloeocystis planctonica*** (West & G.S. West) Lemmermann **(Pl. 3, Fig. C)**
   Prescott, 1982. p. 85, pl. 3, Figs. 10, 11.
   Current name: *Chlamydocapsa planctonica* (West & G.S. West) Fott
   Cell W-7.6–9.5, Colony W-116
   Cells are spherical or ovoid, enveloped by lamellate gelatinous sheath in the copious colonial mucilage.

Order: Chlorococcales

Family: Chlorococcaceae

Genus: *Asterococcus* Scherffel

4. ***Asterococcus limneticus*** G.M. Smith **(Pl. 3, Fig. D)**

Smith, 1920. pl. 20, Figs. 7–10.

Cell W-13.2–14

Cells spherical, solitary or as a colony of four, enclosed by homogenous gelatinous sheath. Stelloid chloroplast is the evident distinguishing character of this genus.

Genus: *Chlorococcum* Meneghini Emend. Starr

5. ***Chlorococcum infusionum*** (Schrank) Meneghini **(Pl. 3, Fig. E)**

Philipose, 1967. p. 73, Fig. 1.

D-10.4–18

Cells spherical and solitary.

Family: Characiaceae

Genus: *Schroederia* Lemmermann

6. ***Schroederia*** sp. 1 **(Pl. 3, Fig. F)**

L-18, W-2.9

Cells solitary, spindle shaped, crescent form, curved. Both poles extended into long fine straight setae.

Family: Micractiniaceae

Genus: *Golenkinia* Chodat

7. ***Golenkinia paucispina*** West & G.S. West **(Pl. 3, Fig. G)**

Kim & Kim, 2012. p. 17, Fig. 7 (a-j).

D-10–11, SP-5.8–7

Cells unicellular, solitary with spherical cell surrounded by short setae. Pseudo colonies are seen in some samples.

Genus: *Golenkiniopsis* Korshikov

8. ***Golenkiniopsis minutissima*** (M.O.P. Iyengar & M.S. Balakrishnan) R. Starr **(Pl. 3, Fig. H)**

Philipose, 1967. p. 103, Fig. 28a.

Current name: *Hegewaldia parvula* (Woronichin) Proschold, C. Bock, W. Luo & L Krienitz

D-5.4–6.3, Bristles L-7.5–9

Cells unicellular, solitary with fine bristles.

Genus: *Trochiscia* Kuetzing

9. ***Trochiscia granulata*** (Reinsch) Hansgirg **(Pl. 3, Fig. I)**

Kim, 2013. p. 108, Fig. 96.

D-20, SP-2.7

Cells spherical with thick colourless membrane densely covered by short warts with blunt tips.

Family: Hydrodictyaceae

Subfamily: Hydrodictyoideae

Genus: *Pediastrum* Meyen

10. ***Pediastrum biradiatum*** var. ***longicornutum*** Gutwinski **(Pl. 3, Fig. J)**

Current name: *Parapediastrum biradiatum* var. *longecornutum* (Gutwinski) P.M. Tsarenko

Philipose, 1967. p. 128, Fig. 44 b.

Cell L-7, W-8, Colony W-12.5

Cells with lobes of marginal cells being bifid ending in horn like processes.

11. ***Pediastrum duplex*** var. ***reticulatum*** Lagerheim **(Pl. 3, Fig. K)**

Current name: *Pediastrum duplex* Meyen

Philipose, 1967. p. 124, Fig. 43 g.

Cell W-6.8–8, Colony W-34.8–40

Cells with inner side concave and outer side with two short truncate processes.

12. ***Pediastrum duplex*** var. ***subgranulatum*** Raciborski **(Pl. 3, Fig. L)**

Current name: *Pseudopediastrum subgranulatum* (Raciborski) Lenarczyk

Philipose, 1967. p. 125, Fig. 43 j.

Cell W-9–14.7, Colony W-44–95.5

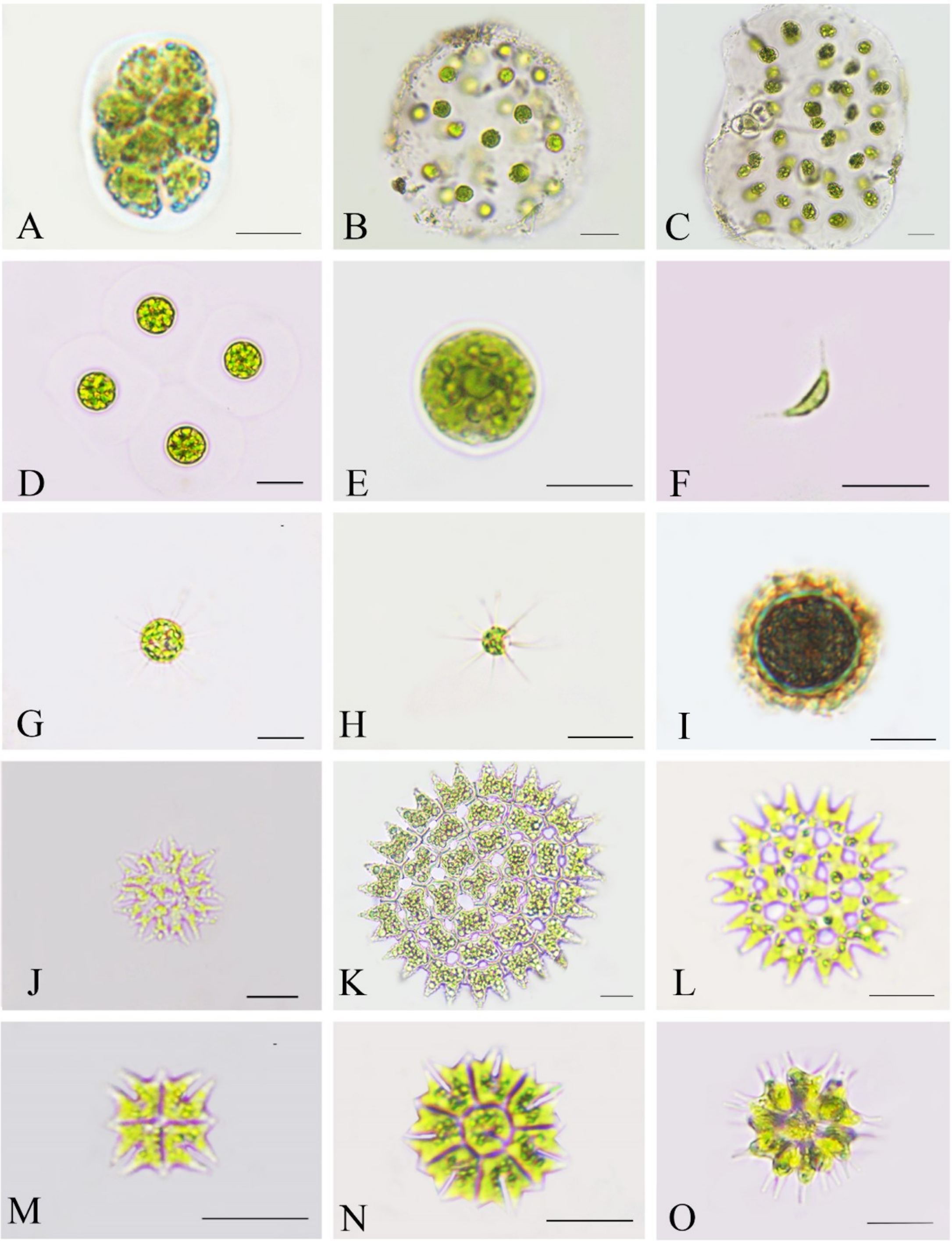
Cells with distinctly granulated cell wall. `

13. ***Pediastrum tetras*** (Ehrenberg) Ralfs **(Pl. 3, Fig. M)**

Current name: *Stauridium tetras* (Ehrenberg) E. Hegewald

Philipose, 1967. p. 129, Fig. 45 f.

Cell W-9, Colony W-13–14



Scale 10µm

PLATE 3 (Figs. A-O): A) *Pandorina cylindricum* M.O.P. Iyengar **B)** *Sphaerocystis schroeteri* Chodat **C)** *Gloeocystis planctonica* (West & G.S. West) Lemmermann **D)** *Asterococcus limneticus* G.M. Smith **E)** *Chlorococcum infusionum* (Schrank) Meneghini **F)** *Schroederia* sp. 1 **G)** *Golenkinia paucispina* West & G.S. West **H)** *Golenkiniopsis minutissima* (M.O.P. Iyengar & M.S. Balakrishnan) R. Starr **I)** *Trochiscia granulata* (Reinsch) Hansgirg **J)** *Pediastrum biradiatum* var. *longicornutum* Gutwinski **K)** *P. duplex* var. *reticulatum* Lagerheim **L)** *P. duplex* var. *subgranulatum* Raciborski **M)** *P. tetras* (Ehrenberg) Ralfs **N)** *P. tetras* var. *tetraodon* (Corda) Hansgirg **O)** *Sorastrum americanum* (Bohlin) Schmidle

Cells at margin divided into two lobes by a deep linear to cuneate incision on the middle of cell. Each lobe is further divided into two lobes. Colonies rectangular without intercellular spaces.

14. ***Pediastrum tetras*** var. ***tetraodon*** (Corda) Hansgirg **(Pl. 3, Fig. N)**

Current name: *Stauridium tetras* var. *tetraodon* (Corda) J.D. Hall & Karol

Philipose, 1967. p. 129, Figs. 45 d, e, g.

Cell W-9.8, Colony W-23.5

Cells with no intercellular spaces. Outer marginal cells with deep incisions resulting in sharp extended horn like processes. In some samples these structures are further lobed.

Genus: *Sorastrum* Kutzing

15. ***Sorastrum americanum*** (Bohlin) Schmidle **(Pl. 3, Fig. O)**

Prescott, 1982. p. 228, pl. 50, Fig. 8.

L-10, W-11, SP-5

Cells heart shaped with stout spine from each angle of outer walls forming spherical colony.

Subfamily: Tetraedronoideae

Genus: *Tetraedron* Kuetzing

16. ***Tetraedron caudatum*** (Corda) Hansgirg **(Pl. 4, Fig. A)**

Philipose, 1967. p. 150, Figs. 64 a-b.

D-3.7, SP-2.5

Cells minute, flat, five sides with one notch in between of a side. Angles of sides rounded and produced into a short straight spine.

17. ***Tetraedron gracile*** (Reinsch) Hansgirg **(Pl. 4, Fig. B)**

Philipose, 1967. p. 154, Figs. 69 a-c.

L-40, W-40

Cells with angles produced into branched processes that are long and well branched in same plane.

18. ***Tetraedron lobulatum*** var. ***polyfurcatum*** G.M. Smith **(Pl. 4, Fig. C)**

Philipose, 1967. p. 158, Figs. 72 a-b.

Wcsp-35, Wssp-18

Cells with short, stunt processes that bifurcate at apices. Processes are not in same plane.

19. ***Tetraedron regulare*** Kutzing **(Pl. 4, Fig. D)**

Philipose, 1967. p. 145, Figs. 60 a-d, f.

W-19.4, SP-6

Cells tetragonal, with concave sides, blunt stout spine on angles.

20. ***Tetraedron regulare*** var. ***torsum*** Brunnthaler **(Pl. 4, Fig. E)**

Current name: *Tetraedriella regularis* var. *torsum* (Brunnthaler) Taskin & Alp

Philipose, 1967. p. 146, Figs. 60 g, j, k, m, n.

L-15.2, W-18.5, I-5.2, SP-2

Cells tetragonal with the two halves twisted in a cruciate manner. Short spine on angles.

21. ***Tetraedron trigonum*** (Nageli) Hansgirg **(Pl. 4, Fig. F)**

Philipose, 1967. p. 142, Figs. 58 i.

W-27.8, SP-6.9–8.7

Cells triangular, flat, sides slightly concave, angles with short and stout spines.

22. ***Tetraedron trigonum*** var. ***longispinum*** Philipose **(Pl. 4, Fig. G)**

Philipose, 1967. p. 144, Figs. 58 j-m.

W-17.6–18, SP-12.4–17.3

Cells triangular with sides slightly concave, angles with long straight spines.

23. ***Tetraedron victoriae*** Woloszynska **(Pl. 4, Fig. H)**

Philipose, 1967. p. 150, Figs. 63 a-b.

L-35.9, W-11

Cells four sided with two of sides deeply emarginate, sides divide cell into cruciate arranged halves.

Family: Oocystaceae

Subfamily: Chlorelloideae

Genus: *Planktosphaeria* G.M. Smith

24. ***Planktosphaeria gelatinosa*** G.M. Smith **(Pl. 4, Fig. I)**

Prescott, 1982. p. 240, pl. 53, Fig. 23.

W-12.8–13.6

Cells spherical with mucilaginous sheath, loosely arranged, and closely clustered as colony. Sometimes seen as solitary in samples.

Subfamily: Oocystoideae

Genus: *Glaucocystis* Itzigsohn emend. Geitler

25. ***Glaucocystis nostochinearum*** Itzigsohn **(Pl. 4, Fig. J)**

Philipose, 1967, p. 188, Fig. 101.

L-16.8–19, W-10–10.6

Cells with blue-green, vermiform, and radiating chromatophores.

26. ***Glaucocystis*** sp.1 **(Pl. 4, Fig. K)**

L-17.4, W-8.7

Cells with truncate apex.

Genus: *Nephrocytium* Nageli

27. ***Nephrocytium agardhianum*** Nageli **(Pl. 4, Fig. L)**

Philipose, 1967. p. 189, Fig. 104.

L-3–6, W-2–7

Cells reniform with rounded ends.

28. ***Nephrocytium allantoideum*** Bohlin **(Pl. 4, Fig. M)**

Bohlin, 1897. p. 18, Tab. 1, Figs. 21–22.

L-9-10.5, W-1.7–2

Cells fusiform, allantoid, cylindrical and convex outwards.

Genus: *Oocystis* Naegeli

29. ***Oocystis lacustris*** Chodat **(Pl. 4, Fig. N)**

Philipose, 1967. p. 181, Fig. 90.

L-7–7.5, W-3.4–4.6

Cells ellipsoid with slight pointed ends. Colonies are with polar nodules.

30. ***Oocystis pusilla*** Hansgirg **(Pl. 4, Fig. O)**

Prescott, 1982. p. 246, pl. 51, Fig. 15, pl. 54, Figs. 4, 5.

L-6.2–9.7, W-4.8–5.6

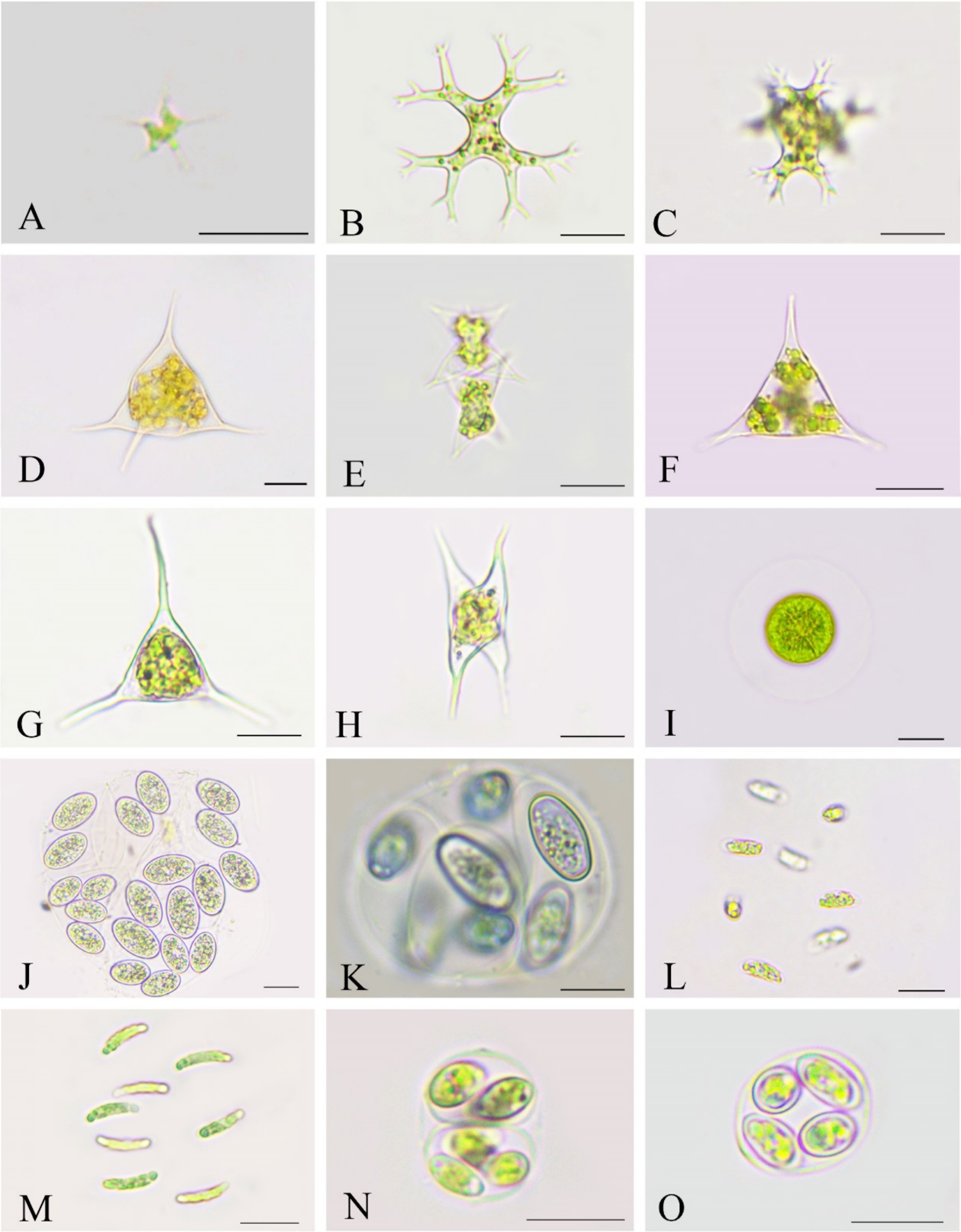
Colony L-18.7, W-15.8

Cells oval with rounded poles. Seen as a colony of four.

31. ***Oocystis solitaria*** Wittrock **(Pl. 5, Fig. A)**

Current name: *Neglectella solitaria* (Wittrock) Stenclova & Kastovsky

Philipose, 1967. p. 180, Fig. 89.



Scale 10µm

PLATE 4 (Figs. A-O): A) *Tetraedron caudatum* (Corda) Hansgirg **B)** *T.gracile* (Reinsch) Hansgirg **C)** *T. lobulatum* var. *polyfurcatum* G.M. Smith **D)** *T. regulare* Kutzing **E)** *T. regulare* var. *torsum* Brunnthaler **F)** *T. trigonum* (Nageli) Hansgirg **G)** *T. trigonum* var. *longispinum* Philipose **H)** *T. victoriae* Woloszynska **I)** *Planktosphaeria gelatinosa* G.M.Smith **J)** *Glaucocystis nostochinearum* Itzigsohn **K)** *Glaucocystis* sp.1 **L)** *Nephrocytium agardhianum* Nageli **M)** *N. allantoideum* Bohlin **N)** *Oocystis lacustris* Chodat **O)** *O. pusilla* Hansgirg

L-42.2. W-26.4

Cells solitary or colonies, with polar nodules and discoid chloroplasts.

Family: Botryococcaceae

Genus: *Botryococcus* Kutzing

32. ***Botryococcus braunii*** Kutzing **(Pl. 5, Fig. B)**

Philipose, 1967, p. 195, Fig. 108.

Cell L-5.2, W-2.6

Cells ovoid, densely packed and arranged in periphery of colony. Colony has irregular shape and has a membrane that encloses cells completely.

Family: Dictyosphaeriaceae

Genus: *Dictyosphaerium* Nageli

33. ***Dictyosphaerium ehrenbergianum*** Nageli **(Pl. 5, Fig. C)**

Philipose, 1967. p. 201, Fig. 111.

L-5–7, W-4.4–5.6

Cells ovoid to ellipsoid, arranged radially united by mucilaginous stalks.

34. ***Dictyosphaerium pulchellum*** H.C. Wood **(Pl. 5, Fig. D)**

Current name: *Mucidosphaerium pulchellum* (H.C. Wood) C. Bock, Proschold & Krienitz

Philipose, 1967. p. 199, Fig. 110.

D-3.5–4.3

Cells round and spherical, connected by thin mucilaginous strands.

35. ***Dictyosphaerium pulchellum*** var. ***ovatum*** Korshikov **(Pl. 5, Fig. E)**

Current name: *Hindakia tetrachotoma* (Printz) C. Bock, Proschold & Krienitz

Korshikov, 1953. p. 337, Fig. 312.

L-5.5–7.1, W-4–4.7

Cells ovoid to subtriangular, arranged in cruciate fashion and are attached at base by mucilaginous strands.

Genus: *Dimorphococcus* A. Braun

36. ***Dimorphococcus lunatus*** A. Braun **(Pl. 5, Fig. F)**

Philipose, 1967. p. 205, Fig. 115.

L-9–15, W-4–9

Cells in group of four, arranged alternately in zig zag fashion, outer reniform or somewhat lunate shaped and inner elongate ovoid shape. Colonies irregular.

Family: Radiococcaceae

Genus: *Eutetramorus* Walton

37. ***Eutetramorus planctonicus*** (Korshikov) Bourrelly **(Pl. 5, Fig. G)**

Current name: *Coenococcus planctonicus* Korshikov

Korshikov, 1953. p. 322, Fig. 295.

Cell W-5.6–7

Cells spherical, tetrahedrally arranged and covered by thin membrane. Colonies with cells 4–8–16–32 or more in a structureless mucilage.

38. ***Eutetramorus polycoccus*** (Korshikov) Komarek **(Pl. 5, Fig. H)**

Current name: *Radiococcus polycoccus* (Korshikov) Kostikov, Darienko, Lukesova & L. Hoffmann

Kim, 2013. p. 89, Fig. 76.

Cell W-5–7, Colony W-32.5–52.4

Cells spherical with 2 or more pyrenoids arranged as colony of 4–8–16 cells in an irregular mucilage.

Genus: *Coenocystis* Korshikov

39. ***Coenocystis subcylindrica*** Korshikov **(Pl. 5, Fig. I)**

Kim, 2013. p. 97, Figs. 84(A-F), 85.

Cell L-5.5–6.9, W-4.4–6, Colony W-36.7

Colonies spherical to ovoid, cells are mostly ovoid and arranged in two planes.

Genus: *Radiococcus* Schmidle

40. ***Radiococcus nimbatus*** (De Wildeman) Schmidle **(Pl. 5, Fig. J)**

Kim, 2013. p. 75, Figs. 62(A-F), 63.

Cell W-3–4

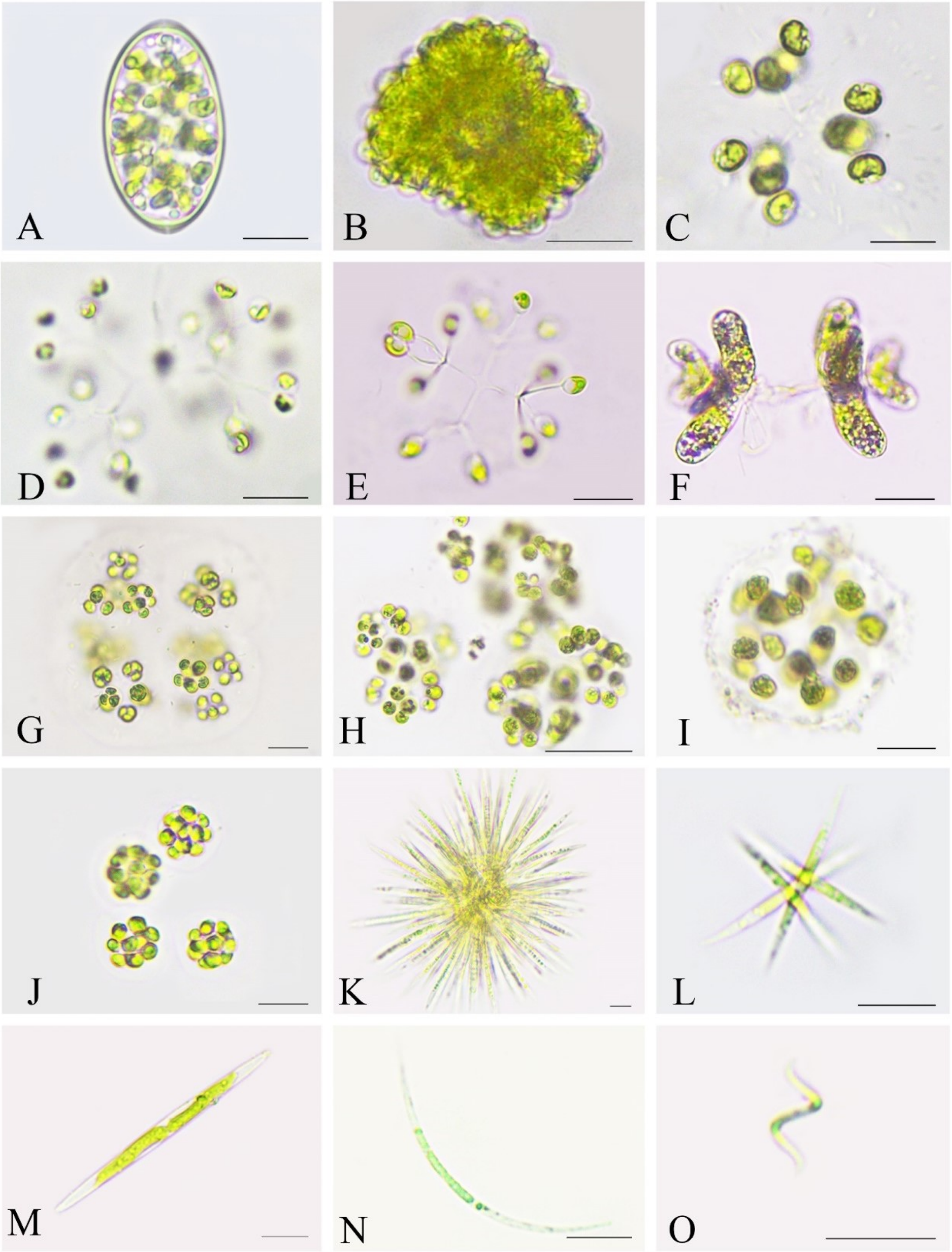
Colonies spherical with cells clustered in centre of mucilage envelope.

Family: Selenastraceae

Genus: *Ankistrodesmus* Corda

41. ***Ankistrodesmus densus*** Korshikov **(Pl. 5, Fig. K)**

Korshikov, 1953. p. 300, Fig. 262.



Scale 10µm

PLATE 5 (Figs. A-O): A) *Oocystis solitaria* Wittrock **B)** *Botryococcus braunii* Kutzing **C)** *Dictyosphaerium ehrenbergianum* Nageli **D)** *D. pulchellum* H.C. Wood **E)** *D. pulchellum* var. *ovatum* Korshikov **F)** *Dimorphococcus lunatus* A. Braun **G)** *Eutetramorus planctonicus* (Korshikov) Bourrelly **H)** *E. polycoccus* (Korshikov) Komarek **I)** *Coenocystis subcylindrica* Korshikov **J)** *Radiococcus nimbatus* (De Wildeman) Schmidle **K)** *Ankistrodesmus densus* Korshikov **L)** *A. falcatus* (Corda) Ralfs **M)** *A. falcatus* var. *acicularis* (A. Braun) G.S. West **N)** *A. falcatus* var. *mirabilis* (West & G.S. West) G.S. West **O)** *A. falcatus* var. *spirilliformis* G.S. West

L-40–60, W-2.5

Cells of uniform thickness with ends pointed and narrowed.

42. ***Ankistrodesmus falcatus*** (Corda) Ralfs **(Pl. 5, Fig. L)**

Philipose, 1967. p. 211, Fig. 121.

L-20–32, W-1.5–5

Cells fusiform with acute apices in bundles of 2–4–8 cells, rarely solitary.

43. ***Ankistrodesmus falcatus*** var. ***acicularis*** (A. Braun) G.S. West **(Pl. 5, Fig. M)**

Current name: *Monoraphidium griffithii* (Berkeley) Komarkova-Legnerova

Smith, 1920. p. 135.

L-30.8–83, W-2–5

Cells usually found solitary in samples, elongated spindle in shape with sharply pointed ends.

44. ***Ankistrodesmus falcatus*** var. ***mirabilis*** (West & G.S.West) G.S.West **(Pl. 5, Fig. N)**

Current name: *Monoraphidium mirabile* (West & G.S. West) Pankow

Smith, 1920. p. 135, pl. 32, Figs. 3–5.

L-50–75, W-1–1.5

Cells solitary, lunate or sigmoid with acute spices.

45. ***Ankistrodesmus falcatus*** var. ***spirilliformis*** G.S. West **(Pl. 5, Fig. O)**

Current name: *Monoraphidium contortum* (Thuret) Komarkova-Legnerova

Philipose, 1967. p. 213, Fig. 121 a, e.

L-11.6–14, W-1–1.2

Cells solitary, spirally curved and with pointed ends.

46. ***Ankistrodesmus spiralis*** (W.B. Turner) Lemmermann **(Pl. 6, Fig. A)**

Philipose, 1967. p. 210, Fig. 119.

L-20–25, W-1–3

Cells acicular with acute spines, spirally twisted around one another in the middle region. Also seen as colonies of 4–8–16 cells.

Genus: *Actinastrum* Lagerheim

47. ***Actinastrum aciculare*** f. ***minimum*** (Huber-Pestalozzi) Compere **(Pl. 6, Fig. B)**

Compere, 1976. p. 97, Fig. 102.

L-7.5–8.5, W-0.6–0.9

Cells with arms radiating from centre forming a star shape.

Genus: *Elakatothrix* Wille

48. ***Elakatothrix lacustris*** Korshikov **(Pl. 6, Fig. C)**

Korshikov, 1953. p. 412, Fig. 414.

Cell L-20, W-2, Colony L-51, W-8

Cells are fusiform arranged in pairs within a gelatinous, fusiform colonies.

Genus: *Kirchneriella* Schmidle

49. ***Kirchneriella contorta*** (Schmidle) Bohlin **(Pl. 6, Fig. D)**

Current name: *Raphidocelis danubiana* (Hindak) Marvan, Komarek & Comas

Smith, 1920. p. 143, pl. 35, Fig. 7.

L-8–14, W-0.7–1.8

Cells cylindrical, arcuate with rounded ends.

50. ***Kirchneriella lunaris*** (Kirchner) Mobius **(Pl. 6, Fig. E)**

Philipose, 1967. p. 222, Fig. 131.

L-8–9, W-3–8

Cells flattened, crescent shaped, with tapering ends.

51. ***Kirchneriella obesa*** (West) West & G.S. West **(Pl. 6, Fig. F)**

Philipose, 1967. p. 224, Fig. 132.

L-7–9, W-3.4–3.6

Cells are crescent shaped but with rounded ends.

Genus: *Selenastrum* Reinsch

52. ***Selenastrum gracile*** Reinsch **(Pl. 6, Fig. G)**

Current name: *Messastrum gracile* (Reinsch) T.S. Garcia

Philipose, 1967. p. 219, Fig. 128.

L-10.6–19, W-3–3.7

Cells lunate to sickle shaped with acute apices.

Family: Coelastraceae

Genus: *Coelastrum* Naegeli

53. ***Coelastrum astroideum*** De Notaris **(Pl. 6, Fig. H)**

Tsarenko & John, 2011. p. 431, pl. 108 H.

D-19

Cells almost spherical with conical bulges. Colonies spherical.

54. ***Coelastrum cambricum*** W. Archer **(Pl. 6, Fig. I)**

Prescott, 1982. p. 229, pl. 53, Fig. 2.

Cells D-5–7.5, Colony D-18–24

Cells spherical enclosed with gelatinous sheath. Each cell has a stout, cylindrical process on apex. Young cells may lack or have small processes. Colonies spherical and held together by remains of old mother cell walls.

55. ***Coelastrum cambricum*** var. ***intermedium*** (Bohlin) G.S. West **(Pl. 6, Fig. J)**

Philipose, 1967. p. 231, Fig. 138 b.

Colony D-37

Cells with short projections of the sheath to connect other cells creating triangular intercellular spaces. Colonies spherical and thickened at poles.

56. ***Coelastrum microporum*** Nageli **(Pl. 6, Fig. K)**

Philipose, 1967. p. 228, Fig. 135.

D-12

Cells spherical to ovoid. Colonies spherical with small intercellular spaces.

Family: Scenedesmaceae

Subfamily: Scenedesmoideae

Genus: *Scenedesmus* Meyen

57. ***Scenedesmus acutiformis*** Schroder **(Pl. 6, Fig. L)**

Current name: *Acutodesmus acutiformis* (Schroder) P.M. Tsarenko & D.M. John

Philipose, 1967. p. 260, Fig. 169.

L-11, W-3.5

Cells cylindrical-fusiform and arranged in a single linear series. Median cells with a lateral longitudinal ridge from pole to pole. Poles acute.

58. ***Scenedesmus acuminatus*** (Lagerheim) Chodat **(Pl. 6, Fig. M)**

Current name: *Tetradesmus lagerheimii* M.J. Wynne & Guiry

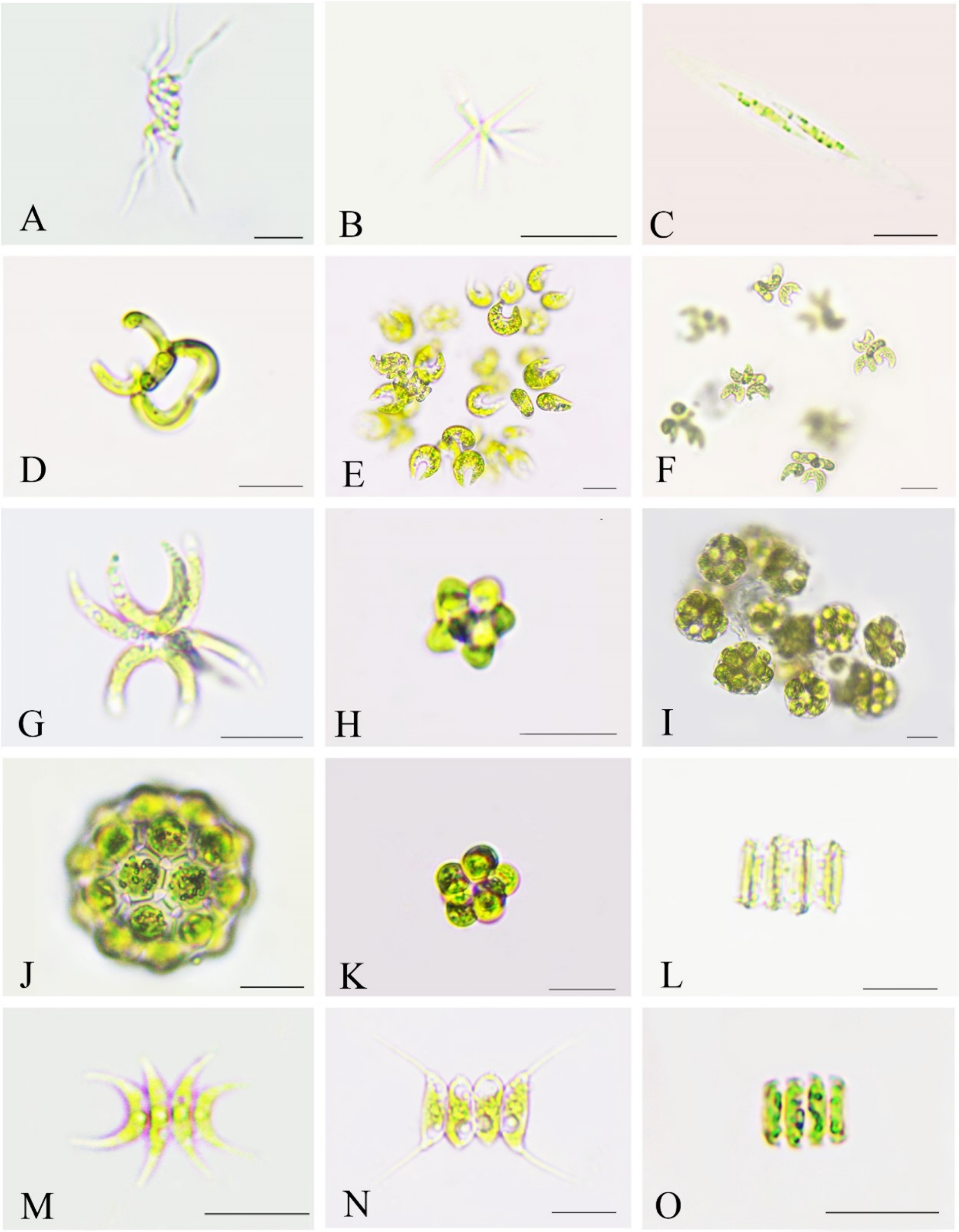
Philipose, 1967. p. 251, Fig. 161.

L-9.7–13.8, W–2

Cells usually four, lunate, fusiform with sharp pointed ends.

59. ***Scenedesmus armatus*** (Chodat) Chodat **(Pl. 6, Fig. N)**

Current name: *Desmodesmus armatus* (Chodat) E.H. Hegewald



Scale 10µm

PLATE 6 (Figs. A-O): A) *Ankistrodesmus spiralis* (W.B. Turner) Lemmermann **B)** *Actinastrum aciculare* f. *minimum* (Huber-Pestalozzi) Compere **C)** *Elakatothrix lacustris* Korshikov **D)** *Kirchneriella contorta* (Schmidle) Bohlin **E)** *K. lunaris* (Kirchner) Mobius **F)** *K. obesa* (West) West & G.S. West **G)** *Selenastrum gracile* Reinsch **H)** *Coelastrum astroideum* De Notaris **I)** *C. cambricum* W. Archer **J)** *C. cambricum* var. *intermedium* (Bohlin) G.S. West **K)** *C. microporum* Nageli **L)** *Scenedesmus acutiformis* Schroder **M)** *S. acuminatus* (Lagerheim) Chodat **N)** *S. armatus* (Chodat) Chodat **O)** *S. arthrodesmiformis* Schrode

Prescott, 1982. p. 276, pl. 62, Fig. 13, 14.
L-7.5–11 W-2.8–3.5 SP-6.2–7

Cells oblong, ellipsoid, with rounded ends. Four-celled terminal cells with long spine at each pole.

60. ***Scenedesmus arthrodesmiformis*** Schroder **(Pl. 6, Fig. O)**

Current name*: Desmodesmus arthrodesmiformis* (Schroder) S.S. An, Friedl & E. Hegewald

Ramos et al., 2015. p. 560, Figs. 4 a-b.

L-7.4, W-2

Cells flat, elliptical to elliptical-fusiform, poles slightly rounded. Usually four celled, arranged linearly. Cells have one inwardly facing convex spine on each pole.

61. ***Scenedesmus bijugus*** var. ***irregularis*** (Wille) G.M. Smith **(Pl. 7, Fig. A)**

Prescott, 1982. p. 277.

L-12, W-5

Cells arranged irregularly in double series.

62. ***Scenedesmus bijugatus*** Kutzing **(Pl. 7, Fig. B)**

Current name: *Tetradesmus obliquus* (Turpin) M.J. Wynne

Philipose, 1967. p. 252, Figs. 164 c, e, f.

L-13, W-5

Cells oblong-ellipsoid to ovoid with broadly rounded ends in single linear series.

63. ***Scenedesmus bijugatus*** f. ***parvus*** (G.M. Smith) Philipose **(Pl. 7, Fig. C)**

Current name: *Verrucodesmus parvus* (G.M. Smith) E. Hegewald

Philipose, 1967. p. 256, Figs. 164 h, j.

L-7, W-3

Cells small, oblong-ovoid, smooth, and arranged in sub alternating series.

64. ***Scenedesmus dimorphus*** (Turpin) Kutzing **(Pl. 7, Fig. D)**

Current name: *Tetradesmus dimorphus* (Turpin) M.J. Wynne

Philipose, 1967. p. 249, Figs. 160 a-c.

L-14.5, W-2.8–2.9

Cells arranged in linear series of 4–8, apices are less lunate and attenuated.

65. ***Scenedesmus longus*** var. ***naegelii*** (Brebisson) G.M. Smith **(Pl. 7, Fig. E)**

Current name: *Scenedesmus naegelii* Brebisson

Prescott, 1982. p. 279, pl. 63, Fig. 24.

L-15, W-5–6, SP-12.5–14.5

Cells with long-curved spine at each pole. 8 cylindrical cells in a single series.

66. ***Scenedesmus opoliensis*** P. Richter **(Pl. 7, Fig. F)**

Current name: *Desmodesmus opoliensis* (P.G. Richter) E. Hegewald

Prescott, 1982. p. 279, pl. 63, Fig. 18.

L-14.9–17, W-5.6–6.4, SP-12–18

Cells have long spine at one pole. Cells 4-8 arranged in single series.

67. ***Scenedesmus quadricauda*** var. ***longispina*** (Chodat) G.M. Smith **(Pl. 7, Fig. G)**

Current name: *Desmodesmus armatus* var. *longispina* (Chodat) E. Hegewald

Philipose, 1967. p. 285, Figs. 187 b, c.

L-8–8.6, W-2.5–3, SP-6–8

Cells ovoid to cylindrical, spines longer than the cell, usually 2–4 celled.

68. ***Scenedesmus quadricauda*** var. ***quadrispina*** (Chodat) G.M. Smith **(Pl. 7, Fig. H)**

Current name: *Desmodesmus abundans* (Kirchner) E.H. Hegewald

Philipose, 1967. Figs. 187 d, j.

L-6.6, W-2, SP-5.2

Cells broadly ovoid, twice long as broad. Poles of terminal cells with short, recurved spine.

69. ***Scenedesmus serratus*** (Corda) Bohlin **(Pl. 7, Fig. I)**

Current name: *Desmodesmus serratus* (Corda) S.S. An, Friedl & E. Hegewald

Prescott, 1982. p. 281, pl. 64, Fig. 8.

L-18.2, W-6.3

Cells oblong- ovate, 4 in a single series. Small longitudinal rows of teeth cells and at poles.

Subfamily: Crucigenoideae

Genus: *Crucigenia* Morren

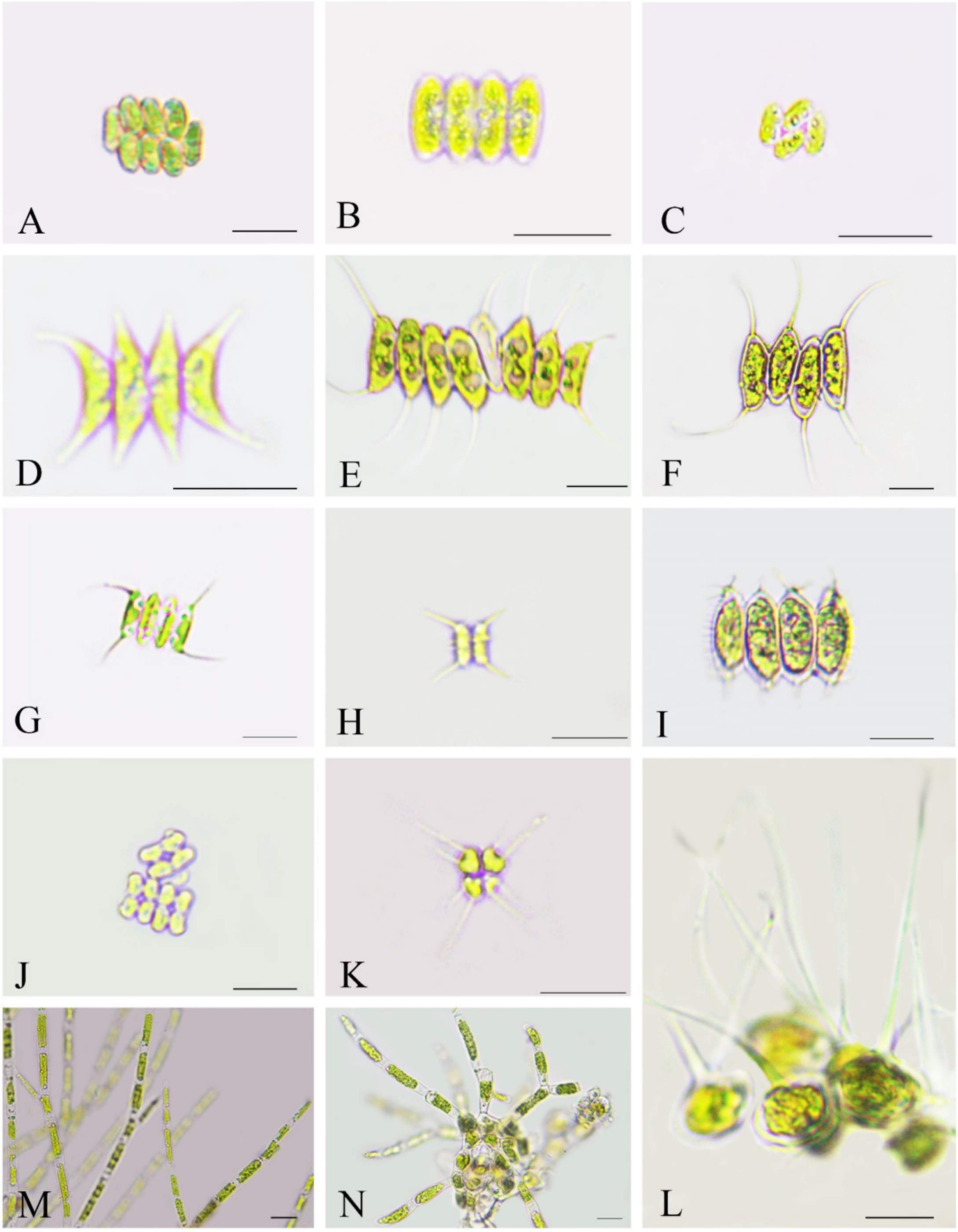
70. ***Crucigenia crucifera*** (Wolle) Kuntze **(Pl. 7, Fig. J)**

Current name: *Willea crucifera* (Wolle) D.M. John, M.J. Wynne & P.M. Tsarenko

Philipose, 1967. p. 240, Fig. 149.

L-3.6–4.3, W-2–2.6

Cells oval or triangular cells of four arranged in a cross.



Scale 10µm

PLATE 7 (Figs. A-N): A) *Scenedesmus bijugus* var. *irregularis* (Wille) G.M. Smith **B)** *S. bijugatus* Kutzing **C)** *S. bijugatus* f. *parvus* (G.M. Smith) Philipose **D)** *S.dimorphus* (Turpin) Kutzing **E)** *S. longus* var. *naegelii* (Brebisson) G.M. Smith **F)** *S. opoliensis* P. Richter **G)** *S. quadricauda* var. *longispina* (Chodat) G.M. Smith **H)** *S. quadricauda* var. *quadrispina* (Chodat) G.M. Smith **I)** *S. serratus* (Corda) Bohlin **J)** *Crucigenia crucifera* (Wolle) Kuntze **K)** *Tetrastrum heteracanthum* (Nordstedt) Chodat **L)** *Chaetosphaeridium globosum* (Nordstedt) Klebahn **M)** *Chaetophora pisiformis* (Roth) C. Agardh **N)** *Coleochaete* sp.1

Genus:*Tetrastrum* Chodat

71. ***Tetrastrum heteracanthum*** (Nordstedt) Chodat **(Pl. 7, Fig. K)**

Philipose, 1967. p. 244, Fig. 156.

D-3.5–4

Cells are heart shaped, arranged in quadrate with long and short setae from outer surface.

Order: Chaetophorales

Family: Chaetosphaeridiaceae

Genus: *Chaetosphaeridium* Klebahn

72. ***Chaetosphaeridium globosum*** (Nordstedt) Klebahn **(Pl. 7, Fig. L)**

Prescott, 1982. p. 131, pl. 14, Figs. 6, 7.

D-8.6–12, Chaetae-35

Cells unicellular, clustered, flask-like, a long fine seta extends from each cell which surrounded by a conical shaped sheath. Basal interconnecting tubes are sometimes visible.

Family: Chaetophoraceae

Genus: Chaetophora F. Schrank

73. ***Chaetophora pisiformis*** (Roth) C. Agardh **(Pl. 7, Fig. M)**

Current name: *Chaetophoropsis pisiformis* (Roth) B. Wen Liu, Qian Xiong, X. Dong Liu, Z. Yu Hu & G. Xiang Liu

Prescott, 1982. p. 119, pl. 13, Figs. 2, 3.

L-20.7–26.4, W-6–7.3

Cells other than main branch slightly shorter and narrower. Filaments are dichotomously branched with pointed apical cell.

Family: Coleochaetaceae

Genus: *Coleochaete* de Brebisson

74. ***Coleochaete*** sp.1 **(Pl. 7, Fig. N)**

L-19–24.6, W-4.6–5

Cells rounded and cushioned at centre from where filaments arise. Filament cells pulvinate and gelatinous with most cells having long bristles.

Order: Oedogoniales

Family: Oedogoniaceae

Genus: *Bulbochaete* C. Agardh

75. ***Bulbochaetae*** sp. 1 **(Pl. 8, Fig. A)**

L-23.3–28.3, W-19.6–20.9

Filaments are branched and have chaetae with swollen bases.

76. ***Bulbochaete*** sp. 2 **(Pl. 8, Fig. B)**

L-47.6–54.5, W-11.3–12.4

Genus: *Oedogonium* Link Ex Hirn

77. ***Oedogonium*** sp. 1 **(Pl. 8, Fig. C)**

Vegetative cells L-89.6–100, W-21.7–29.2

Vegetative cells rectangular and longer than wide. Filaments long, unbranched. Chloroplast parietal and network like. Cap cells are present (**(Pl. 8, Fig. D)**.

78. ***Oedogonium*** sp. 2 **(Pl. 8, Fig. E)**

Vegetative cells L-23–26, W-6

Oogonium L-13.7, W-22.2

Vegetative cells cylindrical and oogonia solitary.

Order: Trentipohliales

Family: Trentepohliaceae

Genus: *Gongrosira* Kutzing

79. ***Gongrosira debaryana*** Rabenhorst **(Pl. 8, Fig. F)**

Prescott, 1982. p. 132, pl. 19, Fig. 3.

L-26–33, W-10.5–12

Cells stout, cylindrical, with convex walls. Filaments arise from a basal prostate group of cells. Vertical filaments are densely packed that terminate in enlarged cells. Horizontal filaments are reduced.

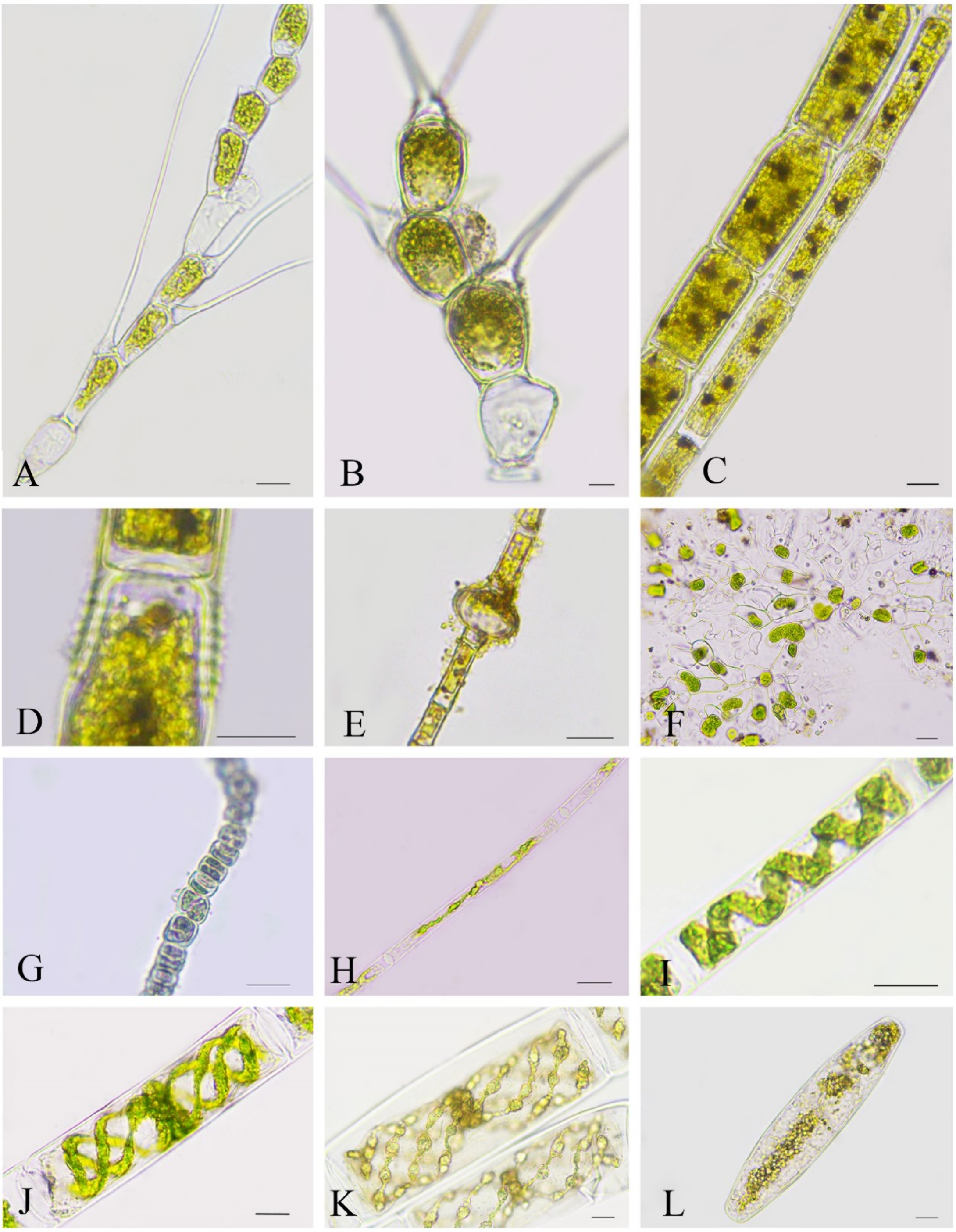
Order: Ulotrichales

Family: Ulotrichaceae

Genus: *Geminella* Turpin

80. ***Geminella*** sp. 1 **(Pl. 8, Fig. G)**

L-4, W-7.3



Scale 10µm

PLATE 8 (Figs. A-L): A) *Bulbochaetae* sp. 1 **B)** *Bulbochaete* sp. 2 **C)** *Oedogonium* sp. 1 **D)** Cap cells of *Oedogonium* sp. 1 **E)** *Oedogonium* sp. 2 **F)** *Gongrosira debaryana* Rabenhorst **G)** *Geminella* sp. 1 **H)** *Mougeotia* sp. 1 **I)** *Spirogyra* sp. 1 **J)** *Spirogyra* sp. 2 **K)** *Spirogyra* sp. 3 **L)** *Netrium digitus* (Brebisson ex Ralfs) Itzigsohn & Rothe

Cells rectangular, surrounded by mucilaginous sheath, sometimes form pairs, and connected by wall ends. Filaments are unbranched, chloroplast parietal, saddle shaped at centre.

Order: Zygnematales

Family: Zygnemataceae

Genus: *Mougeotia* C. Agardh

81. ***Mougeotia*** sp.1 **(Pl. 8, Fig. H)**
L-101, W-5.6–5.9
Cells long, plate like chloroplast, seen twisted often.

Genus: *Spirogyra* Link

82. ***Spirogyra*** sp. 1 **(Pl. 8, Fig. I)**
L-54.8–55.5, W-10–10.9
83. ***Spirogyra*** sp. 2 **(Pl. 8, Fig. J)**
L-129–129.6, W-32.8–33
84. ***Spirogyra*** sp. 3 **(Pl. 8, Fig. K)**
L-128–150.7, W-44.9–54.2

Family: Mesotaeniaceae (Saccoderm Desmids)

Genus: *Netrium* (Nageli) Itzigsohn Et Rothe

85. ***Netrium digitus*** (Brebisson ex Ralfs) Itzigsohn & Roth **(Pl. 8, Fig. L)**
Scott and Prescott, 1961. p. 8, pl. 1, Fig. 5.
L-137–159, W-30.6–35
86. ***Netrium digitus*** var. ***lamellosum*** (Brebisson ex Kutzing) Gronblad **(Pl. 9, Fig. A)**
Scott and Prescott, 1961. p. 8, pl. 1, Fig. 6.
L-164.6, W-36

Family: Gonatozygaceae

Genus: *Gonatozygon* De Bary

87. ***Gonatozygon brebissonii*** De Bary **(Pl. 9, Fig. B)**
West and West, 1904. vol. 1. p. 31, pl. 1. Figs. 8–11.
L-162.2–173.7, W-4.7–5
Cells long, cylindrical with capitate apices.

88. ***Gonatozygon monotaenium*** var. ***pilosellum*** Nordstedt **(Pl. 9, Fig. C)**

West and West, 1904. vol. 1. p. 31.

L-140, W-7.2, SP-1.5–2

Cells long, cylindrical with minute spines and slightly dilated apices.

Family: Desmidiaceae (Placcoderm desmids)

Genus: *Penium* Brebisson ex Ralfs

89. ***Penium margaritaceum*** Brebisson ex Ralfs **(Pl. 9, Fig. D)**

West and West, 1904. vol. 1. p. 83, pl. 8, Figs. 32–35.

L-72–100, W-10–18

Cells with slight median constriction with truncate and rounded apices. Rows of granules present on body.

90. ***Penium spirostriolatum*** J. Barker **(Pl. 9, Fig. E)**

West and West, 1904. vol. 1. p. 88, pl. 9, Figs. 1–8.

L-227, W-24

Cells with slight median constriction with truncate and rounded apices. Rows of granules arranged spirally on cell wall.

Genus: *Closterium* Nitzsch Ex Ralfs

91. ***Closterium abruptum*** West **(Pl. 9, Fig. F)**

Coesel and Meesters, 2007. p. 38, pl. 26, Figs. 7–9.

L-149.7, W-12.7

Cells 12 times longer than width, slightly curved, truncated apices.

92. ***Closterium archerianum*** Cleve ex P. Lundell **(Pl. 9, Fig. G)**

Coesel and Meesters, 2007. p. 40, pl. 16, Fig. 6.

L-135.5, W-13

Cells 10 times longer than width, strongly arched, 10 striae visible, yellow to brown in colour.

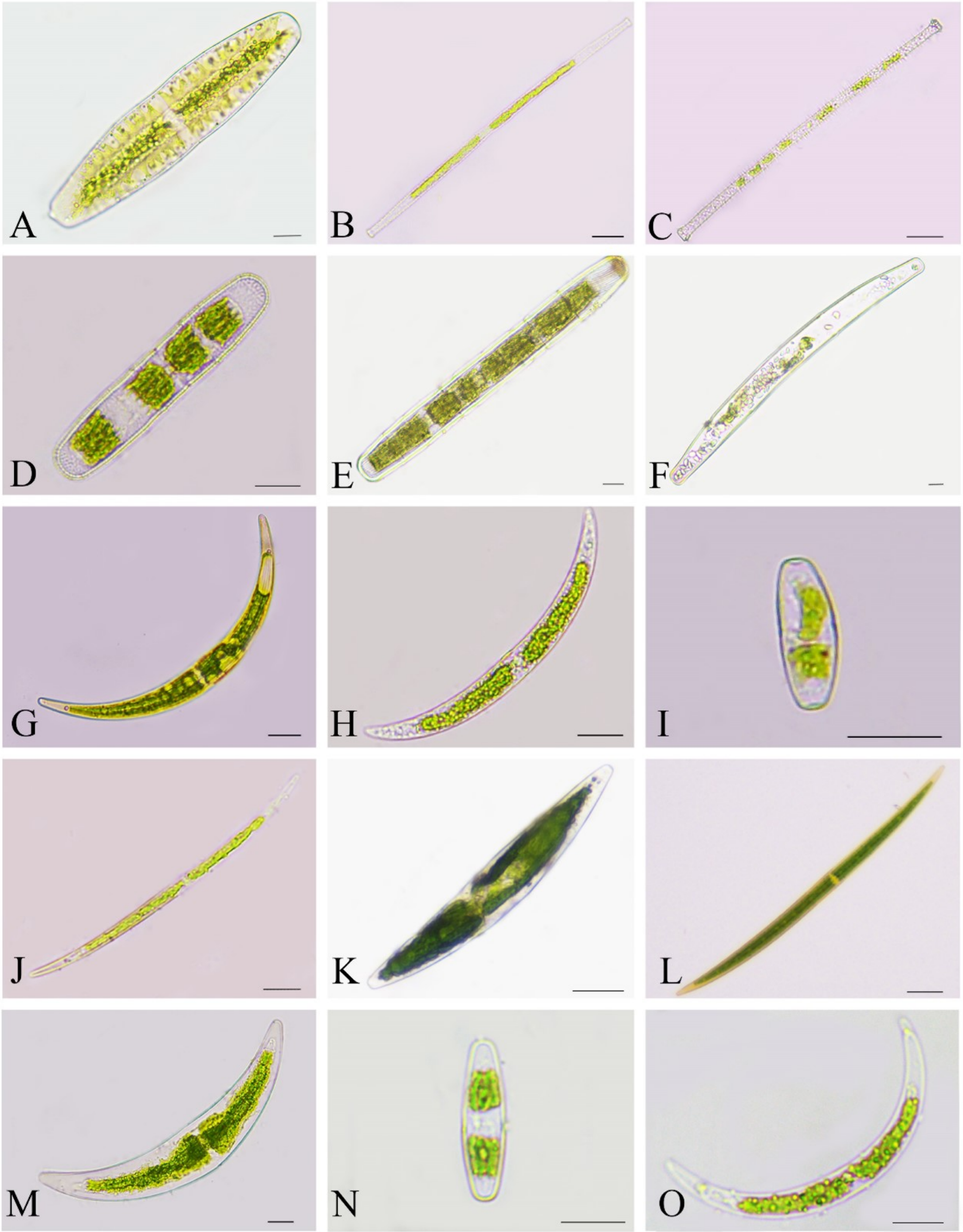
93. ***Closterium dianae*** var. ***minus*** Hieronymus **(Pl. 9, Fig. H)**

Coesel and Meesters, 2007. p. 43, pl. 14, Fig. 2.

L-94.7–159, W-8.6–13

Cells small, 11–12 times longer than width, strongly curved, obliquely truncated apices.

94. ***Closterium infractum*** Messikommer **(Pl. 9, Fig. I)**



Scale 10µm

PLATE 9 (Figs. A-O): A) *Netrium digitus* var. *lamellosum* (Brebisson ex Kutzing) Gronblad **B)** *Gonatozygon brebissonii* De Bary **C)** *G. monotaenium* var. *pilosellum* Nordstedt **D)** *Penium margaritaceum* Brebisson ex Ralfs **E)** *P. spirostriolatum* J. Barker **F)** *Closterium abruptum* West **G)** *C. archerianum* Cleve ex P. Lundell **H)** *C. dianae* var. *minus* Hieronymus **I)** *C. infractum* Messikommer **J)** *C. juncidum* Ralfs **K)** *C. lanceolatum* Kutzing ex Ralfs **L)** *C. lineatum* Ehrenberg ex Ralfs **M)** *C. moniliferum* Ehrenberg ex Ralfs **N)** *C. navicula* (Brebisson) Lutkemuller **O)** *C. parvulum* var. *angustum* West & G.S. West

Current name: *Actinotaenium infractum* (Messikommer) D.B. Williamson

Scott and Prescott, 1961. p. 11, pl. 2, Fig. 10.

L-25, W-10

Cells small, slightly curved, indistinct median constriction, truncate apices.

95. ***Closterium juncidum*** Ralfs **(Pl. 9, Fig. J)**

West and West, 1904. vol. 1, p. 128, pl. 14, Figs. 10–14.

L-103, W-4

Cells more than 25 times longer than width, straight in middle, slightly incurved at the rounded apex.

96. ***Closterium lanceolatum*** Kutzing ex Ralfs **(Pl. 9, Fig. K)**

West and West, 1904. vol. 1. p. 149, pl. 17, Figs. 9–10; pl. 18, Fig. 7.

L-234, W-36.6

Cells 6.5 times longer than width, slightly curved almost straight, gradually narrowed to acutely rounded apex.

97. ***Closterium lineatum*** Ehrenberg ex Ralfs **(Pl. 9, Fig. L)**

West and West, 1904. vol. 1, p. 181, pl. 24, Figs. 1–5.

L-512, W-22.5

Cells large, 23 times longer than width, narrow and striated, straight at centre and slightly curved at apices.

98. ***Closterium moniliferum*** Ehrenberg ex Ralfs **(Pl. 9, Fig. M)**

West and West, 1904. vol. 1, p. 142, pl. 16, Figs. 15–16.

L-234–245, W-36–36.6

Cells 6.5–6.8 times longer than width, inner margin is slightly inflated at centre, apices are obtusely rounded.

99. ***Closterium navicula*** (Brebisson) Lutkemuller **(Pl. 9, Fig. N)**

Scott and Prescott, 1961. p. 12, pl. 2, Fig. 13.

L-30, W-8

Cells longer than broad and straight, slightly truncated, and rounded apex.

100. ***Closterium parvulum*** var. ***angustum*** West & G.S. West **(Pl. 9, Fig. O)**

Hirano, 1992, p. 12, pl. 1, Fig. 6; pl. 3, Fig. 10.

L-51.2-96, W-5-8

Cells small, 10–12 times longer than width, slender and curved with slightly rounded apices. Some of the collected species are smaller than type described.

101. ***Closterium porrectum*** var. ***angustatum*** West & G.S. West **(Pl. 10, Fig. A)**

Scott and Prescott, 1961. p. 13, pl. 2, Fig. 14.

L-102–117, W-12.5–13

Cells 8.5 times longer than width, not strongly curved, 7 striations in body.

102.***Closterium submoniliferum*** var. ***malinvernianum*** (De Notaris) Coesel **(Pl. 10, Fig. B)**

Current name: *Closterium ehrenbergii* var. *malinvernianum* (De Notaris) Rabenhorst

Hirano, 1992, p. 10, pl. 1, Fig. 9; pl. 6, Fig. 8.

L-155.4, W-31.5

Cell 5 times longer than width, stout, ventral side of mid region slightly inflated.

103.***Closterium ulna*** Focke ex W.B. Turner **(Pl. 10, Fig. C)**

Current name: *Closterium directum* W. Archer

West and West, 1904. vol. 1. p. 127, pl. 14, Figs. 7–9.

L-86.5–192, W-10.9–11

Cells are 17–17.5 times longer than breadth, very slightly attenuated to apices which are truncate shaped, series of pyrenoids is seen at median, terminal vacuoles also present. Presence of median girdle band is the distinguishing feature.

104.***Closterium venus*** Kutzing ex Ralfs **(Pl. 10, Fig. D)**

West and West, 1904. vol. 1, p. 137, pl. 15, Figs. 15–20.

L-47–73.7, W-6.2–9

Cells small, 7.5–8 times longer than width, strongly curved.

Genus: *Pleurotaenium* Nageli

105.***Pleurotaenium ehrenbergii*** (Ralfs) De Bary **(Pl. 10, Fig. E)**

Coesel and Meesters, 2007. p. 68, pl. 33, Figs. 2–5.

L-559, W-42.5, I-36.8, W at apices-38

Cells large, 13 times longer than width, cylindrical, almost straight except at basal inflation, slightly attenuated to truncate apex rounded with ring of tubercles. Distinguished by the presence of ring of tubercles and apical granules at apex.

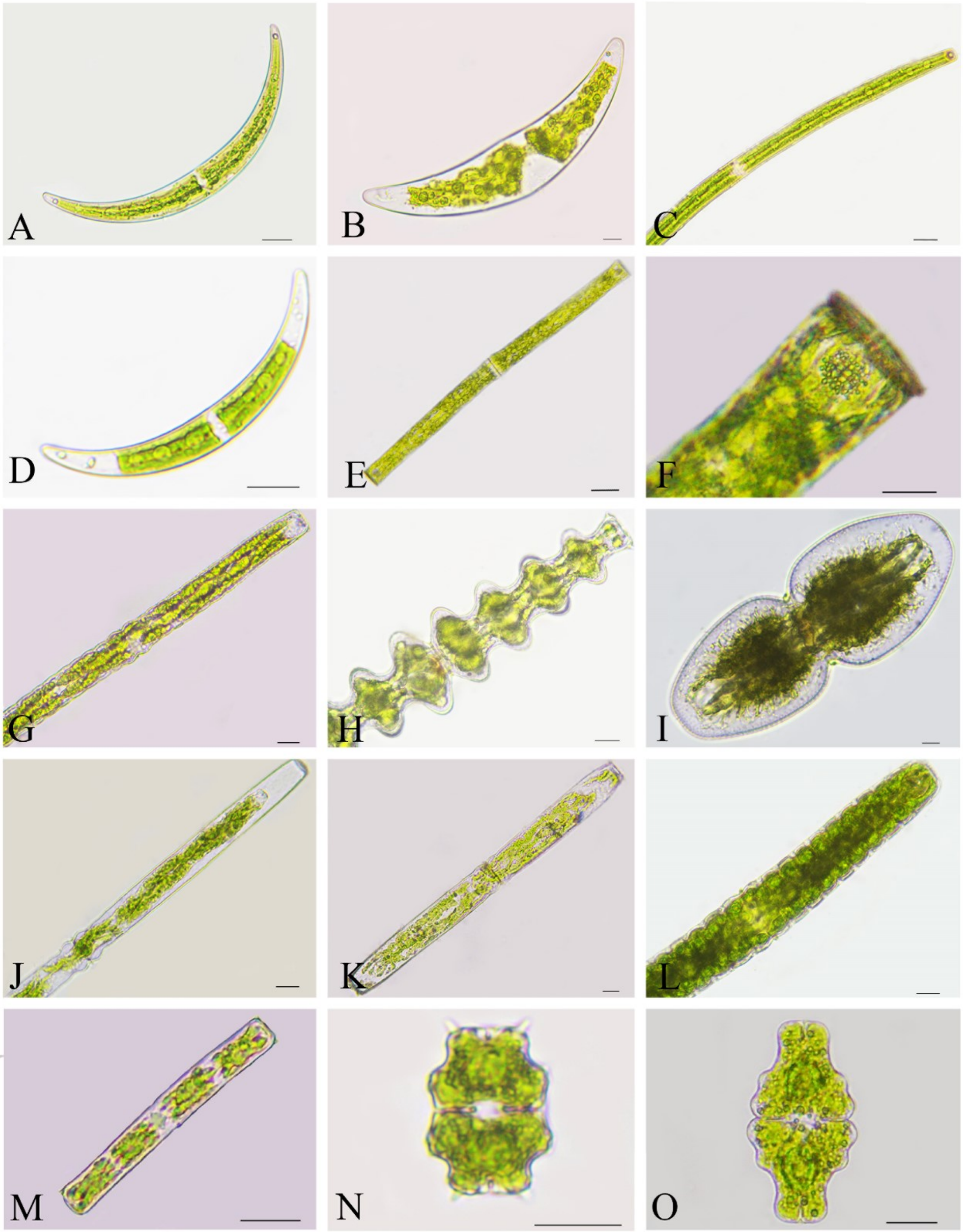
106.***Pleurotaenium ehrenbergii*** var. ***undulatum*** Schaarschmidt **(Pl. 10, Fig. G)**

Scott and Prescott, 1961. p. 15, pl. 3, Fig. 12.

L-201.8–260, W-18.2–18.5, I-14–16, W at apices-11–12.7

Cells cylindric, inflated at base, not attenuated toward truncate apices, apical granules seen.

107.***Pleurotaenium nodosum*** (Bailey ex Ralfs) P. Lundell **(Pl. 10, Fig. H)**



Scale 10µm

PLATE 10 (Figs. A-O): A) *Closterium porrectum* var. *angustatum* West & G.S. West **B)** *C. submoniliferum* var. *malinvernianum* (De Notaris) Coesel **C)** *C. ulna* Focke ex W.B. Turner **D)** *C. venus* Kutzing ex Ralfs **E)** *Pleurotaenium ehrenbergii* (Ralfs) De Bary **F)** Terminal vacuole with small crystals in *P. ehrenbergii* **G)** *P. ehrenbergii* var. *undulatum* Schaarschmidt **H)** *P. nodosum* (Bailey ex Ralfs) P. Lundell **I)** *P. ovatum* var. *inerme* Mobius **J)** *P. trabecula* Nageli K) *P. trabecula* f. *clavatum* (Kutzing ex Ralfs) Reinsch **L)** *P. verrucosum* (Ralfs) H.C. Wood **M)** *Triplastrum abbreviatum* (W.B. Turner) M.O.P. Iyengar & Ramanathan **N)** *Euastrum acanthophorum* f. *minus* A.M. Scott & Prescott **O)** *E. ansatum* Ehrenberg ex Ralfs

West and West, 1904. vol. 1, p. 214, pl. 31, Figs. 3–6.

L-217.5, W-42.4, I-18.4, Width at apices-16.8

Cells large, 5 times longer than width, with nodulous margins which gradually attenuated to dilated apex with conical teeth. Smaller than the species described in references.

108.***Pleurotaenium ovatum*** var. ***inerme*** Mobius **(Pl. 10, Fig. I)**

Scott and Prescott, 1961. p. 17, pl. 6, Fig. 3, 4.

L-131.2–150.2, W-58.8–60.4, I-34–36

Cells large, semi cells ovate, constricted at isthmus and tapered toward end with rounded truncate apex.

109.***Pleurotaenium trabecula*** Nageli **(Pl. 10, Fig. J)**

Coesel and Meesters, 2007. p. 69, pl. 32, Figs. 11–13.

L-337, W-17.4, I-13.8, W at apices-10.2

Cells 19 times longer than wide, cylindric, basal inflation is followed by another small one, almost straight and are slightly attenuated to truncate and rounded apices without tubercles.

110.***Pleurotaenium trabecula*** f. ***clavatum*** (Kutzing ex Ralfs) Reinsch **(Pl. 10, Fig. K)**

Current name: *Pleurotaenium clavatum* (Kutzing ex Ralfs) De Bary

West and West, 1904. vol. 1, p. 211, pl. 31, Figs. 8, 9.

L-287.6, W-24, I-20.3, W at apices-15.3

Cells 12 times longer than diameter, cylindrical and swollen with truncated apex.

111.***Pleurotaenium verrucosum*** (Ralfs) H.C. Wood **(Pl. 10, Fig. L)**

Kim, 2012. p. 83, Fig. 97(A-K).

L-229–312.4, W-28.4–34.3, I-26.5–30.7, W at apices-16.4–19

Cells cylindrical, with numerous equal undulations, slightly attenuated to apex, apical teeth present. Some species are smaller than typical ones in references.

Genus: *Triplastrum* M.O.P. Iyengar & Ramanathan

112.***Triplastrum abbreviatum*** (W.B. Turner) M.O.P. Iyengar & Ramanathan **(Pl. 10, Fig. M)**

Iyengar and Ramanathan, 1942. p. 228, pl. 9.

L-67.7–71, W-7.6–9.3, I-7.2–8.2

Cells small, straight, cylindrical, with slight median constriction. Apices are truncated and slightly lobed, 2–3 lobes usually at an apex, each lobe with a short spine.

Genus: *Euastrum* Ehrenberg ex Ralfs

113.***Euastrum acanthophorum*** f. ***minus*** A.M. Scott & Prescott **(Pl. 10, Fig. N)**

Scott and Prescott, 1961. p. 22, pl. 13, Figs. 6, 7.

L-25.3, W-16.5, I-3.7

Cells trapezoid in outline, apical and basal lobes flat, with rounded angles and have small incision. Short spines at apical and basal angles.

114.***Euastrum ansatum*** Ehrenberg ex Ralfs **(Pl. 10, Fig. O)**

Ralfs, 1848, p. 85, pl. 14, Fig. 2 a-f.

L-55.7–70, W-24.8–33, I-10.2–12

Cells large, semi cells pyramidal, apices truncate, rounded with deep median incision, each semi cell with four tubercles including distinct tubercle near isthmus and less distinct tubercle near lateral lobes.

115.***Euastrum denticulatum*** f. ***incisum*** A.M. Scott & Prescott **(Pl. 11, Fig. A)**

Scott and Prescott, 1961. p. 25, pl. 13, Fig. 12.

L-23.7–30, W-17.3–22, I-4.6–6

Cells with short spines on apical angles with a small incision forming lateral lobes.

116.***Euastrum distortum*** A.M. Scott & Prescott **(Pl. 11, Fig. B)**

Scott and Prescott, 1961. p. 25, pl. 13, Fig. 13.

L-18.8–23, W-9.8–12.7, I-2.5–4.6

Cells small, with deep apical incision open inside and closed outside, a single undulation above the small isthmus on both sides.

117.***Euastrum elegans*** var. ***pseudelegans*** (W.B. Turner) West & G.S. West **(Pl. 11, Fig. C)**

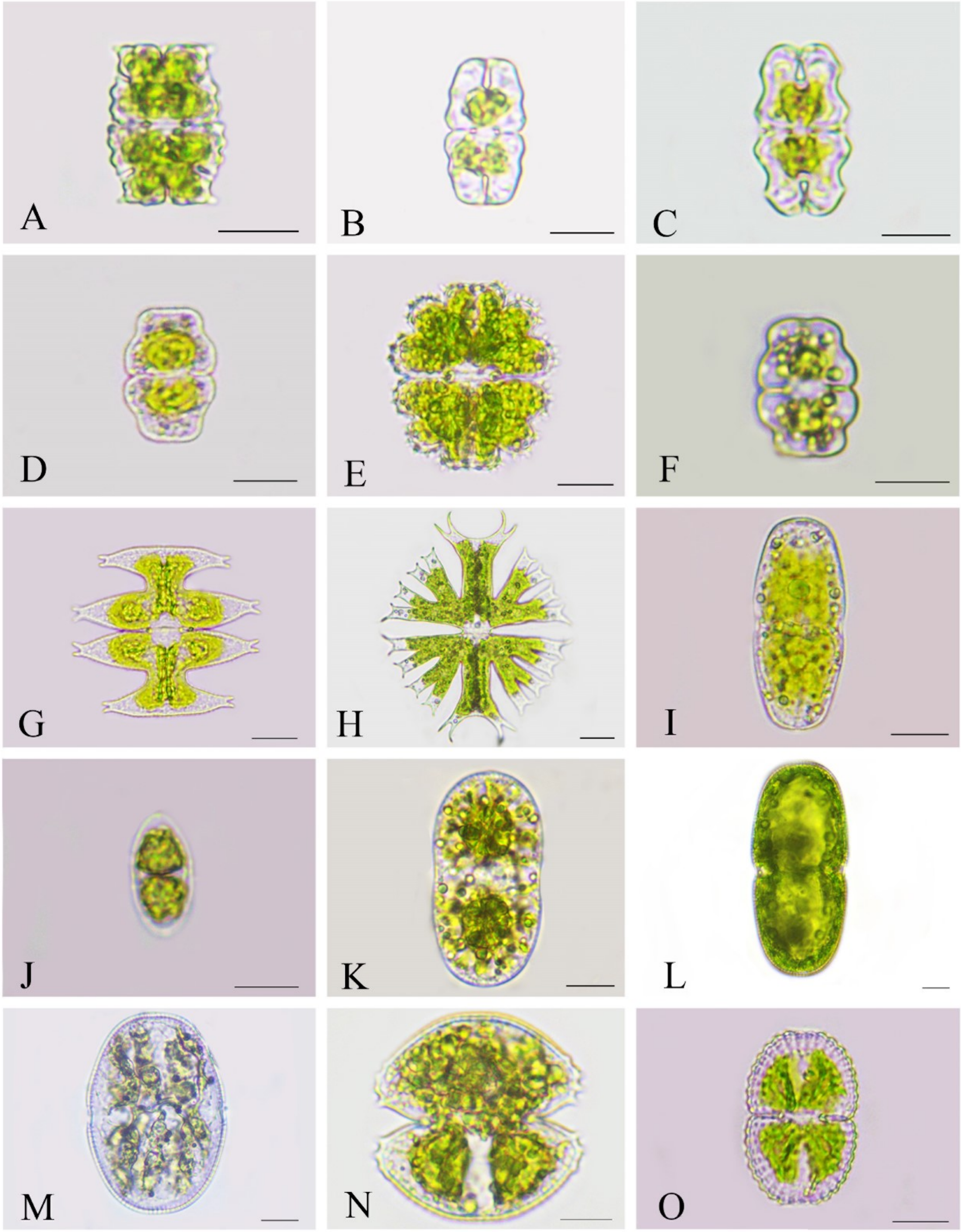
Current name: *Euastrum pseudelegans* W.B. Turner

West and West, 1905. Vol. 2. p. 49, pl. 38, Figs. 22–23.

L-22.4–26.6, W-12.4–14.2, I-3–3.3

Cells smaller than the type described. Semi cells have ellipsoid outline; deep apical incision open inside and closed outside present. Apical and basal angles have short spine; spines are also seen at angles near isthmus.

118. ***Euastrum luetkemuelleri*** F. Ducellier **(Pl. 11, Fig. D)**



Scale 10µm

PLATE 11 (Figs. A-O): A) *Euastrum denticulatum* f. *incisum* A.M. & Prescott **B)** *E. distortum* A.M. Scott & Prescott **C)** *E. elegans* var. *pseudelegans* (W.B. Turner) West & G.S. West **D)** *E. luetkemuelleri* F. Ducellier **E)** *E. spinulosum* Delponte **F)** *E. validum* West & G.S. West **G)** *Micrasterias pinnatifida* Ralfs **H)** *M. radians* W.B. Turner **I)** *Actinotaenium cucurbitinum* (Bisset) Teiling **J)** *A. curtum* (Brebisson ex Ralfs) Teiling ex Ruzicka & Pouzar **K)** *A. diplosporum* (P. Lundell) Teiling **L)** *A. turgidum* var. *minus* H. Croasdale **M)** *A. wollei* (West & G.S. West) Teiling ex Ruzicka & Pouzar **N)** *Cosmarium auriculatum* Reinsch **O)** *C. binum* Nordstedt

Scott and Prescott, 1961. p. 32, pl. 14, Fig. 8.

L-24, W-16, I-6

Semi cells trapeziform with lateral lobes rudimentary. Slight variation in morphology of basal lobe which is almost flat and not as produced and round as the type.

119.***Euastrum spinulosum*** Delponte **(Pl. 11, Fig. E)**

Scott and Prescott, 1961. p. 40, pl. 10, Fig. 3.

L-50.4–55, W-45.5–47, I-11–12

Cells large, distinguished by short spines on widely rounded lobes.

120. ***Euastrum validum*** West & G.S. West **(Pl. 11, Fig. F)**

Coesel and Meesters, 2007. p. 82, pl. 48, Figs. 15–16.

L-17.2, W-12.2, I-4.4

Semi cells trapezoid with rounded angles and truncate apices.

Genus: *Micrasterias* C. Agardh Ex Ralfs

121.***Micrasterias pinnatifida*** Ralfs **(Pl. 11, Fig. G)**

Scott and Prescott, 1961. p. 51, pl. 14, Fig. 17, 18.

L-54.5–56.6, W-61–61.8, I-9.3–11.2

Cells flat, trapezoid in outline, four processes per semi cell separated by deep incisions. Lateral lobes separated from apical lobes by wide incurvation. All lobes have bifid extremities.

122.***Micrasterias radians*** W.B. Turner **(Pl. 11, Fig. H)**

Scott and Prescott, 1961. p. 51, pl. 23, Fig. 1.

L-85–86.5, W-71–74, I-10.4–11.6

Cells flat, circular in outline, semi cells deeply lobed and further lobed by deep incisions and have lobules. Apical and basal lobes have deep incision, protruding and widely separated lobes and curved bifid ends. Smaller specimen than nominal ones.

Genus: *Actinotaenium* (Nageli) Teiling

123.***Actinotaenium cucurbitinum*** (Bisset) Teiling **(Pl. 11, Fig. I)**

Coesel and Meesters, 2007. p. 60, pl. 31, Figs. 9–10.

L-33.4–55, W-16.7–25, I-24

Cells broadly fusiform, semi cells elliptical, slight isthmus, truncate and rounded apices.

124.***Actinotaenium curtum*** (Brebisson ex Ralfs) Teiling ex Ruzicka & Pouzar **(Pl.11,Fig. J)**

Coesel and Meesters, 2007. p. 60, pl. 31, Figs. 11–12.

L-18–22, W-9–10.5

Cells broadly fusiform, isthmus slightly or not visible, apices narrowly rounded.

125.***Actinotaenium diplosporum*** (P. Lundell) Teiling **(Pl. 11, Fig. K)**

Coesel and Meesters, 2007. p. 61, pl. 29, Figs. 1–2.

L-50.9–54.2, W-25.6–27.4, I-24.6–26.6

Cells more cylindric, isthmus very shallow and widely open, apices broadly rounded. Chloroplast asteroid.

126.***Actinotaenium turgidum*** var. ***minus*** H. Croasdale **(Pl. 11, Fig. L)**

Hirano, 1992. p. 21, pl. 13, Fig. 1.

L-96.7–106, W-45–46.8, I-38.5–41

Cells large, cylindrical, slight constriction, cell wall striated, broadly rounded apices.

127.***Actinotaenium wollei*** (West & G.S. West) Teiling ex Ruzicka & Pouzar **(Pl. 11,Fig. M)**

Coesel and Meesters, 2007. p. 64, pl. 31, Fig. 13

L-66, W-41

Cells elliptic, isthmus not clearly visible.

Genus: *Cosmarium* Corda ex Ralfs

128.***Cosmarium auriculatum*** Reinsch **(Pl. 11, Fig. N)**

Scott and Prescott, 1961. p. 54, pl. 26, Fig. 4.

L-36.3–41, W-38–42.7, I-18.3–19.6

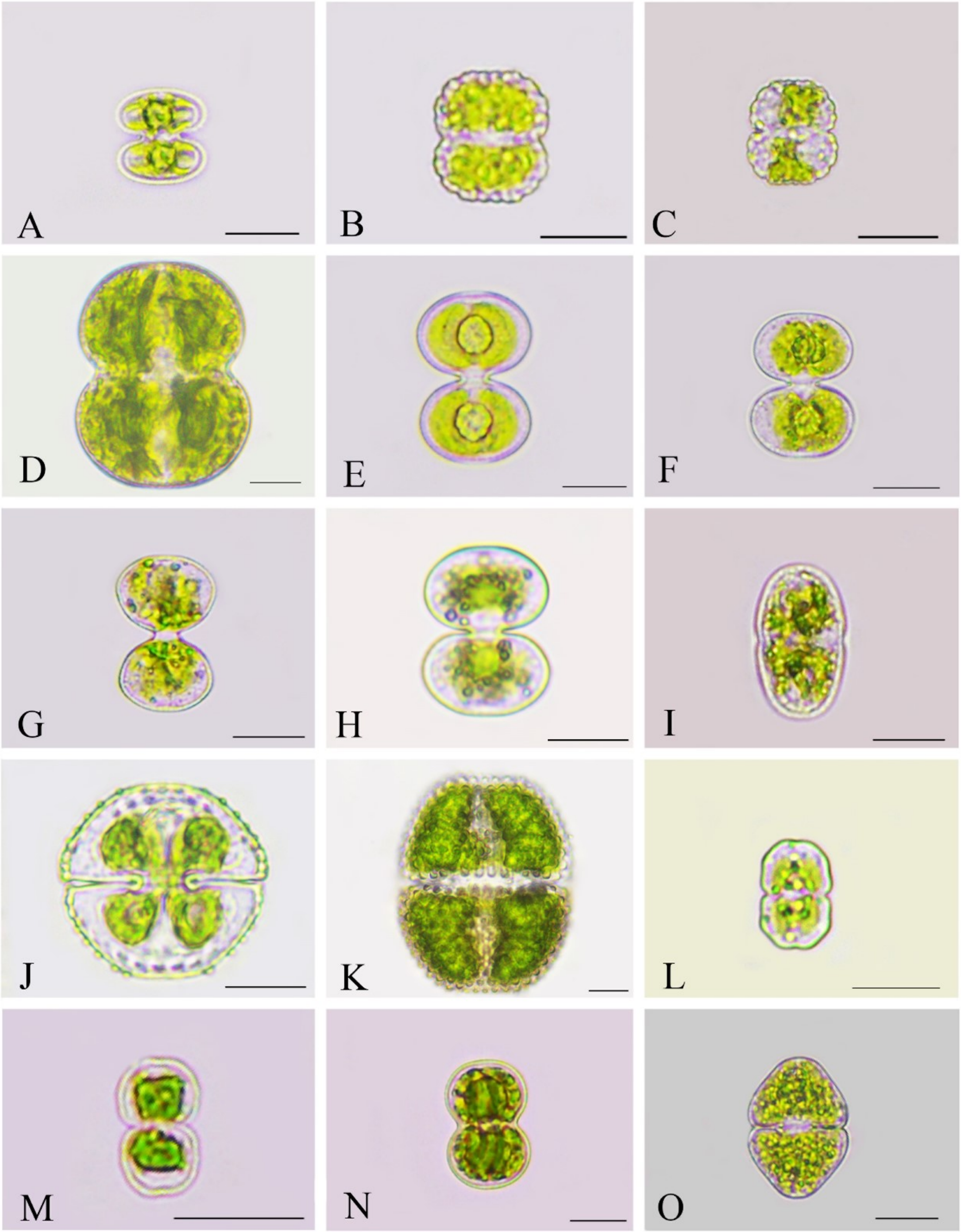
Cells granulate, deep constriction with open sinus, semi cells ellipsoidal with small finger like projections on lateral margins.

129.***Cosmarium binum*** Nordstedt **(Pl. 11, Fig. O)**

West and West, 1908. vol. 3, p. 246, pl. 88, Figs. 10–14.

L-33.3–45, W-26.3–35, I-8.7–25

Cells with numerous marginal crenations, semi cells pyramidate-trapeziform with central tumour.



Scale 10µm

PLATE 12 (Figs. A-O): A) *Cosmarium bioculatum* f. *depressum* Schaarschmidt **B)** *Cosmarium blyttii* Wille **C)** *Cosmarium blyttii* var. *novaesylvae* West & G.S. West **D)** *Cosmarium connatum* Brebisson ex Ralfs **E)** *Cosmarium contractum* O. Kirchner **F)** *Cosmarium contractum* var. *ellipsoideum* (Elfving) West & G.S. West **G)** *Cosmarium contractum* var. *incrassatum* A.M. Scott & Prescott **H)** *Cosmarium contractum* var. *minutum* (Delponte) Coesel **I)** *Cosmarium cucurbita* Brebisson ex Ralfs **J)** *Cosmarium cuneatum* Joshua **K)** *Cosmarium decoratum* West & G.S. West **L)** *Cosmarium difficile* Lutkemuller **M)** *Cosmarium exiguum* W. Archer **N)** *Cosmarium globosum* f. *minus* Boldt **O)** *Cosmarium granatum* Brebisson ex Ralfs

130.***Cosmarium bioculatum*** f. ***depressum*** Schaarschmidt **(Pl. 12, Fig. A)**

Current name: *Cosmarium bioculatum* var. *depressum* (Schaarschmidt) Schmidle

West and West, 1908. vol. 3, p. 166, pl. 61, Figs. 8, 9.

L-19.7–21, W-18–19, I-8.2–8.5

Semi cells elliptic, open sinus, slightly flattened apices.

131.***Cosmarium blyttii*** Wille **(Pl. 12, Fig. B)**

West and West, 1908. vol. 3, p. 225, pl. 86, Figs. 1–4.

L-10–18, W-10–15.7, I-2.3–5

Cells small, semi cells trapeziform with crenations.

132.***Cosmarium blyttii*** var. ***novaesylvae*** West & G.S. West **(Pl. 12, Fig. C)**

West and West, 1908. vol. 3, p. 227, pl. 86, Figs. 5, 6.

L-20.2, W-17

Cells with more prominent crenations on margins of cells.

133.***Cosmarium connatum*** Brebisson ex Ralfs **(Pl. 12, Fig. D)**

West and West, 1908. vol. 3, p. 25, pl. 67, Figs. 15–17.

L-53.4, W-40.8, I-31.8

Cells large, wide, and open sinus. Semi cells transversely subelliptic with slightly flat apex.

134. ***Cosmarium contractum*** O. Kirchner **(Pl. 12, Fig. E)**

West and West, 1905. vol. 2, p. 170, pl. 61, Figs. 23–25.

L-24–33, W-15–20, I-3–4.6

Semi cells oblong elliptic, narrow sinus, presence of single central pyrenoid in each semi cell.

135.***Cosmarium contractum*** var. ***ellipsoideum*** (Elfving) West & G.S. West **(Pl. 12, Fig. F)**

West and West, 1905. vol. 2, p. 172, pl. 61, Figs. 28, 35.

L-32.8, W-23.8, I-5.3

Semi cells more elliptic, apex slightly flattened at middle.

136. ***Cosmarium contractum*** var. ***incrassatum*** A.M. Scott & Prescott **(Pl. 12, Fig. G)**

Scott and Prescott, 1961. p. 56, pl. 27, Fig. 5.

L-22.6–33, W-14.6–19.5, I-3–5

Semi cells elliptic with obtuse lateral angles.

137. ***Cosmarium contractum*** var. ***minutum*** (Delponte) Coesel **(Pl. 12, Fig. H)**

Coesel and Meesters, 2007. p. 112, pl. 61, Fig. 18–20.

L-19.5, W-14.6, I-3.5

Cells smaller than the nominate variety.

138. ***Cosmarium cucurbita*** Brebisson ex Ralfs **(Pl. 12, Fig. I)**

Current name: *Actinotaenium cucurbita* (Brebisson ex Ralfs) Teiling

West and West, 1908. vol. 3, p. 106, pl. 73, Figs. 31–33.

L-25–55, W-14–25, I-13–22

Cells cylindrical, twice as long as broad, slightly constricted, apices convex and rounded.

139. ***Cosmarium cuneatum*** Joshua **(Pl. 12, Fig. J)**

Scott and Prescott, 1961. p. 57, pl. 30, Fig. 3.

L-31.5–33.5, W-31.3–35, I-7.5–8

Cells deeply constricted. Semi cells semicircular with granules on margin except at apex.

140. ***Cosmarium decoratum*** West & G.S. West **(Pl. 12, Fig. K)**

West and West, 1895. p. 61, pl.7, Fig. 21.

L-68–80, W-54–59.6, I-20–27.2

Cells covered with large granules, semi cells trapezoid, apices truncate.

141. ***Cosmarium difficile*** Lutkemuller **(Pl. 12, Fig. L)**

Coesel and Meesters, 2007. p. 116, pl. 67, Figs. 1–5.

L-15.3–16, W-9.5–11, I-3–3.4

Cells small, semi cells subquadrate, basal angles rounded.

142. ***Cosmarium exiguum*** W. Archer **(Pl. 12, Fig. M)**

West and West, 1908. vol. 3, p. 63, pl. 70, Figs. 17–19.

L-15.2–16.5, W-9.5–11

Cells small, deeply constricted, open sinus, semi cells subquadrate with rounded angles.

143. ***Cosmarium globosum*** f. ***minus*** Boldt **(Pl. 12, Fig. N)**

Current name: *Actinotaenium globosum* f. *minus* (Boldt) Kurt Forster ex Compere

West and West, 1908. vol. 3, p. 29, pl. 68, Figs. 1, 2.

L-16–22.5, W-10.6–15.6, I-8.1–13.8

Cells small, semi cells subcircular and slightly constricted.

144. ***Cosmarium granatum*** Brebisson ex Ralfs **(Pl. 12, Fig. O)**

West and West, 1905. vol. 2, p. 186, pl. 63, Figs. 1–3.

L-33.7, W-24, I-7

Cells deeply constricted. semi cells truncate pyramidate with rounded basal angles.

145. ***Cosmarium hammeri*** var. ***protuberans*** West & G.S. West **(Pl. 13, Fig. A)**

West and West, 1905. vol. 2, p. 181, pl. 62, Figs. 20, 21.

L-23.4-24, W-18-18.3, I-6.4

Cells sub hexagonal, semi cells pyramidate with basal angles rounded and truncate apex.

146. ***Cosmarium impressulum*** Elfving **(Pl. 13, Fig. B)**

West and West, 1908. vol. 3, p. 86, pl. 72, Figs. 14–18.

L-24, W-16.5, I-5

Cells with undulate margins and crenations. Semi cells sub semicircular and pyramidate.

147. ***Cosmarium inornatum*** Joshua **(Pl. 13, Fig. C)**

Scott and Prescott, 1961. p. 59, pl. 26, Fig. 13.

L-29.7–34.6, W-16–18, I-10.7–12.26

Cells subcylindrical, sinus widely open, semi cells subquadrate with apex rounded and undulate.

148. ***Cosmarium lundellii*** Delponte **(Pl. 13, Fig. D)**

Scott and Prescott, 1961. p. 60, pl. 25, Fig. 6.

L-37.2–54.7, W-33.8–51.9

Semi cells pyramidate, semi-circular with rounded basal angles.

149. ***Cosmarium lundellii*** var. ***corruptum*** (W.B. Turner) West & G.S. West **(Pl. 13, Fig. E)**

Scott and Prescott, 1961. p. 61, pl. 25, Fig. 9.

L-36.4–52.3, W-34.4–45

Semi cells with apex subtruncate and sinus open towards exterior.

150. ***Cosmarium lundellii*** var. ***ellipticum*** West & G.S. West **(Pl. 13, Fig. F)**

Scott and Prescott, 1961. p. 61, pl. 25, Fig. 8.

L-42.2–45.2, W-34.7–39.6

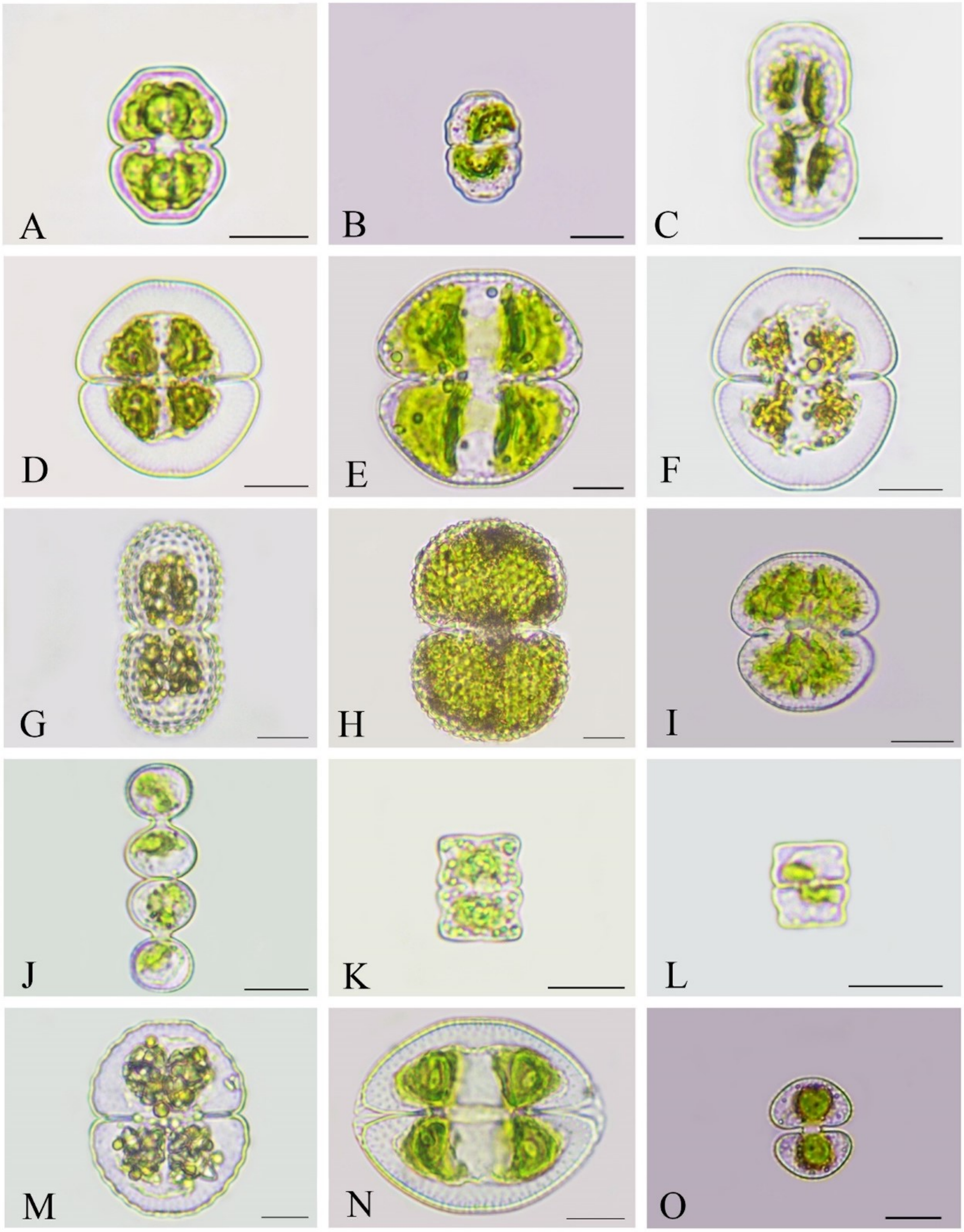
Cells smaller than type specimen. Semi cells sub circular with truncate apex.

151. ***Cosmarium mansangense*** West & G.S. West **(Pl. 13, Fig. G)**

Scott and Prescott, 1961. p. 62, pl. 28, Figs. 11–12.

L-50, W-24.5, I-15.3

Cells cylindrical, uniformly granulate, slightly constricted, semi cells oblong with broadly rounded apices and straight sides.



Scale 10µm

PLATE 13 (Figs. A-O): A) *Cosmarium hammeri* var. *protuberans* West & G.S. West **B)** *C. impressulum* Elfving **C)** *C. inornatum* Joshua **D)** *C. lundellii* Delponte **E)** *C. lundellii* var. *corruptum* (W.B. Turner) West & G.S. West **F)** *C. lundellii* var. *ellipticum* West & G.S. West **G)** *C. mansangense* West & G.S. West **H)** *C. margaritatum* f. *minus* (Boldt) West & G.S. West **I)** *C. medioscrobiculatum* var. *egranulatum* Gutwinski **J)** *C. moniliforme* var. *punctatum* Lagerheim **K)** *C. norimbergense* Reinsch **L)** *C. norimbergense* var. *depressum* (West & G.S. West) Willi Krieger & Gerloff **M)** *C. obtusatum* (Schmidle) Schmidle **N)** *C. obsoletum* (Hantzsch) Reinsch **O)** *C. ocellatum* Eichler & Gutwinski

152. ***Cosmarium margaritatum*** f. ***minus*** (Boldt) West & G.S. West **(Pl. 13, Fig. H)**

West and West, 1912. vol. 4, p. 18, pl. 99, Fig. 9.

L-66, W-46.2, I-14.2

Cells large and uniformly granulated, semi cells rectangular with broadly rounded angles, sinus with dilated extremity.

153. ***Cosmarium medioscrobiculatum*** var. ***egranulatum*** Gutwinski **(Pl. 13, Fig. I)**

Scott and Prescott, 1961. p. 63, pl. 26, Figs. 3.

L-35.4–48, W-31.6–43, I-14–21

Cells medium sized, deeply constricted, open sinus, semi cells sub semicircular, lateral margin slightly produced.

154. ***Cosmarium moniliforme*** var. ***punctatum*** Lagerheim **(Pl. 13, Fig. J)**

West and West, 1908. vol. 3, p. 22, pl. 67, Fig. 4.

L-21.5, W-13.5, I-3

Semi cells circular with very deep constriction.

155. ***Cosmarium norimbergense*** Reinsch **(Pl. 13, Fig. K)**

West and West, 1908. vol. 3, p. 52, pl. 69, Figs. 25–27.

L-16.8–20, W-12.8–14, I-5–5.5

Cells deeply constricted, semi cells subquadrate, rounded angles and retuse with straight apex.

156. ***Cosmarium norimbergense*** var. ***depressum*** (West & G.S. West) Willi Krieger & Gerloff **(Pl. 13, Fig. L)**

West and West, 1908. vol. 3, p. 53, pl. 69, Figs. 28, 29.

L-10–11, W-10, I-2.5–3.5

Semi cells depressed than the nominal variety.

157. ***Cosmarium obtusatum*** (Schmidle) Schmidle **(Pl. 13, Fig. M)**

Hirano, 1992, p. 35, pl. 18, Fig. 31.

L-37–39.6, W-30.7–31.5, I-9.5–10.7

Cells with undulate margins, semi cells truncate-pyramidate and basal angles slightly rounded.

158. ***Cosmarium obsoletum*** (Hantzsch) Reinsch **(Pl. 13, Fig. N)**

West and West, 1905. vol. 2, p. 133, pl. 56, Figs. 1–3.

L-36–46.6, W-40–55, I-13.4–20.3

Cells elliptic, basal angles submamillate, semi cells depressed and semi-circular with slightly flattened apex.

159.***Cosmarium ocellatum*** Eichler & Gutwinski **(Pl. 13, Fig. O)**

West and West, 1905. vol. 2, p. 144, pl. 58, Fig. 6.

L-19–25, W-15–20, I-3.5–5

Cells deeply constricted, linear sinus, semi cells sub semicircular-pyramidate, basal angles and apex is rounded.

160.***Cosmarium ordinatum*** (Borgesen) West & G.S. West **(Pl. 14, Fig. A)**

Oliveira, 2011. p. 33, Figs. 13, 14.

L-20–22.4, W-19–19.8, I-5–5.3

Cells slightly long than broad, semi cells elliptic with granules all over the cell, deep and open sinus.

161.***Cosmarium phaseolus*** var. ***elevatum*** Nordstedt **(Pl. 14, Fig. B)**

Coesel and Meesters, 2007. p. 131, pl. 62, Figs. 3–4

L-20.2–21.6, W-18.3–19

Cells small, semi cells trapezoid, slightly truncate, broadly rounded poles.

162. ***Cosmarium porteanum*** W. Archer **(Pl. 14, Fig. C)**

Scott and Prescott, 1961. p. 65, pl. 28, Fig. 8.

L-15–23.6, W-11–15.4, I-4–7

Cells deeply constricted, isthmus slightly elongated, semi cells elliptic and granulate.

163. ***Cosmarium porteanum*** var. ***nephroideum*** Wittrock **(Pl. 14, Fig. D)**

Scott and Prescott, 1961. p. 66, pl. 28, Fig. 10.

L-29, W-22, I-9.3

Semi cells semicircular elliptic.

164. ***Cosmarium pseudobroomei*** Wolle **(Pl. 14, Fig. E)**

West and West, 1912. vol. 4, p. 22, pl. 100, Figs. 7, 8.

L-32.8–33, W-30.5–31, I-8.8–9.1

Cells granulated, very deeply constricted with slightly dilated extremity. Semi cells oblong rectangular with rounded angles.

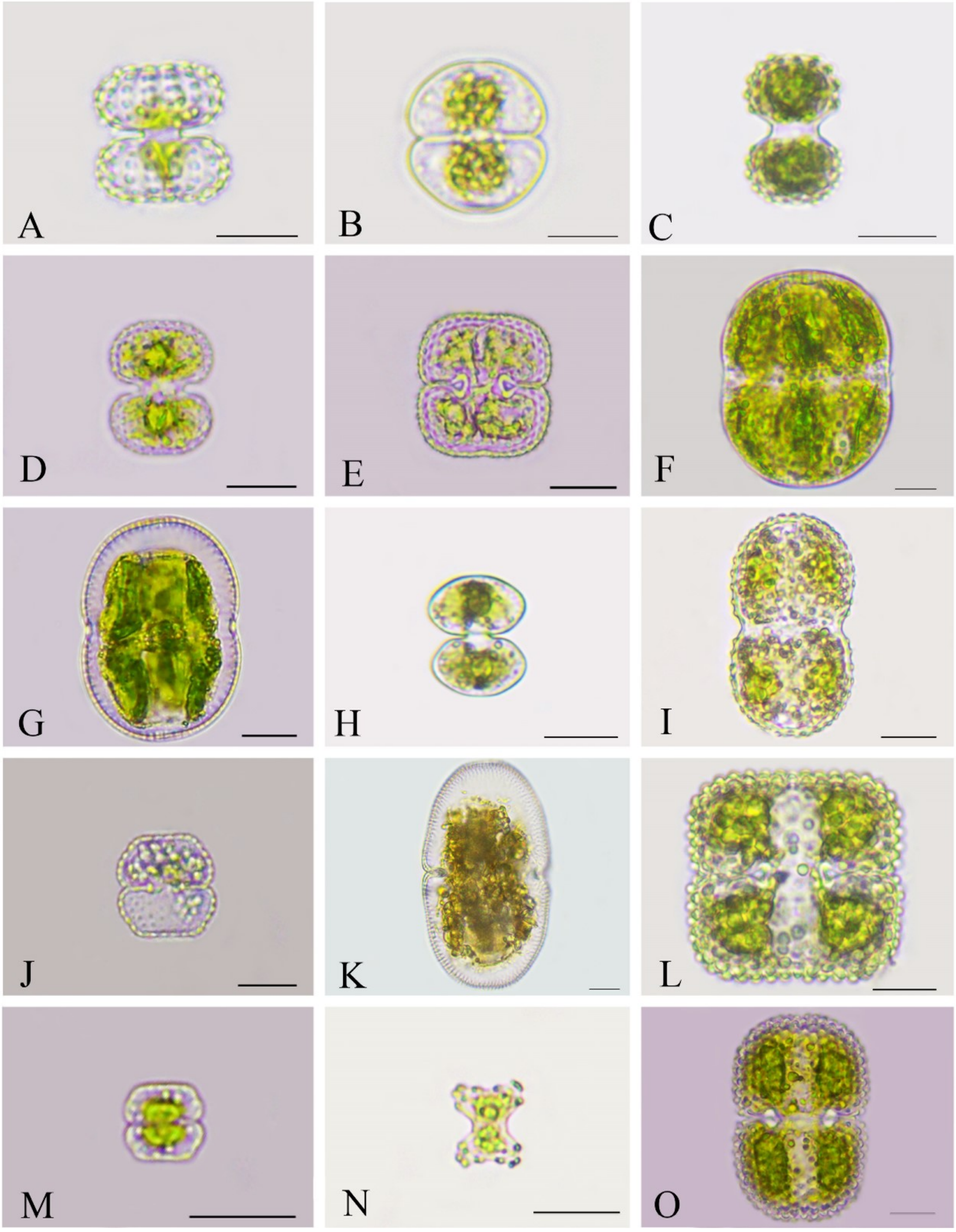
165. ***Cosmarium pseudoconnatum*** Nordstedt **(Pl. 14, Fig. F)**

West and West, 1908. vol. 3, p. 26, pl. 67, Figs. 19–21.

L-53.2, W-43.4

Cells very slightly constricted, semi cells semi-elliptic.

166.***Cosmarium pseudoconnatum*** var. ***ellipsoideum*** West & G.S. West **(Pl. 14, Fig. G)**



Scale 10µm

PLATE 14 (Figs. A-O): A) *Cosmarium ordinatum* (Borgesen) West & G.S. West **B)** *C. phaseolus* var. *elevatum* Nordstedt **C)** *C. porteanum* W.Archer **D)** *C. porteanum* var. *nephroideum* Wittrock **E)** *C. pseudobroomei* Wolle **F)** *C. pseudoconnatum* Nordstedt **G)** *C. pseudoconnatum* var. *ellipsoideum* West & G.S. West **H)** *C. pseudoprotuberans* O. Kirchner **I)** *C. pseudamoenum* Wille **J)** *C. punctulatum* var. *subpunctulatum* (Nordstedt) Borgesen **K)** *Cosmarium pyramidatum* Brebisson ex Ralfs **L)** *C. quadrum* var. *minus* Nordstedt **M)** *C. quadratulum* (F. Gay) De Toni **N)** *C. regnesi* var. *montanum* Schmidle **O)** *C. reniforme* var. *elevatum* West & G.S. West

West and West, 1908. vol. 3, p. 28, pl. 67, Fig. 22.

L-49.5–61.7, W-35.7–43.8

Cells with deeper constriction than nominal variety.

167. ***Cosmarium pseudoprotuberans*** O. Kirchner **(Pl. 14, Fig. H)**

Coesel and Meesters, 2007. p. 134, pl. 61, Fig. 21.

L-18.6–20, W-14.3–16, I-3.4–4

Cells deeply constricted, open sinus, semi cells sub hexagonal elliptic with obtuse lateral angles.

168. ***Cosmarium pseudamoenum*** Wille **(Pl. 14, Fig. I)**

West and West, 1912. vol. 4, p. 31, pl. 102, Figs. 7–9.

L-48.7, W-27.7, I-22

Cells almost cylindrical, slightly constricted, and uniformly granulate. Semi cell oblong with rounded apex.

169. ***Cosmarium punctulatum*** var. ***subpunctulatum*** (Nordstedt) Borgesen **(Pl. 14, Fig. J)**

Scott and Prescott, 1961. p. 67, pl. 31, Fig. 8.

L-20–30.3, W-19.2–25, I-5.5–9.4

Cells granulate, semi cells with truncate apex and rounded angles.

170. ***Cosmarium pyramidatum*** Brebisson ex Ralfs **(Pl. 14, Fig. K)**

West and West, 1905. vol. 2, p. 199, pl. 64, Figs. 5–7.

L-90.5–97, W-50.3–52.3

Cells large, semi cells pyramidal with rounded angles, narrowly truncated apices. Deep and linear sinus.

171. ***Cosmarium quadrum*** var. ***minus*** Nordstedt **(Pl. 14, Fig. L)**

West and West, 1912. vol. 4, p. 21.

L-34.6–45.6, W-37–46.6

Cells rectangular with granules all over the cell, broad and flat apex, deeply constricted with a dilated extremity. Basal angles rounded.

172. ***Cosmarium quadratulum*** (F. Gay) De Toni **(Pl. 14, Fig. M)**

Coesel and Meesters, 2007. p. 137, pl. 67, Figs. 18–20.

L-9.3–11.6, W-7.6–10

Cells small with closed sinus. Semi cells trapeziform, slightly retused and truncate apex.

173. ***Cosmarium regnesi*** var. ***montanum*** Schmidle **(Pl. 14, Fig. N)**

West and West, 1908. vol. 3, p. 39, pl. 68, Figs. 29–31.

L-11.2, W-9.6, I-4.

Cells small, deeply constricted, open sinus. Semi cells oblong rectangular with six small marginal protuberances, three on each side.

174. ***Cosmarium reniforme*** var. ***elevatum*** West & G.S. West **(Pl. 14, Fig. O)**

West and West, 1908. vol. 3, p. 157, pl. 79, Figs. 1, 2; pl. 82, Fig. 15.

L-67.7, W-42.4, I-15

175. ***Cosmarium retusiforme*** (Wille) Gutwinski **(Pl. 15, Fig. A)**

West and West, 1905. vol. 2, p. 180, pl. 62, Figs. 17, 18.

L-17–26, W-14–19, I-3.3–7.6

Cells sub pyramidate, semi cells have deep constriction, angles sharp, and apices truncate.

176. ***Cosmarium scabrum*** W.B. Turner **(Pl. 15, Fig. B)**

Scott and Prescott, 1961. p. 68, pl. 29, Fig. 3.

L-35–57, W-37–56, I-10.5–15

Cells granulate, semi cells rectangular with rounded angles.

177. ***Cosmarium sexangulare*** f. ***minimum*** Nordstedt **(Pl. 15, Fig. C)**

Current name: *Cosmarium sexangulare* P. Lundell

Scott and Prescott, 1961. p. 69, pl. 32, Fig. 10.

L-17.4–19, W-14.8–16.3, I-3.4–4.2

Cells deeply constricted with narrow sinus. Semi cells elliptic hexagonal with rounded angles.

178. ***Cosmarium sexnotatum*** var. ***tristriatum*** (Lutkemuller) Schmidle **(Pl. 15, Fig. D)**

West and West, 1908. vol. 3, p. 228, pl. 86, Figs. 8–9.

L-15.7–22, W-12–15, I-5–5.5

Semi cells small, trapeziform, slightly undulate, and truncate apices. This species is very much like *C. blytti* except in its pyramidate nature.

179. ***Cosmarium speciosum*** P. Lundell **(Pl. 15, Fig. E)**

Coesel and Meesters, 2007. p. 140, pl. 78, Figs. 9–10.

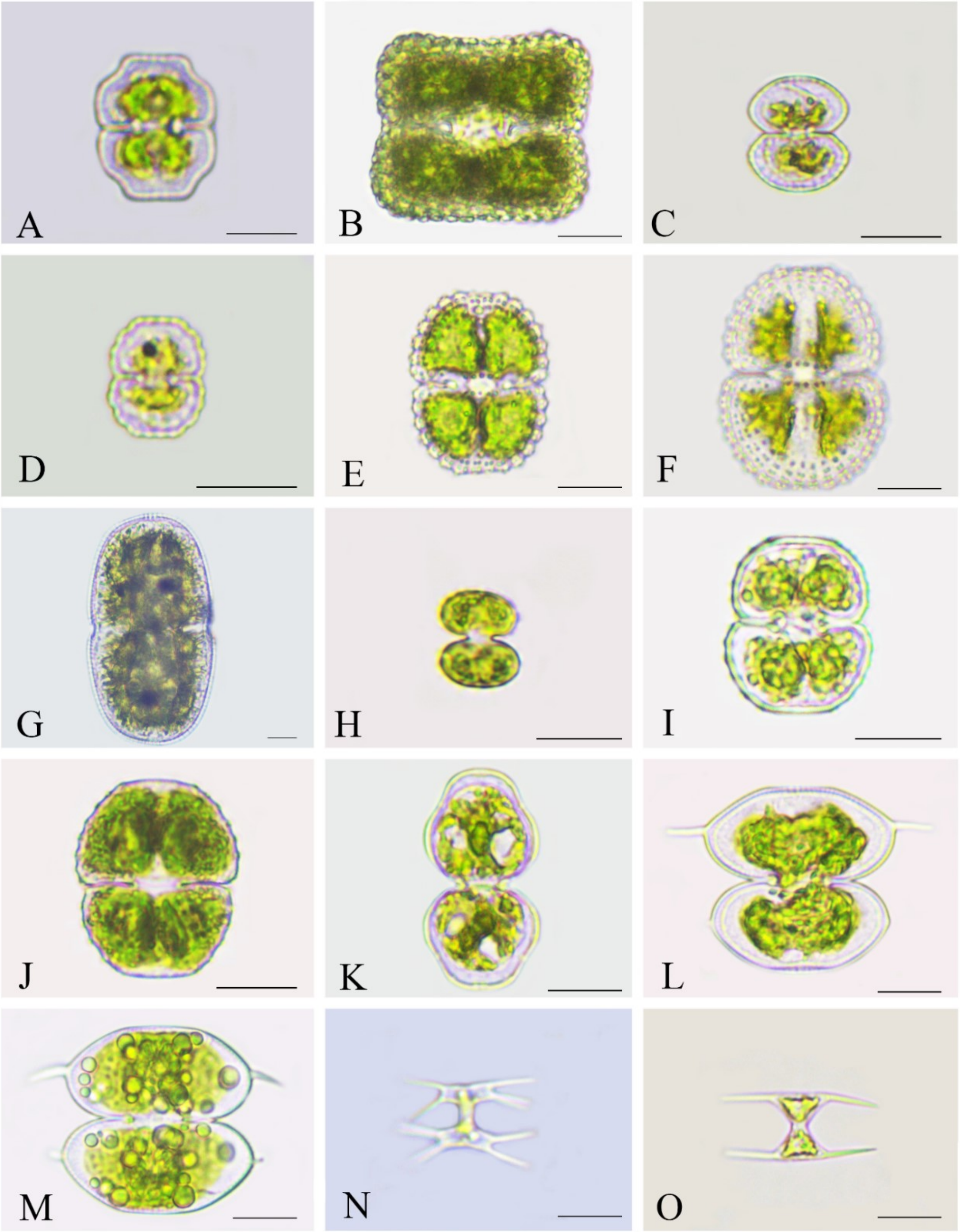
L-38–47.5, W-27–32.6, I-8.7–11

Semi cells sub rectangular with truncate apex. Margins crenate and granules arranged in series.

180. ***Cosmarium subspeciosum*** Nordstedt **(Pl. 15, Fig. F)**

West and West, 1908. vol. 3, p. 252, pl. 89, Fig. 11.

L-42.4–50, W-30.6–35, I-13.5–17



Scale 10µm

PLATE 15 (Figs. A-O): A) *Cosmarium retusiforme* (Wille) Gutwinski **B)** *C. scabrum* W.B. Turner **C)** *C. sexangulare* f. *minimum* Nordstedt **D)** *C. sexnotatum* var. *tristriatum* (Lutkemuller) Schmidle **E)** *C. speciosum* P. Lundell **F)** *C. subspeciosum* Nordstedt **G)** *C. subturgidum* f. *minus* Schmidle **H)** *C. tenue* W. Archer **I)** *C. trachypleurum* var. *nordstedtii* Gutwinski **J)** *C. vitiosum* var. *orientale* A.M. Scott & Prescott **K)** *C. zonatum* P. Lundell **L)** *Arthrodesmus convergens* Ehrenberg ex Ralfs **M)** *A. convergens* f. *curtus* W.B. Turner **N)** *A. octocornis* (Ehrenberg ex Ralfs) W. Archer **O)** *A. triangularis* Lagerheim

Semi cells pyramidate, sub semicircular which gradually attenuate to truncate apex. Small rounded central tumour present. Crenations present on margins and granules are arranged in series.

181.***Cosmarium subturgidum*** f. ***minus*** Schmidle **(Pl. 15, Fig. G)**

Current name: *Actinotaenium capax* var. *minus* (Schmidle) Teiling ex Ruzicka & Pouzar

West and West, 1908. vol. 3, p. 117, pl. 74, Figs. 22–23.

L-65.4–74, W-37–40, I-33–38

Cells slightly constricted, semi cells with truncate and broad apices.

182.***Cosmarium tenue*** W. Archer **(Pl. 15, Fig. H)**

Coesel and Meesters, 2007. p. 146, pl. 61, Figs. 24–28.

L-13.4, W-11.2, I-3.3

Cells small with narrow and open sinus. Semi cells elliptical.

183.***Cosmarium trachypleurum*** var. ***nordstedtii*** Gutwinski **(Pl. 15, Fig. I)**

Hirano, 1992, p. 46, pl. 20, Fig. 9.

L-24.4–30, W-19.6–24.2, I-5–6.5

Cells with slightly dilated sinus, semi cells sub reniform with conical granules, undulate margins, truncate apex.

184. ***Cosmarium vitiosum*** var. ***orientale*** A.M. Scott & Prescott **(Pl. 15, Fig. J)**

Hirano, 1992, p. 48, pl. 20, Fig. 14.

L-29.6, W-25.4, I-7

Cells deeply constricted, semi cells trapeziform, truncate apex, lateral margins with short spines disposed at equal distance.

185. ***Cosmarium zonatum*** P. Lundell **(Pl. 15, Fig. K)**

Scott and Prescott, 1961. p. 73, pl. 28, Fig. 5.

L-42, W-23, I-7

Semi cells subovate, deep wide-open sinus.

Genus: *Arthrodesmus* Ehrenberg ex Ralfs

186. ***Arthrodesmus convergens*** Ehrenberg ex Ralfs **(Pl. 15, Fig. L)**

Current name: *Staurodesmus convergens* (Ehrenberg ex Ralfs) S. Lillieroth

Scott and Prescott, 1961. p. 74, pl. 34, Figs. 7–10.

L-27.3–28.5, Wcsp-41–44.6, I-7.3–9

187.***Arthrodesmus convergens*** f. ***curtus*** W.B. Turner **(Pl. 15, Fig. M)**

Current name: *Staurodesmus convergens* var. *curtus* (W.B. Turner) Kurt Forster

Scott and Prescott, 1961. p. 74, pl. 34, Figs. 5, 6.

L-35–36, Wssp-34.6–35.5, I-9.2–10, SP-7.1–7.7

188. ***Arthrodesmus octocornis*** (Ehrenberg ex Ralfs) W. Archer **(Pl. 15, Fig. N)**

Current name: *Staurodesmus octocornis* (Ehrenberg ex Ralfs) Stastny, Skaloud & Neustupa

Scott and Prescott, 1961. p. 77, pl. 35, Figs. 9–12.

L-9, Wcsp-15.7–19.2, I-2.2–2.5, SP-5.5–5.8

189. ***Arthrodesmus triangularis*** Lagerheim **(Pl. 15, Fig. O)**

Current name: *Staurodesmus triangularis* (Lagerheim) Teiling

Coesel and Meesters, 2013. p. 36, pl. 7, Figs. 1–6.

L-12.3, W-30, I-2.5, SP-9.2–10

Genus: *Xanthidium* Ehrenberg ex Ralfs

190. ***Xanthidium acanthophorum*** var. ***raciborskii*** Gutwinski **(Pl. 16, Fig. A)**

Scott and Prescott, 1961. p. 79, pl. 36, Fig. 12; pl. 37, Fig. 1.

Lcsp-43.6–53.8, W-37.4–41, I-9–10.5

191. ***Xanthidium antilopaeum*** var. ***hebridarum*** West & G.S. West **(Pl. 16, Fig. B)**

Coesel and Meesters, 2007. p. 152, pl. 84, Fig. 1.

Lcsp-48.6–51, Wcsp-60.2–66.7, I-8.5–9.4, SP-6–16.7

192. ***Xanthidium ceylanicum*** West & G.S. West **(Pl. 16, Fig. C)**

West and West, 1902. p. 158, pl. 20. Fig. 24, 25.

L-25.8–26, W-21.5–22, I-5.7–6, SP-1–3.5

Cells deeply constricted, semi cells trapeziform, pyramidal with spines. Spines at apex larger than others.

193. ***Xanthidium spinosum*** (W. Joshua) West & G.S. West **(Pl. 16, Fig. D)**

Scott and Prescott, 1961. p. 84, pl. 37, Figs. 2, 3.

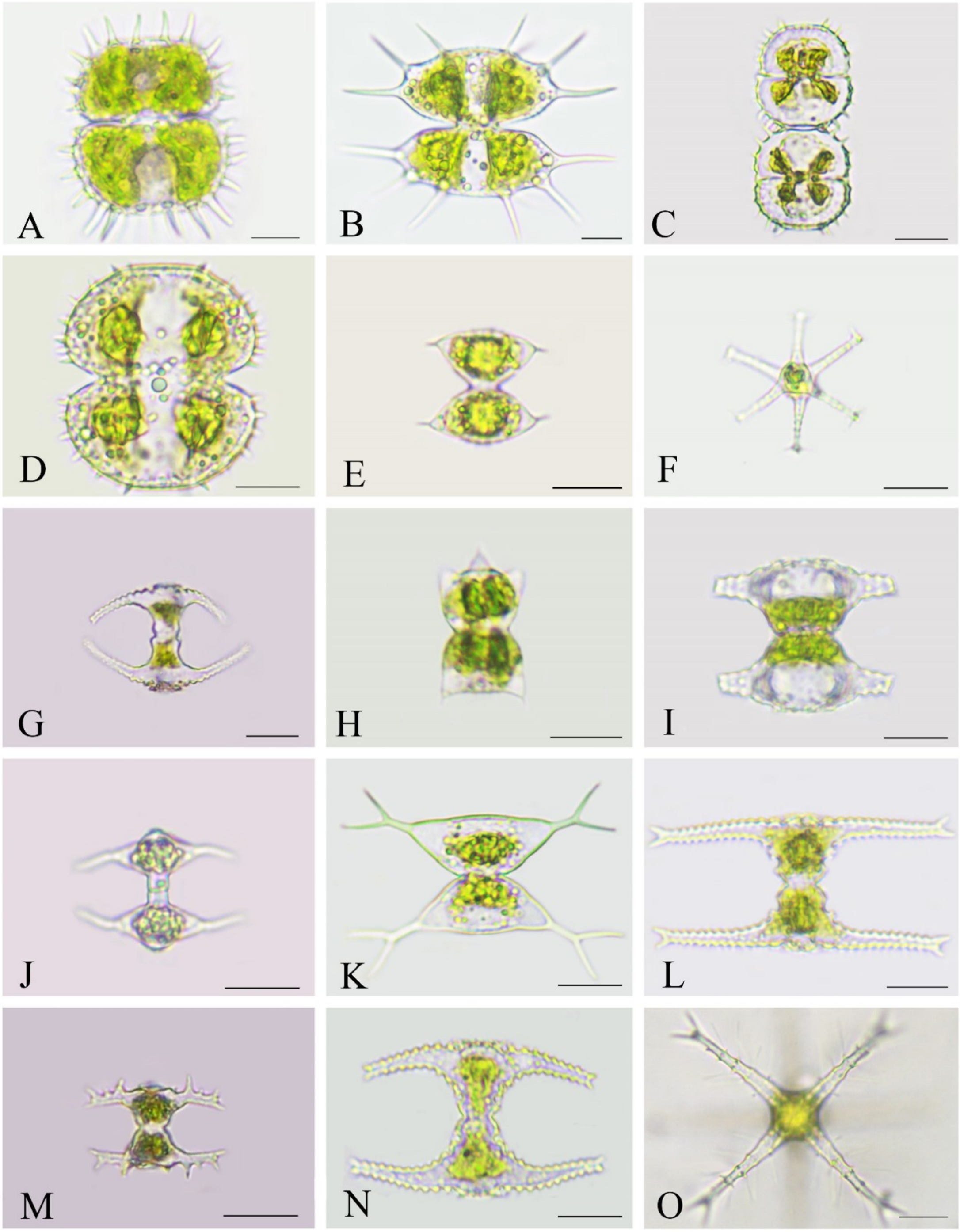
L-41.7–48, W-35–44, I-21–25, SP-1.8–3

Genus: *Staurodesmus* Teiling

194. ***Staurodesmus mucronatus*** var. ***subtriangularis*** (West & G.S. West) Croasdale **(Pl. 16, Fig. E)**

Coesel and Meesters, 2007. p. 164, pl. 87, Figs. 27–30.

L-19.6–20, Wssp-19.4–20.2, I-4.7, SP-1.8–3.5



Scale 10µm

PLATE 16 (Figs. A-O): A) *Xanthidium acanthophorum* var. *raciborskii* Gutwinski **B)** *X. antilopaeum* var. *hebridarum* West & G.S. West **C)** *X. ceylanicum* West & G.S. West **D)** *X. spinosum* (W. Joshua) West & G.S. West **E)** *Staurodesmus mucronatus* var. *subtriangularis* (West & G.S. West) Croasdale **F)** *Staurastrum bigibbum* Skuja **G)** *S. cerastes* var. *pulchrum* A.M. Scott & Gronblad **H)** *S. corniculatum* var. *spinigerum* West **I)** *S. crenulatum* (Nageli) Delponte **J)** *S. cuspidatum* Brebisson **K)** *S. freemanii* var. *nudiceps* A.M. Scott & Prescott **L)** *S. gracile* var. *elongatum* A.M. Scott & Prescott **M)** *S. heimerlianum* var. *sumatranum* A.M. Scott & Prescott **N)** *S. indentatum* f. *minus* A.M. Scott & Prescott **O)** *S. limneticum* var. *burmense* West & G.S. West

Closely allied to *St. dejectum* and *St. apiculatum*. Distinguished by more convex apex and triangular semi cell.

Genus: *Staurastrum* Meyen Ex Ralfs

195. ***Staurastrum bigibbum*** Skuja **(Pl. 16, Fig. F)**

Hirano, 1992. p. 68, pl. 41, Fig. 10.

L-15.5, Wcsp-23, I-6

Cells have three processes in one plane and three in another view.

196. ***Staurastrum cerastes*** var. ***pulchrum*** A.M. Scott & Gronblad **(Pl. 16, Fig. G)**

Hirano, 1992. p. 69, pl. 49, Fig. 7.

L-30–31.2, Wcpr-48–49.7, I-6

Cells with long strongly incurved processes whose basal part is inflated.

197. ***Staurastrum corniculatum*** var. ***spinigerum*** West **(Pl. 16, Fig. H)**

West and West, 1912. vol. 4, p. 164, pl. 125, Figs. 19–22.

L-24.3, W-14, I-9, SP-0.9–1

198. ***Staurastrum crenulatum*** (Nageli) Delponte **(Pl. 16, Fig. I)**

Scott and Prescott, 1961. p. 88, pl. 59, Fig. 10.

Lcsp-15–29, W-20–33, I-4–9

199. ***Staurastrum cuspidatum*** Brebisson **(Pl. 16, Fig. J)**

Current name: *Staurodesmus cuspidatus* (Brebisson) Teiling

Scott and Prescott, 1961. p. 89, pl. 53, Fig. 13.

L-16.5–19.4, Wcsp-25–26, I-3–3.3

200. ***Staurastrum freemanii*** var. ***nudiceps*** A.M. Scott & Prescott **(Pl. 16, Fig. K)**

Scott and Prescott, 1961. p. 92, pl. 43, Fig. 3.

L-25–30, Lcpr-50–55, W-25–28, Wcpr-47–75, I-6–6.5

Cells with two processes that emerge from angles of each semi cell which gets bifid at end.

201. ***Staurastrum gracile*** var. ***elongatum*** A.M. Scott & Prescott **(Pl. 16, Fig. L)**

Scott and Prescott, 1961. p. 94, pl. 57, Fig. 10.

L-24.5–28.2, Wcpr-55–58.7, I-5.5–6

202. ***Staurastrum heimerlianum*** var. ***sumatranum*** A.M. Scott & Prescott **(Pl. 16, Fig. M)**

Hirano, 1992. p. 74, pl. 40, Fig. 2: pl. 49, Fig. 16.

L-16.4, Wcsp-29.3, I-4.7

Cells with open sinus, semi cells have concentric series of short spines on dorsal and ventral margins.

203. ***Staurastrum indentatum*** f. ***minus*** A.M. Scott & Prescott **(Pl. 16, Fig. N)**

Scott and Prescott, 1961. p. 96, pl. 50, Fig. 8, 9.

L-30–40, W-47.6–60, I-4.3–8

Cells with short processes and bifid spine.

204. ***Staurastrum limneticum*** var. ***burmense*** West & G.S. West **(Pl. 16, Fig. O)**

Scott and Prescott, 1961. p. 97, pl. 42, Fig. 2, 3.

L-65–80, Wcsp-65–85, I-10

Cells with four processes radiate from centre with spines along processes which gets trifid at end.

205. ***Staurastrum longipes*** (Nordstedt) Teiling **(Pl. 17, Fig. A)**

Coesel and Meesters, 2013. p. 115, pl. 107, Figs. 4–6; pl. 108, Figs. 1–4.

L-16, Lcpr-40–43.8, Wcpr-54.7–63, I-5–5.7.

Cells trifid with long slender processes and 3 or 4 stout spines at tips.

206. ***Staurastrum orbiculare*** var. ***minus*** Prescott **(Pl. 17, Fig. B)**

Das and Keshri, 2013. p. 176, Fig. 2- l, m.

L-18–24, W-19–25

207. ***Staurastrum punctulatum*** Brebisson **(Pl. 17, Fig. C)**

West and West, 1912. vol. 4, p. 179, pl. 127, Fig. 8–11, 13, 14.

L-28.2–35, W-27–25, I-8–10

208. ***Staurastrum sinense*** Lutkemuller **(Pl. 17, Fig. D)**

Current name: *Staurastrum disputatum* var. *sinense* (Lutkemuller) West & G.S. West

West and West, 1912. vol. 4, p. 176, pl. 126, Fig. 19.

L-18–21, W-18–20, I-6–6.8

209. ***Staurastrum spiniceps*** var. ***trifidum*** A.M. Scott & Prescott **(Pl. 17, Fig. E)**

Scott and Prescott, 1961. p. 108, pl. 58, Fig. 5.

L-32, Wcpr-54.7, I-7.3

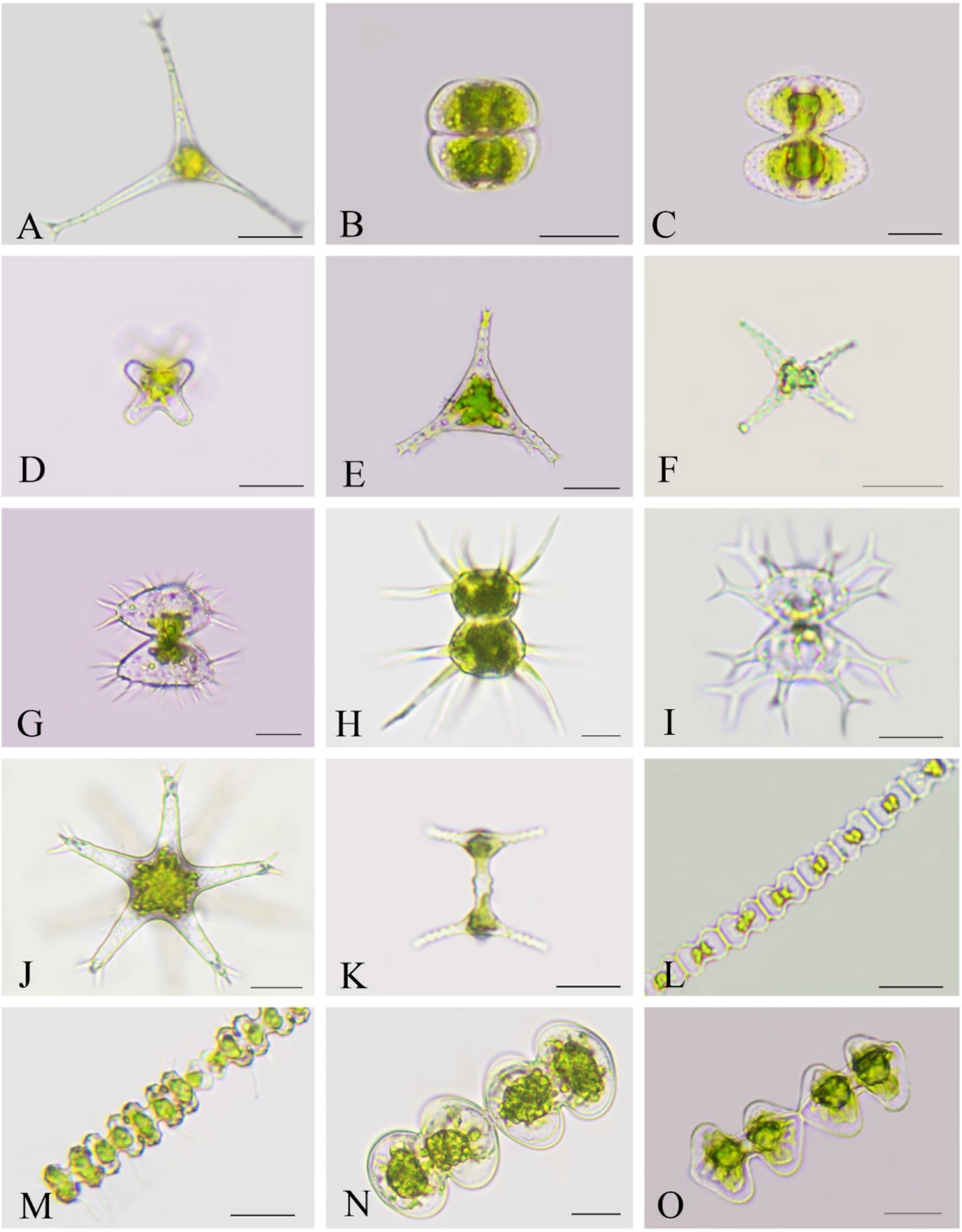
Cells triradiate, trifid processes with serrated margin.

210. ***Staurastrum tetracerum*** Ralfs ex Ralfs **(Pl. 17, Fig. F)**

Scott and Prescott, 1961. p. 112, pl. 57, Fig. 12.

L-23–30, Wcsp-17.4–23, I-3.5–4.5

Cells small, four long strongly diverging processes which are emarginate.



Scale 10µm

PLATE 17 (Figs. A-O): A) *Staurastrum longipes* (Nordstedt) Teiling **B)** *S. orbiculare* var. *minus* Prescott **C)** *S. punctulatum* Brebisson **D)** *S. sinense* Lutkemuller **E)** *S. spiniceps* var. *trifidum* A.M.Scott & Prescott **F)** *S. tetracerum* Ralfs ex Ralfs **G)** *S. teliferum* var. *gladiosum* (W.B.Turner) Coesel & Meesters **H)** *S. tohopekaligense* f. *acuminatum* A.M.Scott & Prescott **I)** *S. tohopekaligense* f. *minus* F.E.Fritsch & M.F.Rich **J**) *S. zonatum* var. *ceylanicum* West & G.S.West **K)** *Staurastrum* sp. 1 **L)** *Sphaerozosma excavatum* Ralfs ex Ralfs **M)** *S. granulatum* J.Roy & Bisset **N)** *Spondylosium moniliforme* P.Lundell **O)** *S. nitens* var. *triangulare* fa *javanicum* Gutwinski

211.***Staurastrum teliferum*** var. ***gladiosum*** (W.B.Turner) Coesel & Meesters **(Pl.17, Fig. G)**

Coesel and Meesters, 2013. p. 157, pl. 44, Figs. 10–13.

L-33.5–38.3, W-33.6–41.6

212.***Staurastrum tohopekaligense*** f. ***acuminatum*** A.M. Scott & Prescott **(Pl. 17, Fig.H)**

Scott and Prescott, 1961. p. 113, pl. 48, Fig. 3.

Lssp-26.5, Wssp-19, I-11–12, SP-12–24.2

Cells with processes that taper to single point rather than bifurcating which is seen in other varieties.

213.***Staurastrum tohopekaligense*** f. ***minus*** F.E. Fritsch & M.F. Rich **(Pl. 17, Fig. I)**

Scott and Prescott, 1961. p. 114, pl. 48, Figs. 4–6.

L-15–26, W-11–18, I-6.6–7, SP-8.4–14

Cells small and processes bifurcate in end.

214.***Staurastrum zonatum*** var. ***ceylanicum*** West & G.S. West **(Pl. 17, Fig. J)**

Scott and Prescott, 1961. p. 119, pl. 59, Fig. 2.

L-50, Lcsp-61, I-14

Cells with five processes radiate from centre with spines on the processes which gets trifid at end.

215.***Staurastrum*** sp. 1 **(Pl. 17, Fig. K)**

L-20, W-25.4, I-2.6

Genus: *Sphaerozosma* Corda ex Ralfs

216.***Sphaerozosma excavatum*** Ralfs ex Ralfs **(Pl. 17, Fig. L)**

Current name: *Teilingia excavata* (Ralfs ex Ralfs) Bourrelly

Hirano, 1966. p. 398, pl. 53, Fig. 22.

L-7.6–9, W-6–7, I-3.5–4

Cells as chain, cells longer than width with deep constriction.

217.***Sphaerozosma granulatum*** J. Roy & Bisset **(Pl. 17, Fig. M)**

West et al., 1923. vol. 5, p. 213, pl. 160, Figs. 6, 7.

L-7.4–9.2, W-6.4–9, I-3–4

Semi cells with small granules on lateral margin.

Genus: *Spondylosium* Brebisson ex Kutzing

218. ***Spondylosium moniliforme*** P. Lundell **(Pl. 17, Fig. N)**

Scott and Prescott, 1961. p. 120, pl. 60, Fig. 11.

L-33–33.3, W-24.5–25.8, I-12.7–12.8

Cells, filamentous, sub elliptic with wide isthmus and rounded apex.

219. ***Spondylosium nitens*** var. ***triangulare*** f. ***javanicum*** Gutwinski **(Pl. 17, Fig. O)**

Current name: *Spondylosium javanicum* (Gutwinski) Gronblad

Scott and Prescott, 1961. p. 120, pl. 60, Fig. 11.

L-31.8–32.8 W-24–25.2 I-7.4–7.8

Cells, filamentous, subtriangular with open sinus and broadly rounded angles.

220. ***Spondylosium planum*** (Wolle) West & G.S. West **(Pl. 18, Fig. A)**

West et al., 1923. vol. 5, p. 222, pl. 160, Figs. 23–25.

L-8.7–9.7 W-7.6–9 I-4.4–4.8

Cells filamentous, small with open sinus. Semi cells elliptical with truncate and flat apices.

Genus: *Onychonema* Wallich

221. ***Onychonema laeve*** var. ***micracanthum*** Nordstedt **(Pl. 18, Fig. B)**

Current name: *Sphaerozosma laeve* var. *micracanthum* (Nordstedt) Thomasson

Scott and Prescott, 1961. p. 121, pl. 60, Fig. 14.

L-12.4–15, Wcsp-19–21, I-2.8–4

Semi cells oblong with converging spine.

Genus: *Groenbladia* Teiling

222. ***Groenbladia*** sp. 1 **(Pl. 18, Fig. C)**

L-10.5–11.5, W-6.5–7.6

Cells barrel shaped, straight, slightly incised sides, and truncate apical margin.

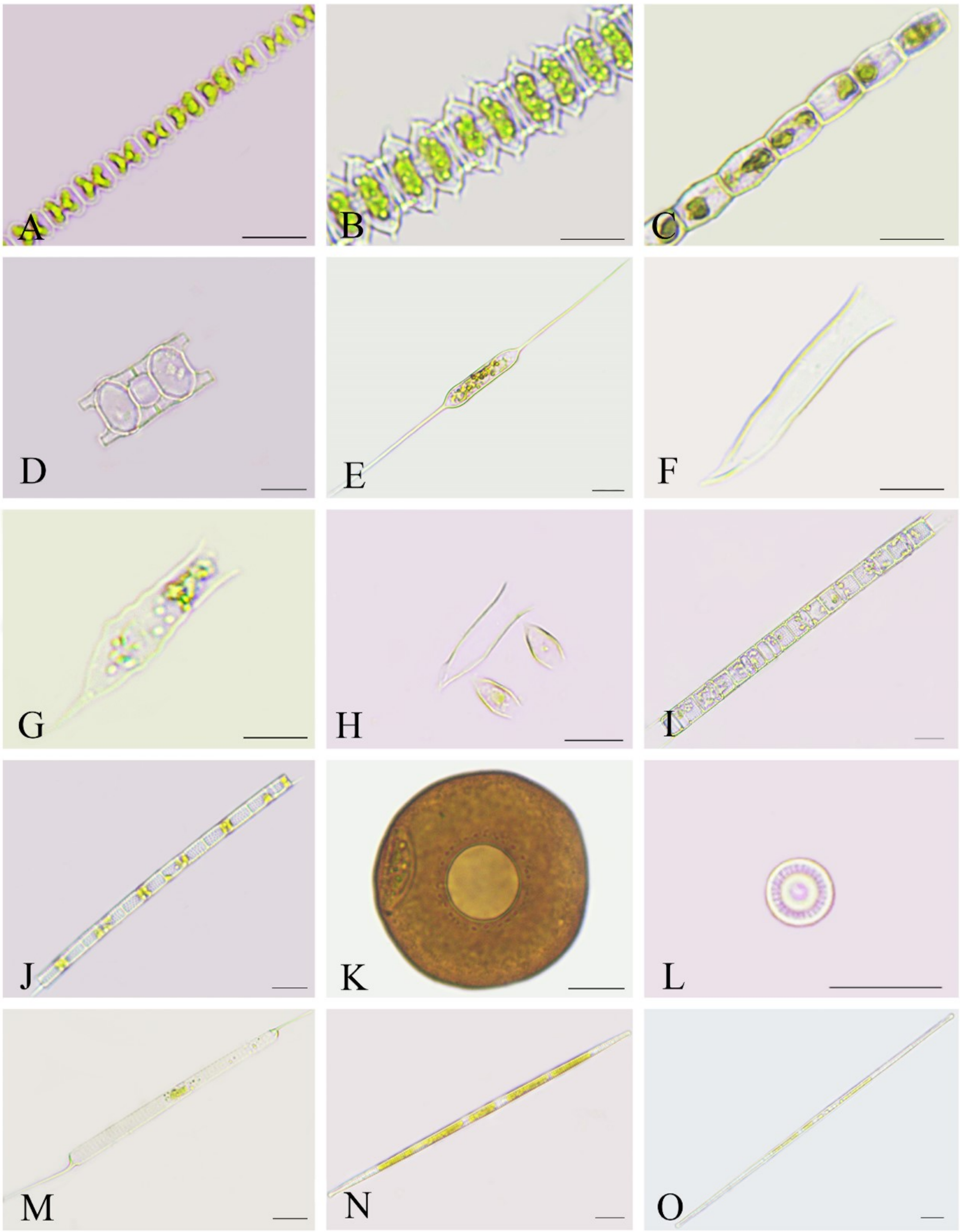
Genus: *Desmidium* C.Agardh ex Ralfs

223. ***Desmidium baileyi*** f. ***longiprocessum*** A.M. Scott & Prescott **(Pl. 18, Fig. D)**

Shaji and Patel, 1990. p. 283, Fig. 3: 9.

L-14.2, W-16.6

Cells rectangular with lateral margins parallel and semi elliptic depression on centre of apices.



Scale 10µm

PLATE 18 (Figs. A-O): A) *Spondylosium planum* (Wolle) West & G.S. West **B)** *Onychonema laeve* var. *micracanthum* Nordstedt **C)** *Groenbladia* sp. 1 **D)** *Desmidium baileyi* f. *longiprocessum* A.M. Scott & Prescott **E)** *Centritractus belonophorus* (Schmidle) Lemmermann **F)** *Dinobryon cylindricum* O.E. Imhof **G)** *D. divergens* O.E. Imhof **H)** *D. sertularia* Ehrenberg **I)** *Melosira granulata* (Ehrenberg) Ralfs **J)** *M. granulata* var. *angustissima* O. Muller **K)** *Actinocyclus normanii* (W.Gregory ex Greville) Hustedt **L)** *Cyclotella* sp. 1 **M)** *Rhizosolenia eriensis* H.L. Smith **N)** *Synedra acus* Kutzing **O)** *Synedra acus* var. *acula* (Kutzing) Grunow

Division: Chrysophyta

Class: Xanthophyceae

Order: Heterococcales

Family: Centritractaceae

Genus: *Centritractus* Lemmermann

224. ***Centritractus belonophorus*** (Schmidle) Lemmermann **(Pl. 18, Fig. E)**

Prescott, 1982. p. 361, pl. 95, Figs. 37, 38.

L-18.6–35.3, W-6.4–6.8

Cells cylindric, elongate with straight spine at each end.

Class: Chrysophyceae

Order: Chrysomonadales

Family: Ochromonadaceae

Genus: *Dinobryon* Ehrenberg

225. ***Dinobryon cylindricum*** O.E. Imhof **(Pl. 18, Fig. F)**

Prescott, 1982. p. 378, pl. 107, Fig. 1.

L-35–44, W-8Lorica elongated and cylindrical.

226.***Dinobryon divergens*** O.E. Imhof **(Pl. 18, Fig. G)**

Prescott, 1982. p. 378, pl. 98, Fig. 7.

L-34–44, W at orifice-7.3–7.7

Lorica with undulate margin.

227. ***Dinobryon sertularia*** Ehrenberg **(Pl. 18, Fig. H)**

Prescott, 1982. p. 378, pl. 98, Fig. 10.

L-33.5, W at orifice-9.7

Each lorica with smooth wall.

Division: Bacillariophyta

Class: Bacillariophyceae

Order: Centrales

Sub Order: Discineae

Family: Coscinodiscaceae

Subfamily: Melosiroideae

Genus: *Melosira* C. Agardh

228.***Melosira granulata*** (Ehrenberg) Ralfs **(Pl. 18, Fig. I)**

Current name: *Aulacoseira granulata* (Ehrenberg) Simonsen

Sarode and Kamat, 1984. p. 18, pl. 1, Fig. 1.

L-11.5–18, W-5–10, SP-5.1–8

Cell wall with granulated markings with spines at end. Rows of areolae spirally disposed.

229.***Melosira granulata*** var. ***angustissima*** O. Muller **(Pl. 18, Fig. J)**

Current name: *Aulacoseira granulata* var. *angustissima* (O. Muller) Simonsen

Sarode and Kamat, 1984. p. 19, pl. 1, Fig. 2.

L-15.2–21, W-3.7–4.8

Narrow long cells with long spine protruding from end cell wall.

Subfamily: Coscinodiscoideae

Genus: *Actinocyclus* Ehrenberg

230.***Actinocyclus normanii*** (W. Gregory ex Greville) Hustedt **(Pl. 18, Fig. K)**

Desikachary, 1989, p. 3, Fig. 5

Valve W-13.9–45

Valves circular and undulated.

Genus: *Cyclotella* (Kutzing) Brebisson

231.***Cyclotella*** sp. 1 **(Pl. 18, Fig. L)**

D-6–9, 15 striae in 10 µm

Valves have middle field with a hole in centre surrounded by radiating lines.

Suborder: Rhizosoleniineae

Family: Rhizosoleniaceae

Genus: *Rhizosolenia* Brightwell

232.***Rhizosolenia eriensis*** H.L. Smith **(Pl. 18, Fig. M)**

Current name: *Urosolenia eriensis* (H.L. Smith) Round & R.M. Crawford

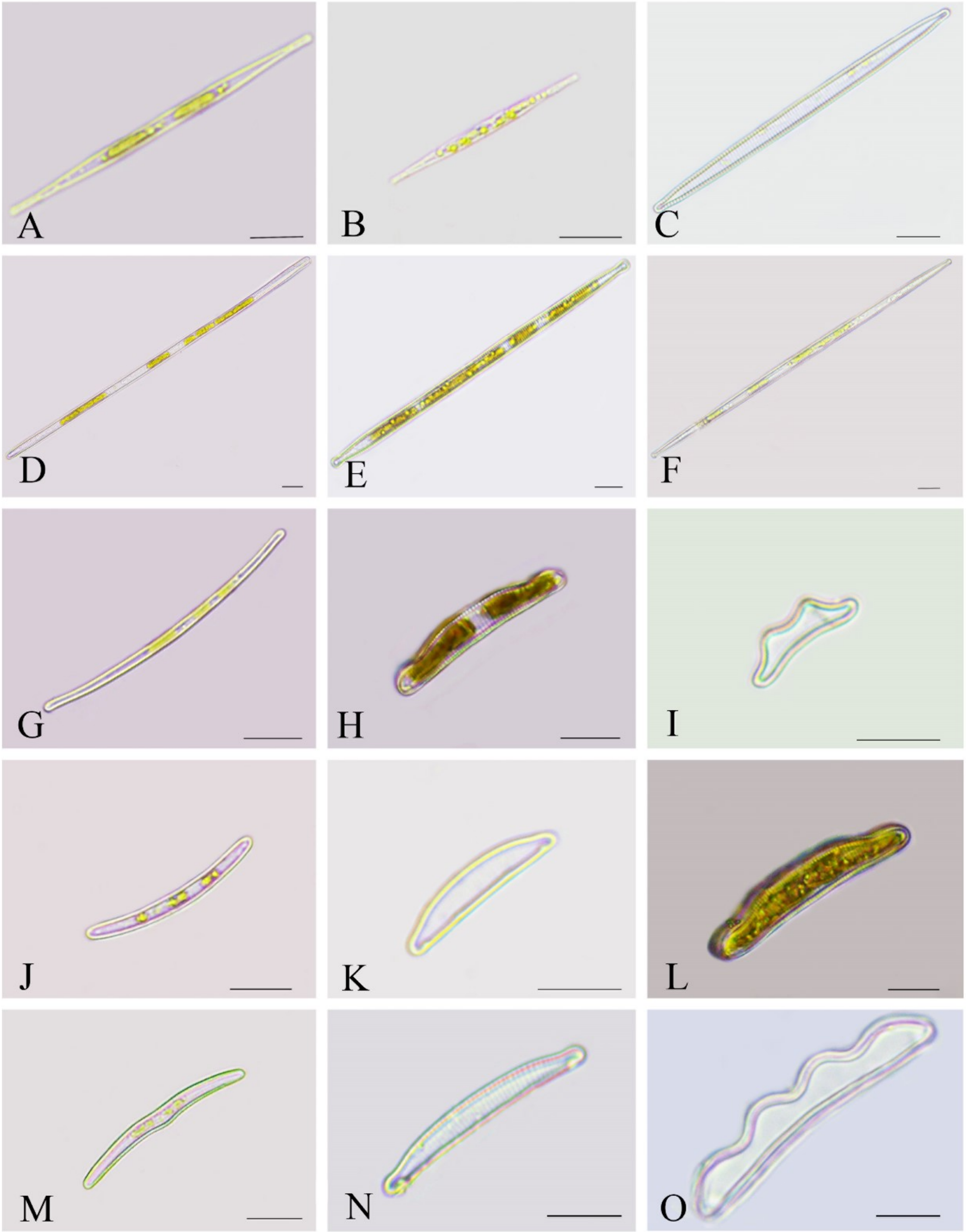
Hustedt, 1930. p. 115, Fig. 92.

L-84.4, W-5, 4 girdle bands in 10 µm

Valves with long extension, girdle bands curved and arranged in zig- zag pattern.

Order: Pennales

Suborder: Araphidineae



Scale 10µm

PLATE 19 (Figs. A-O): A) *Synedra acus* f. *radians* (Kutzing) Hustedt **B)** *S. tabulata* (C.Agardh) Kutzing **C)** *S. ulna* (Nitzsch) Ehrenberg **D)** *S. ulna* var. *aequalis* (Kutzing) Brun **E)** *S. ulna* var. *amphirhynchus* (Ehrenberg) Grunow **F)** *S. ulna* var. *danica* (Kutzing) Van Heurck **G)** *Eunotia alpina* (Nageli) Hustedt **H)** *E. arcus* Ehrenberg **I)** *E. camelus* var. *gibbosa* H.P. Gandhi **J)** *E. lunaris* (Ehrenberg) Grunow **K)** *E. minor* (Kutzing) Grunow **L)** *E. monodon* Ehrenberg **M)** *E. pectinalis* var. *ventralis* (Ehrenberg) Hustedt **N)** *E. valida* Hustedt **O)** *E. zygodon* Ehrenberg (From Pookode Lake)

Family: Fragilariaceae

Genus: *Synedra* Ehrenberg

233.***Synedra acus*** Kutzing **(Pl. 18, Fig. N)**

Current name: *Ulnaria acus* (Kutzing) Aboal

Sarode and Kamat, 1984. p. 30, pl. 2, Fig. 32.

L-53–143.4, W-3–4.2

234.***Synedra acus*** var. ***acula*** (Kutzing) Grunow **(Pl. 18, Fig. O)**

Current name: *Nitzschia acula* (Kutzing) Hantzsch

Sarode and Kamat, 1984. p. 31, pl. 2, Fig. 33.

L-101–160.6, W-2.3–3.4

Valves narrow, linear with slightly capitate ends.

235.***Synedra acus*** f. ***radians*** (Kutzing) Hustedt **(Pl. 19, Fig. A)**

Current name: *Fragilaria radians* (Kutzing) D.M. Williams & Round

Sarode and Kamat, 1984. p. 31, pl. 2, Fig. 34.

L-61.66, W-2.7

Valves narrow, linear with slightly capitate end.

236. ***Synedra tabulata*** (C. Agardh) Kutzing **(Pl. 19, Fig. B)**

Current name: *Tabularia tabulata* (C. Agardh) Snoeijs

Sarode and Kamat, 1984. p. 31, pl. 2, Fig. 37.

L-42.7–50, W-2.7–3.2

Valves linear and narrow with rounded ends.

237.***Synedra ulna*** (Nitzsch) Ehrenberg **(Pl. 19, Fig. C)**

Current name: *Ulnaria ulna* (Nitzsch) Compere

Sarode and Kamat, 1984. p. 31, pl. 2, Fig. 37.

L-97.7–192, W-5.2–6.6

11-12 striae in 10 µm

Valves with coarse striae.

238.***Synedra ulna*** var. ***aequalis*** (Kutzing) Brun **(Pl. 19, Fig. D)**

Current name: *Ulnaria aequalis* (Kutzing) D.M. Williams & Van de Vijver

Hustedt, 1930. p. 152, Fig. 164.

L-265.6, W-6.6

Valves linear with even broadly rounded ends.

239.***Synedra ulna*** var. ***amphirhynchus*** (Ehrenberg) Grunow **(Pl. 19, Fig. E)**

Current name: *Ulnaria amphirhynchus* (Ehrenberg) Compere & Bukhtiyarova

Venkataraman, 1939. p. 308, Figs. 28, 30, 31, 32.

L-157.6, W-6.2

Valves have capitate ends.

240.***Synedra ulna*** var. ***danica*** (Kutzing) Van Heurck **(Pl. 19, Fig. F)**

Current name: *Ulnaria danica* (Kutzing) Compere & Bukhtiyarova.

Sarode and Kamat, 1984. p. 32, pl. 2, Fig. 41.

L-191.6, W-5

Valves with rounded and capitate ends.

Suborder: Raphidioidineae

Family: Eunotiaceae

Subfamily: Eunotioideae

Genus: *Eunotia* Ehrenberg

241.***Eunotia alpina*** (Nageli) Hustedt **(Pl. 19, Fig. G)**

Current name: *Eunotia naegelii* Migula

Sarode and Kamat, 1984. p. 35, pl. 2, Fig. 45.

L-72.2–77, W-2.4–2.5

Valves slightly arcuate and slightly inflated ends.

242.***Eunotia arcus*** Ehrenberg **(Pl. 19, Fig. H)**

Sarode and Kamat, 1984. p. 35, pl. 2, Fig. 46.

L-50.8, W-7.7

Valves with dorsal margin arcuate, ventral margin slightly constricted and rounded smooth at ends.

243.***Eunotia camelus*** var. ***gibbosa*** H.P. Gandhi **(Pl. 19, Fig. I)**

Current name: *Eunotia indosinica* Glushchenko & Kulikovskiy

Sarode and Kamat, 1984. p. 36, pl. 2, Fig. 50.

L-19.3, W-4.2

Valves curve with 2 humps on dorsal side.

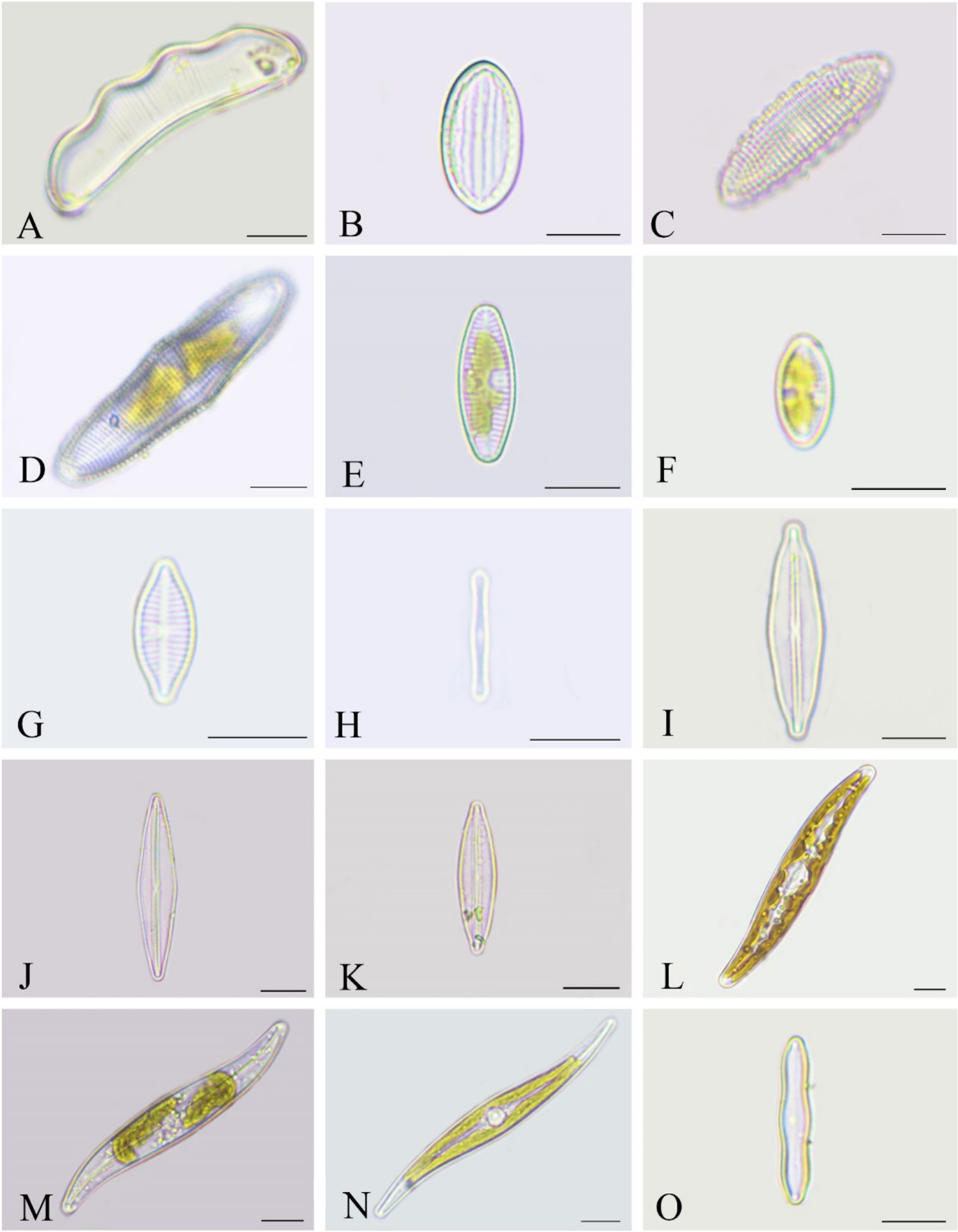
244.***Eunotia lunaris*** (Ehrenberg) Grunow **(Pl. 19, Fig. J)**

Sarode and Kamat, 1984. p. 410, pl. 3, Fig. 62.

L-47–99, W-4–4.8

Valves arcuate in dorsal side and with rounded ends.

245.***Eunotia minor*** (Kutzing) Grunow **(Pl. 19, Fig. K)**



Scale 10µm

PLATE 20 (Figs. A-O): A) *Eunotia zygodon* Ehrenberg (From Heart Lake, Papanasini River, Banasurasagar Dam) B**)** *Cocconeis placentula* Ehrenberg **C)** *Achnanthes crenulata* Grunow **D)** *A. elata* (Leuduger-Fortmorel) H.P. Gandhi **E)** *A. lanceolata* (Brebisson ex Kutzing) Grunow **F)** *A. lanceolata* var. *elliptica* Cleve **G)** *A. lanceolata* var. *rostrata* Hustedt **H)** *Achnanthes microcephala* (Kutzing) Grunow **I)** *Frustulia rhomboides* var. *crassinervia* (Brebisson ex W. Smith) Ross **J**) *F. krammeri* Lange-Bertalot & Metzeltin **K)** *F. saxonica* Rabenhorst **L)** *Gyrosigma acuminatum* (Kutzing) Rabenhorst **M)** *G. kuetzingii* (Grunow) Cleve **N)** *Gyrosigma* sp.1 **O)** *Caloneis silicula* (Ehrenberg) Cleve

Joh, 2010. p. 41, Fig. 32.

L-25.5–28, W-4–5

Valves linear with flat or slightly arched dorsal margin, broadly rounded to sub capitate ends.

246.***Eunotia monodon*** Ehrenberg **(Pl. 19, Fig. L)**

Joh, 2010. p. 43, Figs. 33, 34.

L-45–65.8, W-9–10.5

Valves slightly arcuate with slightly capitate and rounded ends.

247.***Eunotia pectinalis*** var. ***ventralis*** (Ehrenberg) Hustedt **(Pl. 19, Fig. M)**

Current name: *Eunotia pectinalis* var. *ventricosa* (Ehrenberg) Grunow

Joh, 2010. p. 55, Fig. 48.

L-54, W-4.4

Valves have swelling in ventral side.

248.***Eunotia valida*** Hustedt **(Pl. 19, Fig. N)**

Hustedt, 1930. p. 178, Fig. 229.

L-39–62, W-4–4.4

Valves with slight capitate ends.

249.***Eunotia zygodon*** Ehrenberg **(Pl. 19, Fig. O, Pl. 20, Fig. A)**

Taylor et al, 2016. p. 292, Figs. 1–5.

Valves are bi-undulate at dorsal side and have broadly rounded ends. The specimens of this species observed from Heart Lake, Papanasini River, Banasurasagar Dam found to be similar in morphology and have L-40.7–84.4, W-10–14. Whereas a slightly different form is found from Pookode Lake with L-56.6–164.4, W-8–10. All belong to the same species as these variations are considered by Taylor et al. (2016) as the transition of typical *E. zygodon* like cells to *E. monodon* var. *tropica*.

Suborder: Monoraphidineae

Family: Achnanthaceae

Subfamily: Cocconeoideae

Genus: *Cocconeis* Ehrenberg

250.***Cocconeis placentula*** Ehrenberg **(Pl. 20, Fig. B)**

Sarode and Kamat, 1984. p. 49, pl. 4, Fig. 95.

L-26, W-12.7

Valves elliptical with thin raphe and distinct marginal rim.

Genus: *Achnanthes* Bory

251.***Achnanthes crenulata*** Grunow **(Pl. 20, Fig. C)**

Gandhi, 1960. p. 85, Figs. 17–18.

L-40, W-13

Valves broad, lanceolate, margin crenulate, ends acutely rounded.

252.***Achnanthes elata*** (Leuduger-Fortmorel) H.P. Gandhi **(Pl. 20, Fig. D)**

Gandhi, 1960. p. 82, Figs. 3–7, 10

L-65.4, W-16

Valves are fusiform, linear-lanceolate, broadly tumid in middle with sub cuneate rounded ends.

253.***Achnanthes lanceolata*** (Brebisson ex Kutzing) Grunow **(Pl. 20, Fig. E)**

Current name: *Planothidium lanceolatum* (Brebisson ex Kutzing) Lange-Bertalot

Hustedt, 1930. p. 207, Fig. 306 a.

L-15.8–25, W-7–8.7

Valves elliptic- lanceolate with broadly rounded ends.

254.***Achnanthes lanceolata*** var. ***elliptica*** Cleve **(Pl. 20, Fig. F)**

Current name: *Planothidium ellipticum* (Cleve) M.B. Edlund.

Cleve, 1891. p. 192, pl. 3, Fig. 10, 11.

L-14, W-7

255.***Achnanthes lanceolata*** var. ***rostrata*** Hustedt **(Pl. 20, Fig. G)**

Current name: *Planothidium rostratoholarcticum* Lange-Bertalot & Bak.

Hustedt, 1930. p. 208, Fig. 306 b.

L-13–17.6, W-6–7

256.***Achnanthes microcephala*** (Kutzing) Grunow **(Pl. 20, Fig. H)**

Hustedt, 1930. p. 201, Fig. 286.

Current name: *Achnanthidium minutissimum* (Kutzing) Czarnecki

L-8–15.5, W-2–2.5

Valves linear lanceolate with broadly rounded capitate ends.

Suborder: Biraphidineae

Family: Naviculaceae

Subfamily: Naviculoideae

Genus: *Frustulia* Rabenhorst

257.***Frustulia rhomboides*** var. ***crassinervia*** (Brebisson ex W. Smith) Ross **(Pl. 20, Fig. I)**

Current name: *Frustulia crassinervia* (Brebisson ex W. Smith) Lange-Bertalot & Krammer

Kulikovskiy et al., 2016. p. 264, pl. 66, Figs. 10–12.

L-45–48.4, W-10–12.5

Valves elliptic-lanceolate, weakly undulate with rostrate ends.

258.***Frustulia krammeri*** Lange-Bertalot & Metzeltin **(Pl. 20, Fig. J)**

Kulikovskiy et al., 2016. p. 264, pl. 67, Figs. 1–3.

L-62.5–62.8, W-13.2–14

Valves lanceolate, ends rounded without constriction.

259.***Frustulia saxonica*** Rabenhorst **(Pl. 20, Fig. K)**

Sarode and Kamat, 1984. p. 8, pl. 6, Fig. 139.

L-41–62, W-9.7–13

Valves lanceolate with constricted and rounded ends.

Genus: *Gyrosigma* Hassall

260.***Gyrosigma acuminatum*** (Kutzing) Rabenhorst **(Pl. 20, Fig. L)**

Hustedt, 1930. p. 222, Fig. 329.

L-80.2, W-13.3

Valves slender, sigmoid.

261.***Gyrosigma kuetzingii*** (Grunow) Cleve **(Pl. 20, Fig. M)**

Hustedt, 1930. p. 224, Fig. 333.

L-84.2, W-12.8

Valves slightly sigmoid, lanceolate with round ends.

262.***Gyrosigma*** sp.1 **(Pl. 20, Fig. N)**

L-95.7, W-11.5

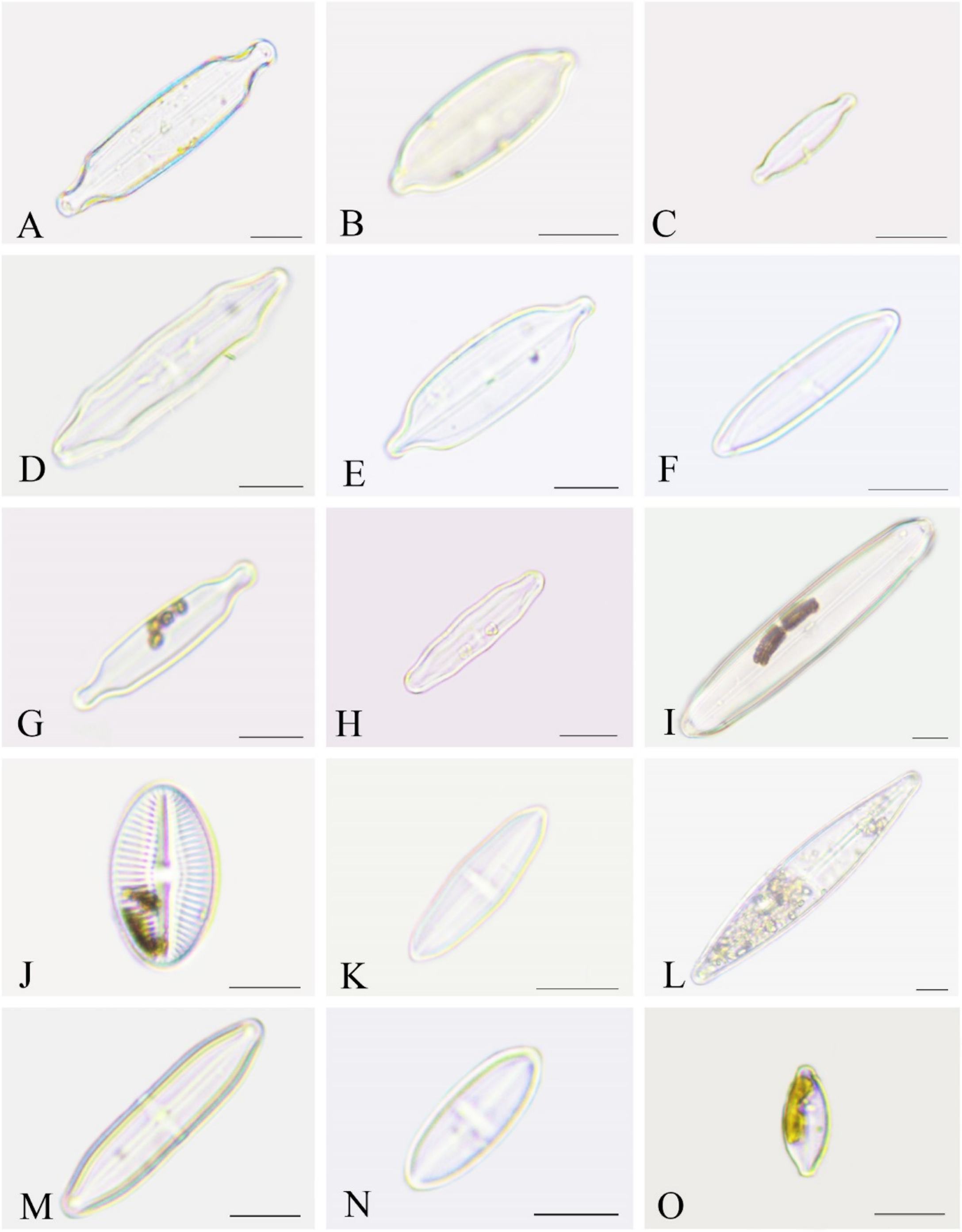
Genus: *Caloneis* Cleve

263.***Caloneis silicula*** (Ehrenberg) Cleve **(Pl. 20, Fig. O)**

Sarode and Kamat, 1984. p. 74, pl. 8, Fig. 168.

L-25–31.6, W-5.5–5.8

Valves linear lanceolate with tri-undulate margin.



Scale 10µm

PLATE 21 (Figs. A-O): A) *Neidium capitellatum* H.P. Gandhi **B)** *N. dubium* (Ehenberg) Cleve **C)** *N. globiceps* var. *biglobosum* A. Cleve **D)** *N. gracile* Hustedt **E)** *N. grande* H.P. Gandhi **F)** *N. iridis* f. *dhulense* Sarode & N.D. Kamat **G)** *N. longiceps* (W. Gregory) R.Ross **H)** *N. longiceps* var. *undulatum* A. Cleve **I)** *N. pseudogracile* Kobayasi **J**) *Diploneis elliptica* (Kutzing) Cleve **K)** *Stauroneis obtusa* var. *nagpurensis* P.T. Sarode & N.D. Kamat **L)** *S. phoenicenteron* var. *intermedia* (Dippel) A. Cleve **M)** *S. phoenicenteron* f. *producta* H.P. Gandhi **N)** *Stauroneis* sp. 1 **O)** *Navicula anglica* Ralfs

Genus: *Neidium* Pfitzer

264.***Neidium capitellatum*** H.P. Gandhi **(Pl. 21, Fig. A)**

Sarode and Kamat, 1984. p. 74, pl. 8, Fig. 168.

L-80.2, W-18.5

Valves linear elliptical with capitate and rounded ends.

265.***Neidium dubium*** (Ehenberg) Cleve **(Pl. 21, Fig. B)**

Hustedt, 1930. p. 246, Fig. 384 a.

L-33.6, W-11.7

Valves broad and linear with rostrate and slightly capitate ends.

266.***Neidium globiceps*** var. ***biglobosum*** A. Cleve **(Pl. 21, Fig. C)**

Cleve-Euler, 1955. p. 113, Figs. 1165 b, e.

L-28, W-6.3

Valves linear lanceolate with constricted rounded ends.

267.***Neidium gracile*** Hustedt **(Pl. 21, Fig. D)**

Siver et al, 2003. p. 140, Figs. 43–56.

L-47–57.5, W-10.6–12.3

Valves linear, tri-undulate with wedge shaped, pointed ends.

268.***Neidium grande*** H.P. Gandhi **(Pl. 21, Fig. E)**

Gandhi, 1959. p. 313, Fig. 8.

L-47.7–48, W-14.8–15.2

Valves linear elliptical, broad with slightly elongated ends.

269.***Neidium iridis*** f. ***dhulense*** Sarode & N.D. Kamat **(Pl. 21, Fig. F)**

Sarode and Kamat, 1984. p. 83, pl. 9, Fig. 194.

L-34.8–40, W-8.2–9.5

Valves linear elliptical with wedge shaped and rounded ends.

270.***Neidium longiceps*** (W. Gregory) R. Ross **(Pl. 21, Fig. G)**

Cleve-Euler, 1955. p. 112, Figs. 1163 a-d.

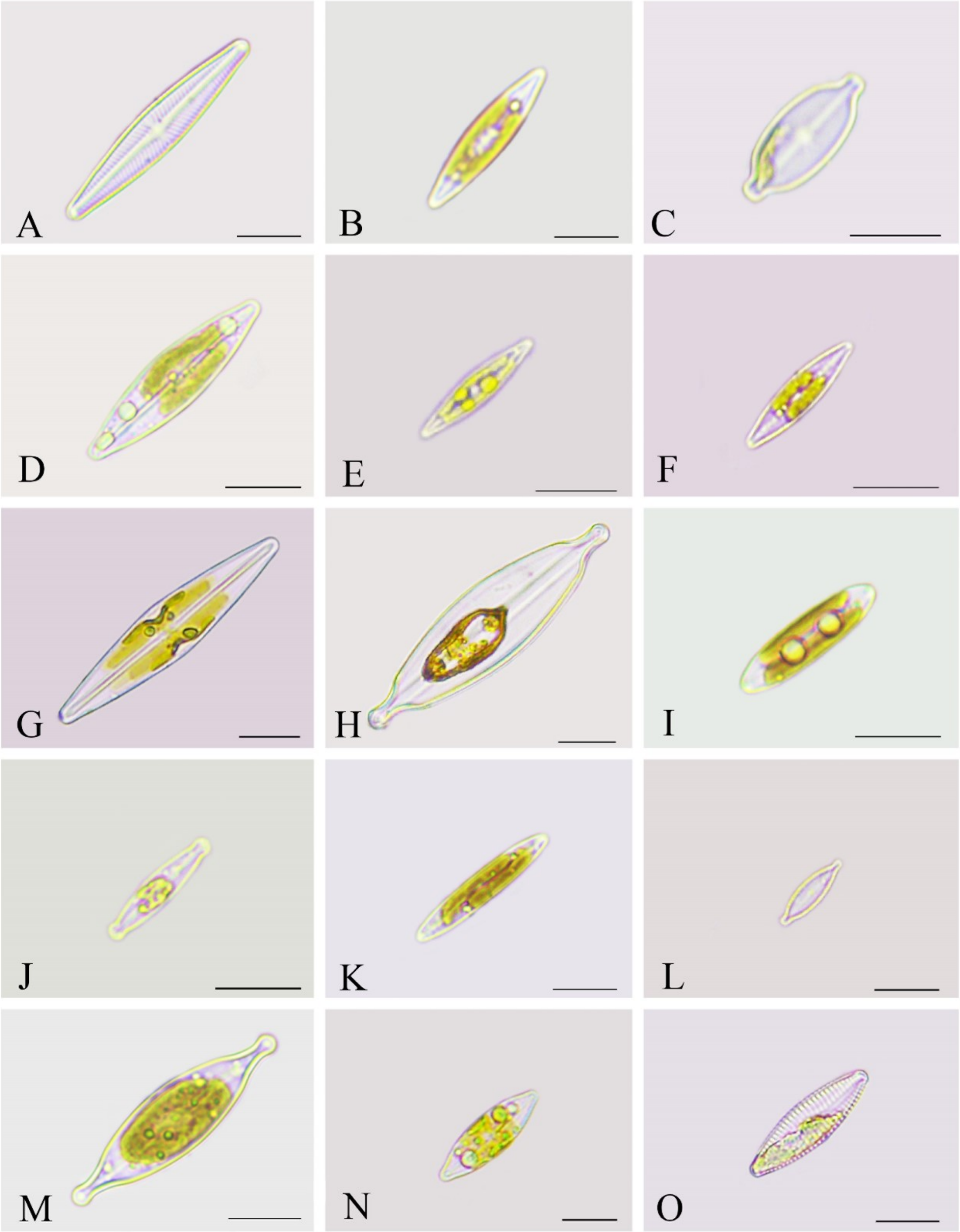
L-31.6–35, W-7.2–7.3

Valves linear with capitate ends.

271.***Neidium longiceps*** var**. *undulatum*** A. Cleve **(Pl. 21, Fig. H)**

Current name: *Neidium affine* var. *hankensis* (Skvortzov) C.W. Reimer

Cleve-Euler, 1955. p. 112, Fig. 1163 f.



Scale 10µm

PLATE 22 (Figs. A-O): A) *Navicula cari* f. *indica* Sarode & Kamat **B)** *N. cincta* var. *heufleri* (Grunow) Grunow **C)** *N. constans* var. *symmetrica* Hustedt **D)** *N. cryptocephala* Kutzing **E)** *N. cryptocephala* var. *exilis* Grunow **F)** *N. cryptocephala* var. *veneta* (Kutzing) Rabenhorst **G)** *N. cuspidata* (Kutzing) Kutzing **H)** *N. cuspidata* var. *ambigua* (Ehrenberg) Kirchner **I)** *N. densistriata* Hustedt **J)** *N. disjuncta* Hustedt **K)** *N. feuerbornii* f. *minor* Cholnoky **L)** *N. gregaria* Donkin **M)** *N. halophila* f. *robusta* Hustedt **N)** *N. laterostrata* Hustedt **O)** *N. mutica* Kutzing

L-46.5, W-11

Valves tri-undulate with rostrate ends.

272. ***Neidium pseudogracile*** Kobayasi **(Pl. 21, Fig. I)**

Siver et al, 2003. p. 140, Figs. 35–42.

L-109.7, W-20

Valves long with sagittate ends.

Genus: *Diploneis* Ehrenberg ex Cleve

273. ***Diploneis elliptica*** (Kutzing) Cleve **(Pl. 21, Fig. J)**

Hustedt, 1930. p. 250, Fig. 395.

L-32–36.6, W-18.5–20.5

Cells ovoid, distinctly lobed on either side of a long axis.

Genus: *Stauroneis* Ehrenberg

274. ***Stauroneis obtusa*** var. ***nagpurensis*** P.T. Sarode & N.D. Kamat **(Pl. 21, Fig. K)**

Sarode and Kamat, 1984. p. 95, pl. 10, Fig. 220.

L-29.7, W-8.6

Valves linear, lanceolate with acute and rounded ends.

275. ***Stauroneis phoenicenteron*** var. ***intermedia*** (Dippel) A. Cleve **(Pl. 21, Fig. L)**

Sarode and Kamat, 1984. p. 95, pl. 11, Fig. 228.

L-90.9, W-17

Valves lanceolate, with obtusely produced ends.

276. ***Stauroneis phoenicenteron*** f. ***producta*** H.P. Gandhi **(Pl. 21, Fig. M)**

Sarode and Kamat, 1984. p. 94, pl. 11, Fig. 226.

L-31–36.3, W-7.8

Valves narrowly lanceolate with slightly constricted and produced ends.

277. ***Stauroneis*** sp. 1 **(Pl. 21, Fig. N)**

L-20, W-7.4

Genus: *Navicula* Bory

278. ***Navicula anglica*** Ralfs **(Pl. 21, Fig. O)**

Current name: *Placoneis elginensis* (W. Gregory) E.J. Cox

Hustedt, 1930. p. 303, Figs. 530, 531.

L-19, W-8

Valves elliptic lanceolate with slightly constricted and rounded ends.

279. ***Navicula cari*** f. ***indica*** Sarode & Kamat **(Pl. 22, Fig. A)**

Sarode and Kamat, 1984. p. 104, pl. 11, Fig. 246.

L-48–50.6, W-8.2–9

Valves narrowly lanceolate with broadly rounded ends.

280. ***Navicula cincta*** var. ***heufleri*** (Grunow) Grunow **(Pl. 22, Fig. B)**

Current name: *Navicula heufleri* Grunow

Sarode and Kamat, 1984. p. 105, pl. 11, Fig. 249.

L-23.3–27.5, W-5.2–5.9

Valves narrow with rounded ends.

281. ***Navicula constans*** var. ***symmetrica*** Hustedt **(Pl. 22, Fig. C)**

Current name: *Placoneis symmetrica* (Hustedt) Lange-Bertalot

Sarode and Kamat, 1984. p. 106, pl. 12, Fig. 255.

L-22, W-9

Valves elliptic lanceolate with sub capitate ends.

282. ***Navicula cryptocephala*** Kutzing **(Pl. 22, Fig. D)**

Sarode and Kamat, 1984. p. 106, pl. 12, Fig. 254.

L-32.4–37.6, W-8.6–10

Valves lanceolate with rounded ends.

283. ***Navicula cryptocephala*** var. ***exilis*** Grunow **(Pl. 22, Fig. E)**

Current name: *Brachysira exilis* (Kutzing) Rouned & D.G. Mann

Sarode and Kamat, 1984. p. 106, pl. 12, Fig. 255.

L-26.7, W-5.5

Valves narrowly lanceolate with rounded ends.

284. ***Navicula cryptocephala*** var. ***veneta*** (Kutzing) Rabenhorst **(Pl. 22, Fig. F)**

Current name: *Navicula veneta* Kutzing

Sarode and Kamat, 1984. p. 107, pl. 12, Fig. 257.

L-14.7–36.6, W-4–7.4

Valves lanceolate with acute and rounded ends.

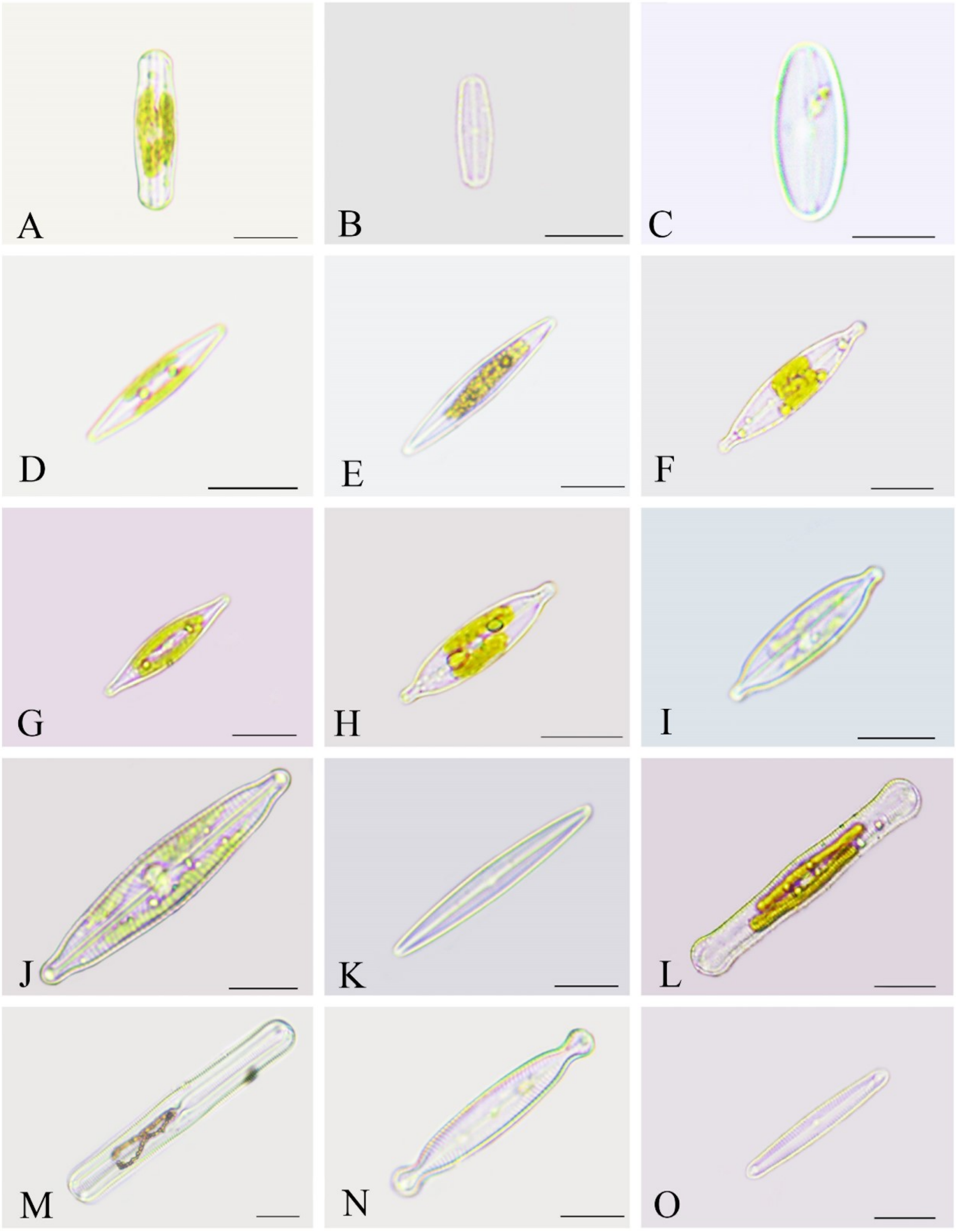
285. ***Navicula cuspidata*** (Kutzing) Kutzing **(Pl. 22, Fig. G)**

Current name: *Craticula cuspidata* (Kutzing) D.G.Mann

Sarode and Kamat, 1984. p. 107, pl. 12, Fig. 258.

L-70.4, W-14.6

Valves rhombic lanceolate with acute and rounded ends.



Scale 10µm

PLATE 23 (Figs. A-O): A) *Navicula pupula* f. *capitata* (Skvortzov & Mayer) Hustedt **B)** *N. protracta* Grunow **C)** *N. pygmaea* var. *indica* Skvortzov **D)** *N. radiosa* var. *minutissima* (Grunow) Cleve **E)** *N. radiosa* var. *tenella* (Brebisson ex Kutzing) Van Heurck **F)** *N. rhynchocephala* Kutzing **G)** *N. rhynchocephala* var. *tenua* Skvortzov **H)** *N. salinarum* var. *intermedia* (Grunow) Cleve **I)** *N. subrhynchocephala* Hustedt **J)** *N. viridula* (Kutzing) Ehrenberg **K)** *Navicula* sp. 1 **L)** *Pinnularia acrosphaeria* f. *minor* Cleve **M)** *P. acrosphaeria* f. *undulata* (Cleve) Hustedt **N)** *P. braunii* var. *amphicephala* (Ant.Mayer) Hustedt **O)** *P. braunii* f. *subconica* G.S. Venkataraman

286. ***Navicula cuspidata*** var. ***ambigua*** (Ehrenberg) Kirchner **(Pl. 22, Fig. H)**

Current name: *Craticula ambigua* (Ehrenberg) D.G. Mann.

Sarode and Kamat, 1984. p. 108, pl. 12, Fig. 261.

L-80.3, W-18.9

Valves rhombic lanceolate with constricted and capitate ends.

287. ***Navicula densistriata*** Hustedt **(Pl. 22, Fig. I)**

Current name: *Achnanthidium petersenii* (Hustedt) C.E. Wetzel, Ector, D.M. Williams & Juttner

Hustedt, 1930. p. 288, Fig. 485.

L-22.5–33.3, W-6–6.6

Valves linear, elliptic with broadly rounded ends.

288. ***Navicula disjuncta*** Hustedt **(Pl. 22, Fig. J)**

Current name: *Myriactula pulvinata* (Kutzing) Kuntze

Sarode and Kamat, 1984. p. 111, pl. 13, Fig. 270.

L-19.3–26, W-4.4–6.5

Valves linear lanceolate with constricted and capitate ends.

289. ***Navicula feuerbornii*** f. ***minor*** Cholnoky **(Pl. 22, Fig. K)**

Cholnoky, 1959. p. 38, Fig. 207.

L-26.7–31.6, W-5–5.5

Valves linear lanceolate with broad and rounded ends.

290. ***Navicula gregaria*** Donkin **(Pl. 22, Fig. L)**

Sarode and Kamat, 1984. p. 112, pl. 13, Fig. 273.

L-20.3–26, W-5.5–6

Valves small, lanceolate with slightly capitate ends.

291. ***Navicula halophila*** f. ***robusta*** Hustedt **(Pl. 22, Fig. M)**

Current name: *Craticula halophila* (Grunow) D.G. Mann

Sarode and Kamat, 1984. p. 112, pl. 13, Fig. 277.

L-42.8, W-11.4

Valves elliptic lanceolate with prominent capitate ends.

292. ***Navicula laterostrata*** Hustedt **(Pl. 22, Fig. N)**

Sarode and Kamat, 1984. p. 113, pl. 13, Fig. 281.

L-23–27.4, W-9

Valves elliptic lanceolate with rounded ends.

293. ***Navicula mutica*** Kutzing **(Pl. 22, Fig. O)**

Current name: *Luticola mutica* (Kutzing) D.G. Mann

Hustedt, 1930. p. 274, Fig. 453 a.

L-34.7, W-9.7

Valves lanceolate with broadly rounded ends.

294. ***Navicula pupula*** f. ***capitata*** (Skvortzov & Mayer) Hustedt **(Pl. 23, Fig. A)**

Current name: *Sellaphora pupula* f. *capitata* (Skvortzov & K.I. Meyer) Poulin

Sarode and Kamat, 1984. p. 118, pl. 13, Fig. 296.

L-30.4, W-8.2

Valves linear with slightly constricted and broadly capitate ends.

295. ***Navicula protracta*** Grunow **(Pl. 23, Fig. B)**

Current name: *Prestauroneis protracta* (Grunow) Kulikovskiy & Glushchenko

Sarode and Kamat, 1984. p. 117, pl. 13, Fig. 294.

L-18.4–21, W-5.5–6.6

Valves linear elliptical with constricted and broadly rostrate ends.

296. ***Navicula pygmaea*** var. ***indica*** Skvortzov **(Pl. 23, Fig. C)**

Skvortsov, 1935. p. 182, pl. 1, Fig. 14.

L-20.2, W-8.3

Valves elliptical with obtuse ends. H shaped hyaline area with a constriction in middle present.

297. ***Navicula radiosa*** var. ***minutissima*** (Grunow) Cleve **(Pl. 23, Fig. D)**

Sarode and Kamat, 1984. p. 120, pl. 14, Fig. 305.

L-25–33, W-4.3–5.2

Valves narrow and lanceolate with obtuse ends.

298. ***Navicula radiosa*** var. ***tenella*** (Brebisson ex Kutzing) Van Heurck **(Pl. 23, Fig. E)**

Sarode and Kamat, 1984. p. 120, pl. 14, Fig. 306.

L-38.2, W-6.5

Valves narrow and lanceolate with acute and rounded ends.

299. ***Navicula rhynchocephala*** Kutzing **(Pl. 23, Fig. F)**

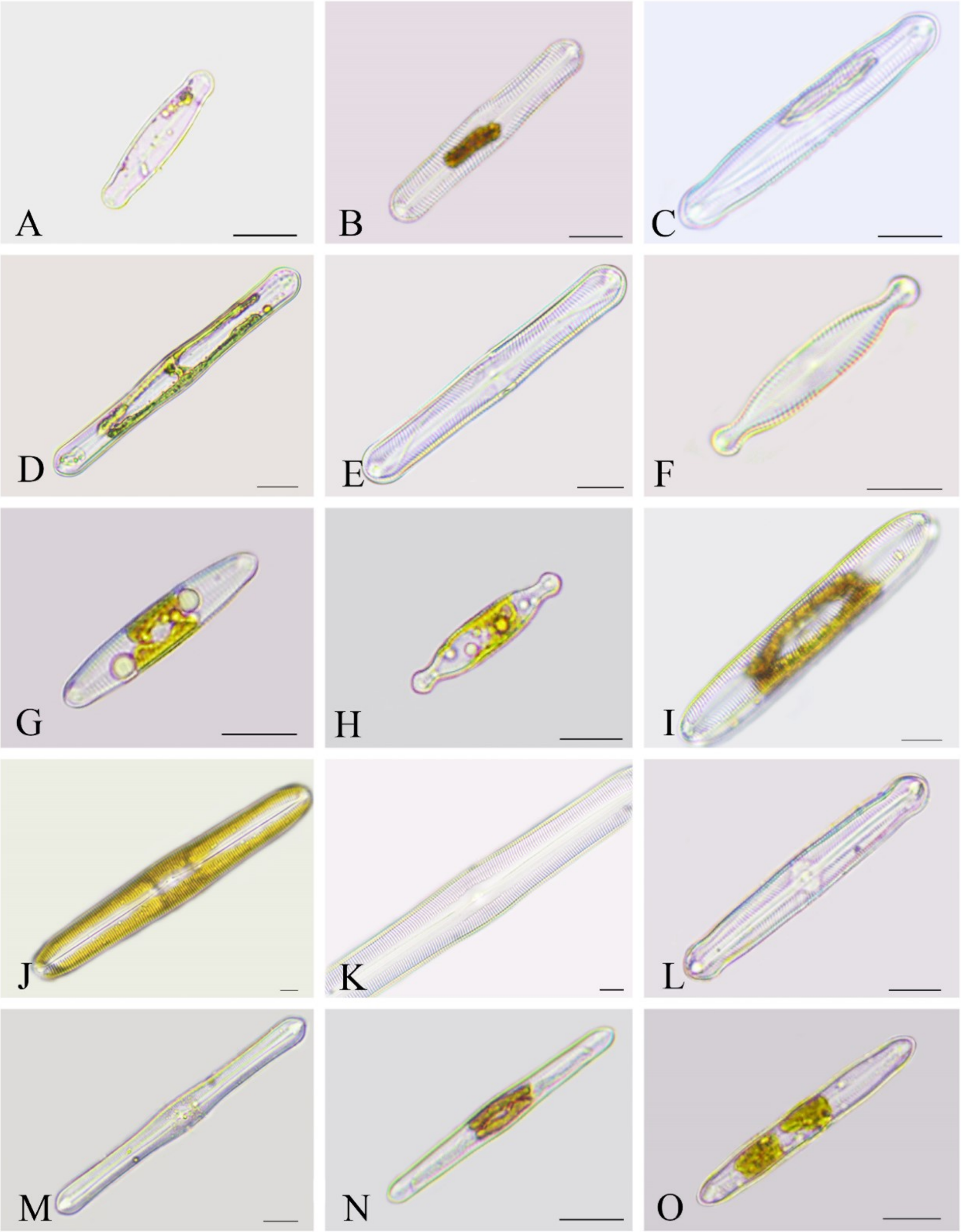
Sarode and Kamat, 1984. p. 121, pl. 14, Fig. 308.

L-46.3, W-10.4

Valves lanceolate with rounded and capitate ends.

300. ***Navicula rhynchocephala*** var. ***tenua*** Skvortzov **(Pl. 23, Fig. G)**

Sarode and Kamat, 1984. p. 122, pl. 14, Fig. 312.



Scale 10µm

PLATE 24 (Figs. A-O): A) *Pinnularia brebissonii* var. *hybrida* (Grunow) A. Cleve **B)** *P. cardinaliculus* Cleve **C)** *P. conica* H.P.Gandhi **D)** *P. gibba* (Ehrenberg) Ehrenberg **E)** *P. graciloides* Hustedt **F)** *P. interrupta* f. *minutissima* (Hustedt) Hustedt **G)** *P. isostauron* (Ehrenberg) Cleve **H)** *P. lundii* Hustedt **I)** *P. major* var. *linearis* Cleve **J**) *P. neglecta* (Ant.Mayer) Berg **K)** *P. neomajor* var. *inflata* Krammer **L)** *P. panhalgarhensis* H.P.Gandhi **M)** *P. pseudoluculenta* H.P.Gandhi **N)** *P. subcapitata* var. *subrostrata* Krammer **O)** *P. subgibba* var. *undulata* Krammer

L-29, W-6.2

Valves lanceolate with sub capitate ends.

301. ***Navicula salinarum*** var. ***intermedia*** (Grunow) Cleve **(Pl. 23, Fig. H)**

Current name: *Navicula capitatoradiata* H. Germain ex Gasse

Sarode and Kamat, 1984. p. 123, pl. 14, Fig. 315.

L-31–32, W-7.8

Valves lanceolate with capitate ends.

302. ***Navicula subrhynchocephala*** Hustedt **(Pl. 23, Fig. I)**

Sarode and Kamat, 1984. p. 124, pl. 14, Fig. 320.

L-30.8–31.8, W-7.5–7.8

Valves lanceolate with produced capitate ends.

303. ***Navicula viridula*** (Kutzing) Ehrenberg **(Pl. 23, Fig. J)**

Hustedt, 1930. p. 297, Fig. 503.

L-56.5, W-11

Valves linear lanceolate with obtuse rounded ends.

304. ***Navicula*** sp. 1 **(Pl. 23, Fig. K)**

L-46.6, W-6.4

Genus: *Pinnularia* Ehrenberg

305. ***Pinnularia acrosphaeria*** f. ***minor*** Cleve **(Pl. 23, Fig. L)**

Current name: *Pinnularia acrosphaeria* W. Smith

Cleve-Euler, 1955. p. 25, Fig. 1022 d.

L-43.5–70.3, W-9.3–10.2

Valves slightly inflated in middle with swollen and broad ends.

306. ***Pinnularia acrosphaeria*** f. ***undulata*** (Cleve) Hustedt **(Pl. 23, Fig. M)**

Sarode and Kamat, 1984. p. 133, pl. 15, Fig. 341.

L-77, W-11.4

Valves linear, inflated in middle with swollen and broad ends.

307. ***Pinnularia braunii*** var. ***amphicephala*** (Ant. Mayer) Hustedt **(Pl. 23, Fig. N)**

Current name: *Pinnularia mayeri* Krammer

Sarode and Kamat, 1984. p. 136, pl. 15, Fig. 351.

L-46–54, W-8–8.7

Valves linear elliptical with slightly constricted and rounded ends.

308. ***Pinnularia braunii*** f. ***subconica*** G.S. Venkataraman **(Pl. 23, Fig. O)**

Venkataraman, 1939, p. 337, Fig. 113.

L-43.4, W-6

Valves linear lanceolate with slightly capitate ends.

309.***Pinnularia brebissonii*** var. ***hybrida*** (Grunow) A. Cleve **(Pl. 24, Fig. A)**

Current name: *Pinnularia microstauron* (Ehrenberg) Cleve

Cleve-Euler, 1955. p. 54, Figs. 1072 h, i.

L-30.4–40, W-6.8–8.7

Valves sublinear with slightly constricted and rounded ends.

310.***Pinnularia cardinaliculus*** Cleve **(Pl. 24, Fig. B)**

Sarode and Kamat, 1984. p. 138, pl. 16, Fig. 358.

L-71.4–73, W-12–12.5

Valves linear with slightly inflated at middle and rounded ends.

311.***Pinnularia conica*** H.P. Gandhi **(Pl. 24, Fig. C)**

Gandhi, 1959. p. 111, Figs. 57, 58.

L-61.3, W-9.8

Valves linear lanceolate with slightly cuneate ends.

312.***Pinnularia gibba*** (Ehrenberg) Ehrenberg **(Pl. 24, Fig. D)**

Hustedt, 1930. p. 327, Figs. 600 a, b.

L-60.4–106.9, W-8.5–12

Valves linear lanceolate with swollen and broadly rounded ends.

313.***Pinnularia graciloides*** Hustedt **(Pl. 24, Fig. E)**

Joh, 2012. p. 48, Figs. 39, 40.

L-72.4–85, W-10.3–11.2

Valves linear with delicate tri-undulate margins and rounded capitate ends.

314.***Pinnularia interrupta*** f. ***minutissima*** (Hustedt) Hustedt **(Pl. 24, Fig. F)**

Current name: *Pinnularia biceps* f. *minutissima* (Hustedt) A.Cleve

Hustedt, 1930. p. 327, Figs. 600 a, b.

L-40–52, W-7–8.4

315.***Pinnularia isostauron*** (Ehrenberg) Cleve **(Pl. 24, Fig. G)**

Sarode and Kamat, 1984. p. 144, pl. 17, Fig. 379.

L-48, W-9.3

Valves linear with broad and sub cuneate ends.

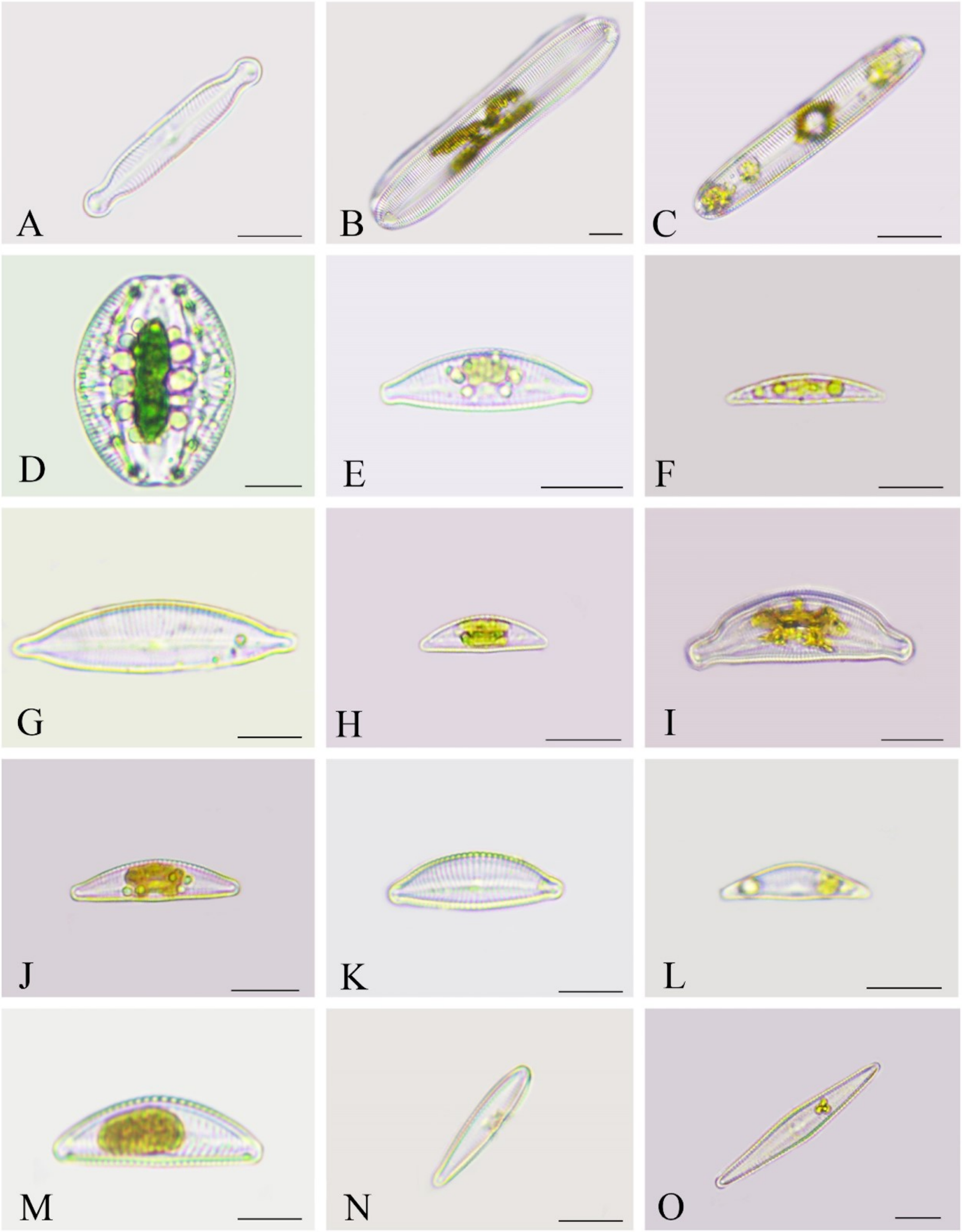
316.***Pinnularia lundii*** Hustedt **(Pl. 24, Fig. H)**

Sarode and Kamat, 1984. p. 146, pl. 17, Fig. 386.

L-43.6, W-9.7

Valves linear lanceolate with constricted and broadly capitate ends.

317.***Pinnularia major*** var. ***linearis*** Cleve **(Pl. 24, Fig. I)**



Scale 10µm

PLATE 25 (Figs. A-O): A) *Pinnularia termes* var. *termitina* (Ehrenberg) A. Cleve **B)** *P. viridis* (Nitzsch) Ehrenberg **C)** *P. viridis* var. *intermedia* Cleve **D)** *Amphora* sp.1 **E)** *Cymbella affinis* Kutzing **F)** *C. gracilis* (Rabenhorst) Cleve **G)** *C. pseudocuspidata* H.P. Gandhi **H)** *C. pusilla* Grunow **I)** *C. tumida* (Brebisson) Van Heurck **J)** *C. tumidula* Grunow **K)** *C. turgidula* Grunow **L)** *C. ventricosa* (C. Agardh) C. Agardh **M)** *C. ventricosa* var. *arcuata* Skvortzov **N)** *Gomphonema abbreviatum* C. Agardh **O)** *G. gracile* Ehrenberg

Sarode and Kamat, 1984. p. 147, pl. 17, Fig. 387.

L-98.3, W-16

Valves linear, slightly inflated middle with cuneate and rounded ends.

318.***Pinnularia neglecta*** (Ant. Mayer) Berg **(Pl. 24, Fig. J)**

Cleve-Euler, 1955. p. 80, Fig. 1112.

L-174–204.2, W-26–27.4

Valves linear, slightly inflated in middle with swollen and rounded ends.

319.***Pinnularia neomajor*** var. ***inflata*** Krammer **(Pl. 24, Fig. K)**

Joh, 2012. p. 64, Figs. 55 a-e.

L-222.2, W-27.2

Valves linear, slightly inflated in middle with swollen and rounded ends.

320.***Pinnularia panhalgarhensis*** H.P. Gandhi **(Pl. 24, Fig. L)**

Sarode and Kamat, 1984. p. 151, pl. 18, Fig. 400.

L-64–89, W-11–12.3

321.***Pinnularia pseudoluculenta*** H.P. Gandhi **(Pl. 24, Fig. M)**

Sarode and Kamat, 1984. p. 152, pl. 18, Fig. 404.

L-92–109.4, W-10.7–11

Valves linear and narrow and slightly inflated at middle and ends. Smaller than type specimen considered.

322.***Pinnularia subcapitata*** var. ***subrostrata*** Krammer **(Pl. 24, Fig. N)**

Joh, 2012. p. 89, Figs. 85 a-p.

L-52.5–53, W-6.4

Valves linear lanceolate with subrostrate ends.

323.***Pinnularia subgibba*** var. ***undulata*** Krammer **(Pl. 24, Fig. O)**

Joh, 2012. p. 93, Figs. 89 a-g.

L-70.3, W-9.8

Valves linear, undulate with cuneate ends.

324.***Pinnularia termes*** var. ***termitina*** (Ehrenberg) A. Cleve **(Pl. 25, Fig. A)**

Current name: *Pinnularia termitina* (Ehrenberg) R.M. Patrick

Sarode and Kamat, 1984. p. 157, pl. 19, Fig. 420.

L-42.8–45.2, W-7.5–7.6

Valves narrow, linear with strongly constricted with rounded capitate ends.

325.***Pinnularia viridis*** (Nitzsch) Ehrenberg **(Pl. 25, Fig. B)**

Cleve-Euler, 1955. p. 73, Fig. 1103 a, b.

L-103.4–142, W-20–22.5

Valves linear, elliptic with slightly narrowed and rounded ends.

326. ***Pinnularia viridis*** var. ***intermedia*** Cleve **(Pl. 25, Fig. C)**

Current name: *Pinnularia neomajor* var. *intermedia* (Cleve) Krammer.

Cleve-Euler, 1955. p. 74, Fig. 1103 c, d.

L-93.3, W-14

Valves linear with broadly rounded ends.

Subfamily: Gomphocymbelloideae

Genus: *Amphora* Ehrenberg ex Kutzing

327. ***Amphora*** sp.1 **(Pl. 25, Fig. D)**

L-34.2–37.6, W-23.5–26.5

Genus: *Cymbella* C. Agardh

328. ***Cymbella affinis*** Kutzing **(Pl. 25, Fig. E)**

Hustedt, 1930. p. 158, Fig. 1242.

L-31, W-9

Valves with strongly convex dorsal side, slightly convex ventral side and constricted, rostrate ends.

329. ***Cymbella gracilis*** (Rabenhorst) Cleve **(Pl. 25, Fig. F)**

Current name: *Encyonema gracile* Rabenhorst

Cleve-Euler, 1955. p. 129, Figs. 1184 a, b.

L-29, W-5

Valves semi lanceolate, convex dorsal margin and straight ventral margin with rounded ends.

330. ***Cymbella pseudocuspidata*** H.P. Gandhi **(Pl. 25, Fig. G)**

Gandhi, 1959. p. 117, Fig. 75.

L-32–41.8, W-9–10.3

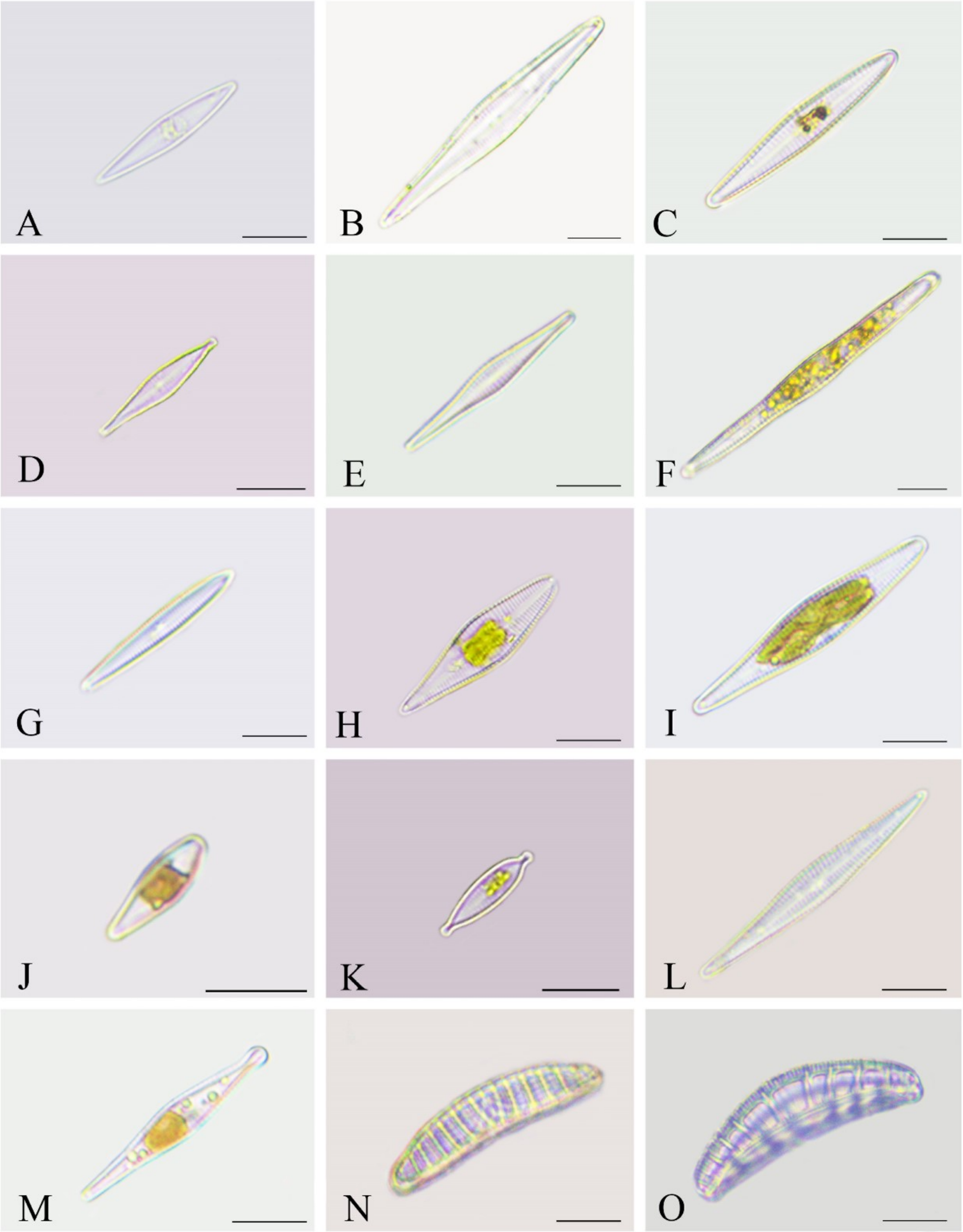
Valves linear, lanceolate, with constricted and produced ends.

331. ***Cymbella pusilla*** Grunow **(Pl. 25, Fig. H)**

Current name: *Navicymbula pusilla* (Grunow) Krammer

Sarode and Kamat, 1984. p. 175, pl. 20, Fig. 464.

L-25.6, W-7



Scale 10µm

PLATE 26 (Figs. A-O): A) *Gomphonema gracile* var. *auritum* (A. Braun ex Kutzing) Van Heurck **B)** *G. gracile* var. *major* Grunow **C)** *G. gracile* var. *naviculoides* (W. Smith) Grunow **D)** *G. gracile* var. *subcapitatum* H.P. Gandhi **E)** *G. hebridense* W. Gregory **F)** *G. intricatum* var. *fossile* Pantocsek **G)** *G. intricatum* var. *pumilum* Grunow **H)** *G. lacus-rankala* H.P. Gandhi **I)** *G. lanceolatum* Ehrenberg **J)** *G. olivaceum* (Hornemann) Ehrenberg **K)** *G. sphaerophorum* Ehrenberg **L)** *G. spicula* H.P. Gandhi **M)** *G. subtile* Ehrenberg **N)** *Epithemia zebra* (Ehrenberg) Kutzing **O)** *Epithemia* sp. 1

Valves with dorsal margin convex and ventral margin almost straight, ends acute and round.

332. ***Cymbella tumida*** (Brebisson) Van Heurck **(Pl. 25, Fig. I)**

Hustedt, 1930. p. 366, Fig. 677.

L-54.3–57.4, W-14–16.2

Valves broadly naviculoid and curved with rostrate ends.

333. ***Cymbella tumidula*** Grunow **(Pl. 25, Fig. J)**

Sarode and Kamat, 1984. p. 177, pl. 21, Fig. 470.

L-37.5, W-9.2

Valves lanceolate, dorsal margin convex and ventral margin slightly convex with rounded ends.

334. ***Cymbella turgidula*** Grunow **(Pl. 25, Fig. K)**

Hustedt, 1930. p. 362, Fig. 670.

L-28–34, W-9.8–10.4

Valves with strongly convex dorsal margin and almost straight ventral margin, rostrate ends.

335. ***Cymbella ventricosa*** (C. Agardh) C. Agardh **(Pl. 25, Fig. L)**

Current name: *Encyonema ventricosum* (C. Agardh) Grunow

Hustedt, 1930. p. 359, Fig. 661.

L-18–24, W-4.8–5.8

Valves strongly convex on dorsal side and straight on ventral side with acute and rounded ends.

336. ***Cymbella ventricosa*** var. ***arcuata*** Skvortzov **(Pl. 25, Fig. M)**

Sarode and Kamat, 1984. p. 178, pl. 21, Fig. 47.

L-30.4, W-10

Valves with raphe arcuate.

Family: Gomphonemaceae

Genus: *Gomphonema* Ehrenberg

337. ***Gomphonema abbreviatum*** C. Agardh **(Pl. 25, Fig. N)**

Current name: *Rhoicosphenia abbreviata* (C. Agardh) Lange-Bertalot

Hustedt, 1930. p. 379, Fig. 722.

L-16.6–39, W-3.2–6.3

Valves linear, broadly rounded apex and narrowly rounded base.

338. ***Gomphonema gracile*** Ehrenberg **(Pl. 25, Fig. O)**

Hustedt, 1930. p. 376, Fig. 702.

L-56–67.7, W-9.7–11

Valves lanceolate and clavate with attenuated ends.

339. ***Gomphonema gracile*** var. ***auritum*** (A. Braun ex Kutzing) Van Heurck **(Pl. 26, Fig. A)**

Current name: *Gomphonema auritum* A. Braun ex Kutzing

Cleve-Euler, 1955. p. 186, Fig. 1281 i.

L-24.2–32.2, W-4.5–5.6

Valves small, lanceolate, clavate with acute and round ends.

340. ***Gomphonema gracile*** var. ***major*** Grunow **(Pl. 26, Fig. B)**

Cleve-Euler, 1955. p. 186, Fig. 1281 d, e.

L-69.8–85, W-9.4–10.5

Valves narrow and lanceolate with acute and rounded ends.

341. ***Gomphonema gracile*** var. ***naviculoides*** (W. Smith) Grunow **(Pl. 26, Fig. C)**

Current name: *Gomphonema naviculoides* W. Smith

Sarode and Kamat, 1984. p. 187, pl. 22, Fig. 503.

L-45.5–53.3, W-7.8–8.4

Valves lanceolate, almost isopolar with attenuated ends.

342. ***Gomphonema gracile*** var. ***subcapitatum*** H.P. Gandhi **(Pl. 26, Fig. D)**

Sarode and Kamat, 1984. p. 187, pl. 22, Fig. 504.

L-33, W-6.3

Valves lanceolate, clavate with constricted and sub capitate apex.

343. ***Gomphonema hebridense*** W. Gregory **(Pl. 26, Fig. E)**

Cleve-Euler, 1955. p. 181, Fig. 1274.

L-40.6–46.6, W-5.5–6.8

Valves lanceolate, slightly inflated in middle with rounded ends.

344. ***Gomphonema intricatum*** var. ***fossile*** Pantocsek **(Pl. 26, Fig. F)**

Sarode and Kamat, 1984. p. 188, pl. 22, Fig. 508.

L-80.9, W-8.3

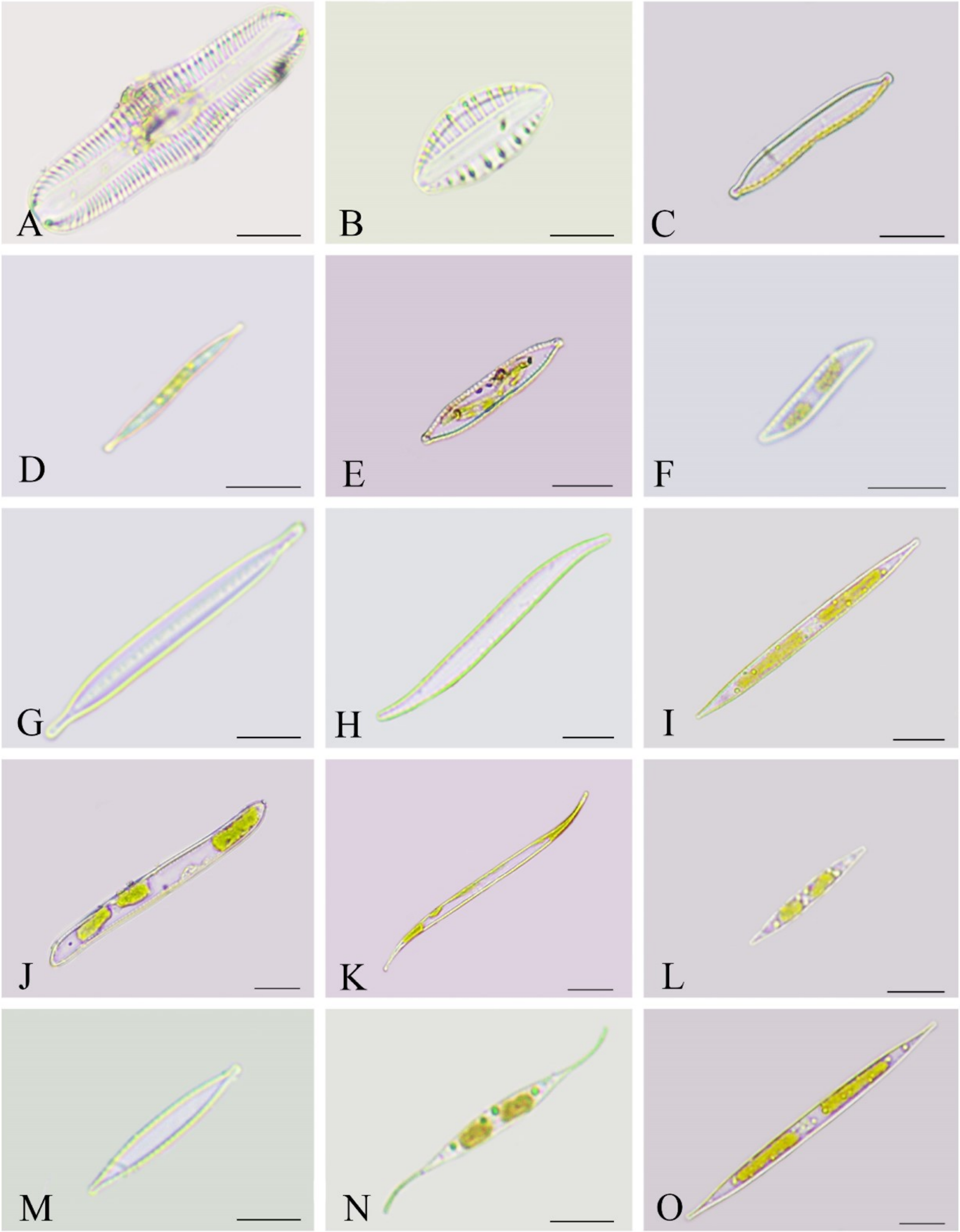
Valves narrow and lanceolate, slightly inflated in middle with rounded ends.

345. ***Gomphonema intricatum*** var. ***pumilum*** Grunow **(Pl. 26, Fig. G)**

Current name: *Gomphonema pumilum* (Grunow) E. Reichardt & Lange-Bertalot

Sarode and Kamat, 1984. p. 189, pl. 22, Fig. 509.

L-24.2–36.7, W-4.4–5.3



Scale 10µm

PLATE 27 (Figs. A-O): A) *Rhopalodia gibba* (Ehr.) Muell. **B)** *R. gibberula* (Ehrenberg) O. Muller **C)** *Hantzschia amphioxys* f. *capitata* O. Muller **D)** *Hantzschia* sp. 1 **E)** *Nitzschia apiculata* (W.Gregory) Grunow **F)** *N. filiformis* (W.Smith) Van Heurck **G)** *N. heufleriana* Grunow **H)** *N. ignorata* Krasske **I)** *N. intermedia* Hantzsch ex Cleve & Grunow **J)** *N. obtusa* W. Smith **K)** *N. lorenziana* var. *subtilis* Grunow **L)** *N. palea* (Kutzing) W. Smith **M)** *N. perminuta* Grunow **N)** *N. reversa* W. Smith **O)** *N. sublinearis* Hustedt

Valves lanceolate, clavate with broadly rounded ends.

346. ***Gomphonema lacus-rankala*** H.P. Gandhi **(Pl. 26, Fig. H)**

Sarode and Kamat, 1984. p. 189, pl. 22, Fig. 511.

L-53.5, W-13.6

Valves broad, lanceolate, clavate with constricted and rounded apex.

347. ***Gomphonema lanceolatum*** Ehrenberg **(Pl. 26, Fig. I)**

Current name: *Gomphonema grunowii* R.M. Patrick & Reimer

Sarode and Kamat, 1984. p. 190, pl. 22, Fig. 514.

L-54.2, W-10.6

Valves lanceolate and clavate with distinctly rounded ends.

348. ***Gomphonema olivaceum*** (Hornemann) Ehrenberg **(Pl. 26, Fig. J)**

Current name: *Gomphonella olivacea* (Hornemann) Rabenhorst

Hustedt, 1930. p. 378, Fig. 719.

L-16, W-5.3

Valves broad, clavate with broadly rounded apex and attenuated base.

349. ***Gomphonema sphaerophorum*** Ehrenberg **(Pl. 26, Fig. K)**

Sarode and Kamat, 1984. p. 196, pl. 23, Fig. 534.

L-23.8, W-6.2

Valves ovate, clavate with capitate round apex and base.

350. ***Gomphonema spicula*** H.P. Gandhi **(Pl. 26, Fig. L)**

Current name: *Gomphonema spiculoides* H.P. Gandhi

Gandhi, 1958. p. 501, Fig. 28.

L-55, W-7.5

Valves narrow, lanceolate, clavate with acute apex and gradually attenuated base.

351. ***Gomphonema subtile*** Ehrenberg **(Pl. 26, Fig. M)**

Cleve-Euler, 1955. p. 177, Fig. 1268 a, b.

L-38.7, W-6.7

Valves narrow, lanceolate, clavate with slightly capitate apex.

Family: Epithemiaceae

Subfamily: Epithemioideae

Genus: *Epithemia* Kützing

352. ***Epithemia zebra*** (Ehrenberg) Kutzing **(Pl. 26, Fig. N)**

Current name: *Epithemia adnata* (Kutzing) Brebisson

Hustedt, 1930. p. 384, Fig. 729.

L-34, W-7

Valves slightly curved, dorsally convex. ends bluntly rounded.

353. ***Epithemia*** sp. 1 **(Pl. 26, Fig. O)**

L-45.2, W-10.3

Subfamily: Rhopalodioideae

Genus: *Rhopalodia* O.Muller

354. ***Rhopalodia gibba*** (Ehr.) Muell. **(Pl. 27, Fig. A)**

Current name: *Epithemia gibba* (Ehrenberg) Kutzing

Hustedt 1930, p. 390, Fig. 740.

L-62.4–78, W-18.2–19

Valves elongated, inflated in middle with a slight notch with rounded corners.

355. ***Rhopalodia gibberula*** (Ehrenberg) O. Muller **(Pl. 27, Fig. B)**

Hustedt, 1930. p. 390, Fig. 740.

L-30.8, W-15.7

Valves elliptical with truncated ends.

Family: Nitzschiaceae

Subfamily: Nitzschioideae

Genus: *Hantzschia* Grunow

356. ***Hantzschia amphioxys*** f. ***capitata*** O. Muller **(Pl. 27, Fig. C)**

Hustedt, 1930. p. 394, Fig. 748.

L-46.7, W-6.6

Valves linear, ventral margin convex, arcuate with depression in middle and ends are constricted and capitate.

357. ***Hantzschia*** sp. 1 **(Pl. 27, Fig. D)**

L-30.4, W-2.8

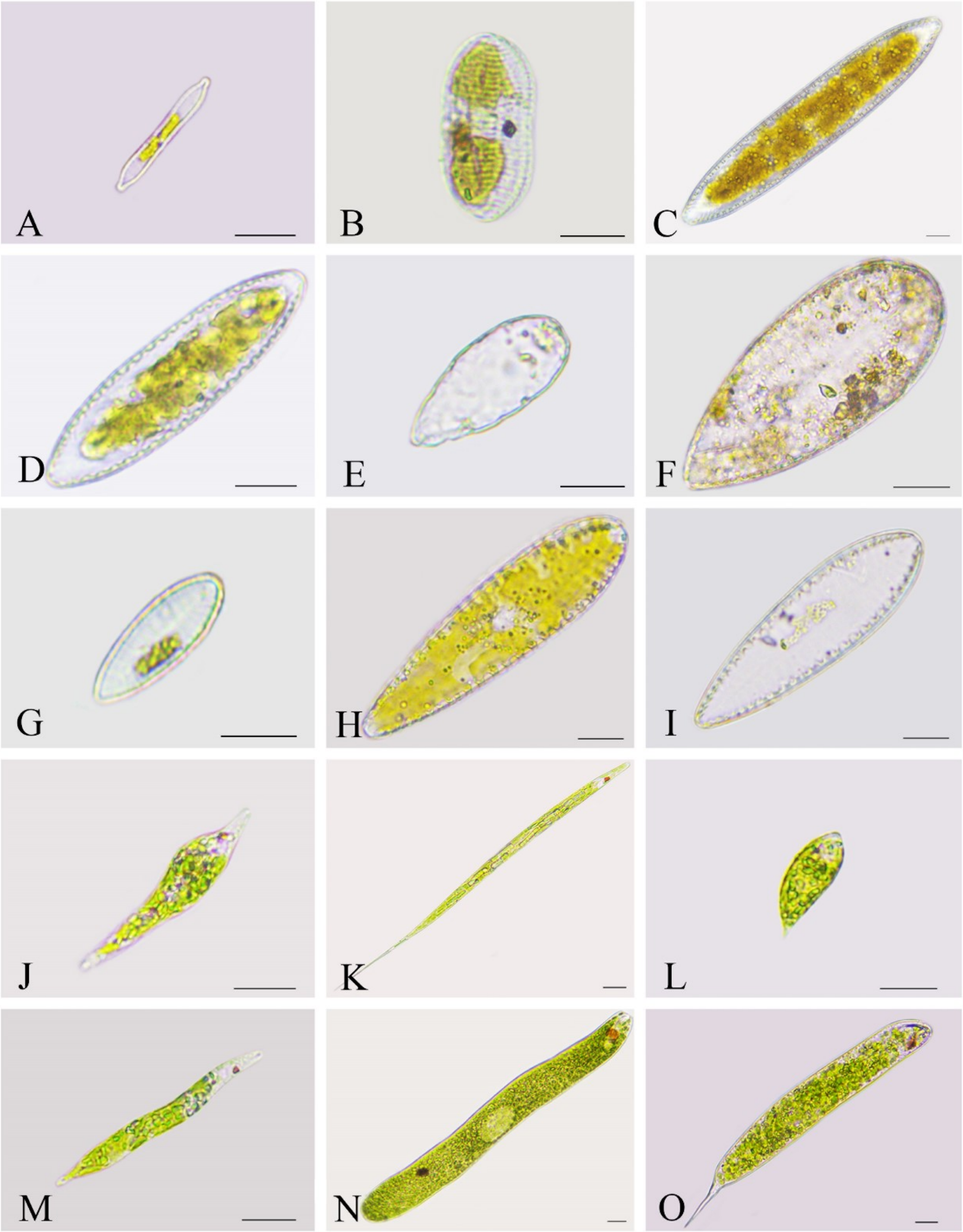
Genus: *Nitzschia* Hassall

358. ***Nitzschia apiculata*** (W. Gregory) Grunow **(Pl. 27, Fig. E)**

Current name: *Tryblionella apiculata* W. Gregory

Hustedt, 1930. p. 401, Fig. 765.

L-43.7, W-7.7



Scale 10µm

PLATE 28 (Figs. A-O): A) *Nitzschia thermalis* var. *minor* Hilse **B)** *N. tryblionella* var. *victoriae* (Grunow) Grunow **C)** *Surirella biseriata* Brebisson **D)** *S. linearis* W. Smith **E)** *S. ovata* var. *salina* (W. Smith) Rabenhorst **F)** *S. robusta* var. *splendida* (Ehrenberg) Van Heurck **G)** *S. subsalsa* W. Smith **H)** *S. tenera* W. Gregory **I)** *S. tenera* var. *nervosa* A.W.F. Schmidt **J)** *Astasia harrisii* Pringsheim **K)** *Euglena acus* (O.F. Muller) Ehrenberg **L)** *E. agilis* H.J. Carter **M)** *E. deses* (O.F. Muller) Ehrenberg **N)** *E. ehrenbergii* G.A. Klebs **O)** *E. oxyuris* Schmarda

Valves linear, cuneate with apiculate ends.

359. ***Nitzschia filiformis*** (W. Smith) Van Heurck **(Pl. 27, Fig. F)**

Sarode and Kamat, 1984. p. 216, pl. 25, Fig. 589.

L-23.3, W-4

Valve small, sigmoid with obtuse and rounded ends.

360. ***Nitzschia heufleriana*** Grunow **(Pl. 27, Fig. G)**

Sarode and Kamat, 1984. p. 217, pl. 26, Fig. 594.

L-48.4, W-4.7

Valves linear with slightly produced and rounded ends.

361. ***Nitzschia ignorata*** Krasske **(Pl. 27, Fig. H)**

Current name: *Nitzschia nana* Grunow

Hustedt, 1930. p. 422, Fig. 819.

L-53.2, W-4.4

Valves linear, sigmoid with obliquely rounded ends.

362. ***Nitzschia intermedia*** Hantzsch ex Cleve & Grunow **(Pl. 27, Fig. I)**

Sarode and Kamat, 1984. p. 218, pl. 26, Fig. 598.

L-80–84.7, W-5.7–5.8

Valves linear, lanceolate with constricted and sub capitate ends.

363. ***Nitzschia obtusa*** W. Smith **(Pl. 27, Fig. J)**

Sarode and Kamat, 1984. p. 221, pl. 26, Fig. 608.

L-88.6, W-8.3

Valves slightly sigmoid with cuneate and bluntly rounded ends.

364. ***Nitzschia lorenziana*** var. ***subtilis*** Grunow **(Pl. 27, Fig. K)**

Hustedt, 1930. p. 423, Fig. 820.

L-67–90.3, W-3.3–4

Valves linear, lanceolate, sigmoid with slender ends.

365. ***Nitzschia palea*** (Kutzing) W. Smith **(Pl. 27, Fig. L)**

Hustedt, 1930. p. 416, Fig. 801.

L-31, W-4.2

Valves linear, sub lanceolate with constricted and slightly capitate ends.

366. ***Nitzschia perminuta*** Grunow **(Pl. 27, Fig. M)**

Sarode and Kamat, 1984. p. 223, pl. 26, Fig. 614.

L-22.3–28.9, W-3.2–4

Valves linear, lanceolate with capitate ends.

367. ***Nitzschia reversa*** W. Smith **(Pl. 27, Fig. N)**

Smith, 1853. p. 43, pl. 15, Fig. 121.

L-42.6, W-4

Valves with long attenuated ends which are bent in opposite directions.

368. ***Nitzschia sublinearis*** Hustedt **(Pl. 27, Fig. O)**

Hustedt, 1930. p. 411, Fig. 786.

L-81.5, W-6.1

Valves linear, lanceolate with gradually attenuated truncate ends.

369. ***Nitzschia thermalis*** var. ***minor*** Hilse **(Pl. 28, Fig. A)**

Hustedt, 1930. p. 403, Fig. 772.

L-35.5, W-4.8

Valves small, linear, lanceolate with a compression in middle and apiculate ends.

370. ***Nitzschia tryblionella*** var. ***victoriae*** (Grunow) Grunow **(Pl. 28, Fig. B)**

Current name: *Tryblionella victoriae* Grunow

Hustedt, 1930. p. 399, Fig. 758.

L-36.3, W-17.3

Valves broad, linear with sub cuneate ends.

Family: Surirellaceae

Subfamily: Surirelloideae

Genus: *Surirella* Turpin

371. ***Surirella biseriata*** Brebisson **(Pl. 28, Fig. C)**

Sarode and Kamat, 1984. p. 230, pl. 27, Fig. 639.

L-81–168.6, W-20–32

Valves isopolar, lanceolate with cuneate and acutely rounded ends.

372. ***Surirella linearis*** W. Smith **(Pl. 28, Fig. D)**

Current name: *Iconella linearis* (W. Smith) Ruck & Nakov

Sarode and Kamat, 1984. p. 231, pl. 28, Fig. 647.

L-64–75, W-18–20.6

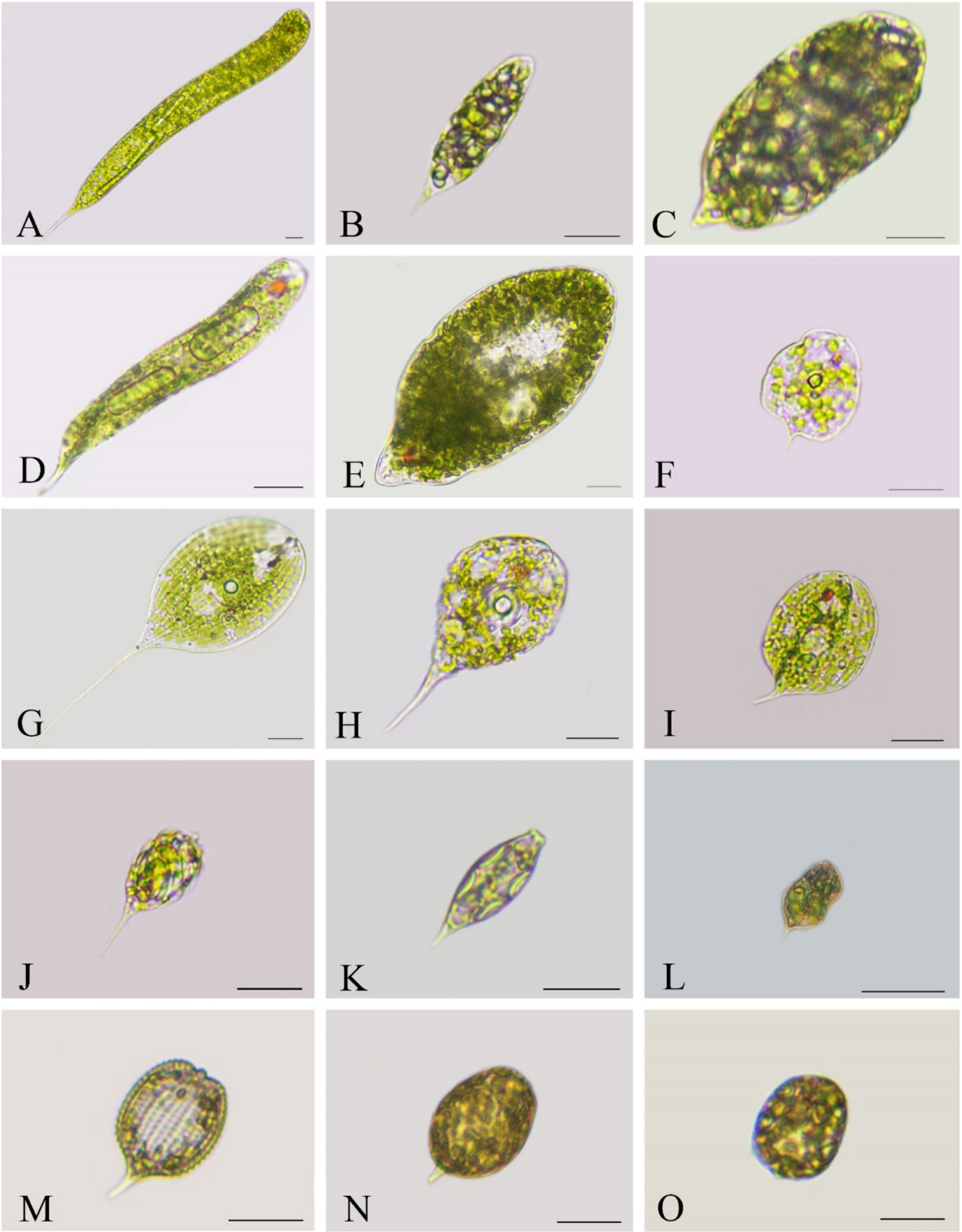
Valves isopolar, linear with cuneate ends.

373. ***Surirella ovata*** var. ***salina*** (W. Smith) Rabenhorst **(Pl. 28, Fig. E)**

Current name: *Surirella salina* W. Smith.

Hustedt, 1930. p. 442, Fig. 866.

L-35.7, W-15



Scale 10µm

PLATE 29 (Figs. A-O): A) *Euglena oxyuris* var. *major* Woronichin **B)** *E. proxima* P.A. Dangeard **C)** *E. splendens* P.A. Dangeard **D)** *E. tripteris* (Dujardin) Diesing **E)** *Euglena* sp.1 **F)** *Phacus acuminatus* A. Stokes **G)** *P. longicauda* (Ehrenberg) Dujardin **H)** *P. longicauda* (Ehrenberg) **I)** *P. pleuronectes* (O.F. Muller) Nitzsch ex Dujardin **J)** *P. splendens* Pochmann **K)** *Lepocinclis acicularis* France **L)** *L. constricta* Matvienko **M)** *L. hispidula* (Eichwald) Daday **N)** *L. ovum* (Ehrenberg) Lemmermann **O)** *L. ovum* var. *dimidio-minor* (Deflandre) Conrad

Valves broad and ovate with narrow basal end.

374.***Surirella robusta*** var. ***splendida*** (Ehrenberg) Van Heurck **(Pl. 28, Fig. F)**

Current name: *Iconella splendida* (Ehrenberg) Ruck & Nakov

Hustedt, 1930. p. 437, Figs. 851–852.

L-121.6, W-51.5

Valves ovate with broad rounded ends.

375.***Surirella subsalsa*** W. Smith **(Pl. 28, Fig. G)**

Sarode and Kamat, 1984. p. 234, pl. 27, Fig. 646.

L-27.7–34, W-10–12.5

Valves ovate lanceolate with cuneate base.

376.***Surirella tenera*** W. Gregory **(Pl. 28, Fig. H)**

Current name: *Iconella tenera* (W. Gregory) Ruck & Nakov

Sarode and Kamat, 1984. p. 234, pl. 28, Fig. 654.

L-102.2–110, W-24.4–27.3

Valves linear, ovate with broad round apex and broad cuneate base.

377. ***Surirella tenera*** var. ***nervosa*** A.W.F. Schmidt **(Pl. 28, Fig. I)**

Current name: *Iconella nervosa* (A.W.F. Schmidt) C. Cocquyt & R. Jahn

Sarode and Kamat, 1984. p. 234, pl. 28, Fig. 656.

L-97–125, W-28.6–30

Valves linear, ovate with round apex and cuneate base.

Division: Euglenophyta

Class: Euglenophyceae

Order: Euglenales

Family: Astasiaceae

Genus: *Astasia* Dujardin

378. ***Astasia harrisii*** Pringsheim **(Pl. 28, Fig. J)**

Wolowski, 1998. p. 44, Figs. 162 –164.

L-56, W-12.4

Cells fusiform, slightly bent and extending at posterior end.

Family: Euglenaceae

Genus: *Euglena* Ehrenberg

379. ***Euglena acus*** (O.F. Muller) Ehrenberg **(Pl. 28, Fig. K)**

Current name: *Lepocinclis acus* (O.F. Muller) B. Marin & Melkonian

Philipose, 1982, p. 564, Figs. 1a-g.

L-109–188.5, W-9.7–11

Cells long, spindle shaped, fine tapering tail at posterior end. Disc like chloroplasts present.

380. ***Euglena agilis*** H.J. Carter **(Pl. 28, Fig. L)**

Wolowski, 1998. p. 26, Figs. 73–81, pl. 5:1–13.

L-31.5, W-11.7

Cells fusiform with short tail.

381. ***Euglena deses*** (O.F. Muller) Ehrenberg **(Pl. 28, Fig. M)**

Wolowski, 1998. p. 38, Figs. 15–127.

L-69.4, W-7.2

Cells cylindrical, oblong shaped.

382. ***Euglena ehrenbergii*** G.A. Klebs **(Pl. 28, Fig. N)**

Wolowski, 1998. p. 24, Figs. 59–62.

L-200.2, W-22.4

Cells cylindrical, flat, slightly truncate at anterior and rounded at posterior end.

383. ***Euglena oxyuris*** Schmarda **(Pl. 28, Fig. O)**

Current name: *Lepocinclis oxyuris* (Schmarda) B. Marin & Melkonian

Wolowski, 1998. p. 15, Figs. 20–21.

L- 164.3–182, W-21.6

Cells cylindrical, with rounded anterior end and sharp posterior tail.

384. ***Euglena oxyuris*** var. ***major*** Woronichin **(Pl. 29, Fig. A)**

Current name: *Lepocinclis gracillimoides* Zakrys & Chaber

Wolowski, 1998. p. 16, Fig. 24.

L-296, W-31

Cells cylindrical with a posterior sharp tail.

385. ***Euglena proxima*** P.A. Dangeard **(Pl. 29, Fig. B)**

Current name: *Euglenaformis proxima* (P.A. Dangeard) M.S. Bennett & Triemer

Wolowski, 1998. p. 21, Figs. 43, 44.

L-41, W-11.4

Cells fusiform with narrowing anterior end and posterior end with a short tail.

386. ***Euglena splendens*** P.A. Dangeard **(Pl. 29, Fig. C)**

Wolowski et al., 2013, p. 668, Figs. 26, 27.

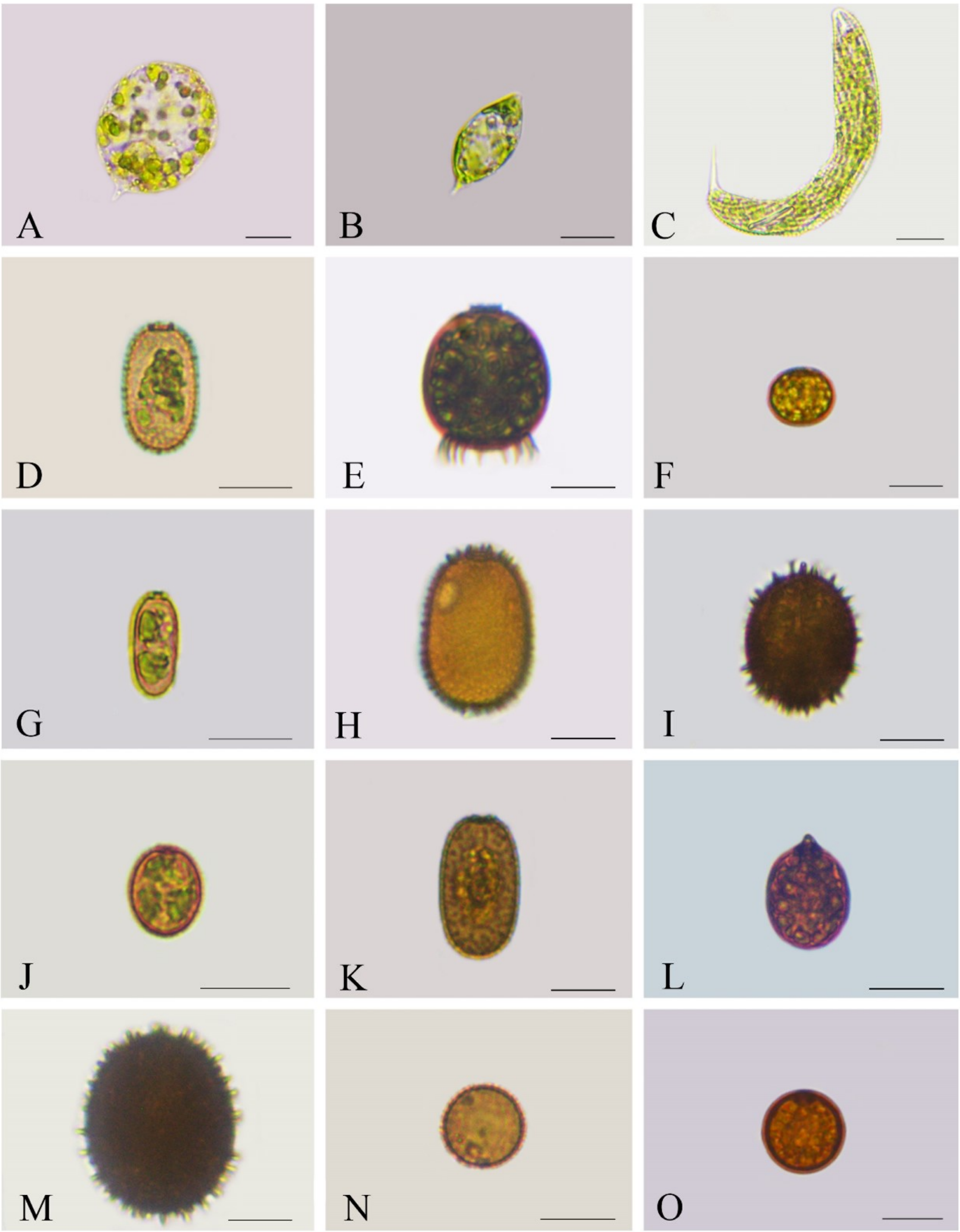


PLATE 30 (Figs. A-O): A) *L. ovum* var. *globulus* (Perty) Lemmermann **B)** *Lepocinclis playfairiana* (Deflandre) Deflandre **C)** *L. spirogyroides* B. Marin & Melkonian **D)** *Trachelomonas abrupta* Svirenko **E)** *T. armata* (Ehrenberg) F. Stein **F)** *T. curta* A.M. Cunha **G)** *T. cylindrica* Ehrenberg **H)** *T. hispida* (Perty) F. Stein **I)** *T. hispida* var. *duplex* Deflandre **J)** *T. intermedia* P.A. Dangeard **K)** *T. lacustris* Drezepolski **L)** *T. planctonica* Svirenko **M)** *T. superba* Svirenko **N)** *T. sculpta* Balech **O)** *T. volvocina* (Ehrenberg) Ehrenberg

L-48.5–51.7, W-22.4–24.6

Cells oval with small projection in posterior end.

387.***Euglena tripteris*** (Dujardin) Diesing **(Pl. 29, Fig. D)**

Current name: *Lepocinclis tripteris* (Dujardin) B. Marin & M. Melkonian

Wolowski, 1998. p. 19, Figs. 37–39.

L-86, W-12.4

Cells fusiform, twisted with a posterior tail.

388.***Euglena*** sp.1 **(Pl. 29, Fig. E)**

L-109.4, W-54.3

Genus: *Phacus* Dujardin

389. ***Phacus acuminatus*** A. Stokes **(Pl. 29, Fig. F)**

Wolowski, 1998. p. 71, Figs. 238, pl. 25–6, 8.

L-20–27, W-15.6–21

Cells broad and oval with an incision at anterior and short extension at posterior end.

390. ***Phacus longicauda*** (Ehrenberg) Dujardin **(Pl. 29, Fig. G, H)**

Wolowski, 1998. p. 84, Figs. 291–294, pl. 28–9.

L-71.3–117.2, W-34.3–41.5

Anterior end broadly rounded, one paramylon body, sharply pointed tail at posterior end.

391. ***Phacus pleuronectes*** (O.F. Muller) Nitzsch ex Dujardin **(Pl. 29, Fig. I)**

Philipose, 1984. p. 528, Fig. 27.

L-30–46.6, W-25–30.8

Cells broad, oval with sharp tail at posterior end.

392.***Phacus splendens*** Pochmann **(Pl. 29, Fig. J)**

Current name: *Monomorphina pyrum* (Ehrenberg) Mereschkowsky

Wolowski, 1998. p. 86, Fig. 303, pl. 29–1, 2.

L-34–36.7, W-12.5–15

Cells ovoid, spirally striated with a conical tail.

Genus: Lepocinclis Perty

393. ***Lepocinclis acicularis*** Franc **(Pl. 29, Fig. K)**

Wolowski, 1998. p. 68, Figs. 218, 219.

L-24.7–31.2, W–8-8.7

Cells fusiform with needle like tail at posterior end. Conspicuous plate shaped chloroplasts arranged laterally.

394. ***Lepocinclis constricta*** Matvienko **(Pl. 29, Fig. L)**

Current name: *Discoplastis constricta* (Matvienko) Zakrys & Lukomska

Kim and Lee, 2022. p. 5, Fig. 10.

L-25, W-12

Cells fusiform, constricted in middle and with small straight tail at posterior end.

395. ***Lepocinclis hispidula*** (Eichwald) Daday **(Pl. 29, Fig. M)**

Current name: *Phacus hispidulus* (Eichwald) Klebs

Philipose, 1984. p. 543, Fig. 46.

L-25.5–30, W-16–18

Cells with anterior rounded with small bump and posterior end with slightly bent short tail. Longitudinal rows of sharp papillae seen.

396. ***Lepocinclis ovum*** (Ehrenberg) Lemmermann **(Pl. 29, Fig. N)**

Wolowski, 1998. p. 66, Fig. 208 –210, pl. 4–4.

L-17–28, W-12.5–18

Cells broad, elliptical with short extension at posterior end.

397. ***Lepocinclis ovum*** var. ***dimidio-minor*** (Deflandre) Conrad **(Pl. 29, Fig. O)**

Philipose, 1984. p. 510, Fig. 4 e-f.

L-14.7, W-10

Cells ellipsoid with short tail.

398. ***Lepocinclis ovum*** var. ***globulus*** (Perty) Lemmermann **(Pl. 30, Fig. A)**

Current name: *Lepocinclis globulus* Perty

Wolowski, 1998. p. 67, Figs. 211–212, pl. 24–5.

L-15.5–43, W-12.2–30

Cells ovoid with small projection at posterior end.

399. ***Lepocinclis playfairiana*** (Deflandre) Deflandre **(Pl. 30, Fig. B)**

Current name: *Lepocinclis fusiformis* (H.J. Carter) Lemmermann

Wolowski, 1998. p. 68, pl. 24–6, 7.

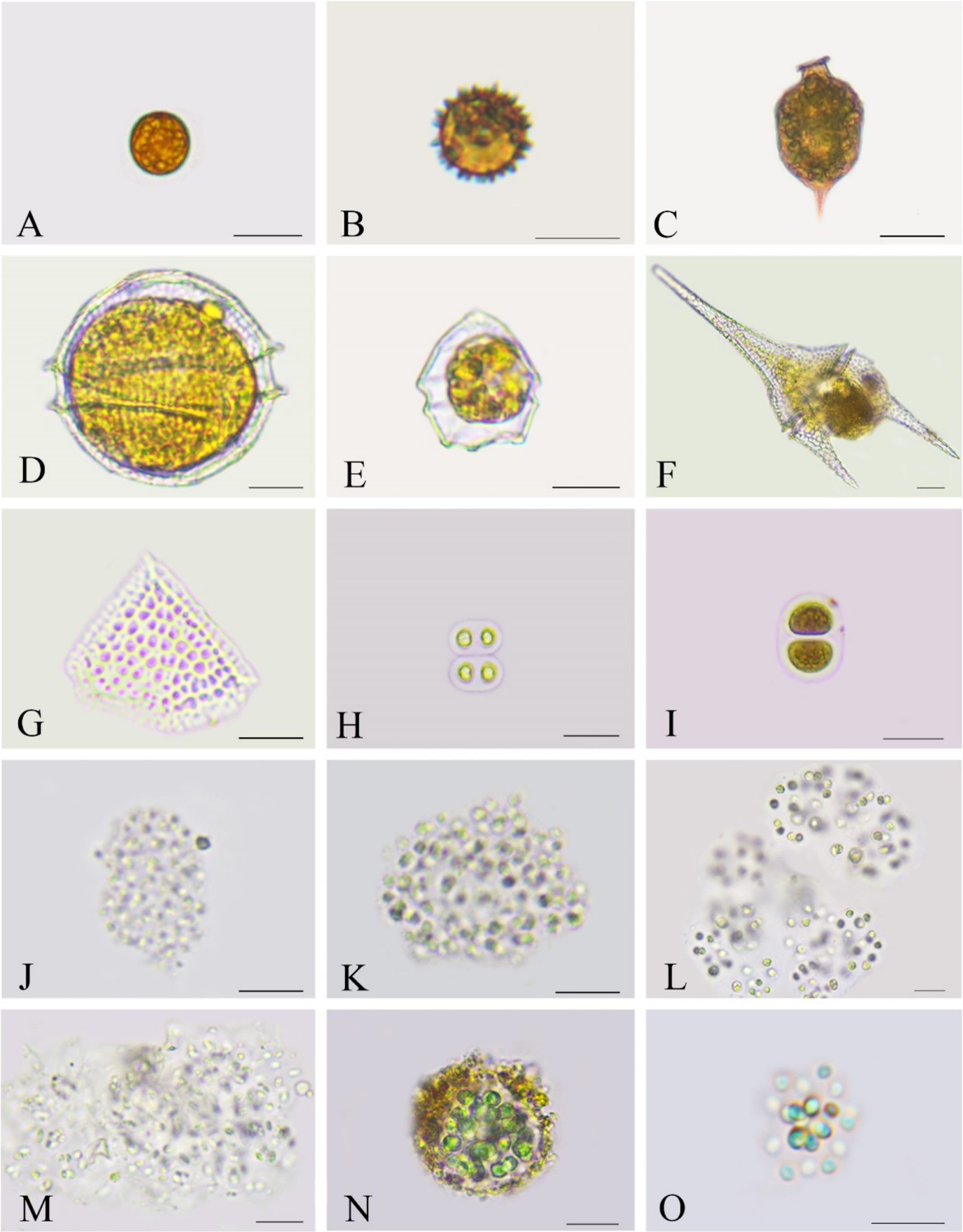
L-34.3, W-15.6

Cells fusiform with short posterior tail.

400. ***Lepocinclis spirogyroides*** B. Marin & Melkonian **(Pl. 30, Fig. C)**

Wolowski et al., 2013. p. 671, Figs. 38, 86.

L-97, W-10



Scale 10µm

PLATE 31 (Figs. A-O): A) *Trachelomonas volvocinopsis* Svirenko **B)** *T. woycickii* Koczwara **C)** *Strombomonas* sp. 1 **D)** *Peridinium cinctum* (O.F. Muller) Ehrenberg **E)** *P. inconspicuum* Lemmermann **F)** *Ceratium furcoides* (Levander) Langhans **G)** *Triceratium* sp. 1 **H)** *Chroococcus minutus* (Kutzing) Nageli **I)** *C. turgidus* (Kutzing) Nageli **J)** *Aphanocapsa delicatissima* West & G.S. West **K)** *A. elachista* West & West **L)** *A. pulchra* (Kutzing) Rabenhorst **M)** *Aphanothece nidulans* P. Richter **N)** *Coelosphaerium dubium* Grunow **O)** *C. kuetzingianum* Nageli

Cells elongated, cylindrical, and spirally striated with sharp tail at posterior end.

Genus: *Trachelomonas* Ehrenberg

401.***Trachelomonas abrupta*** Svirenko **(Pl. 30, Fig. D)**

Wolowski, 1998. p. 54, pl. 16, Fig. 10.

L-21–22, W-11.7–12.5

Lorica ellipsoid- cylindrical with rounded ends, yellow-brown colour and covered by uniform small spines.

402.***Trachelomonas armata*** (Ehrenberg) F. Stein **(Pl. 30, Fig. E)**

Philipose, 1988. p. 350, Fig. 26 a.

L-30, W-23.2

Lorica slightly ovoid, with rounded ends. Posterior end with crown of well-developed curved spines.

403.***Trachelomonas curta*** A.M. Cunha **(Pl. 30, Fig. F)**

Wolowski, 1998. p. 52, pl. 12, Fig. 3.

L-9.4–13.5, W-10.7–15

Lorica ovoid compressed and smooth.

404.***Trachelomonas cylindrica*** Ehrenberg **(Pl. 30, Fig. G)**

Philipose, 1988. p. 343, Fig. 17 a.

L-14–18, W-6.6–8.5

Lorica cylindrical, parallel sides with rounded ends.

405.***Trachelomonas hispida*** (Perty) F. Stein **(Pl. 30, Fig. H)**

Islam and Muniruzzaman, 1981. p. 114, pl. 4, Figs. 119–126, pl. 5, Figs. 137, 139.

L-23.4–32, W-19.4–21.2

Lorica ovoid, densely covered by sharp evenly distributed spines.

406.***Trachelomonas hispida*** var. ***duplex*** Deflandre **(Pl. 30, Fig. I)**

Current name: *Trachelomonas duplex* (Deflandre) Coute & Tell

Prescott, 1955. pl. 2, Fig. 8.

L-25.3–29.3, W-21–22.2

Lorica ovoid covered with short spines at anterior and posterior ends.

407.***Trachelomonas intermedia*** P.A. Dangeard **(Pl. 30, Fig. J)**

Philipose, 1988. p. 341, Fig. 14 a.

L-11.2–13, W-9.2–10.5

Lorica subspherical, ellipsoidal and smooth.

408.***Trachelomonas lacustris*** Drezepolski **(Pl. 30, Fig. K)**

Prescott, 1982. p. 415, pl. 83, Figs. 14, 15; pl. 85, Fig. 15.

L-20–21, W-10.2–11.8

Lorica cylindrical and densely granulated.

409.***Trachelomonas planctonica*** Svirenko **(Pl. 30, Fig. L)**

Wolowski, 1998. p. 62, Figs. 196–197, pl. 21, Figs. 1–7.

L-18.2–23, W-13–16

Lorica elliptic with protruding neck with dentate collar.

410.***Trachelomonas superba*** Svirenko **(Pl. 30, Fig. M)**

Wolowski, 1998. p. 59, Fig. 190.

L-29.6, W-24.5

Lorica elliptical, covered by sharp spines and without collar.

411.***Trachelomonas sculpta*** Balech **(Pl. 30, Fig. N)**

Wolowski and Walne, 2007. p. 417, Fig. 79.

D-14.2

Lorica spherical and smooth.

412.***Trachelomonas volvocina*** (Ehrenberg) Ehrenberg **(Pl. 30, Fig. O)**

Current name: *Trachelomonas cervicula* A. Stokes

Wolowski, 1998. p. 47, Figs. 169–170, pl. 10, Fig. 1–3.

D-13–18

Lorica globular, reddish brown and smooth.

413.***Trachelomonas volvocinopsis*** Svirenko **(Pl. 31, Fig. A)**

Philipose, 1988. p. 329, Figs. 2 a, b.

W-12–13

Lorica round and smooth with several numerous discoid chloroplasts.

414.***Trachelomonas woycickii*** Koczwara **(Pl. 31, Fig. B)**

Wolowski and Walne, 2007. p. 417, Fig. 79.

W-15, SP-1.2–1.5

Lorica globose covered with short spines.

Genus: *Strombomonas* Deflandre

415.***Strombomonas*** sp. 1 **(Pl. 31, Fig. C)**

L-15, W-8

Division: Pyrrhophyta

Class: Dinophyceae

Order: Peridiniales

Family: Peridiniaceae

Genus: *Peridinium* Ehrenberg

416.***Peridinium cinctum*** (O.F. Muller) Ehrenberg **(Pl. 31, Fig. D)**

Prescott, 1982. p. 432, pl. 91, Figs. 1–4.

L-41.4, W-36.6

Cells sub globose with broad, and spiral transverse furrow.

417.***Peridinium inconspicuum*** Lemmermann **(Pl. 31, Fig. E)**

Current name: *Parvodinium inconspicuum* (Lemmermann) Carty

Prescott, 1982. p. 433, pl. 90, Figs. 22–24.

L-19–22.4, W-16.5–18

Cells ovoid with slightly produced apical region and broad and round posterior pole.

Family: Ceratiaceae

Genus: *Ceratium* F. Schrank

418.***Ceratium furcoides*** (Levander) Langhans **(Pl. 31, Fig. F)**

Lewis and Dodge, 2011. p. 262, pl. 67, Fig. b.

L-157.8, W-48

Cells large, with two unequal serrated horns.

Genus: *Triceratium* Ehrenberg

419.***Triceratium*** sp. 1 **(Pl. 31, Fig. G)**

L-24.7, W-28.7

Cells are solitary, flat, triangular, and porous.

Division: Cyanophyta

Class: Cyanophyceae

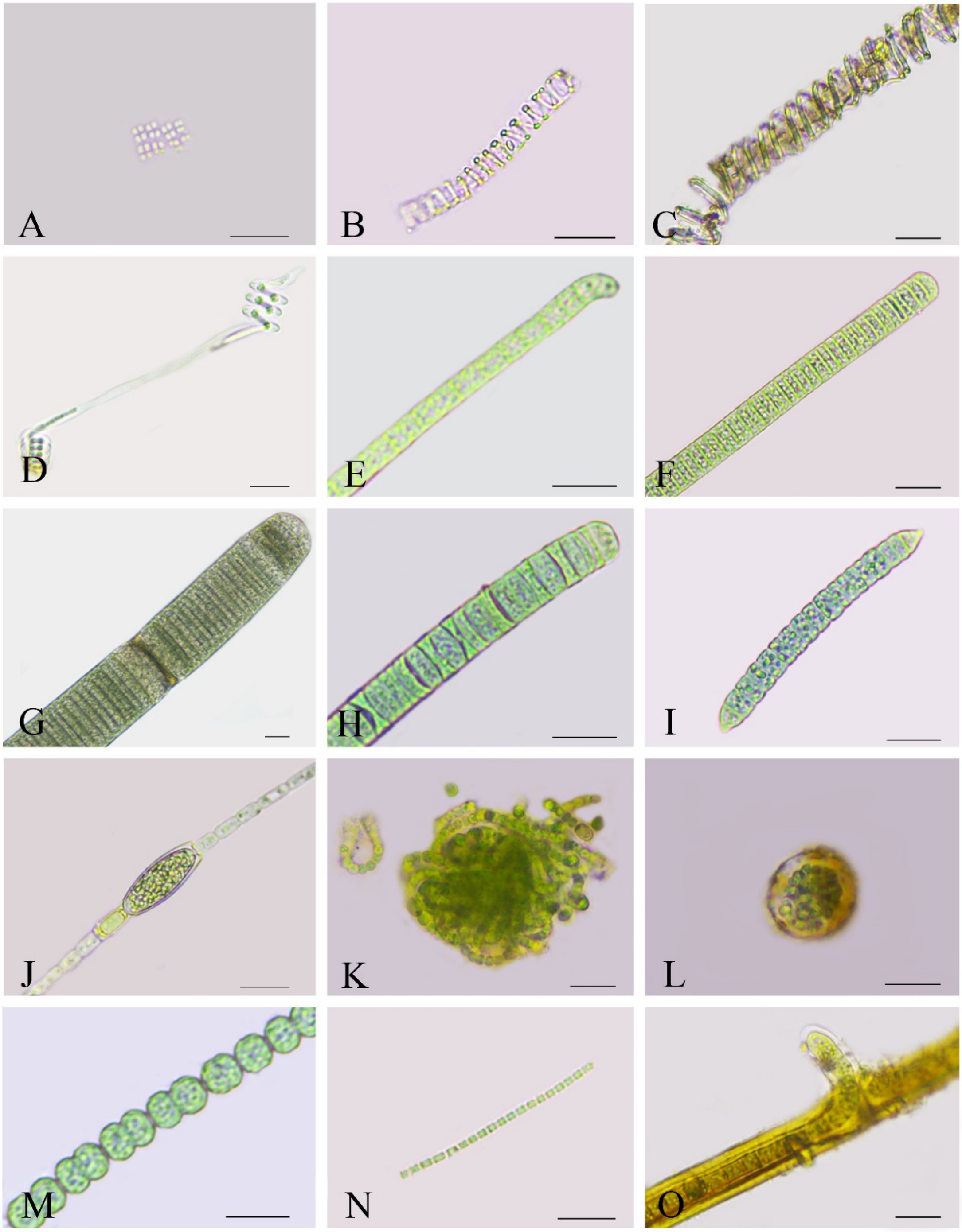
Order: Chroococcales

Family: Chroococcaceae

Genus: *Chroococcus* Nageli

420.***Chroococcus minutus*** (Kutzing) Nageli **(Pl. 31, Fig. H)**

Desikachary, 1959. p. 103, pl. 24, Fig. 4, pl. 26, Figs. 4, 15.



Scale 10µm

PLATE 32 (Figs. A-O): A) *Merismopedia minima* G. Beck **B)** *Spirulina subtilissima* Kutzing ex Gomont **C)** *Spirulina* sp. 1 **D)** *Spirulina* sp. 2 **E)** *Oscillatoria formosa* Bory ex Gomont **F)** *O. limosa* Ag.ex Gomont **G)** *O. princeps* Vaucher ex Gomont **H)** *O. subbrevis* Schmidle **I)** *Oscillatoria* sp. 1 **J)** *Cylindrospermum muscicola* var. *longisporum* Dixit **K)** *Nostoc muscorum* C. Agardh ex Bornet & Flahault **L)** *Nostoc* sp. 1 **M)** *Anabaena* sp. 1 **N)** *Pseudanabaena catenata* Lauterborn **O)** *Scytonema ocellatum* Lyngbye ex Bornet & Flahault

Cell W-4, Colony W-15

Cells light blue-green, spherical with sheath.

421.***Chroococcus turgidus*** (Kutzing) Nageli **(Pl. 31, Fig. I)**

Desikachary, 1959. p. 101, pl. 26, Fig. 6.

Cell D-11.2, Colony W-16

Cells olive green or yellowish, spherical, or ellipsoidal with sheath.

Genus: *Aphanocapsa* Nageli

422.***Aphanocapsa delicatissima*** West & G.S. West **(Pl. 31, Fig. J)**

Prescott, 1982. p. 453, pl. 101, Figs. 8, 9.

Cell L-0.6–1.1, colony W-44.1

Colonies bluish colour, spherical or elliptical, minute in colourless mucilage.

423.***Aphanocapsa elachista*** West & West **(Pl. 31, Fig. K)**

Desikachary, 1959. p. 132, pl. 21, Fig. 5.

W-1.5–1.9, Colony W-86.4

Cells pale blue-green, small, often in pairs, separated in colourless mucilage, colonies spherical or ellipsoid.

424.***Aphanocapsa pulchra*** (Kutzing) Rabenhorst **(Pl. 31, Fig. L)**

Current name: *Microcystis smithii* Komarek & Anagnostidis

Desikachary, 1989. p. 132, pl. 21, Fig. 2.

W-2.5–4

Cells pale blue-green, spherical, and loosely arranged in homogeneous mucilage.

Genus: *Aphanothece* Nageli

425. ***Aphanothece nidulans*** P. Richter **(Pl. 31, Fig. M)**

Desikachary, 1989. p. 138, pl. 22, Fig. 1.

L-2.5–3.2, W-0.9–1.3

Cells short, cylindric, rounded apices distributed in colourless mucilage.

Genus: *Coelosphaerium* Nageli

426. ***Coelosphaerium dubium*** Grunow **(Pl. 31, Fig. N)**

Desikachary, 1989. p. 147, pl. 28, Figs. 10, 11, 14, 15.

Cell W-4–5, Colony W-34

Cells are blue-green, spherical and in a firm colonial mucilage, colony spherical with closely packed cells.

427. ***Coelosphaerium kuetzingianum*** Nageli **(Pl. 31, Fig. O)**

Desikachary, 1989. p. 148, pl. 28, Figs. 7, 8.

W-1.6–2.6, Colony W-18.5

Cells spherical closely or loosely arranged, colony spherical with thin mucilaginous envelope.

Genus: *Merismopedia* Meyen

428. ***Merismopedia minima*** G. Beck **(Pl. 32, Fig. A)**

Desikachary, 1959. p. 154, pl. 29, Fig. 11.

W-0.8–1, Colony W-3

Cells are spherical to oval, grouped as four, arranged as a single plate.

Order: Nostocales

Family: Oscillatoriaceae

Genus: *Spirulina* Turpin ex Gomont

429.***Spirulina subtilissima*** Kutzing ex Gomont **(Pl. 32, Fig. B)**

Desikachary, 1959. p. 196, pl. 36, Fig. 10.

Trichome W-0.5–0.7, distance between spirals-1.5–2.2

Trichomes yellowish green, regularly spirally coiled.

430.***Spirulina*** sp. 1 **(Pl. 32, Fig. C)**

Trichome W-1.5–1.8, distance between spirals-3.5–5.4

431.***Spirulina*** sp. 2 **(Pl. 32, Fig. D)**

Trichome W-1.4–1.7, distance between spirals-2.2–3

Genus: *Oscillatoria* Vaucher ex Gomont

432.***Oscillatoria formosa*** Bory ex Gomont **(Pl. 32, Fig. E)**

Current name: *Kamptonema formosum* (Bory ex Gomont) Strunecky, Komarek & J. Smarda

Desikachary, 1959. p. 232, pl. 40, Fig. 15.

L-2–3.5, W-3.4–4

Trichomes blue-green, straight, slightly attenuated and curved at apex, rounded-conical apical cell.

433.***Oscillatoria limosa*** Ag. ex Gomont **(Pl. 32, Fig. F)**

Desikachary, 1959. p. 206, pl. 42, Fig. 11.

L- 3–3.8, W-10.5–11

Trichome light blue or blue-green, straight, not attenuated at apex, broadly rounded apex.

434.***Oscillatoria princeps*** Vaucher ex Gomont **(Pl. 32, Fig. G)**

Desikachary, 1959. p. 210, pl. 37, Figs. 1, 10, 11, 13, 14.

L-3.2–5, W-31.4–33.2

Trichomes black-green, mostly straight, slightly curved at the end, slightly attenuated at the end, and flatly rounded apex.

435.***Oscillatoria subbrevis*** Schmidle **(Pl. 32, Fig. H)**

Desikachary, 1959. p. 207, pl. 40, Fig. 1; pl. 37, Fig. 2.

L-1–2, W-7.3–9

Trichomes pale green and nearly straight.

436. ***Oscillatoria*** sp. 1 **(Pl. 32, Fig. I)**

L-3–4.1, W-7.4–8.2

Family: Nostocaceae

Genus: *Cylindrospermum* Kutzing ex Bornet & Flahault

437. ***Cylindrospermum muscicola*** var. ***longisporum*** Dixit **(Pl. 32, Fig. J)**

Desikachary, 1959. p. 367, pl. 64, Figs. 2, 10.

Cell L-6.7–8, W-4–4.6

Heteocyst L-11.5, W-6

Akinete L-28.6, W-11.3

Cells are elongated, heterocyst is common at the end of each trichome.

Genus: *Nostoc* Vaucher ex Bornet & Flahault

438. ***Nostoc muscorum*** C. Agardh ex Bornet & Flahault **(Pl. 32, Fig. K)**

Current name: *Desmonostoc muscorum* (Bornet & Flahault) Hrouzek & Ventura

Desikachary, 1959. p. 385, pl. 70, Fig. 2.

Cell L-2.2–2.8, W-3–3.3

Akinete L-6, W-3

Cells blue-green, spherical, barrel shape, first globose, gelatinous. Heterocyst spherical to barrel shaped. Filaments are densely entangled.

439.***Nostoc*** sp. 1 **(Pl. 32, Fig. L)**

L-2–3, W-2.2–2.6

Cells blue-green and oval. Filaments are enclosed in a firm circular sheath.

Genus: *Anabaena* Bory ex Bornet & Flahault

440.***Anabaena*** sp. 1 **(Pl. 32, Fig. M)**

L-6–6.2, W-6.7–6.8

Cells pale blue-green, barrel-shaped. Filaments solitary, trichomes moniliform.

Genus: *Pseudanabaena* Lauterborn

441. ***Pseudanabaena catenata*** Lauterborn **(Pl. 32, Fig. N)**

Desikachary, 1959. p. 419.

L-2, W-1.5

Apical cell L-2.5, W-1.5

Cells cylindrical, truncated at ends.

Genus: *Scytonema* C. Agardh ex E. Bornet & C. Flahault

442. ***Scytonema ocellatum*** Lyngbye ex Bornet & Flahault **(Pl. 32, Fig. O)**

Desikachary 1959, p. 467, pl. 92, Fig. 3

Trichome L-7.8–8.6, W-10–14.4, sheath W-3–3.3, heterocyst W-6.6–9

Cells shorter than broad or sometimes quadrate, heterocyst flat, subquadrate and rounded if deformed. Blue-green trichome, false branched, with yellow to brown colour sheath, colourless in young filament.

4.1.2 New records from the study

From the study, 12 new reports to India and 119 new reports to Kerala were recorded and are listed below.

4.1.2.1 New reports to India

1) *Cosmarium mansangense* West & G.S. West
2) *Cosmarium moniliforme* var. *punctatum* Lagerheim
3) *Cosmarium regnesi* var. *montanum* Schmidle

4) *Cosmarium zonatum* P. Lundell
5) *Elakatothrix lacustris* Korshikov
6) *Euastrum distortum* A.M. Scott & Prescott
7) *Nephrocytium allantoideum* Bohlin
8) *Pinnularia subcapitata* var. *subrostrata* Krammer
9) *Pleurotaenium trabecula* f. *clavatum* (Kutzing ex Ralfs) Reinsch
10) *Scenedesmus arthrodesmiformis* Schroder
11) *Staurastrum heimerlianum* var. *sumatranum* A.M. Scott & Prescott
12) *Staurastrum tohopekaligense* f. *acuminatum* A.M. Scott & Prescott

4.1.2.2 New reports to Kerala

1) *Achnanthes crenulata* Grunow
2) *Achnanthes elata* (Leuduger-Fortmorel) H.P. Gandhi
3) *Achnanthes lanceolata* var. *elliptica* Cleve
4) *Achnanthes lanceolata* var. *rostrata* Hustedt
5) *Actinastrum aciculare* f. *minimum* (Huber-Pestalozzi) Compere
6) *Actinotaenium cucurbitinum* (Bisset) Teiling
7) *Closterium abruptum* West
8) *Closterium infractum* Messikommer
9) *Closterium parvulum* var. *angustum* West & G.S. West
10) *Closterium porrectum var. angustatum* West & G.S. West
11) *Closterium submoniliferum* var. *malinvernianum* (De Notaris) Coesel
12) *Closterium ulna* Focke ex W.B. Turner
13) *Closterium archerianum* Cleve ex P. Lundell
14) *Closterium juncidum* Ralfs
15) *Coenocystis subcylindrica* Korshikov
16) *Cosmarium bioculatum* f. *depressum* Schaarschmidt
17) *Cosmarium difficile* Lutkemuller
18) *Cosmarium globosum* f. *minus* Boldt
19) *Cosmarium inornatum* Joshua
20) *Cosmarium norimbergense* Reinsch
21) *Cosmarium ocellatum* Eichler & Gutwinski
22) *Cosmarium ordinatum* (Borgesen) West & G.S. West

23) *Cosmarium phaseolus* var. *elevatum* Nordstedt

24) *Cosmarium pseudamoenum* Wille

25) *Cosmarium pseudoconnatum* var. *ellipsoideum* West & G.S. West

26) *Cosmarium pseudoprotuberans* O. Kirchner

27) *Cosmarium reniforme* var. *elevatum* West & G.S. West

28) *Cosmarium subturgidum* f. *minus* Schmidle

29) *Cosmarium tenue* W. Archer

30) *Cymbella gracilis* (Rabenhorst) Cleve

31) *Cymbella pseudocuspidata* H.P.Gandhi

32) *Cymbella pusilla* Grunow

33) *Cymbella tumidula* Grunow

34) *Cymbella turgidula* Grunow

35) *Cymbella ventricosa* var. *arcuata* Skvortzov

36) *Epithemia argus* (Ehrenberg) Kutzing

37) *Euastrum luetkemuelleri* F. Ducellier

38) *Euastrum validum* West & G.S. West

39) *Euglena ehrenbergii* G.A. Klebs

40) *Euglena oxyuris* var. *major* Woronichin

41) *Eunotia alpina* (Nageli) Hustedt

42) *Eunotia pectinalis* var. *ventralis* (Ehrenberg) Hustedt

43) *Eunotia zygodon* Ehrenberg

44) *Eutetramorus planctonicus* (Korshikov) Bourrelly

45) *Eutetramorus polycoccus* (Korshikov) Komarek

46) *Frustulia krammeri* Lange-Bertalot & Metzeltin

47) *Gloeocystis planctonica* (West & G.S. West) Lemmermann

48) *Gomphonema abbreviatum* C. Agardh

49) *Gomphonema gracile* var. *auritum* (A. Braun ex Kutzing) Van Heurck

50) *Gomphonema gracile* var. *naviculoides* (W. Smith) Grunow

51) *Gomphonema hebridense* W. Gregory

52) *Gomphonema intricatum* var. *fossile* Pantocsek

53) *Gomphonema intricatum* var. *pumilum* Grunow

54) *Gomphonema lacus-rankala* H.P. Gandhi

55) *Gomphonema spicula* H.P. Gandhi

56) *Gonatozygon brebissonii* De Bary

57) *Lepocinclis constricta* Matvienko
58) *Navicula anglica* Ralfs
59) *Navicula cincta* var. *heufleri* (Grunow) Grunow
60) *Navicula cryptocephala* var. *exilis* Grunow
61) *Navicula densistriata* Hustedt
62) *Navicula disjuncta* Hustedt
63) *Navicula feuerbornii* f. *minor* Cholnoky
64) *Navicula halophila* f. *robusta* Hustedt
65) *Navicula pygmaea* var. *indica* Skvortzov
66) *Navicula radiosa* var. *minutissima* (Grunow) Cleve
67) *Navicula radiosa* var. *tenella* (Brebisson ex Kutzing) Van Heurck
68) *Navicula rhynchocephala* var. *tenua* Skvortzov
69) *Navicula salinarum* var. *intermedia* (Grunow) Cleve
70) *Navicula viriduloides* var. *lanceolata* H.P. Gandhi
71) *Neidium capitellatum* H.P. Gandhi
72) *Neidium dubium* (Ehenberg) Cleve
73) *Neidium globiceps* var. *biglobosum* A. Cleve
74) *Neidium gracile* Hustedt
75) *Neidium grande* H.P. Gandhi
76) *Neidium iridis* f. *dhulense* Sarode & N.D. Kamat
77) *Neidium longiceps* (W. Gregory) R. Ross
78) *Neidium longiceps* var. undulatum A. Cleve
79) *Neidium pseudogracile* Kobayasi
80) *Nitzschia heufleriana* Grunow
81) *Nitzschia lorenziana* var. *subtilis* Grunow
82) *Nitzschia thermalis* var. *minor* Hilse
83) *Nitzschia tryblionella* var. *victoriae* (Grunow) Grunow
84) *Pinnularia acrosphaeria* f. *undulata* (Cleve) Hustedt
85) *Pinnularia braunii* f. *subconica* G.S. Venkataraman
86) *Pinnularia brebissonii* var. *hybrida* (Grunow) A. Cleve
87) *Pinnularia graciloides* Hustedt
88) *Pinnularia interrupta* f. *minutissima* (Hustedt) Hustedt
89) *Pinnularia neglecta* (Ant. Mayer) Berg
90) *Pinnularia neomajor* var. *inflata* Krammer

91) *Pinnularia pseudoluculenta* H.P. Gandhi
92) *Pinnularia subgibba* var. *undulata* Krammer
93) *Pinnularia viridis* var. *intermedia* Cleve
94) *Sorastrum americanum* (Bohlin) Schmidle
95) *Sphaerozosma excavatum* Ralfs ex Ralfs
96) *Spirulina subtilissima* Kutzing ex Gomont
97) *Staurastrum cerastes* var. *pulchrum* A.M. Scott & Gronblad
98) *Staurastrum freemanii* var. *nudiceps* A.M. Scott & Prescott
99) *Staurastrum indentatum* f. *minus* A.M. Scott & Prescott
100) *Staurastrum limneticum* var. *burmense* West & G.S.West
101) *Staurastrum multispiniceps* A.M. Scott & Prescott
102) *Staurastrum orbiculare* var. *minus* Prescott
103) *Staurastrum teliferum* var. *gladiosum* (W.B. Turner) Coesel & Meesters
104) *Staurodesmus mucronatus* var. *subtriangularis* (West & G.S. West) Croasdale
105) *Stauroneis obtusa* var. *nagpurensis* P.T. Sarode & N.D. Kamat
106) *Surirella linearis* W. Smith
107) *Surirella ovata* var. *salina* (W. Smith) Rabenhorst
108) *Surirella subsalsa* W. Smith
109) *Synedra acus* f. *radians* (Kutzing) Hustedt
110) *Synedra acus* var. *acula* (Kutzing) Grunow
111) *Synedra ulna* var. *aequalis* (Kutzing) Brun
112) *Synedra ulna* var. *danica* (Kutzing) Van Heurck
113) *Tetraedron victoriae* Woloszynska
114) *Trachelomonas curta* A.M. Cunha
115) *Trachelomonas sculpta* Balech
116) *Trachelomonas woycickii* Koczwara
117) *Trochiscia granulata* (Reinsch) Hansgirg
118) *Triplastrum abbreviatum* (W.B. Turner) M.O.P. Iyengar & Ramanathan
119) *Xanthidium ceylanicum* West & G.S. West

4.2 Ecological studies

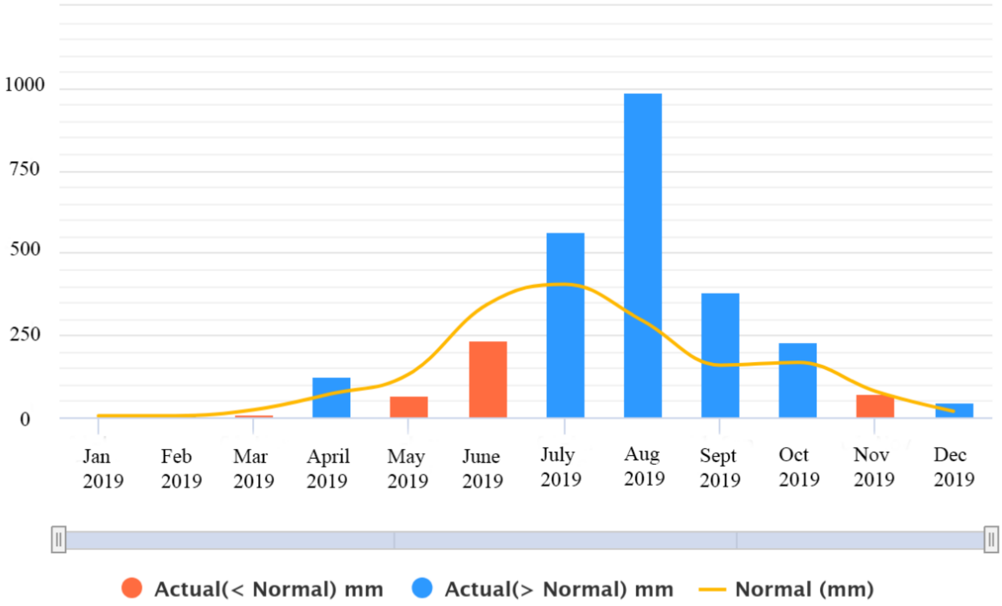
4.2.1 Physicochemical parameter analysis

Selected eight physicochemical parameters (temperature, pH, total dissolved solids, electrical conductivity, dissolved oxygen, nitrate, phosphate, and silicate) were tested on six sites in three different seasons from 2019–2021 (Appendix 3). The collection sites include Pookode Lake (S1), Banasurasagar Dam (S2), Kuruva Islands (S3), Heart Lake (S4), Karapuzha Dam (S5) and Papanasini River (S6). From the recorded values, the mean and standard deviation are calculated and given in the table (Appendix 3). The range of each parameter in different seasons and study sites was demonstrated in graphs. The parameters were checked for normality using the One-Sample Kolmogorov-Smirnov Test. If found normal, One-way ANOVA using Microsoft Excel at 5% level to verify whether the seasonal and spatial variation of the parameters is significant (Appendix 4–19).

4.2.1.1 Meteorological data

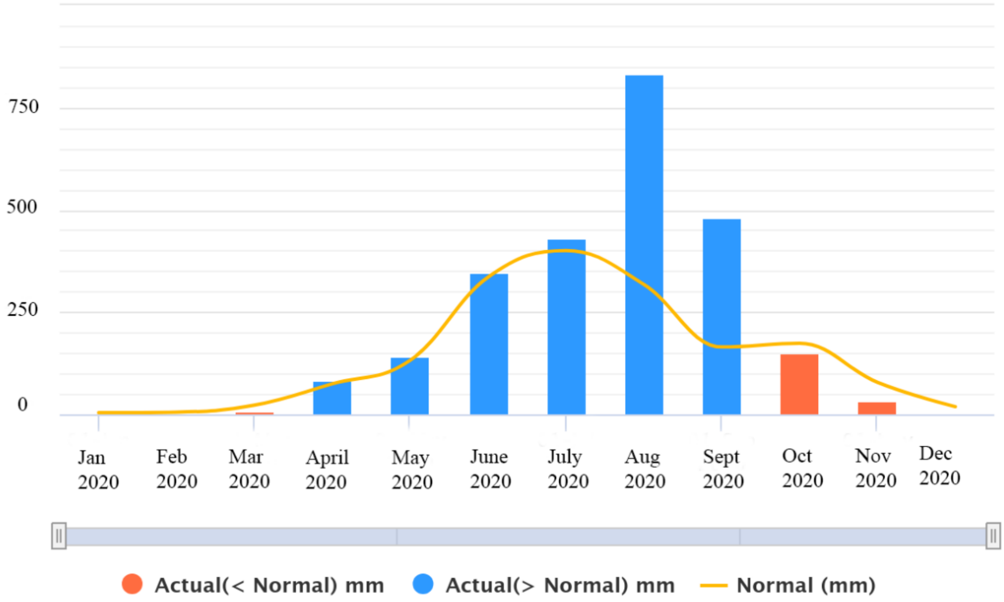
4.2.1.1.1 Rainfall

Wayanad experiences drastic climate change and rainfall patterns. The seasonal variation of parameters can be accurately explained with the rainfall data. The rainfall data is retrieved from the Kerala Water Resource Information System (KWRIS). The study period is from April 2019 to March 2021. The monthly rainfall trend in 2019, 2020 and 2021 at Wayanad is depicted in figure 2, figure 3 and figure 4 respectively. The graphs also show the normal rainfall pattern and the deviation of the current rainfall data from the expected trend. From figure 2, Wayanad received more than normal rainfall in April, July, August, September, October and December 2019. In 2019, rainfall is deficient in the months of March, May, June and November. In 2020, excess rainfall is obtained in the months of April to September while rainfall is deficient in October to December (Figure 3). In 2021, only March is rainfall deficient, and all other months have excess rainfall (Figure 4).



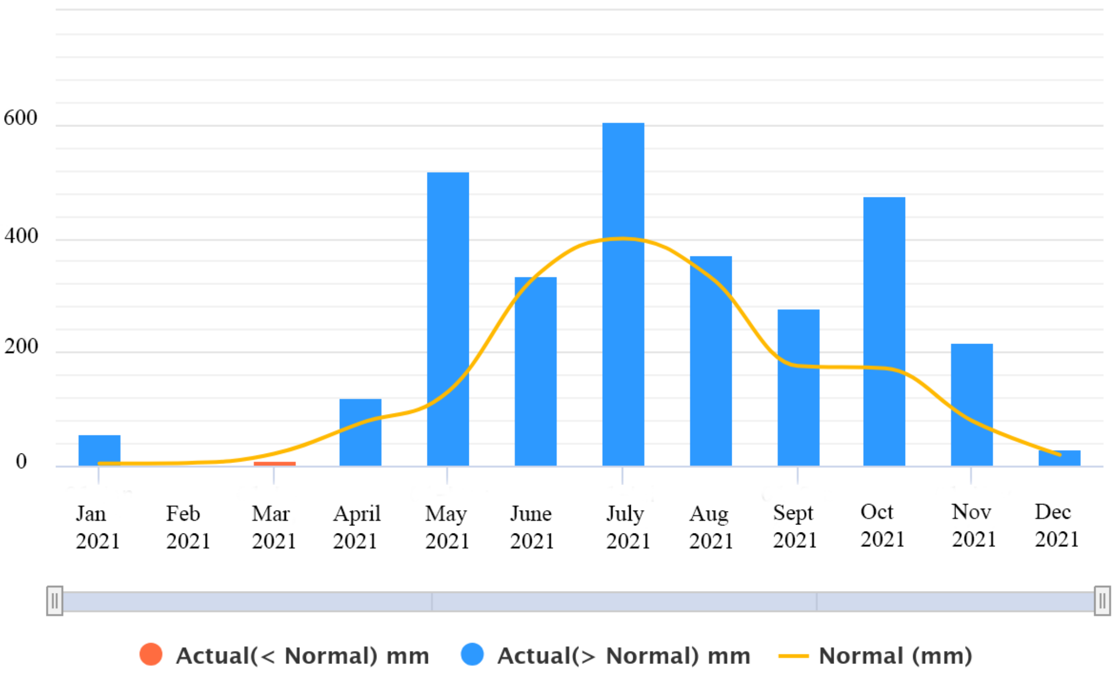
Source: KeralaWRIS

Figure 2. Graph showing monthly rainfall of Wayanad district in the year 2019



Source: KeralaWRIS

Figure 3. Graph showing monthly rainfall of Wayanad district in the year 2020



Source: KeralaWRIS

Figure 4. Graph showing monthly rainfall of Wayanad district in the year 2021

Pearson’s coefficient of correlation is performed at a 5% level to find the correlation between parameters (Appendix 20) and a correlation plot is prepared (Figure 5). The boxed circles in the plot are the ones with significant correlation. Temperature shows positive correlations with pH, TDS, nitrate and silicate and a significant positive correlation with EC. pH is positively correlated with temperature, nitrate, and phosphate while negatively correlated with TDS. TDS is positively correlated with temperature, nitrate, and phosphate and negatively correlated with pH. TDS is significantly correlated positively with EC and silicate. EC is positively correlated with nitrate and phosphate and significantly with temperature, TDS and silicate. DO shows positive correlations with nitrate and silicate and a negative correlation with phosphate. Nitrate shows positive correlations with all parameters. Phosphate shows positive correlations with every parameter except DO. Phosphate does not correlate with temperature. Silicate is positively correlated with temperature, DO, nitrate and phosphate and significantly correlated positively with TDS and EC.

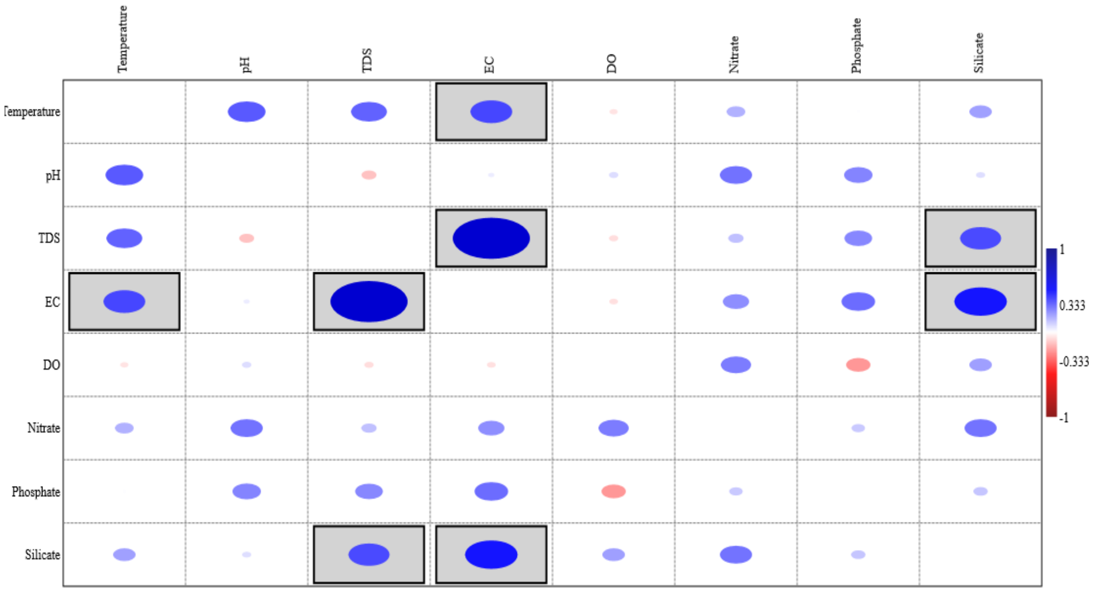


Figure 5. Correlation plot showing relationship between parameters analysed from the study area

4.2.1.2 Temperature

Temperature ranges from 22.8 to 33.33˚C in the study area. Seasonal variation and spatial variation in the range of temperature are analysed in Figure 6 and Figure 7 respectively. Season-wise, MO2 has the lowest mean temperature and PRE2 has the highest mean temperature. Site-wise, S1 has the lowest mean temperature and S4 has the highest. Seasonal and spatial variations of temperature in each site of the study area in two years are given in Figure 8. Mean temperature is minimum at PO2 of S6 (22.8 ±0.17) and maximum at PO2 of S4 (33.33 ±0.57). One-way ANOVA is performed at a 5% level, and both seasonal and spatial variations are found significant ($p < 0.05$). The Pearson's coefficient of correlation is performed with other parameters at a 5% level. Temperature shows a significant positive correlation with EC (Figure 5).

In S1, PRE2 has the highest temperature and PO2 has the lowest. Temperature is high in pre-monsoon, drops in monsoon and drops slightly in post-monsoon. In S2, PRE2 has the highest and MO2 has the lowest temperature. The same trend of temperature decline of S1 is here in the first year. In the second year, the temperature drop of monsoon gets back after post-monsoon. In S3, PRE1 has the highest and PO2 has the lowest temperature. The temperature decreased in monsoon gets elevated in the post-monsoon of the first year, but temperature declines along the seasons in the second year. In S4, PO2 have the highest and MO1 has the lowest temperature. Both years have temperatures that declined in monsoon and went on an increase in post-monsoon. In S5, the highest temperature is at PO2 and MO1 has the lowest. Temperature drops at monsoon increased more than pre-monsoon in post-monsoon of both years. In S6, MO1 has the highest and PO2 has the lowest temperature. The first year shows a different trend, the temperature of monsoon is higher than pre-monsoon and this increased temperature stays the same in post-monsoon also. In the second year, the temperature drops during the monsoon and lowers again in post-monsoon.

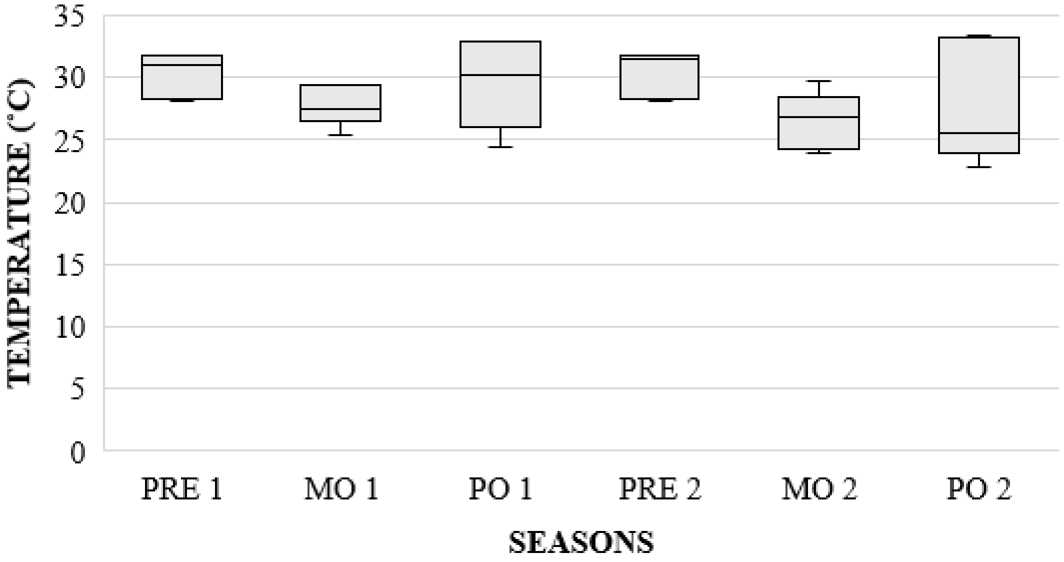


Figure 6. Graph showing seasonal variation in the range of temperature in the study area

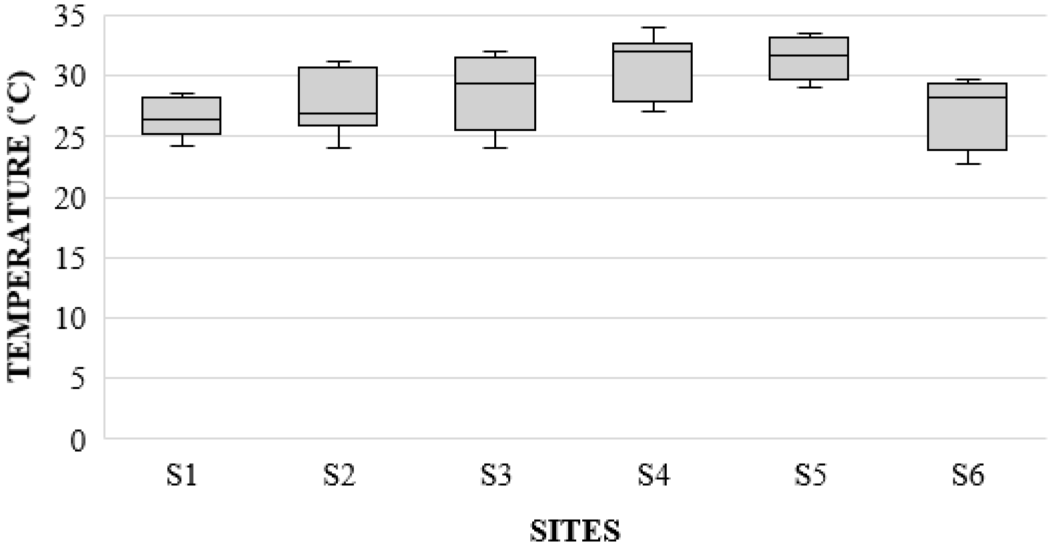


Figure 7. Graph showing spatial variation in the range of temperature in the study area

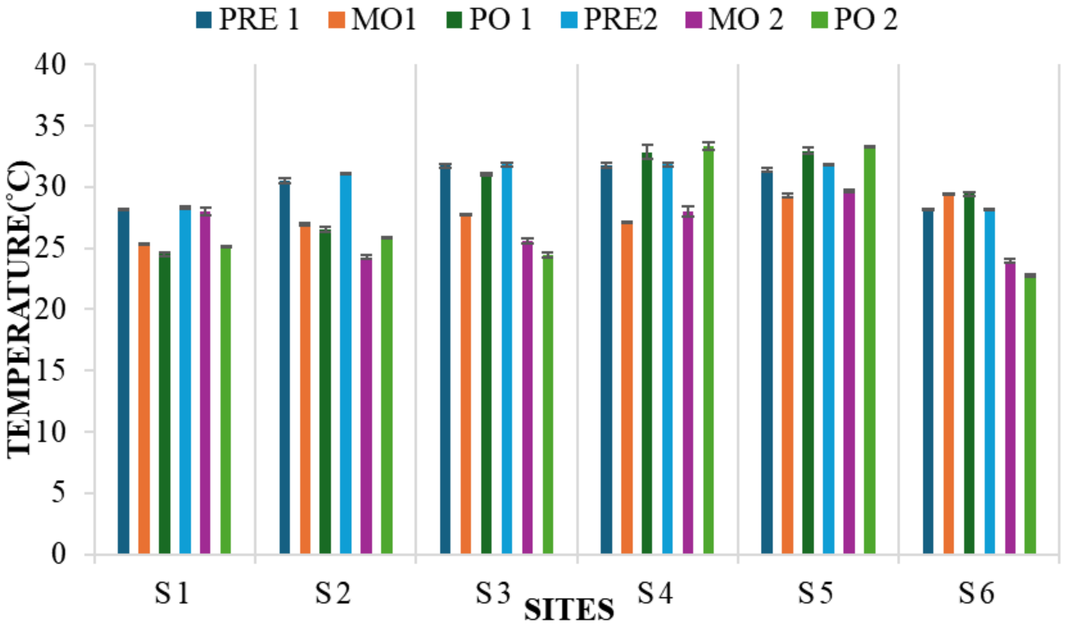


Figure 8. Graph showing seasonal and spatial variation of temperature in study sites

4.2.1.3 pH

pH ranges from 6.13 to 9.53 in the study area. Seasonal variation and spatial variation in the range of pH are depicted in Figure 9 and Figure 10 respectively. Season-wise, MO2 has the lowest mean pH and PRE1 has the highest mean pH. Site-wise, S5 have the lowest and S4 has the highest mean pH value. Seasonal and spatial variations of pH in each site of the study area in two years are given in Figure 11. Mean pH is minimum at MO2 of S1(6.13 ±0.20) and maximum at PO1 of S4(9.53 ±0.15). ANOVA for seasonal variation of the parameter is found significant ($p < 0.05$) and site-wise variation is observed insignificant ($p \geq 0.05$).

In S1, the highest pH is in PRE1 and the lowest in MO2. pH drops in monsoon and remains the same in post-monsoon. But in the second year, post-monsoon regains pH drop in monsoon. In S2, MO1 has the highest pH and lowest in PO2. pH elevates slightly in monsoon and then drops in post-monsoon in the first year. In the second year, pH drops in monsoon and stays the same in post-monsoon. In S3, PRE1 shows the highest and PO2 shows the lowest value. pH drops in monsoon and reduces again in post-monsoon. In S4, PO1 have the highest and MO2 has the lowest. pH increases in monsoon, and it again increases in post-monsoon. In the second year, pH slightly decreases in monsoon but elevates in post-monsoon with pH more than in pre-monsoon. In S5, the highest value is in PRE1 and the lowest in PRE2. pH reduces in monsoon which again reduces in post-monsoon. In the second year, pH slightly increases in monsoon and elevates in post-monsoon more than that in pre-monsoon. In S6, pH is high in PRE1 and low in MO2. Post-monsoon gains back the pH drop of monsoon.

The Pearson's coefficient of correlation shows no significant correlation (Figure 5). The pH in MO2 (6.13 ±0.20) of S1 has an acidic nature beyond permissible limits. The pH noted in PO1 of S4 (9.53 ±0.15), PRE1 (9.13 ±0.25) and MO1 (8.86 ±0.05) of S5 tend to have an alkaline nature beyond the permissible limit of WHO (1999).

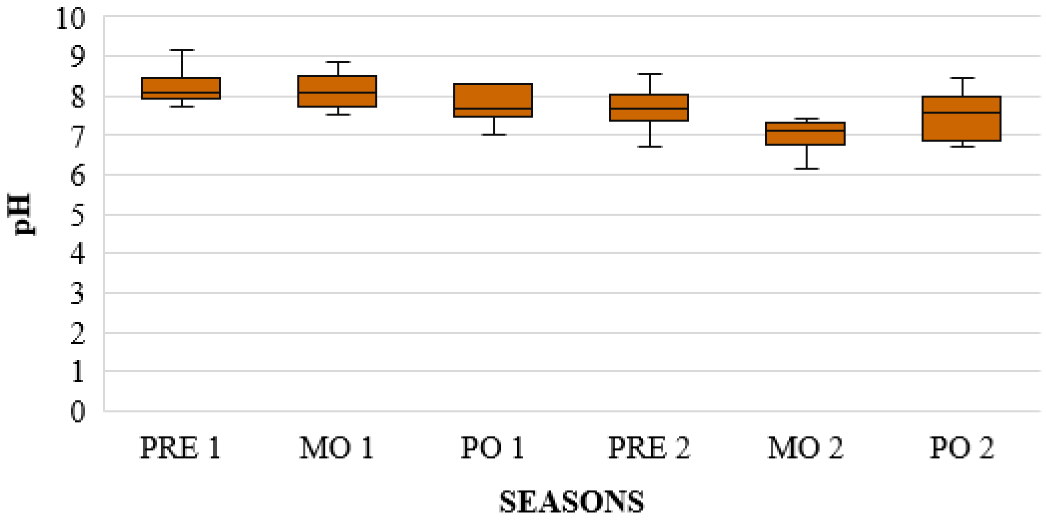


Figure 9. Graph showing seasonal variation in the range of pH in the study area

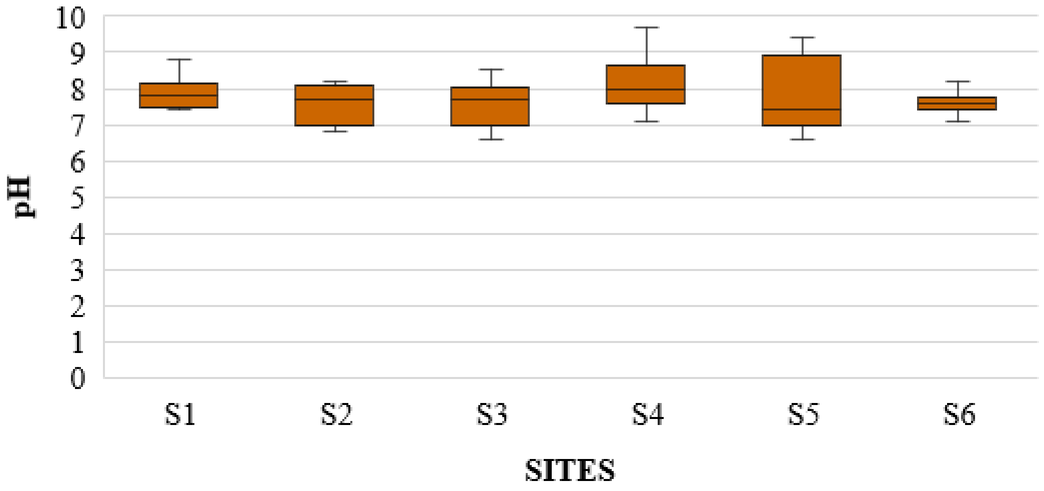


Figure 10. Graph showing spatial variation in the range of pH in the study area

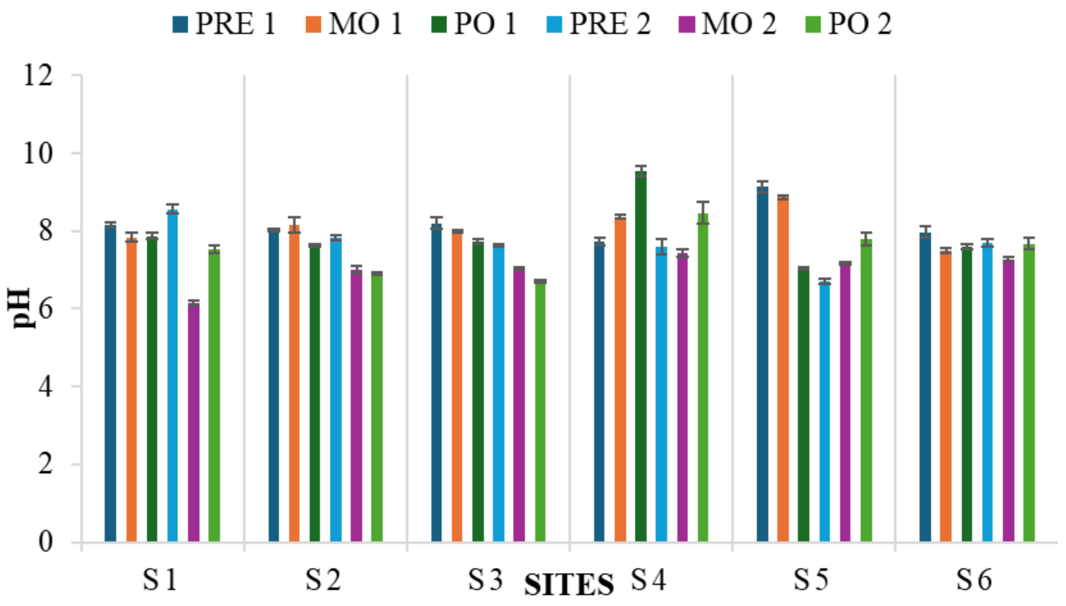


Figure 11. Graph showing the seasonal and spatial variation of pH in study sites

4.2.1.4 Total Dissolved Solids (TDS)

The TDS of the study area ranges from 5.6 ppm to 100 ppm. The variation in the range of TDS is depicted seasonally in Figure 12 and spatially in Figure 13. Seasonally, the mean TDS have the lowest value in PO2 and highest in MO1. Monsoon seasons increase TDS value in both years. Spatially, the mean TDS is lowest in S4 and highest in S3. Seasonal and spatial variations of TDS in each site of the study area in two years are given in Figure 14. TDS is minimum at PO2 of S2 (5.6 ±0.36) and maximum at PRE2 of S3 (100 ±1). One-way ANOVA is performed at a 5% level and shows significant variation across sites ($p < 0.05$). But no significant variation across seasons ($p > 0.05$) in sites.

In S1, the highest TDS is in MO2 and the lowest is in PO2. TDS levels slightly decrease in monsoon and then in post-monsoon. In the second year, TDS levels rise in monsoon and get reduced in post-monsoon. In S2, the highest is in PRE2 and the lowest is in PO2. The level of TDS is almost the same in monsoon, and it slightly decreases in post-monsoon. In the second year, the levels reduce in monsoon and get further reduced in post-monsoon. In S3, the highest is in PRE2 and the lowest is in MO2. TDS remains the same in monsoon and then reduced in post-monsoon. In the second year, TDS reduced in monsoon gets increased in post-monsoon. In S4, the highest is in MO2 and the lowest is in PO1. TDS slightly increase in monsoon and decreases in post-monsoon. Next year, the monsoon causes a slight increase in TDS which gets reduced in post-monsoon. In S5, the highest is in PRE2 and the lowest is in PO1. TDS levels slightly increase in monsoon and decrease in post-monsoon. The second year shows a decrease in monsoon and then an increase in post-monsoon. In S6, the highest is in MO1 and the lowest is in PO2. TDS elevate in monsoon and then decrease in post-monsoon. Next year, TDS slightly decrease in monsoon and post-monsoon. Pearson's coefficient of correlation with other parameters is analysed at a 5% level. A significant positive correlation with EC and silicate is observed (Figure 5). All values of TDS are within permissible limits prescribed by WHO (1999).

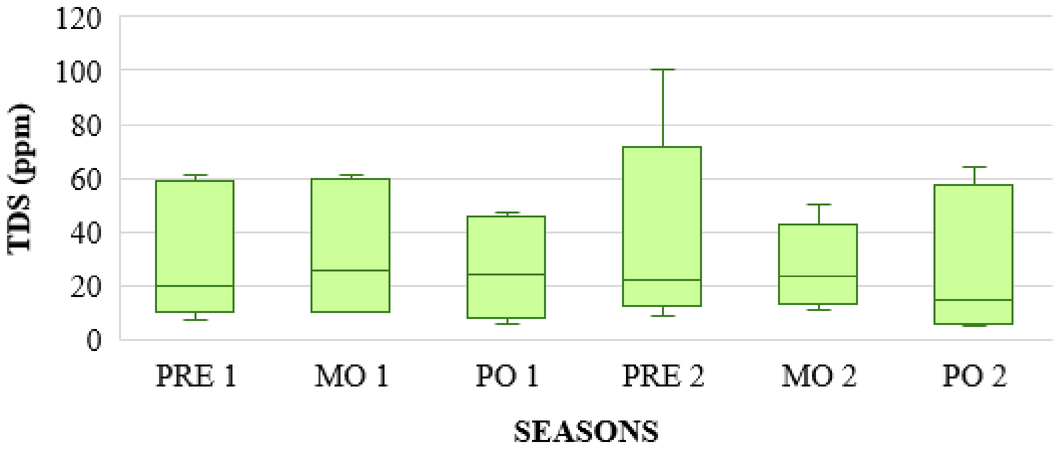


Figure 12. Graph showing seasonal variation in the range of TDS in the study area

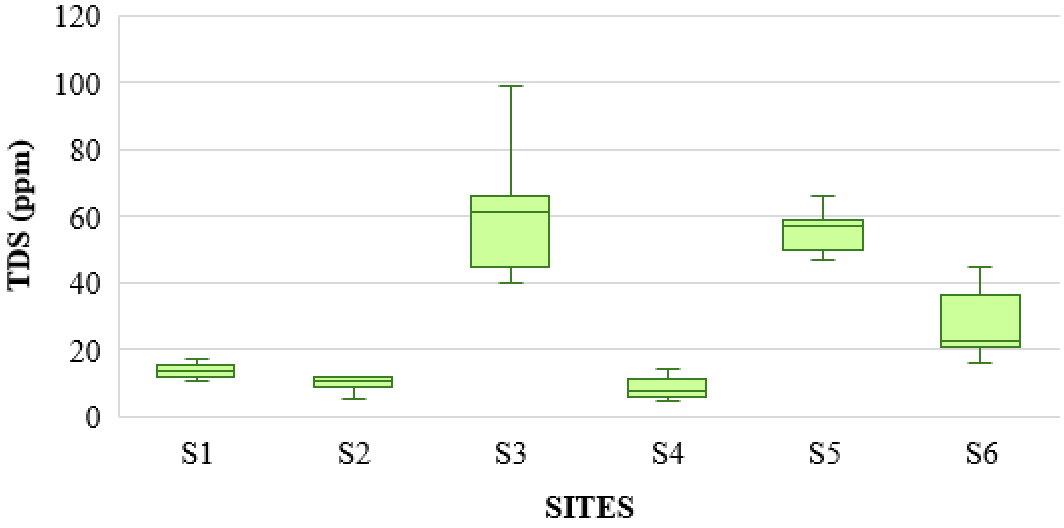


Figure 13. Graph showing spatial variation in the range of TDS in the study area

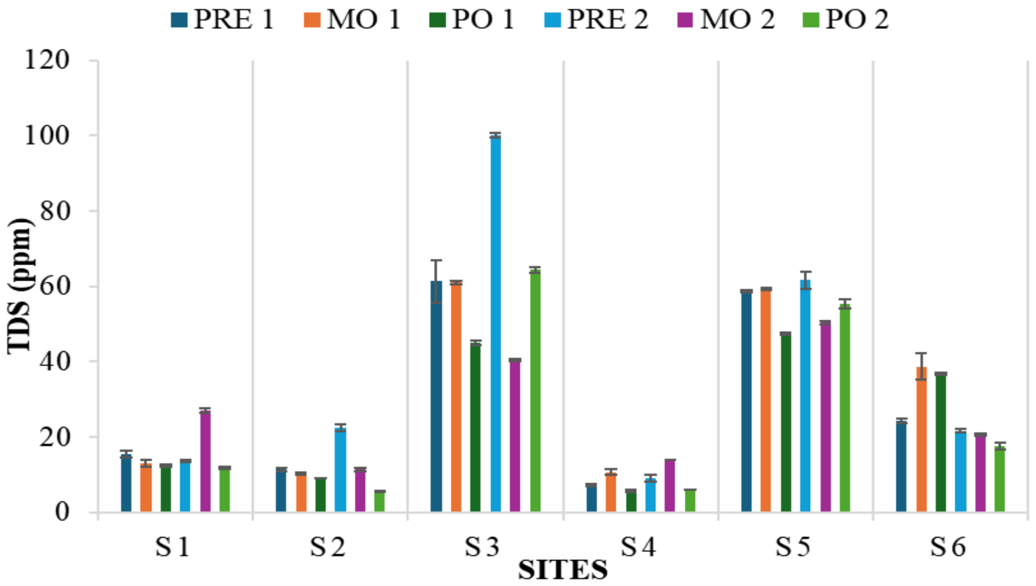


Figure 14. Graph showing the seasonal and spatial variation of TDS in study sites

4.2.1.5 Electrical Conductivity (EC)

Electrical Conductivity ranges between 6.66 µmho/cm and 135.66 µmho/cm. The range of EC across seasons (figure 15) and across sites (figure 16) is represented. Seasonally, EC has the lowest mean value in MO1 and the highest in PRE1. Spatially, S4 has the lowest mean EC and S5 has the highest. Seasonal and spatial variations of EC in each site of the study area in two years are given in Figure 17. EC is minimum at MO2 of S4 (6.66 ±0.57) and maximum at first PRE1 of S3 (135.66 ±8.50). One-way ANOVA reveals the spatial variation of the parameter is significant ($p < 0.05$) and seasonal variation is insignificant.

In S1, PRE1 has the highest and MO2 has the lowest value. The EC values slightly drop in monsoon and again drop in post-monsoon of the first year. In the second year, the drop in monsoon is regained by post-monsoon. In S2, PRE1 have a high value and PRE2 have the lowest value. The drop in monsoon is followed by post-monsoon too. But in the second year, EC elevates in monsoon with a decrease in post-monsoon. In S3, the highest value is in PRE1 and the lowest in MO1. There is a sudden decline in EC during monsoon which tries to regain in post-monsoon. But in the second year, the EC increases in monsoon and then decreases post-monsoon. In S4, the highest value is at MO1 and the lowest is at MO2. In the first year, EC rises in monsoon and then decreases in post-monsoon. In the second year, EC drops in monsoon and increases in post-monsoon. In S5, PRE2 has the highest and PO1 has the lowest EC. EC has a slight increase in monsoon and a drop in post-monsoon. In the next year, the drop is in monsoon which causes an increase in post-monsoon. The high value of EC is at MO1 and lowest at PO2 in S6. There is a slight increase in monsoon and a slight decrease in post-monsoon. Almost the same EC is maintained in the year. In the next year, EC slightly decreased in monsoon and post-monsoon. Pearson's coefficient of correlation with other parameters is analysed at a 5% level. A significant positive correlation with temperature, TDS and silicate is noted (Figure 5).

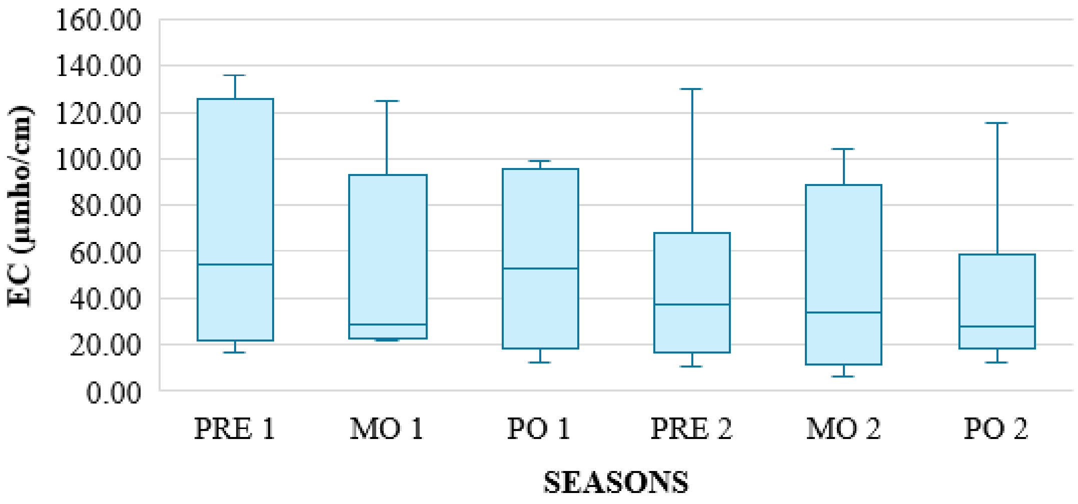


Figure 15. Graph showing seasonal variation in the range of EC in the study area

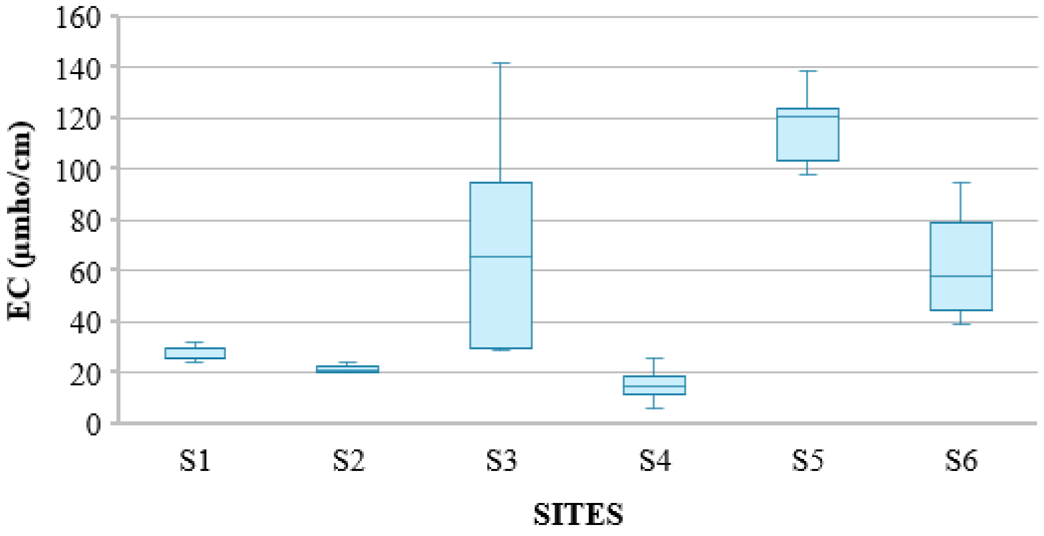


Figure 16. Graph showing spatial variation in the range of EC in the study area

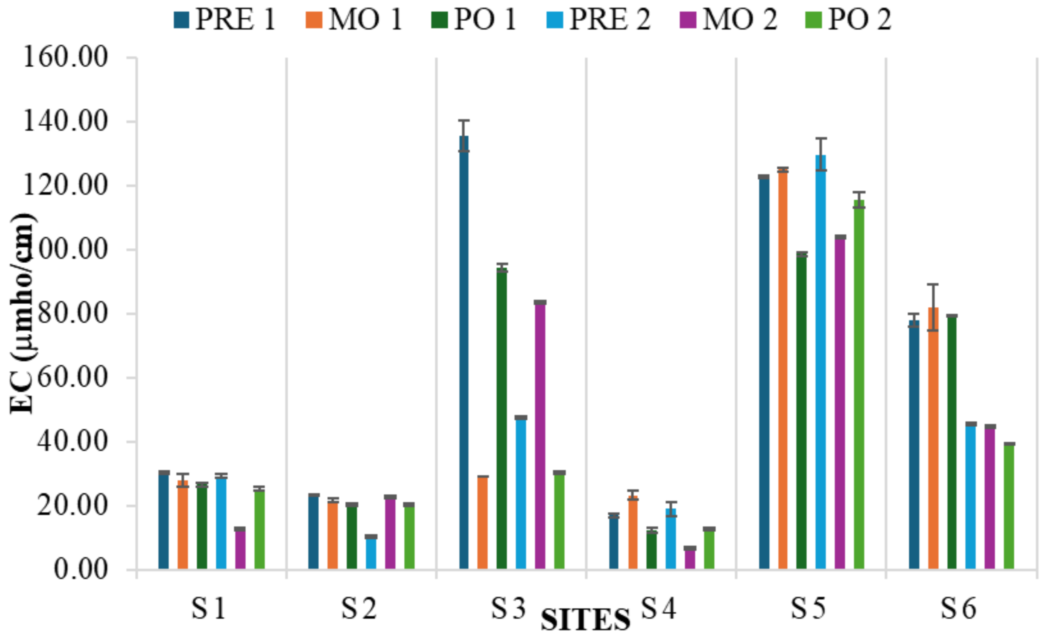


Figure 17. Graph showing the seasonal and spatial variation of EC in study sites

4.2.1.6 Dissolved oxygen (DO)

The study area has dissolved oxygen ranges between 3.8 mg/L and 7.5 mg/L. The range of DO across seasons and sites is represented in figure 18 and 19 respectively. Seasonally, PRE1 has the lowest and PO2 has the highest value of mean DO. Spatially, DO has a minimum mean value in S5 and a maximum in S6. Seasonal and spatial variations of DO in each site of the study area in two years are given in Figure 20. Dissolved oxygen is minimum at PRE2 of S5 (3.8 ±0.1) and maximum at PRE1 of S6 (7.5 ±0.2). One-way ANOVA is performed at a 5% level stating significant variation across all sites ($p < 0.05$) and no significant variation across seasons ($p > 0.05$).

In S1, PO2 have the highest and MO1 has the lowest DO. DO drops in monsoon and rises in post-monsoon. In the second year also, the same pattern was observed. In S2, PRE 1 have the highest and PO1 has the lowest DO levels. DO drops in monsoon and then again drops in post-monsoon. In the second year, DO rises in monsoon and declines in post-monsoon. In S3, PO have the highest and MO1 has the lowest DO levels. Here DO drops in monsoon and gains in post-monsoon. DO increases slightly in the monsoon and declines in post-monsoon in the second year. In S4, the highest DO value is at PO2 and the lowest is at PRE1. Here monsoon has a high DO value in the first year with a drop in pre-monsoon and post-monsoon season. But in the second year, a contrast pattern is seen. In monsoon, a drop in DO is observed which increases in post-monsoon. In S5, PO1 have the highest and PRE2 have the lowest DO levels. DO increases in monsoon and further increases in post-monsoon. The same pattern is seen in the second year too. In S6, PRE 1 have the highest and PO1 has the lowest DO values. Pearson's coefficient of correlation with other parameters is analysed 5% level. DO has no significant correlation with any of the selected parameters (Figure 5). DO values are below the permissible limit in S1 except in PRE2 and PO2 seasons. In S2, only PRE1 and MO2 have permissible DO. In S3, MO1 and PO2 have low DO. In S4, PRE1, PO1 and MO2 have low DO. Only PO1 and PO2 of S5 have DO within limits in S5. In S6, only PO1 have a low DO.

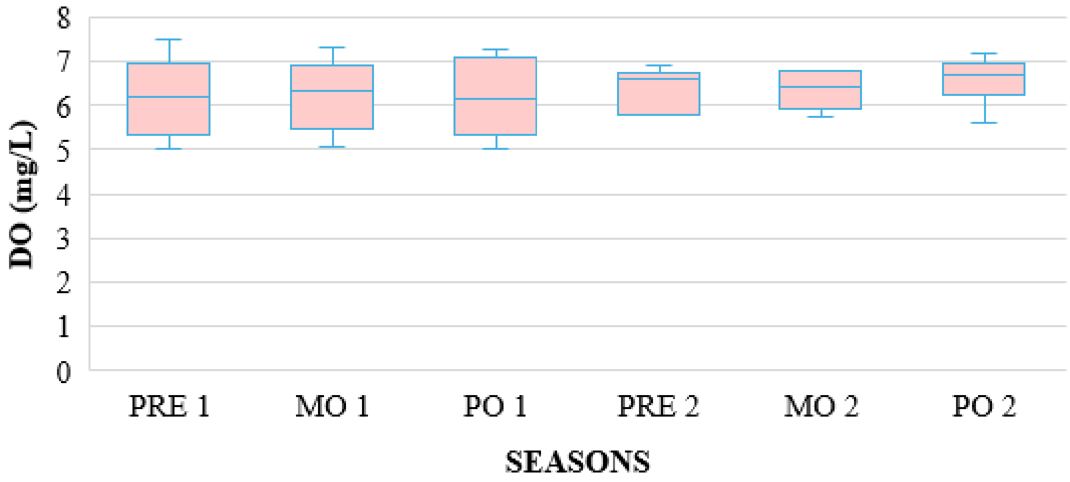


Figure 18. Graph showing seasonal variation in the range of DO in the study area

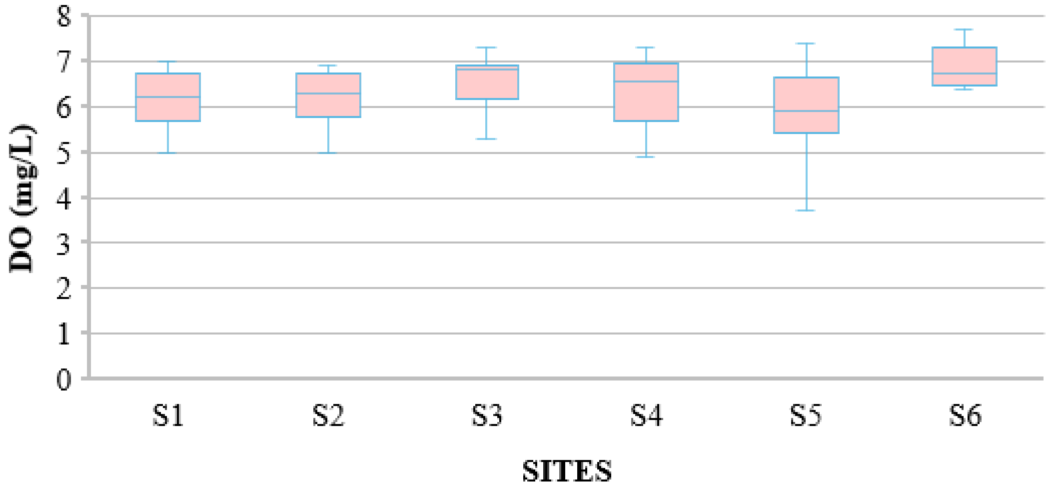


Figure 19. Graph showing spatial variation in the range of DO in the study area

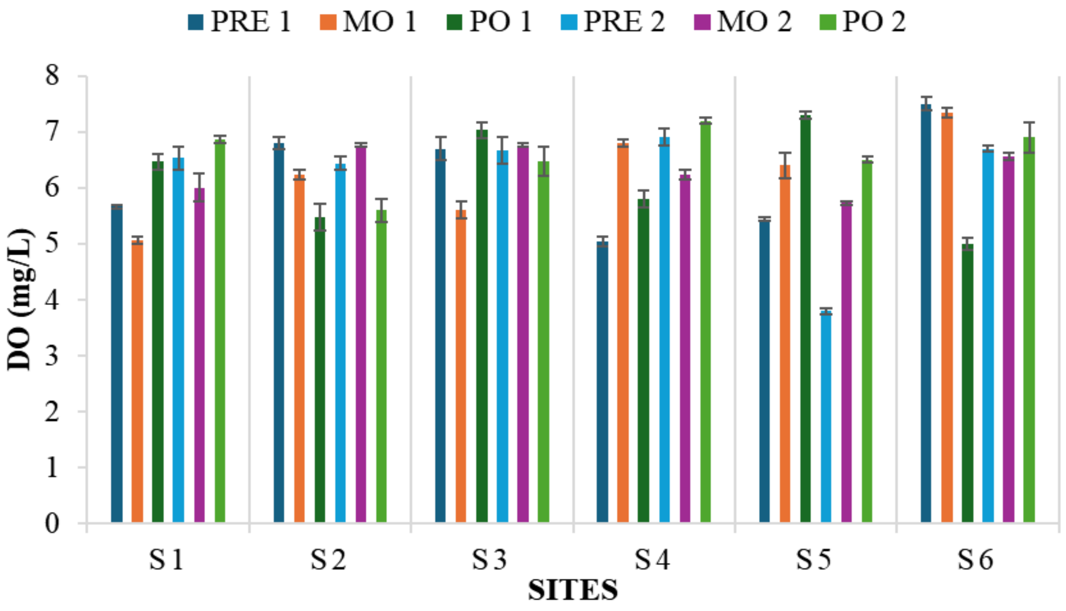


Figure 20. Graph showing the seasonal and spatial variation of DO in study sites

4.2.1.7 Nitrate

Nitrate ranged between 0.002 mg/L and 0.13 mg/L in the study area. The range of nitrate across seasons and sites is illustrated in Figure 21 and Figure 22 respectively. Seasonally, mean nitrate is lowest in PO2 and highest in PRE2. Spatially lowest mean nitrate is observed at S1 and the highest at S2. Seasonal and spatial variations of nitrate in each site of the study area in two years are given in Figure 23. Nitrate is minimum at PRE1 of S4 (0.002 ±0.001) and maximum at PRE2 of S3 (0.13 ±0.01). One-way ANOVA is performed at a 5% level and no significant variation is found across sites on nitrate ($p>0.05$). Significant variations across seasons ($p <0.05$) were found.

In S1, PRE2 have the highest, and PO2 have the lowest nitrate. Nitrate decreases in monsoon and again in post-monsoon of both years. In S2, the same trend is seen in the first year but in the second year, monsoon raises nitrate levels which are again lower in post-monsoon. MO2 has the highest and PO2 have the lowest value. In S3, PRE2 have the highest nitrate and PO2 have the lowest values. Nitrate slightly lowers in monsoon and increases slowly in post-monsoon. In the second year, monsoon reduces nitrate which is again reduced at post-monsoon. In S4, PO2 have the highest and PRE1 have the lowest values. Monsoon increases nitrate which gets reduced in post-monsoon. In the second year, monsoon reduces nitrate which gets elevated in post-monsoon. In S5, nitrate increases in monsoon and lowers in post-monsoon. In the second year, nitrate decreases in monsoon and post-monsoon. PRE 2 have the highest and PRE1 has the lowest nitrate. In S6, monsoon increases nitrate which gets lowered by post-monsoon. In the second year, nitrate is reduced in monsoon and post-monsoon. MO1 have the highest and PO2 has the lowest values of nitrate.

Pearson's coefficient of correlation with other parameters is analysed at a 5% level. No significant correlation was observed (Figure 5). Nitrate values observed from the study area are within permissible limits.

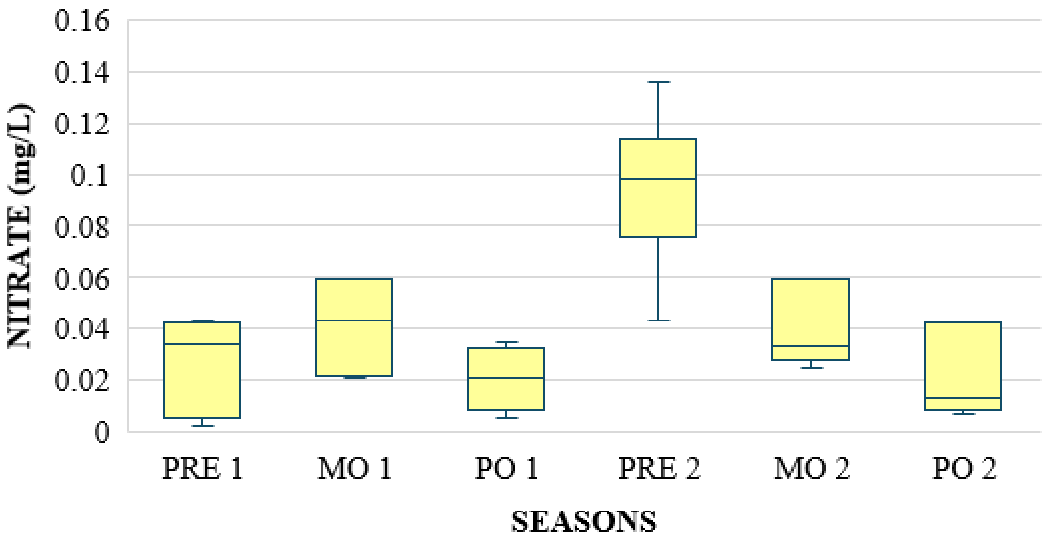


Figure 21. Graph showing seasonal variation in the range of nitrate in the study area

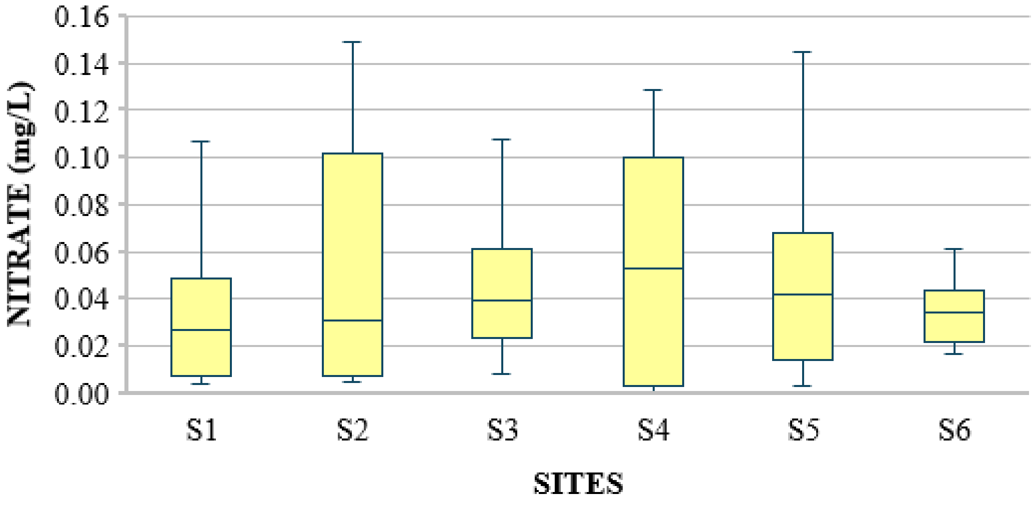


Figure 22. Graph showing spatial variation in the range of nitrate in the study area

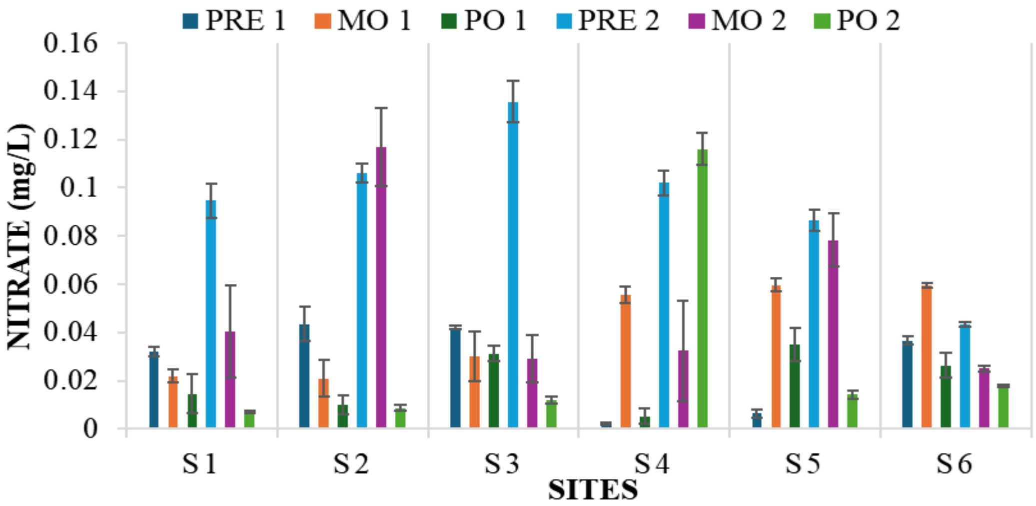


Figure 23. Graph showing the seasonal and spatial variation of nitrate in study sites

4.2.1.8 Phosphate

Phosphate ranges from 0.01 mg/L to 0.2 mg/L in the study area. The range of phosphate across seasons is shown in Figure 24 and across sites in Figure 25. Seasonally, the lowest mean phosphate is recorded in PO2 and the highest in PRE1. Spatially, S1 has the lowest mean phosphate and S5 has the highest mean value of phosphate. Seasonal and spatial variations of phosphate in each site of the study area in two years are given in Figure 26. Phosphate is minimum at MO2 of S1 (0.01 ±0.002) and maximum at PRE2 of S6 (0.21 ±0.01). One-way ANOVA is performed at a 5% level. Significant influence is found across sites on phosphate ($p < 0.05$) and no significant variation across seasons ($p > 0.05$).

In S1, PRE1 have the highest and MO2 has the lowest phosphate. Phosphate gradually decreases along seasons in the first year. But in the second year, a different pattern is observed. The drop in monsoon is increased in post-monsoon. In S2, PRE1 have the highest and PRE2 have the lowest values for phosphate. In the first year, the pattern remains the same. In the second year, an elevation is noted in the monsoon which comes back to normal in post-monsoon. In S3, PRE1 have the highest and PO1 has the lowest content. In the first year, monsoon maintains the phosphate level of pre-monsoon. But a drop in the level is experienced in post-monsoon. In the next year, an increase is seen in monsoon which then lowers in post-monsoon. In S4, PRE1 have the highest and MO1 has the lowest phosphate values. In the first year, a drop in the level of phosphate is seen in monsoon which comes back to the previous level in post-monsoon. In the second year, phosphate elevates in monsoon and then back to the previous level in post-monsoon. In S5, PRE1 have the highest and PRE2 have the lowest phosphate present. In the first year, pre-monsoon and monsoon have similar phosphate content which is slightly lower in post-monsoon. In the next year, phosphate rises in monsoon and drops in post-monsoon. In S6, PRE2 have the highest and PRE1 has the lowest phosphate observed. Monsoon elevates phosphate in the first year and then gets lowered in post-monsoon. In the second year, monsoon drops phosphate which then starts increasing in post-monsoon. Pearson's coefficient of correlation shows no correlation with other parameters is analysed at a 5% level (Figure 5). All values of phosphate are within permissible limits (WHO 1999).

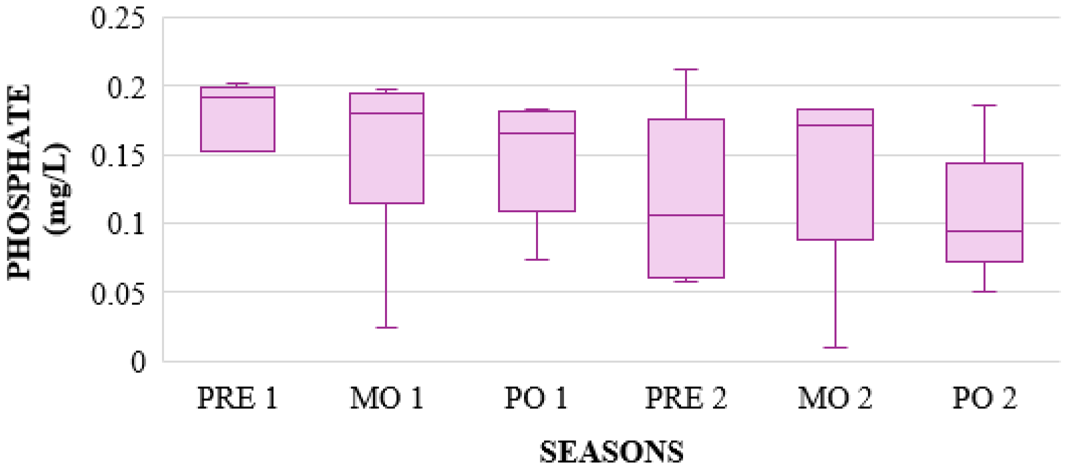


Figure 24. Graph showing seasonal variation in the range of phosphate in the study area

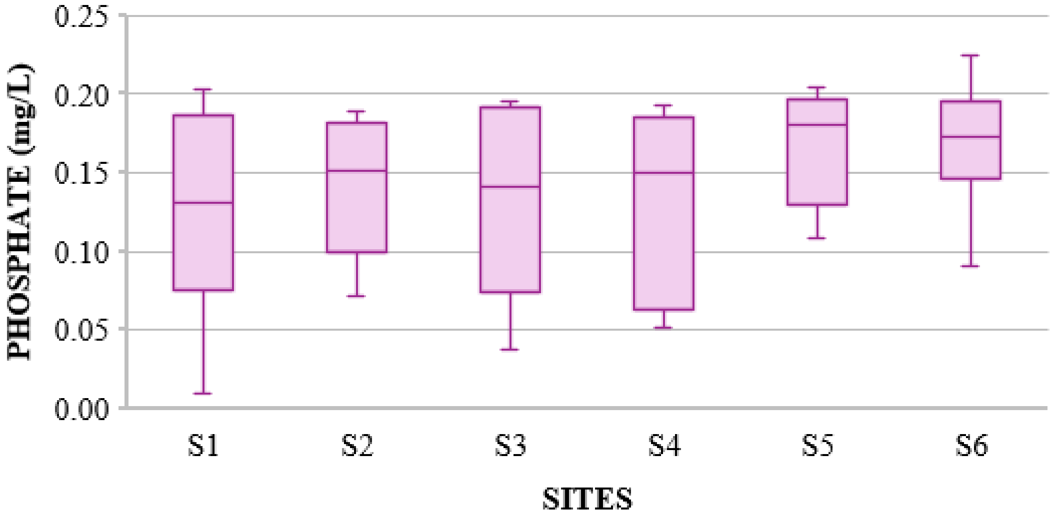


Figure 25. Graph showing spatial variation in the range of phosphate in the study area

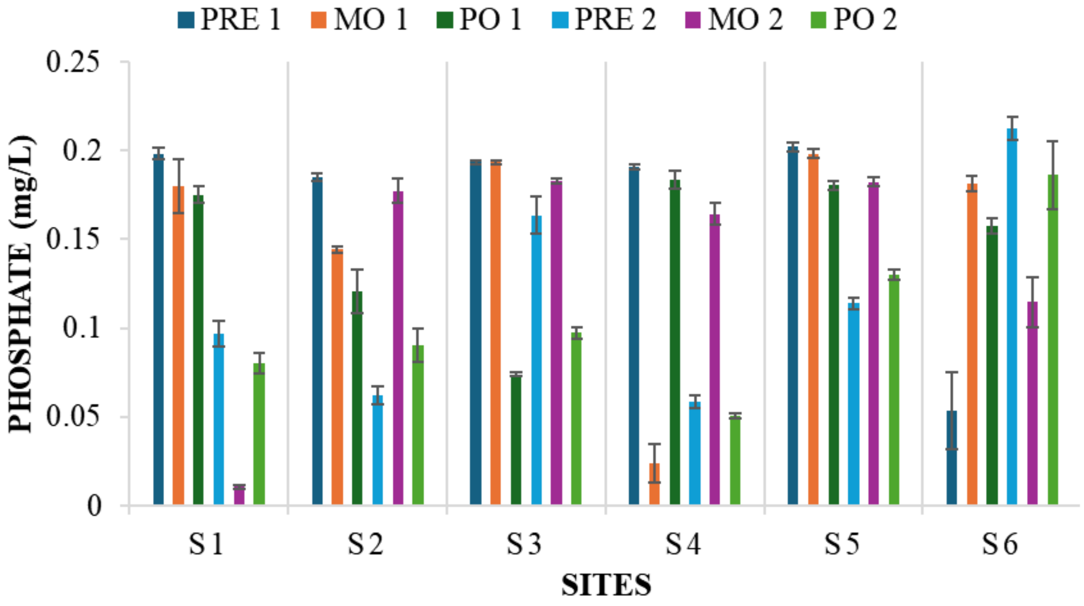


Figure 26. Graph showing the seasonal and spatial variation of phosphate in the study site

4.2.1.9 Silicate

A range between 0.005 mg/L and 1.23 mg/L of silicate is observed from the study area. The range of variations in silicate across seasons is depicted in Figure 27 and across sites in Figure 28. Across the season, PRE2 has the lowest mean silicate and PO1 has the highest. Site-wise analysis shows S2 have the lowest mean silicate and S6 with a high mean value of silicate. Seasonal and spatial variations of silicate in each site of the study area in two years are given in Figure 29. Silicate is minimum at PRE2 of S4 (0.005 ±0.001) and maximum at PO1 of S3 (1.23 ±0.13). One-way ANOVA was performed at a 5% level, and both seasonal and spatial variations were significant ($p < 0.05$).

In S1, PO2 have the highest, and PRE2 have the lowest silicate content. Monsoon causes a rise in silicate which lowers in post-monsoon. In the second year, monsoon and post-monsoon increase silicate content. In S2, MO2 have the highest and MO1 has the lowest phosphate levels. Monsoon decreases silicate which slightly rises in post-monsoon in both years. In S3, PO1 have the highest and PO2 has the lowest phosphate. In the first year, monsoon slightly lowers phosphate but elevates in post-monsoon. In the second year, silica content shows very slight variations and remains almost the same. In S4, PO2 have the highest and PRE2 has the lowest silica. In the first year, a slight increase is seen in the monsoon which came back to the previous level in post-monsoon. In the second year, an increase is seen in monsoon and post-monsoon. In S5, MO1 have the highest and MO2 has the lowest phosphate contents. Monsoon elevates phosphate in the first year which in post-monsoon gets decreased. In the second year, a slight decrease is seen in the monsoon and post-monsoon, an increase is observed. In S6, PO1 have the highest and PO2 has the lowest silica content. Silicate continuously increases in monsoon and post-monsoon. In the second year, monsoon shows an increase, but a sudden drop is seen in post-monsoon. Pearson's coefficient of correlation showed significant positive correlation with TDS and EC at a 5% level (Figure 5).

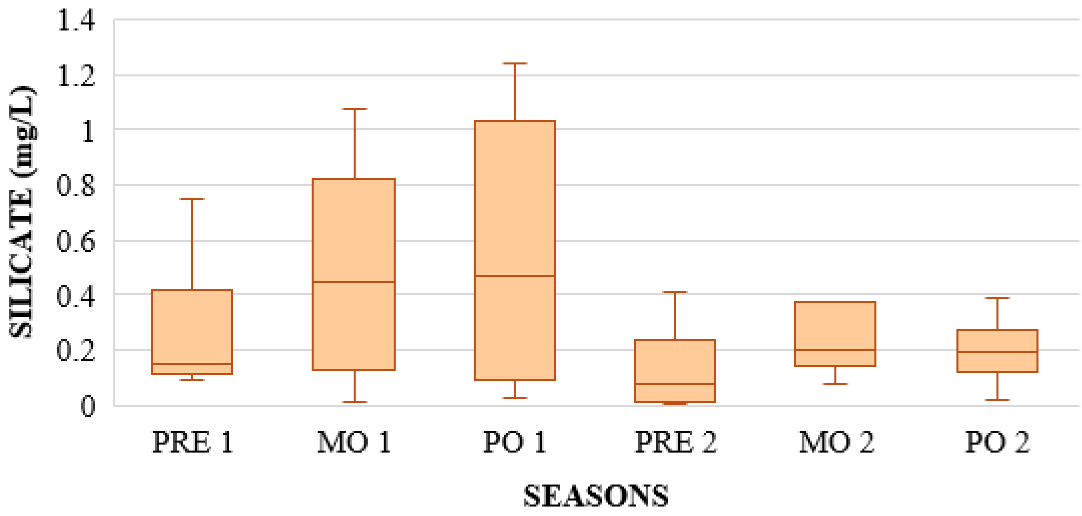


Figure 27. Graph showing seasonal variation in the range of silicate in the study area

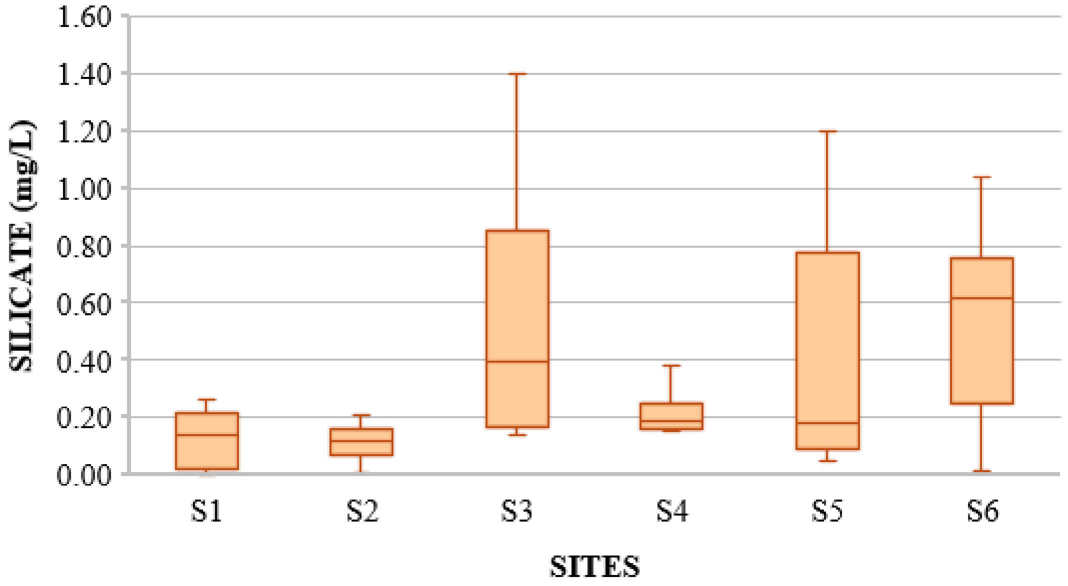


Figure 28. Graph showing spatial variation in the range of silicate in the study area

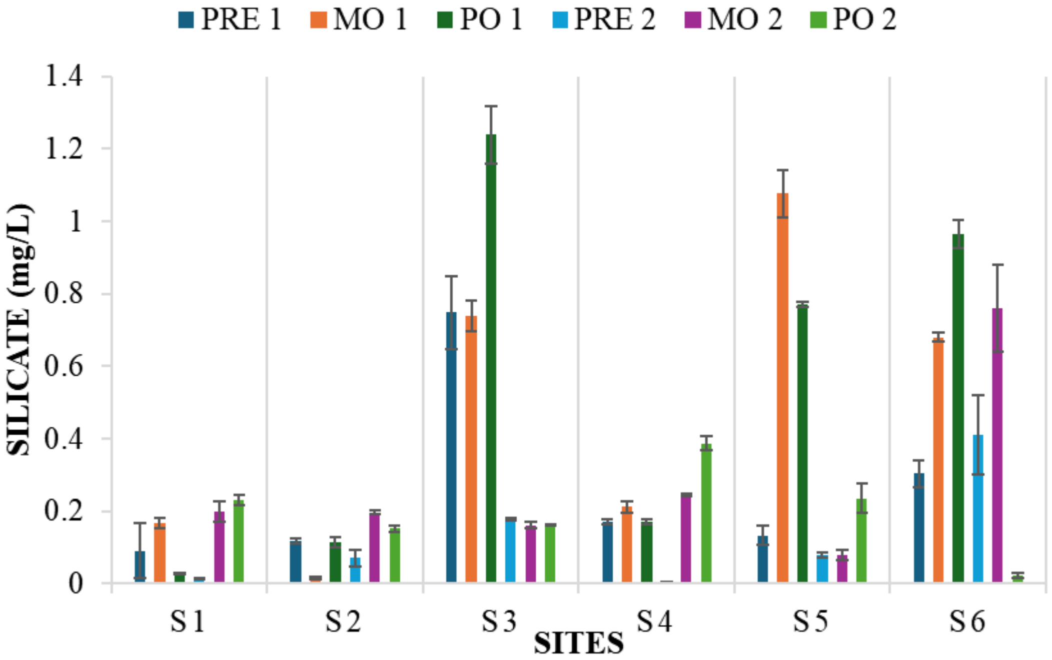


Figure 29. Graph showing the seasonal and spatial variation of silicate in study sites

4.2.2 Quantitative analysis

4.2.2.1. Number of algal cells

A total of 30,10,000 cells were enumerated. Cells of each algal genus corresponding to each season and site were enumerated (Appendix 2). Seasonal and spatial variation in number of cells within each genus were shown in Table 4 and Table 5 respectively.

Table 4. Seasonal quantitative analysis of algae from the study area

Sl. No.	GENUS	PRE1	MO1	PO1	PRE2	MO2	PO2
1	*Achnanthes*	0	1500	2500	28000	4500	7000
2	*Actinastrum*	2500	8500	0	0	0	0
3	*Actinocyclus*	1000	2500	500	1000	0	500
4	*Actinotaenium*	0	3000	5500	15000	3000	7000
5	*Amphora*	500	0	0	3000	0	0
6	*Ankistrodesmus*	6500	16000	10500	17000	2500	7000
7	*Aphanocapsa*	500	4500	1000	2000	0	500
8	*Aphanothece*	0	0	0	500	0	0
9	*Arthrodesmus*	1500	4500	5500	2000	5000	1500
10	*Astasia*	0	0	0	0	0	500
11	*Asterococcus*	500	500	2000	500	1000	0
12	*Botryococcus*	500	500	1500	0	0	0
13	*Bulbochaete*	1000	1500	8500	1500	0	1500
14	*Caloneis*	0	0	0	1500	0	0

Sl. No.	GENUS	PRE1	MO1	PO1	PRE2	MO2	PO2
15	*Centritractus*	1000	1000	0	500	500	0
16	*Ceratium*	0	0	500	0	500	0
17	*Chaetophora*	0	0	1000	0	0	0
18	*Chaetosphaeridium*	1000	0	0	0	0	500
19	*Chlorococcum*	3000	5000	2000	1500	1000	0
20	*Chroococcus*	0	5000	0	0	0	0
21	*Closterium*	2000	11000	4000	5500	3000	4000
22	*Cocconeis*	0	1000	0	12000	2000	4000
23	*Coelastrum*	4000	2000	6500	2000	1000	4500
24	*Coelosphaerium*	500	1000	1000	0	0	500
25	*Coenocystis*	500	3500	2000	500	0	0
26	*Coleochaete*	0	0	0	1000	0	0
27	*Cosmarium*	48000	122000	89000	107500	35000	65000
28	*Crucigenia*	1500	1500	0	500	0	0
29	*Cyclotella*	8500	31000	5000	1500	14000	6500
30	*Cylindrospermum*	0	13500	0	0	0	500
31	*Cymbella*	3500	12000	28500	31500	4500	4000
32	*Desmidium*	0	500	0	0	0	0
33	*Dictyosphaerium*	3000	500	0	2000	0	500
34	*Dimorphococcus*	0	500	0	0	0	0
35	*Dinobryon*	500	3500	5000	0	5500	0
36	*Elakatothrix*	0	0	500	0	0	0
37	*Epithemia*	0	0	0	1000	0	0
38	*Euastrum*	5500	9500	11000	10500	9000	9000
39	*Euglena*	13500	23000	10500	3000	8000	3000
40	*Eunotia*	500	23500	36000	13000	5500	1000
41	*Eutetramorus*	1000	4000	1500	1500	1500	3500
42	*Frustulia*	500	3000	22000	20000	2000	500
43	*Geminella*	0	3000	3000	0	500	0
44	*Glaucocystis*	0	0	0	500	500	2000
45	*Gloeocapsa*	0	0	0	500	0	0
46	*Golenkinia*	0	0	1000	0	0	0
47	*Golenkiniopsis*	1000	0	5000	500	0	0
48	*Gomphonema*	17500	33500	73500	82000	12000	48000
49	*Gonatozygon*	500	3000	0	0	0	500
50	*Gongrosira*	0	500	0	0	0	0
51	*Groenbladia*	0	0	0	1500	0	0
52	*Gyrosigma*	500	0	4000	1500	1000	0
53	*Hantzschia*	0	0	1000	500	0	0
54	*Kirchneriella*	1500	3000	1000	500	1500	500
55	*Lepocinclis*	5000	1000	5000	1500	1000	500
56	*Melosira*	23500	19500	24500	18000	12500	7500
57	*Merismopedia*	500	2500	0	0	1000	0
58	*Micrasterias*	0	2000	500	1500	0	2000
59	*Mougeotia*	0	5500	3000	0	0	0
60	*Navicula*	25000	47500	134500	89000	26000	28000

Sl. No.	GENUS	PRE1	MO1	PO1	PRE2	MO2	PO2
61	*Neidium*	4000	3500	14500	3000	9500	3500
62	*Nephrocytium*	0	0	0	0	3000	2000
63	*Netrium*	0	500	0	500	0	0
64	*Nitzschia*	2000	14500	26000	6000	4500	500
65	*Nostoc*	500	1500	500	0	0	0
66	*Oedogonium*	1500	14500	4500	4500	0	1000
67	*Onychonema*	0	3000	1500	4000	0	1500
68	*Oocystis*	500	1000	1000	1000	0	2000
69	*Oscillatoria*	0	4500	4000	1000	500	500
70	*Pandorina*	0	500	0	0	0	0
71	*Pediastrum*	3500	2500	16500	4000	1000	4000
72	*Penium*	0	0	500	0	500	0
73	*Peridinium*	19000	14000	6000	500	2000	0
74	*Phacus*	500	4000	10000	4000	0	0
75	*Pinnularia*	12000	20000	87500	31000	16000	4000
76	*Planktosphaeria*	0	500	500	500	0	0
77	*Pleurotaenium*	0	0	2500	2000	4500	7500
78	*Pseudanabaena*	0	500	0	0	0	0
79	*Radiococcus*	500	1500	500	0	1000	0
80	*Rhizosolenia*	0	0	0	0	500	0
81	*Rhopalodia*	500	3000	500	1000	500	0
82	*Scenedesmus*	12000	24500	28500	12500	2000	2500
83	*Schroederia*	0	1500	0	0	0	0
84	*Selenastrum*	1500	1500	2000	1500	0	1000
85	*Sorastrum*	0	500	0	0	0	0
86	*Sphaerocystis*	500	0	1000	0	500	0
87	*Sphaerozosma*	0	4500	3500	5500	0	2500
88	*Spirogyra*	9000	1000	0	2000	0	0
89	*Spirulina*	0	500	1500	500	1000	0
90	*Spondylosium*	0	3000	0	500	0	0
91	*Staurastrum*	23500	87500	53000	48000	29000	31500
92	*Staurodesmus*	2000	4500	7500	3000	7500	1500
93	*Stauroneis*	500	0	0	2000	1000	0
94	*Strombomonas*	1500	0	0	0	0	0
95	*Surirella*	4500	6000	19000	4000	5500	4000
96	*Synedra*	8500	13000	13000	19500	5000	10500
97	*Tetraedron*	1500	7000	500	500	3000	500
98	*Tetrastrum*	0	1000	0	0	0	0
99	*Trachelomonas*	94500	46500	53500	56000	17000	14500
100	*Triceratium*	0	0	500	0	0	0
101	*Triplastrum*	1000	1500	0	500	0	2500
102	*Xanthidium*	0	5000	1500	4500	1500	5000

Table 5. Spatial quantitative analysis of algae from the study area

Sl. No.	GENUS	S1	S2	S3	S4	S5	S6
1	*Achnanthes*	500	3000	4000	0	1000	17500
2	*Actinastrum*	2000	0	0	7500	500	500
3	*Actinocyclus*	1000	0	0	0	2500	1000
4	*Actinotaenium*	23000	4500	0	4000	1000	500
5	*Amphora*	0	0	0	0	3500	0
6	*Ankistrodesmus*	19000	4500	500	21500	9000	3000
7	*Aphanocapsa*	6000	0	0	0	1500	500
8	*Aphanothece*	0	0	0	0	500	0
9	*Arthrodesmus*	4000	7500	500	4000	4000	0
10	*Astasia*	0	0	0	500	0	0
11	*Asterococcus*	0	0	0	0	4500	0
12	*Botryococcus*	0	0	0	0	2500	0
13	*Bulbochaete*	500	500	500	2500	4000	3000
14	*Caloneis*	0	1500	0	0	0	0
15	*Centritractus*	2000	0	500	0	500	0
16	*Ceratium*	0	1000	0	0	0	0
17	*Chaetophora*	0	0	0	0	0	500
18	*Chaetosphaeridium*	0	0	0	0	1500	0
19	*Chlorococcum*	3500	1500	3000	1000	1500	1000
20	*Chroococcus*	2500	0	0	0	2500	0
21	*Closterium*	6500	2000	4000	3500	11500	1000
22	*Cocconeis*	1000	0	0	0	0	9000
23	*Coelastrum*	11500	1500	3500	0	3500	0
24	*Coelosphaerium*	0	0	500	500	0	1000
25	*Coenocystis*	1500	1000	0	0	1000	1500
26	*Coleochaete*	0	0	0	0	1000	0
27	*Cosmarium*	200500	66000	8000	11000	154000	13500
28	*Crucigenia*	500	0	1500	0	1500	0
29	*Cyclotella*	4000	44000	2000	500	16000	0
30	*Cylindrospermum*	500	0	500	1500	11500	0
31	*Cymbella*	16500	11500	9000	9000	27000	5500
32	*Desmidium*	0	500	0	0	0	0
33	*Dictyosphaerium*	3500	0	0	2500	0	0
34	*Dimorphococcus*	500	0	0	0	0	0
35	*Dinobryon*	9000	5000	0	0	500	0
36	*Elakatothrix*	0	500	0	0	0	0
37	*Epithemia*	0	0	0	0	0	500
38	*Euastrum*	9500	27000	2500	6500	7000	1000
39	*Euglena*	1000	5500	15000	28000	4500	3500
40	*Eunotia*	27500	6500	1500	7500	2500	17000
41	*Eutetramorus*	8500	2000	0	0	1500	500
42	*Frustulia*	2000	31000	500	10500	0	2000

Sl. No.	GENUS	S1	S2	S3	S4	S5	S6
43	*Geminella*	3500	0	0	0	0	1500
44	*Glaucocystis*	0	0	0	0	3000	0
45	*Gloeocystis*	0	0	0	0	500	0
46	*Golenkinia*	0	0	0	0	0	1000
47	*Golenkiniopsis*	0	0	0	6500	0	0
48	*Gomphonema*	30500	54000	21500	7500	70000	41500
49	*Gonatozygon*	1000	0	0	0	3000	0
50	*Gongrosira*	500	0	0	0	0	0
51	*Groenbladia*	2000	0	0	0	0	0
52	*Gyrosigma*	0	0	7000	0	0	0
53	*Hantzschia*	0	0	0	0	500	500
54	*Kirchneriella*	4500	1500	0	1000	1000	0
55	*Lepocinclis*	7000	500	1500	0	0	2500
56	*Melosira*	16500	43000	5500	30000	4500	3000
57	*Merismopedia*	0	1000	0	0	1000	1000
58	*Micrasterias*	3500	0	0	0	2500	0
59	*Mougeotia*	0	3000	500	3000	2000	0
60	*Navicula*	38500	49000	46000	53500	57000	53000
61	*Neidium*	1000	1000	4500	20500	0	5500
62	*Nephrocytium*	0	4500	0	0	500	0
63	*Netrium*	0	500	0	0	500	0
64	*Nitzschia*	3000	9000	18500	0	10000	6500
65	*Nostoc*	0	0	0	0	2500	0
66	*Oedogonium*	6500	4500	0	1000	9000	2500
67	*Onychonema*	10000	0	0	0	0	0
68	*Oocystis*	3500	0	0	1000	1000	0
69	*Oscillatoria*	2500	3500	2000	0	2500	0
70	*Pandorina*	500	0	0	0	0	0
71	*Pediastrum*	3000	0	1000	20000	500	3500
72	*Penium*	0	500	0	0	500	0
73	*Peridinium*	10500	12500	3000	11500	3000	0
74	*Phacus*	5000	0	1000	6000	500	3000
75	*Pinnularia*	15000	26000	22000	28500	21000	29000
76	*Planktosphaeria*	0	0	0	0	1500	0
77	*Pleurotaenium*	0	1500	0	10500	2500	1000
78	*Pseudanabaena*	0	0	0	500	0	0
79	*Radiococcus*	500	1500	0	0	1500	0
80	*Rhizosolenia*	0	500	0	0	0	0
81	*Rhopalodia*	0	0	500	500	4500	0
82	*Scenedesmus*	4000	0	16500	38500	7000	8000
83	*Schroederia*	0	0	0	1500	0	0
84	*Selenastrum*	7000	0	0	500	0	0
85	*Sorastrum*	500	0	0	0	0	0

Sl. No.	GENUS	S1	S2	S3	S4	S5	S6
86	*Sphaerocystis*	0	1000	0	0	1000	0
87	*Sphaerozosma*	16000	0	0	0	0	0
88	*Spirogyra*	0	500	500	0	2000	4500
89	*Spirulina*	1000	1500	0	0	0	500
90	*Spondylosium*	0	0	0	0	3500	0
91	*Staurastrum*	148000	82500	1000	14000	24000	1500
92	*Staurodesmus*	5000	11000	500	3500	4000	1000
93	*Stauroneis*	0	500	500	1500	0	500
94	*Strombomonas*	0	500	1000	0	0	0
95	*Surirella*	0	1000	8500	24500	2000	3500
96	*Synedra*	4000	4000	10500	14500	24500	6000
97	*Tetraedron*	2500	3500	500	500	6000	0
98	*Tetrastrum*	0	0	0	1000	0	0
99	*Trachelomonas*	129500	37500	15000	24500	19500	28000
100	*Triceratium*	0	500	0	0	0	0
101	*Triplastrum*	0	0	0	500	5000	0
102	*Xanthidium*	4500	11000	500	0	1500	0

Figure 30 shows seasonal distribution of number of cells, where highest number of cells are seen in PO1 (874000 cells/litre) and lowest is at MO2 (276500 cells/litre). From the figure 31, showing spatial distribution of number of cells, highest number of cells is observed at S1 (844000 cells/litre) and lowest is at S3 (247000 cells/litre).

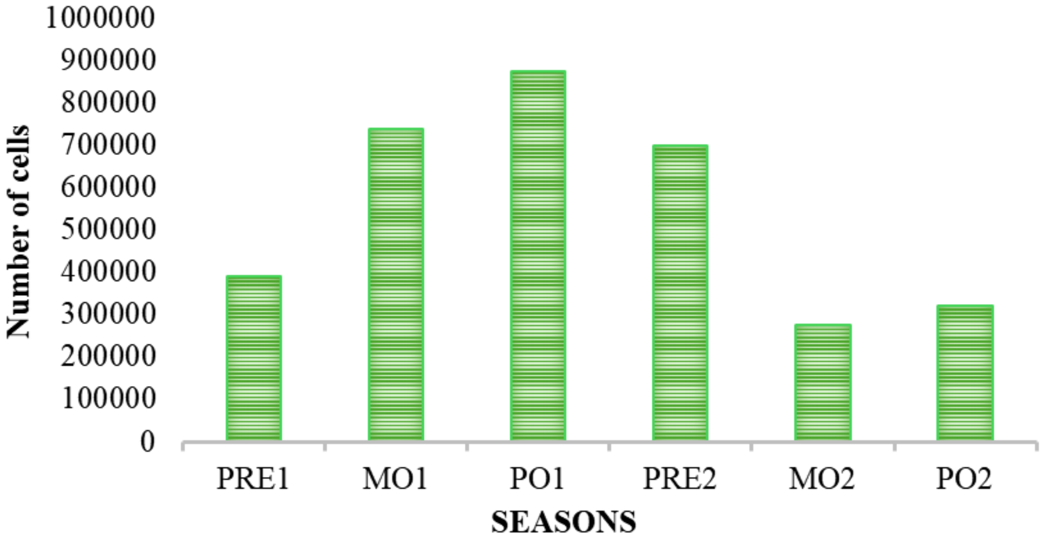


Figure 30. Graph showing seasonal distribution of number of algal cells in studyarea

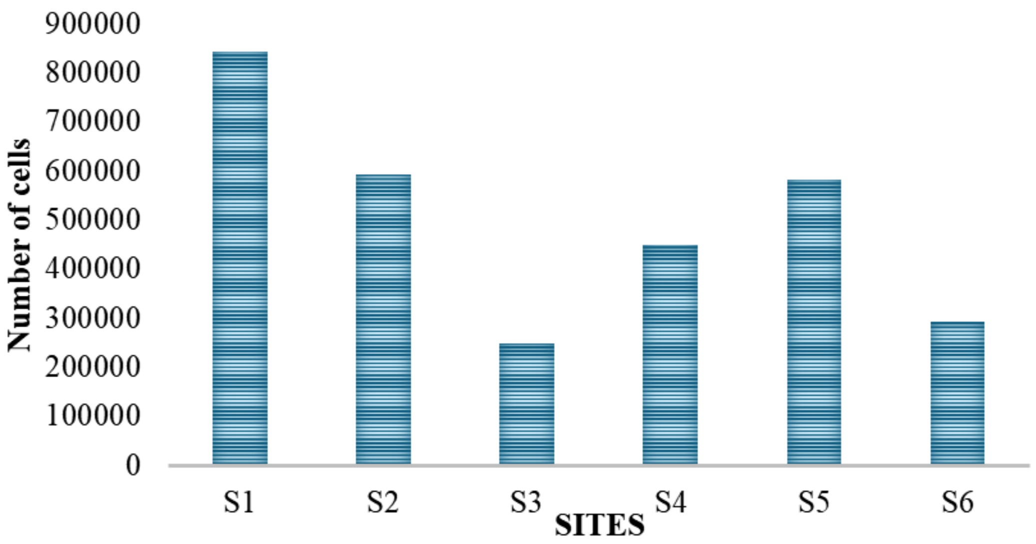


Figure 31. Graph showing the spatial distribution of the number of algal cells in the study area

4.2.3.2 Class-wise analysis of algae

Out of 11 classes, 7 are represented from the study area. Class-wise analysis of algae from the study area is interpreted in a pie diagram (Figure 32). Chlorophyceae has the highest abundance (44%) followed by Bacillariophyceae (42%). Xanthophyceae has the lowest abundance (0.09%).

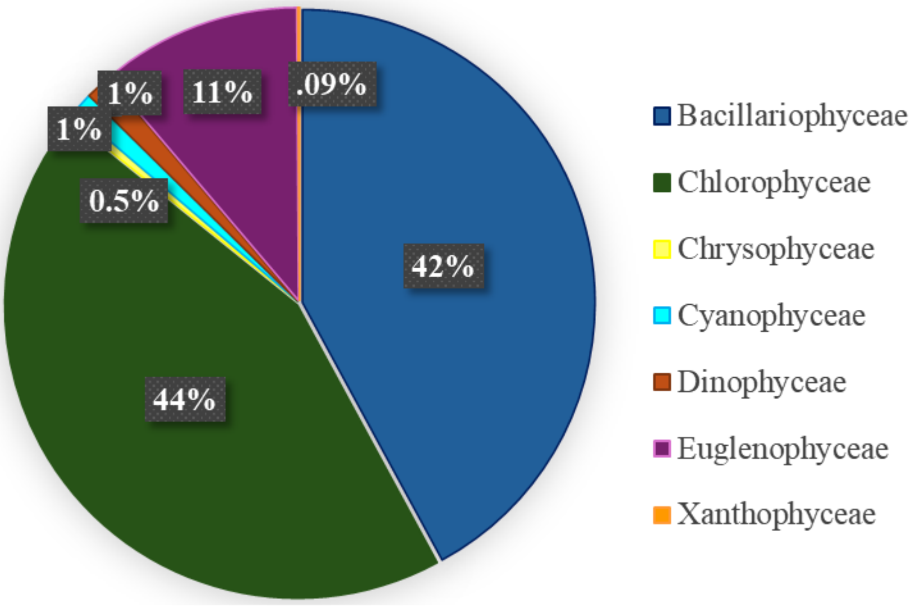


Figure 32. Pie diagram showing class-wise abundance of algae from the study area

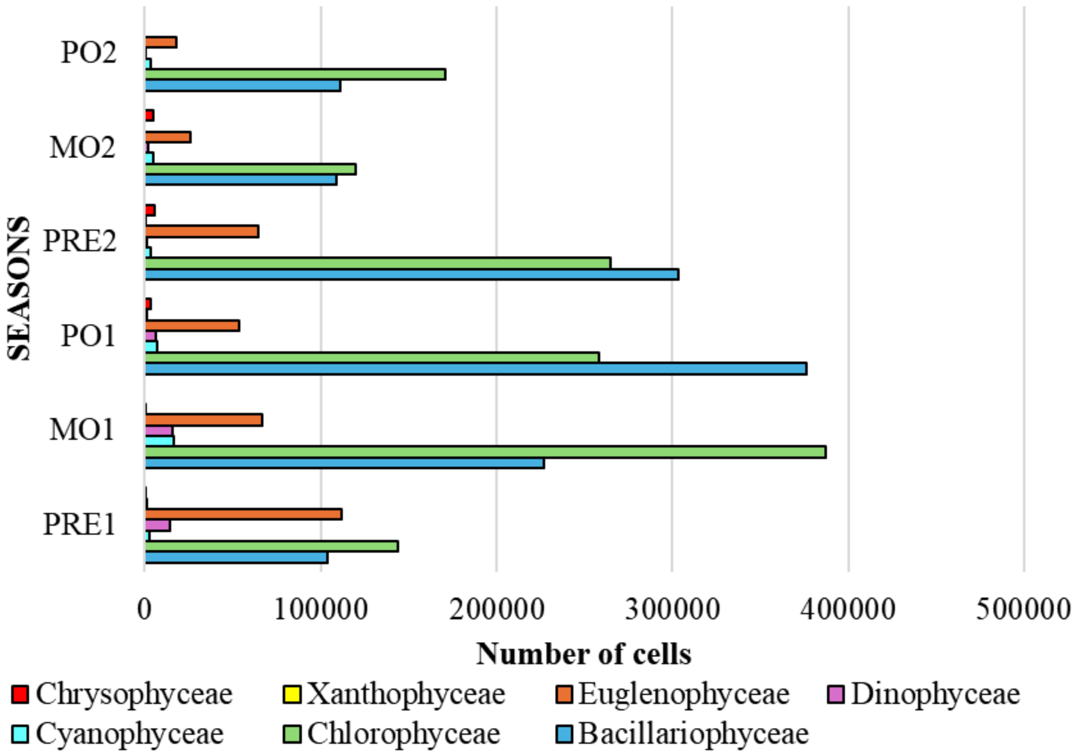


Figure 33. Graph showing the class-wise seasonal distribution of algal cells from the study area

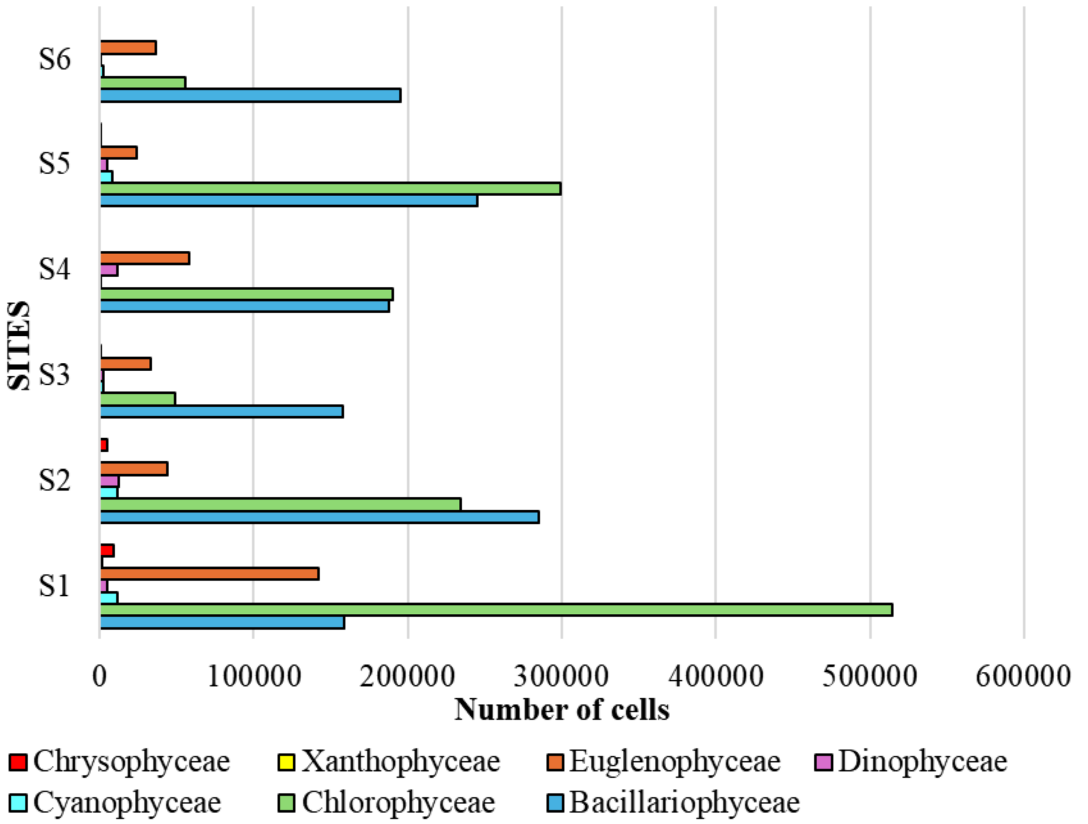


Figure 34. Graph showing the class-wise spatial distribution of algal cells from the study area

Class-wise seasonal distribution of algal cells is depicted in Figure 33. PRE1 (144000), MO1 (387000), MO2 (119500) and PO2 (170500) have Chlorophyceae as dominant class whereas PRE2 (303500) and PO1 (376500) have Bacillariophyceae as dominant class. Chlorophyceae (387000), Cyanophyceae (16500) and Dinophyceae (15500) are highest in MO1. Bacillariophyceae (376500) is highest in PO1. Euglenophyceae (111500) is highest in PRE1. Chrysophyceae is highest in PRE2(5500). Xanthophyceae is highest in PRE1 (1000) and PO1 (1000).

Class-wise spatial distribution of algal cells is depicted in Figure 34. Chlorophyceae is the dominant class in S1 (514500), S4 (190500), and S5 (299500) while in S2 (285000), S3 (158000), and S6 (195000), Bacillariophyceae is the dominant class. Class Chlorophyceae (514500), Cyanophyceae (12000), Euglenophyceae (142500), Chrysophyceae (14500) and Xanthophyceae (11000) are highest in S1. Class Bacillariophyceae (285000) and Dinophyceae (12500) are highest in S2.

4.2.3 Community structure and diversity analysis

4.2.3.1 Frequent and dominant algal genera

The most frequent genera and dominant genera from the study area were calculated from the samples using frequency index (F%) and quantitative dominance index (DI %) respectively (Table 6). Genera *Gomphonema* and *Navicula* have the highest frequency of 97.2%. *Cosmarium* is the most dominant genus with 15% dominance in study area.

Table 6. Frequent and dominant algal genera from the study area and their respective frequency index (F%) and dominance index (DI%)

	FREQUENT GENERA	F%	DOMINANT GENERA	DI%
1	*Gomphonema*	97.2%	*Cosmarium*	15%
2	*Navicula*	97.2%	*Navicula*	9.8%
3	*Cosmarium*	91.6%	*Staurastrum*	9%
4	*Pinnularia*	86%	*Trachelomonas*	8.4%
5	*Melosira*	77.7%	*Gomphonema*	7.4%
6	*Cymbella*	77.7%	*Pinnularia*	4.7%
7	*Trachelomonas*	75%	*Melosira*	3.4%
8	*Staurastrum*	72.2%	*Cymbella*	2.6%
9	*Synedra*	70.2%	*Scenedesmus*	2.3%
10	*Euastrum*	69.4%	*Cyclotella*	2.1%

The most diverse genus of study area is *Cosmarium* with 56 species followed by *Navicula* with 27 species. *Pinnularia* has 22 species and *Staurastrum* has 21 species. A total of 16 genera are presented in all seasons and sites. The ten frequent genera listed in Table 5, are present in all seasons and sites. Moreover, *Ankistrodesmus*, *Bulbochaete*, *Closterium*, *Euglena*, *Eunotia*, and *Staurodesmus* are the other genera presented in all seasons and sites.

Frequent genera present in all sites of respective season and its dominant algal genera is presented in Table 7. Frequent genera present in all seasons of respective site and its dominant algal genera is identified in Table 8.

Table 7. Frequent and dominant algal genera of each season

SEASONS	FREQUENT GENERA	DOMINANT GENERA
PRE1	*Ankistrodesmus, Cosmarium, Navicula, Trachelomonas*	*Trachelomonas*
MO1	*Cosmarium, Cymbella, Gomphonema, Pinnularia, Synedra*	*Cosmarium*
PO1	*Cosmarium, Cymbella, Gomphonema, Navicula, Pinnularia*	*Navicula*
PRE2	*Cymbella. Gomphonema, Pinnularia, Synedra*	*Cosmarium*
MO2	*Navicula, Pinnularia*	*Cosmarium*
PO2	*Gomphonema, Navicula*	*Cosmarium*

Table 8. Frequent and dominant algal genera from the study sites

SITES	FREQUENT GENERA	DOMINANT GENERA
S1	*Ankistrodesmus, Cosmarium, Melosira, Navicula, Staurastrum, Trachelomonas*	*Cosmarium*
S2	*Cosmarium, Euastrum, Cyclotella, Gomphonema, Melosira, Navicula, Staurastrum*	*Staurastrum*
S3	*Gomphonema, Navicula*	*Navicula*
S4	*Cosmarium, Cymbella, Euglena, Gomphonema, Melosira, Navicula, Neidium, Pediastrum, Pinnularia, Scenedesmus, Surirella, Synedra*	*Navicula*
S5	*Ankistrodesmus, Cosmarium, Cymbella, Gomphonema, Navicula, Staurastrum*	*Cosmarium*
S6	*Gomphonema*	*Navicula*

4.2.3.2 Algal genera exclusive to seasons and sites

Algae exclusively present in specific seasons and sites are listed in Table 9 and Table 10 respectively. From Table 9, PRE2 has 6 genera, MO1 has 9 genera, and PO1 has 3 genera exclusive to the season while PRE1, MO2 and PO2 have a single genus exclusive to each season. In Table 10, S1, S2, S4, S5, and S6 have 7 genera, 6 genera, 5 genera, 11 genera and 3 genera exclusive to themselves respectively. S3 has no genus exclusive to the site.

Table 9. Algal genera exclusive to different seasons

SEASONS	EXCLUSIVE ALGAL GENERA
PRE1	*Strombomonas*
MO1	*Chroococcus*, *Desmidium*, *Dimorphococcus*, *Gongrosira*, *Pandorina*, *Pseudanabaena*, *Schroederia*, *Sorastrum*, *Tetrastrum*
PO1	*Triceratium*, *Golenkinia*, *Elakatothrix*
PRE2	*Aphanothece*, *Caloneis*, *Coleochaete*, *Epithemia*, *Gloeocapsa*, *Groenbladia*
MO2	*Rhizosolenia*
PO2	*Astasia*

Table 10. Algal genera exclusive to different sites

SITES	EXCLUSIVE ALGAL GENERA
S1	*Dimorphococcus*, *Gongrosira*, *Groenbladia*, *Onychonema*, *Pandorina*, *Sorastrum*, *Sphaerozosma*
S2	*Triceratium, Rhizosolenia, Elakatothrix, Desmidium, Ceratium, Caloneis*
S3	Nil
S4	*Tetrastrum, Schroederia, Pseudanabaena, Golenkiniopsis, Astasia*
S5	*Amphora, Aphanothece, Asterococcus, Botryococcus, Chaetosphaeridium, Coleochaete, Glaucocystis, Gloeocystis, Nostoc, Planktosphaeria, Spondylosium*
S6	*Golenkinia, Epithemia, Chaetophora*

4.2.3.3 Diversity analysis

Diversity indices provide an accurate expression of diversity in an area. Diversity indices such as Simpson's dominance index, Pielou's evenness index, and Margalef's richness index are calculated in each season of study sites. Shannon-Weiner's diversity index is used as it deals with both richness and evenness and is considered as most reliable index for diversity. Several genera and cells along with indices like Simpson's dominance index, Pielou's evenness index, Margalef's richness index and Shannon-Weiner's diversity index are compared within different seasons of six sites (Table 11).

Table 11. Seasonal and spatial variation in the number of cells, genera, dominance, evenness, richness and diversity indices in different study sites of the study area

	PRE1	MO1	PO1	PRE2	MO2	PO2
S1						
No of Genera	20	51	29	34	19	34
No. of cells	115000	240000	118500	230500	56000	84500
Simpson's dominance index	0.23	0.13	0.14	0.11	0.18	0.09
Pielou's evenness index	0.34	0.28	0.37	0.36	0.48	0.5
Margalef's richness index	1.71	4.44	2.65	2.99	1.73	3.17
Shannon Weiner's diversity index	1.99	2.75	2.48	2.63	2.26	2.91
S2						
No. of genera	23	24	27	27	32	15
No. of cells	93500	110500	90500	117500	97500	83500
Simpson's dominance index	0.14	0.1	0.07	0.09	0.08	0.17
Pielou's evenness index	0.44	0.54	0.61	0.52	0.57	0.51
Margalef's richness index	2	2.06	2.27	2.14	2.69	1.23
Shannon Weiner's diversity index	2.36	2.6	2.8	2.61	2.91	2.04
S3						
No. of genera	22	25	22	16	18	11
No. of cells	46500	63000	71000	26000	31500	9000
Simpson's dominance index	0.12	0.09	0.1	0.1	0.09	0.12
Pielou's evenness index	0.51	0.58	0.61	0.73	0.74	0.83
Margalef's richness index	2.14	2.26	1.88	1.47	1.64	1.09
Shannon Weiner's diversity index	2.51	2.72	2.6	2.46	2.59	2.21
S4						
No. of genera	25	30	26	24	16	20
No. of cells	50000	118500	125500	74000	44000	37500

Simpson’s dominance index	0.06	0.07	0.05	0.1	0.1	0.08
Pielou's evenness index	0.69	0.58	0.79	0.56	0.73	0.75
Margalef’s richness index	2.31	2.65	2.12	2.05	1.4	1.7
Shannon Weiner's diversity index	2.9	2.92	3.03	2.6	2.46	2.67
S5						
No. of genera	33	47	26	31	15	24
No. of cells	56000	163000	135000	129500	28500	72000
Simpson’s dominance index	0.1	0.1	0.14	0.15	0.14	0.17
Pielou's evenness index	0.54	0.42	0.39	0.36	0.62	0.41
Margalef’s richness index	2.83	4.08	2.28	2.54	1.36	2.05
Shannon Weiner's diversity index	2.85	3.05	2.4	2.42	2.23	2.3
S6						
No. of genera	9	24	32	13	8	11
No. of cells	15000	22000	166500	62000	9500	17000
Simpson’s dominance index	0.19	0.08	0.09	0.19	0.27	0.14
Pielou's evenness index	0.71	0.71	0.49	0.51	0.65	0.75
Margalef’s richness index	0.77	2.24	2.43	1.02	0.71	0.95
Shannon Weiner's diversity index	1.86	2.87	2.75	1.9	1.65	2.11

In S1, the highest number of cells (240000) and genera (51) is observed in MO1. Lowest number of cells (56000) and genera (19) in MO2. Dominance is highest in PRE1 (0.23) and least in PO2 (0.09). The highest evenness is seen in PO2 (0.5) and the lowest in MO1 (0.28). Highest richness index in MO1 (4.44) and lowest in PRE1 (1.71). The highest diversity index is at PO2 (2.91) and the lowest in PRE1 (1.99).

In S2, the highest number of genera is in MO2 (32) and cells (117500) in PRE2. The lowest number of genera (15) and cells (83500) is in PO2. Dominance index is high in PO2 (0.17) and low in PO1 (0.07). The highest evenness is observed in PO1 (0.61) and the lowest in PRE1 (0.44). The highest richness is observed in MO2 (2.69) and the least in PO2 (1.23). Highest diversity at MO2 (2.91) and least at PO2 season (2.04).

In S3, the highest number of genera is in MO1 (25) and cells (71000) in the PO1 season. The least number of genera (11) and cells (9000) is in PO2. Dominance is high in PRE1 (0.12) and PO2 (0.12) with the lowest in MO1 (0.09) and MO2

(0.09). The highest evenness is seen in PO2 (0.83) and the least in PRE1 (0.51). Highest richness index in MO1 (2.26) and lowest at PO2 (1.09). The highest diversity index is at MO1 (2.72) and the lowest is at PO2 (2.21).

In S4, the highest number of genera is in MO1 (30) and cells in PO1 (125500) season. The least number of genera is represented by MO2 (16) and the least number of cells by PO2 (37500). Dominance is high in PRE2 (0.1) and MO2 (0.1). PO1 (0.05) have the least dominance index. High evenness is seen in PO1 (0.79) and lowest in MO2 (0.56). A high richness index is observed in MO1 (2.65) and the least in MO2 (1.4). High diversity index at MO1 (3.03) and lowest in MO2 (2.46).

In S5, MO1 represents the highest number of genera (47) and cells (163000) while MO2 (15) show the least number of genera (28500) and cells. Dominance is high in PO2 (0.17) and least in MO1 (0.1) and PRE1 (0.1). High evenness is seen in MO2 (0.62) and the least in PRE2 (0.36). The highest richness index is in MO1 (4.08) and the least in MO2 (1.36). High diversity index at MO1 (3.05) and lowest at MO2 (2.23).

In S6, the highest number of genera (32) and cells (333000) is observed in the PO1 season. The least number of genera (8) and cells (19000) were noted in MO2. Dominance is high in MO2 (0.27) and lowest in MO1 (0.08). High evenness is seen in PO2 (0.75) and the least in PO1 (0.49). A high richness index is observed in PO1 (2.43) and MO2 (0.71) has the least. The highest diversity index is at MO1 (2.87) and the least at MO2 (1.65).

The most efficient and widely used diversity index, the Shannon-Weiner diversity index is analysed seasonally and spatially in the study sites (Figure 35). The highest value of the diversity index is found at MO1 of S5 (3.05) and lowest at MO2 of S6 (1.65). In S1, PO2 (2.91) have the highest and PRE1 (1.99) have the lowest diversity index. In S2, MO2 (2.91) have the highest and PO2 (2.04) have the lowest diversity. In S3, MO1 (2.72) have the highest and PO2 (2.21) have the lowest value. In S4, PO1 (3.03) have the highest and MO2 (2.46) have the lowest diversity. In S5, MO1 (3.05) has the highest and MO2 (2.23) have the lowest diversity. In S6, MO1 (2.87) have the highest and MO2 (1.65) have the lowest diversity index.

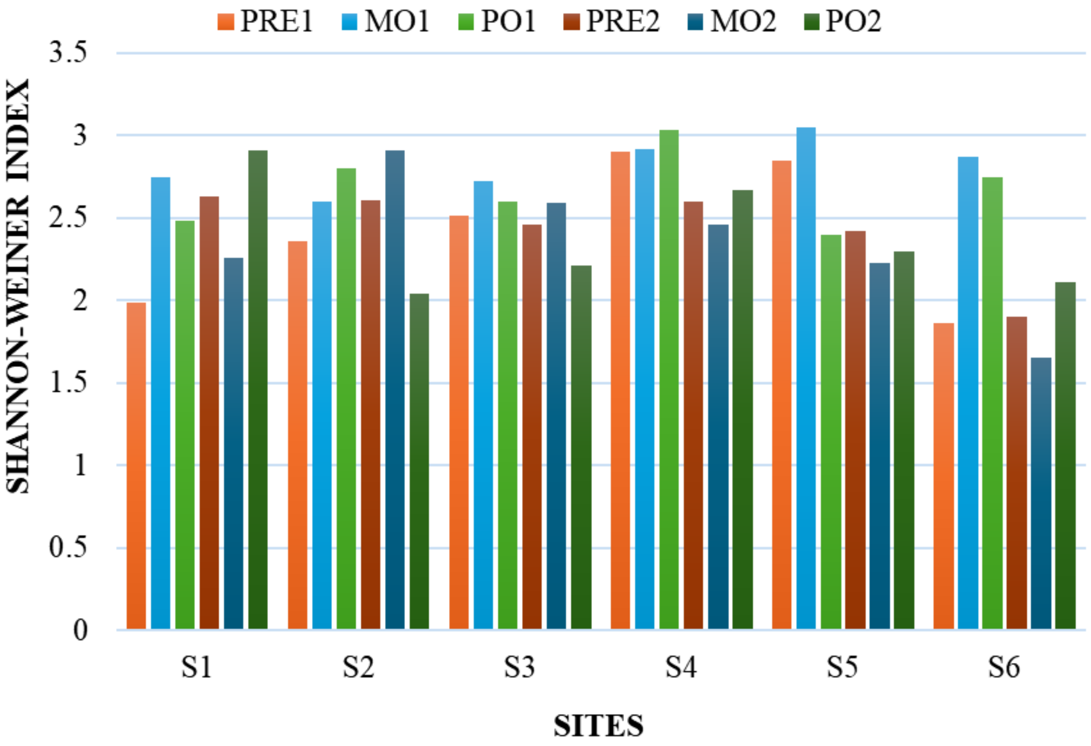


Figure 35. Seasonal and spatial variation of Shannon-Weiner Diversity Index in study sites

Table 12. Seasonal variation in number of cells, genera, dominance, evenness, richness and diversity indices in the study area

	PRE 1	**MO 1**	**PO 1**	**PRE 2**	**MO 2**	**PO 2**
No. of genera	59	76	65	68	51	50
No. of cells	391000	740000	874000	702000	276500	321000
Simpson's dominance index	0.09	0.06	0.06	0.07	0.05	0.08
Pielou's evenness index	0.33	0.38	0.36	0.31	0.51	0.39
Margalef's richness index	4.5	5.55	4.67	4.97	3.99	3.86
Shannon-Weiner diversity index	2.98	3.38	3.16	3.07	3.25	2.98

Table 13. Spatial variation in the number of cells, genera, dominance, evenness, richness and diversity indices in the study area

	S1	S2	S3	S4	S5	S6
No. of genera	61	53	43	46	68	46
No. of cells	844000	593000	247000	449500	583500	292000
Simpson's dominance index	0.11	0.07	0.07	0.05	0.10	0.08
Pielou's evenness index	0.26	0.38	0.46	0.54	0.30	0.40
Margalef's richness index	4.39	3.91	3.38	3.45	5.04	3.57
Shannon-Weiner diversity index	2.79	3.00	2.99	3.22	3.02	2.92

Seasonal variation in diversity is given in the table 12. Highest number of genera (76) and number of cells (740000) is present in MO1. PRE1 has high dominance (0.09). Evenness is high at MO2 (0.51), and richness is high at MO1 (5.55). Shannon diversity index shows a high value at MO1 (3.38).

Spatial variation in diversity is given in Table 13. The highest number of genera (61) and number of cells is present in S1 (844000). S1 also has high dominance (0.11). Evenness is high at S4 (0.54), and richness is high at S5 (5.04). Shannon diversity index shows a high value at S4 (3.22).

4.2.3.4 Hierarchical Cluster Analysis (HCA)

Hierarchical cluster analysis aids in grouping similar seasons and sites based on the algal flora present. HCA across seasons is estimated by the Bray-Curtis similarity matrix and is presented as a dendrogram in Figure 36. The dendrogram formed two distinct groups at a similarity of 0.525. The first group comprises MO2, PO2, and PRE1 and the second group comprises PRE2, PO1, and MO1. In the first group, MO2 and PO2 are similar meanwhile in the second group, PRE2 and PO1 are found similar. PO2 and MO1 stand dissimilar.

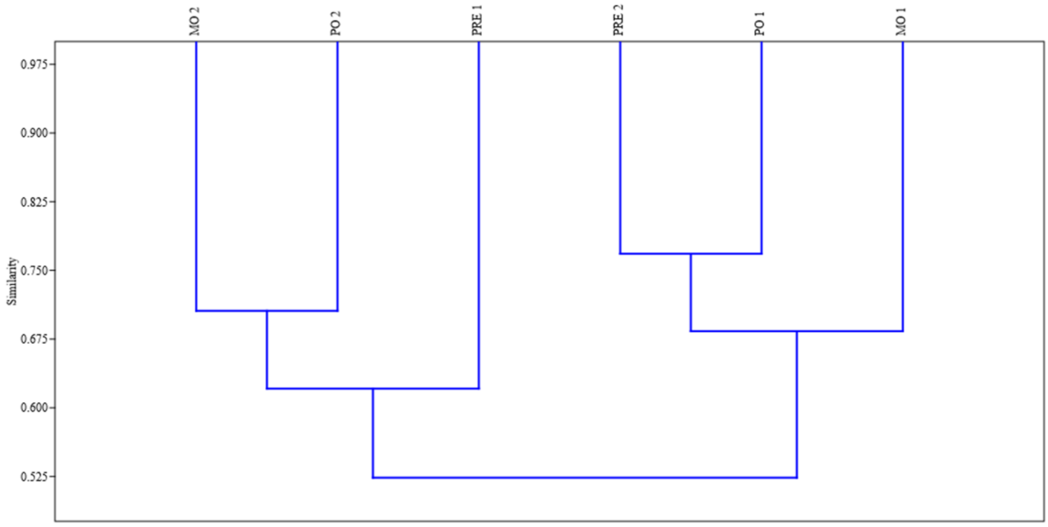


Figure 36. Dendrogram of Hierarchical cluster Analysis of algae of different seasons in the study area

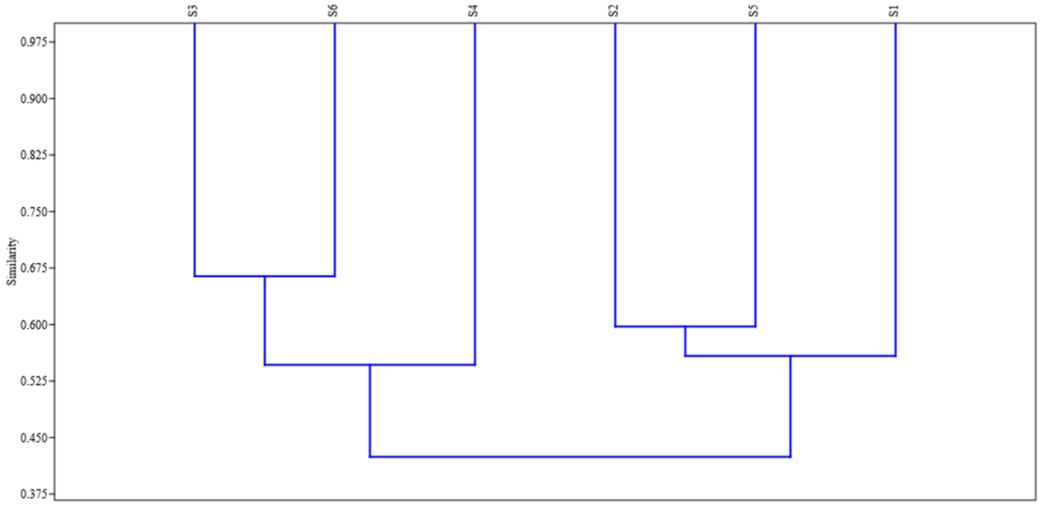


Figure 37. Dendrogram of Hierarchical cluster Analysis of algae in different sites of the study area

The HCA of sites in the study area is given as a dendrogram in Figure 37. The result shows the division of two groups at a similarity level of 0.430. The first group has S3, S6 and S4. Among them, S3 and S6 are more related. The second group consists of S2, S5 and S1. Here, S2 and S5 are more connected. S1 and S4 have a distinct and unique flora.

4.2.3.5 Non-metric multidimensional scaling (NMDS) analysis

Non-metric multidimensional scaling (NMDS) analysis is employed to discover the similarity of algal flora across seasons and sites in the study area. NMDS across seasons is presented in Figure 38. The scatter plot has each season arranged distant which indicates that the flora of each season is not similar. The dots of the first years 1, 3 and 5 are in the lower region of the plot. The closeness of 3 and 5 implies that monsoon and post-monsoon flora are similar. The second year includes 2,4 and 6. These are in the upper region of the plot.

NMDS across sites is plotted to comprehend spatial similarities and a scatter plot is prepared (Figure 39). The result exhibits close similarity in the algal flora of S3 and S6. S2 and S5 also share related flora. S1 and S4 were found isolated and have unique flora. The scatter plot of NMDS with convex hulls is represented in Figure 40. This reveals that S1, S2 and S5 are in the same quadrat while S3, S4 and S6 are in the same quadrat. S2 and S5 share matching flora while S3 and S6 have more similar flora.

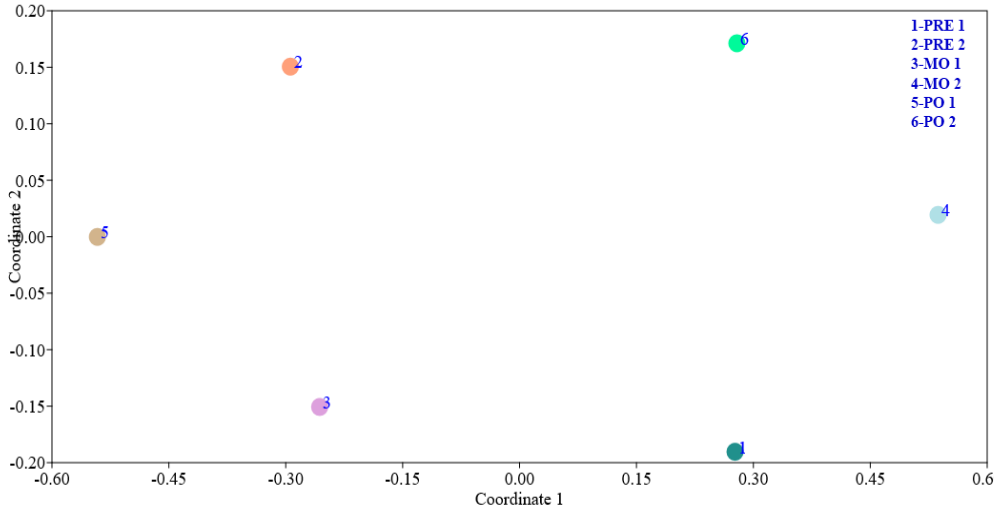


Figure 38. Scatter plot of NMDS analysis of different seasons in the study area

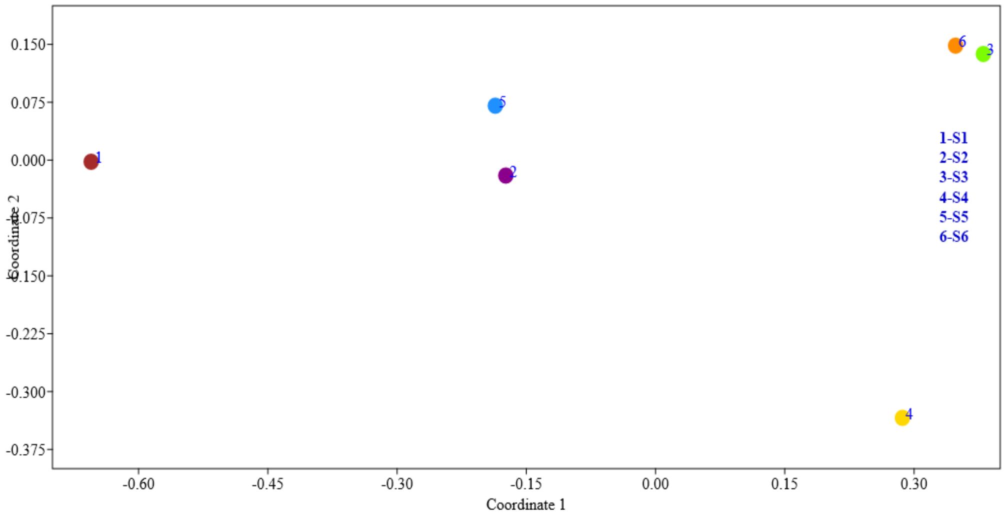


Figure 39. Scatter plot of NMDS analysis of different sites in the study area

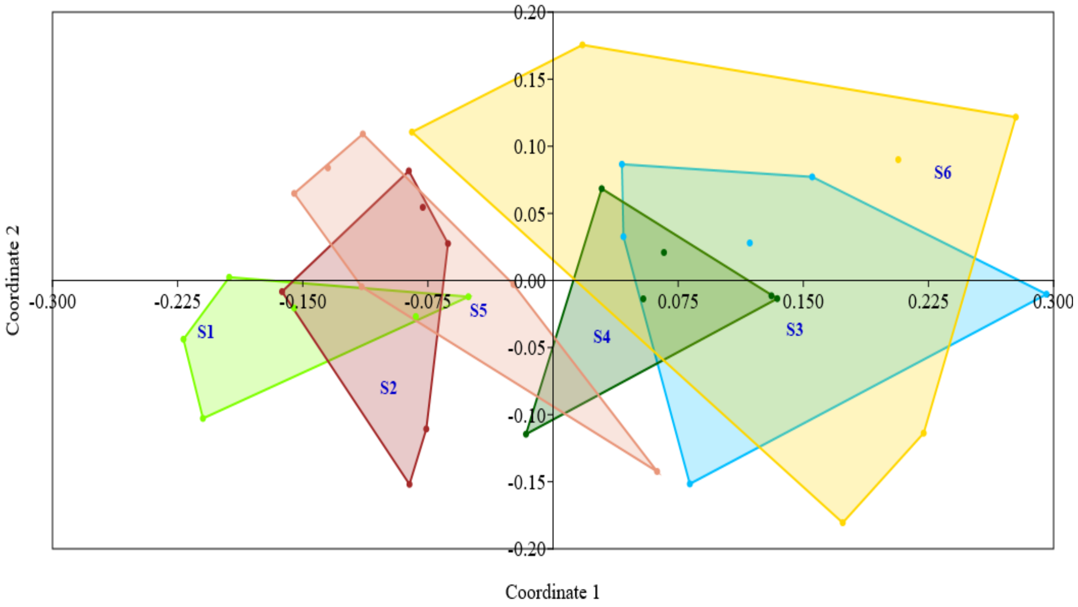


Figure 40. Scatter plot of NMDS analysis with convex hulls across sites in the study area

4.2.4 Correlation Analysis

4.2.4.1 Canonical Correspondence Analysis (CCA)

Canonical Correspondence Analysis (CCA) is performed to understand the relationship between algae and physicochemical parameters. This is performed across seasons and sites of the study area. Out of 100 genera, the 30 most frequent algal genera in the study area were selected and listed in Table 14 along with the respective abbreviation.

Table 14. Most frequent algal genera and its corresponding abbreviations used in CCA analysis

ALGAL GENUS	ABBREVIATION	ALGAL GENUS	ABBREVIATION
Achnanthes	ACH	*Navicula*	NAV
Actinotaenium	ACT	*Neidium*	NEI
Ankistrodesmus	ANK	*Nitzschia*	NIT
Closterium	CLO	*Pediastrum*	PED
Cocconeis	COC	*Peridinium*	PER
Cosmarium	COS	*Pinnularia*	PIN
Cyclotella	CYC	*Pleurotaenium*	PLE
Cylindrospermum	CYL	*Scenedesmus*	SCE
Cymbella	CYM	*Sphaerozosma*	SPH
Euglena	EUG	*Spirogyra*	SPI
Eunotia	EUN	*Staurastrum*	STA
Eusatrum	EUA	*Staurodesmus*	STD
Frustulia	FRU	*Surirella*	SUR
Gomphonema	GOM	*Synedra*	SYN
Melosira	MEL	*Trachelomonas*	TRA

Based on the Eigenvalues, Axis 1 and Axis 2 summarize the variance in data and using the tri-plot correlation of algae with parameters across seasons can be found (Appendix 21). Blue dots are algal genera, and the green lines are environmental variables considered. The length of the arrow relates to the importance of the variable. Tri-plot produced by CCA of seasons in the study area is given in Figure 41. The plot visualizes the relationship between algae, seasons and environmental variables. Both axes account for 63.6% variation. Axis 1 has an eigenvalue of 0.12 with 39.42% of variation and axis 2 has a 0.08 eigenvalue with 24.27% of variation (Appendix 20). Temperature (0.11), pH (0.52), EC (0.79), phosphate (0.82), and silicate (0.11) have a positive correlation with axis 1. DO (0.75), TDS (0.16), and nitrate (0.26) have a positive correlation on axis 2. PRE1 (0.76), MO1 (0.27) and MO2 (0.04) are positively correlated on axis 1. PRE2 (0.10), MO1 (0.23), MO2 (0.11) and PO2 (0.45) have positive canonical values on axis 2. *Spirogyra* (4.36), *Cylindrospermum* (2.11), and *Peridinium* (3.30) have a strong positive correlation with axis 1 as canonical values are above 2. *Staurodesmus*, *Trachelomonas*, *Cosmarium*, *Melosira*, *Staurastrum*, *Euglena*, *Scenedesmus*, *Cyclotella*, *Ankistrodesmus* and *Closterium* also have positive values in axis 1. *Cylindrospermum* (3.22), *Pleurotaenium* (2.44) and *Cocconeis* (2.37) have strong positive canonical values on axis 2. *Sphaerozosma*, *Cosmarium*, *Staurastrum*, *Gomphonema*, *Euglena*, *Achnanthes*, *Synedra*, *Cyclotella*, *Euastrum*, *Ankistrodesmus*, *Actinotaenium*, *Closterium*, *Cocconeis* also have positive canonical value on axis 2. Algal genera such as *Cylindrospermum*, *Cosmarium*, *Closterium*, *Staurastrum*, *Euglena*, *Cyclotella*, *Ankistrodesmus* and *Closterium* are positively correlated in axes 1 & 2. Seasons MO1 and MO2 are also positively correlated in both axes.

CCA plot (Figure 42) showing spatial correlation of algae with parameters showing 70.77% variation. They have Eigenvalues 0.25 and 0.14 for axes 1 and 2 respectively. Axis 1 has a 45.85% variation and Axis 2 have a 24.92% variation (Appendix 22). TDS, EC, DO, phosphate and silicate are positively correlated in axis 2 while no parameters are positively correlated in axis 1. S1 and S5 are positively correlated in axis (Appendix 23) 1. S3, S5 and S6 are positively correlated in axis 2. *Sphaerozosma* (3.14) has a strong positive correlation with axis 1. *Trachelomonas*, *Cosmarium*, *Staurastrum*, *Eunotia*, *Ankistrodesmus*, *Actinotaenium*, and *Closterium* are also positively correlated with axis 1. *Spirogyra* (3.72), *Achnanthes* (3.54) and *Cocconies* (4.52) are correlated positively and strongly with axis 2. *Cylindrospermum*, *Cosmarium*, *Navicula*, *Gomphonema*, *Pinnularia*, *Synedra*, *Eunotia*, *Nitzschia* and *Closterium* are also correlated positively with axis 2. *Cosmarium*, *Eunotia* and *Closterium* are seen as positively correlated with both axes.

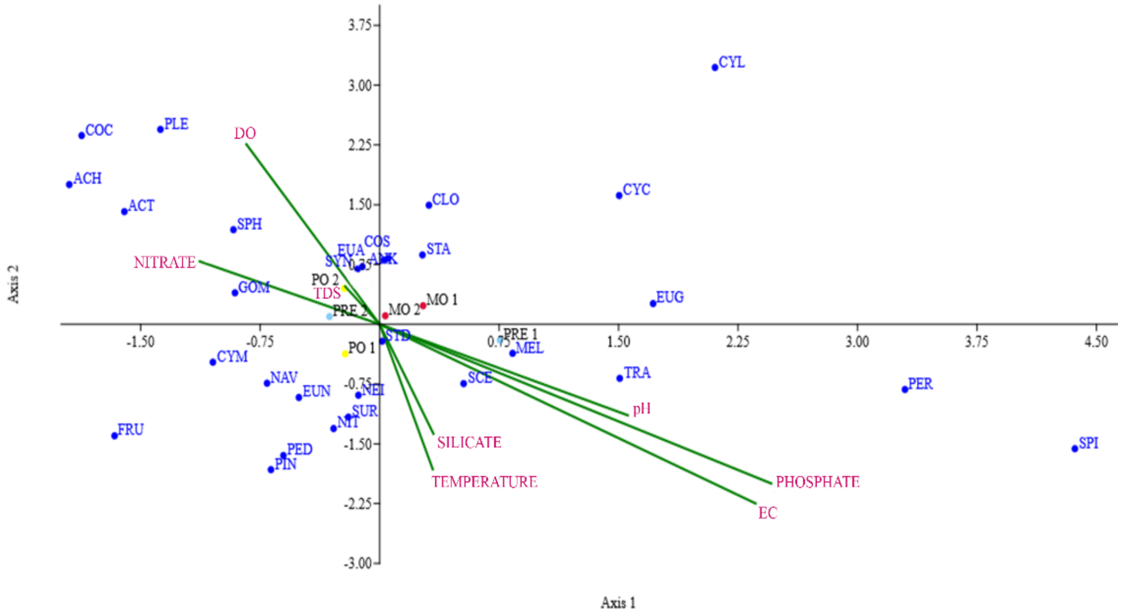


Figure 41. Tri-plot of CCA analysis across seasons in the study area

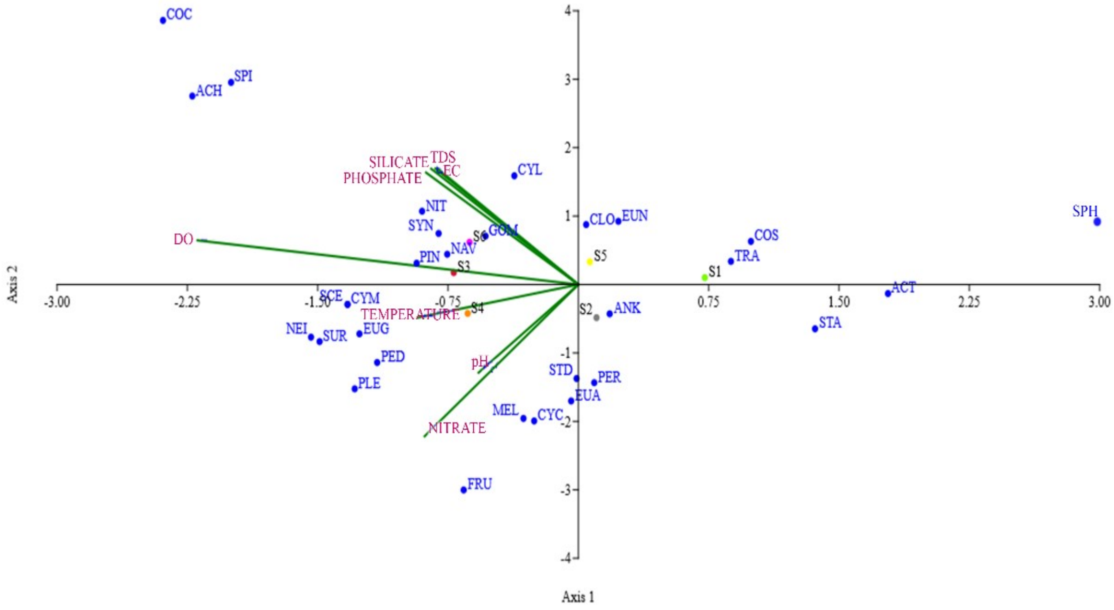


Figure 42. Tri-plot of CCA analysis across sites in the study area

4.2.4.2 Indicator analysis

Indicator analysis was done for seasons (Figure 43) and sites (Figure 44). The most characteristic species in a season or site is thus understood. From the table of p values, taxa with significant p values (p ≤ 0.05) are indicator genera of that season (Appendix 25) or site (Appendix 26). The species with significant values have their dots boxed. Figure 40 is the indicator analysis plot across seasons in the study area. Genera like *Trachelomonas* and *Peridinium* are the indicators for PRE1. *Gomphonema*, *Cymbella*, *Achnanthes* and Synedra are the indicators for PRE2. *Euglena* and *Cyclotella* for MO1 and *Navicula*, *Pinnularia*, *Cymbella* and *Frustulia* for PO2. MO2 and PO1 have no significant indicator genera. *Trachelomonas*, *Cosmarium*, *Staurastrum*, and *Eunotia* are the indicators for S1. *Melosira*, *Peridinium*, *Frustulia*, *Cyclotella* are indicators of S2. S3 have no significant indicator. *Melosira*, *Euglena* and *Scenedesmus* are indicators of S4. *Cosmarium*, *Gomphonema*, *Cymbella* and *Synedra* are indicators of S5. *Achnanthes* is the indicator for S6.

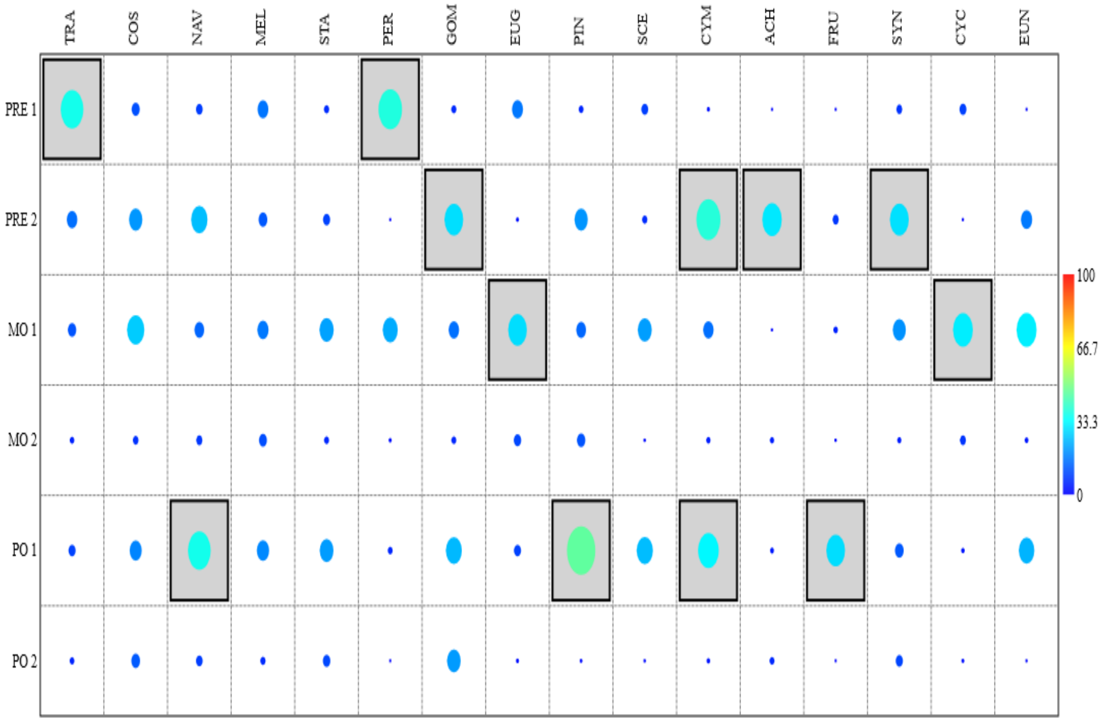


Figure 43. Indicator analysis plot across seasons of the study area

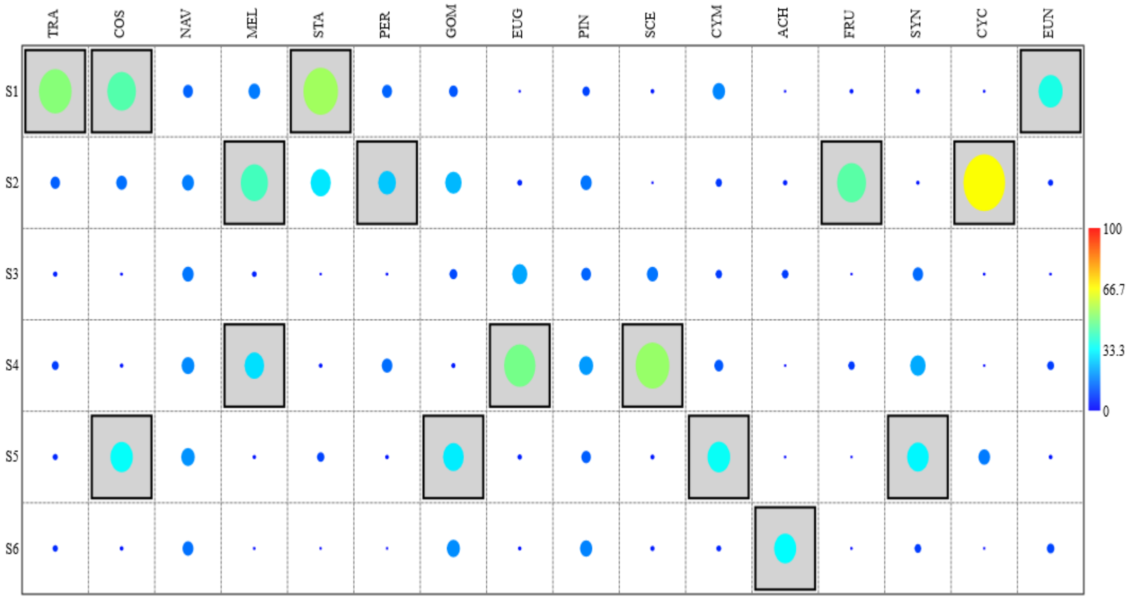


Figure 44. Indicator analysis plot across sites of the study area

4.2.5 Pollution analysis

4.2.5.1 Nutrient Pollution Index (NPI)

Nutrient Pollution Index reveals the principal nutrients nitrate and phosphate in the water bodies. NPI was calculated across seasons and sites. NPI is lowest in PO2 (0.021) and highest in PRE1 (0.034) among seasons (Table 15). Among sites, S4 has the lowest (0.023) and highest in S5 (0.034) (Table 16).

Table 15. Nutrient Pollution Index results across seasons in the study area

SEASON	Nutrient Pollution Index
PRE 1	0.034
MO1	0.032
PO1	0.030
PRE2	0.024
MO2	0.028
PO2	0.021

Table 16. Nutrient Pollution Index results across sites in the study area

SITE	Nutrient Pollution Index
S1	0.025
S2	0.027
S3	0.031
S4	0.023
S5	0.034
S6	0.030

4.2.5.2 Palmer's Pollution Index

Pollution analysis using Palmer's pollution Index is calculated seasonally (Table 17) and spatially (Table 18). Seasonal pollution analysis using the index revealed a score of 4 in PRE2 and PO1 seasons and zero in other seasons. According to the index, S2 and S5 have a score of 4. S4 and S6 have a value of 3. *Gomphonema* and *Navicula* are the only pollution-tolerant genus of algae present in the study area. S1 and S3 have zero values.

Table 17. Palmer's Algal Pollution Genus Index results across seasons in the study area

Sl No.	ALGAL GENERA	SCORE	PRE1	MO1	PO1	PRE2	MO2	PO2
1	***Gomphonema***	**1**	0	0	1	1	0	0
2	***Navicula***	**3**	0	0	3	3	0	0
	Total score		**0**	**0**	**4**	**4**	**0**	**0**

Table 18. Palmer's Algal Pollution Genus Index results across sites in the study area

Sl No.	ALGAL GENERA	SCORE	S1	S2	S3	S4	S5	S6
1	***Gomphonema***	**1**	0	1	0	0	1	0
2	***Navicula***	**3**	0	3	0	3	3	3
	Total score		**0**	**4**	**0**	**3**	**4**	**3**

4.2.5.3 Boyd’s Diversity Index (H)

Boyd’s diversity index is also calculated seasonally (Table 19) and spatially (Table 20) in the study area. On seasonal analysis, MO1 have the highest value (5.62) and PO2 has the lowest (3.94). S5 have the highest H value (5.04) and S3 have the lowest (3.38).

Table 19. Boyd’s diversity index of different seasons of the study area

SEASON	Boyd’s Diversity Index(H)
PRE1	4.50
MO1	5.62
PO1	4.67
PRE2	5.05
MO2	3.99
PO2	3.94

Table 20. Boyd’s pollution index of different sites of the study area

SITE	Boyd’s Diversity Index(H)
S1	4.39
S2	3.91
S3	3.38
S4	3.45
S5	5.04
S6	3.57

Chapter 5

Discussion

5.1 Taxonomical studies

High-altitude areas exhibit unique ecological and physiological conditions that significantly influenced the vegetation in these regions. However, studies on algae in such high-altitude areas remained limited. Wayanad, one of the high-altitude districts in Kerala, was renowned for its extensive forest cover in the state, and its location within the Western Ghats, a recognized biodiversity hotspot. The study area revealed numerous endemic and rare species. Moreover, Wayanad's fragile ecosystem rendered it highly susceptible to landslides (WGEEP, 2011). Therefore, taxonomical, and ecological investigations of algae in the freshwater resources of Wayanad emerged as an urgent and promising area of research. According to the Census Report on Water bodies, a total of 1,943 water bodies were recorded in Wayanad, including 1,434 ponds, 73 tanks, 2 lakes, and 2 reservoirs (Government of India, 2023). This study represented a pioneering effort to explore the algal flora of Wayanad.

5.1.1 Systematic account

Algae were collected from various habitats of study area (Plate 1) resulting in a total of 442 taxa belonging to 392 species and 106 genera (Table 3). The division Chlorophyta contributed the highest number of taxa, with 224 identified, followed by Bacillariophyta, which accounted for 150 taxa. Similar findings were reported in the water bodies of Central India (Srivastava et al., 2018) and the Western Himalaya (Kadam et al., 2020), where Chlorophyta emerged as the dominant division. Chrysophyta and Pyrrhophyta were the least represented divisions, with only four taxa each.

The study recorded seven classes of algae out of eleven, with Class Chlorophyceae being the most represented, followed by Bacillariophyceae. Comparable observations were noted in the algal flora of Idukki (John, 2008), which included nine classes, with Chlorophyceae as the dominant class. Xanthophyceae was the least represented class, with a single species. Phaeophyceae was not observed, as it is marine. Additionally, Class Chloromonadineae, Cryptophyceae, and Rhodophyceae were absent from the collections.

Among the orders, Heterococcales was the least represented, with a single species, while Zygnematales and the family Desmidiaceae were the most represented, comprising 143 taxa and 135 taxa, respectively. The genus *Cosmarium* exhibited the highest species diversity, with 56 taxa, reflecting a high representation of desmids. This high desmid diversity indicated low levels of pollution in the study area, as previously noted by Munawar (1970), Seenayya (1971), Rao (1975), and Coesel (1983). The genus *Navicula*, a cosmopolitan group capable of thriving in diverse conditions, was the next most diverse genus, with twenty-seven taxa documented.

5.1.2 New records from the study

Of the twelve species newly reported in India, one belonged to Bacillariophyceae, while the remaining species were from the family Chlorophyceae. Most of these new records from the study area consisted of desmids, which are known to thrive in nutrient-poor water bodies (Coesel, 1977) like those in Wayanad. Among the newly recorded species, four were identified as *Cosmarium*, two as *Staurastrum*, and one each as *Euastrum* and *Pleurotaenium*. A new variety of diatom, *Pinnularia subcapitata* var. *subrostrata*, was reported for the first time in India. New records of species from the order Chlorococcales included *Elakatothrix lacustris*, *Scenedesmus arthrodesmiformis*, and *Nephrocytium allantoideum*. Another species, *Elakatothrix viridis*, previously reported from a high-altitude lake in India (Das & Keshri, 2012), further assured the high altitude specificity of the genus.

Of the 119 species newly reported in Kerala, 66 were diatoms, 38 were desmids, eight belonged to Chlorococcales, six to Euglenophyceae, and one to Cyanophyceae. The genus *Triplastrum*, which has a limited distribution and is typically found in warm climates such as Africa, France, Turkestan, Japan, and India (Coesel, 1996), was documented in the study area. *Triplastrum abbreviatum* was recorded in India (Jose et al., 2022) for the first time in 79 years since the initial report by Iyengar and Ramanathan (1942). Similarly, *Achnanthes crenata* and *Achnanthes elata* were reported in India for the first time in 64 years since Gandhi (1960c). The study also recorded *Actinastrum aciculare* var. *minimum*, marking the second report of this species in India after Jena and Adhikary (2007). Rare genus with limited distributions, such as *Trochiscia*, were also observed in the study area. *Trochiscia granulata* was reported as the third occurrence in India, following earlier reports by Gupta (2012) and Jaiswal (2017).

These new and rare reports underline the significance and the gap in algal exploration in biodiversity-rich areas like Wayanad. The distinctive climate and physiological conditions of high-altitude districts such as Wayanad provide a habitat for rare algae species. The current study revealed a remarkable diversity of algae, emphasizing the strong influence of the study site's geography and climate on algal composition.

5.2 Ecological studies

5.2.1 Physico-chemical parameters

Eight physicochemical parameters such as temperature, pH, total dissolved solids, electrical conductivity, dissolved oxygen, nitrate, phosphate, and silicate were tested seasonally in six study sites for two years. The results showed that the trend of these parameters vary according to water bodies and seasons.

5.2.1.1 Meteorological data

5.2.1.1.1. Rainfall

Rainfall profoundly impacted the physicochemical properties and algal diversity of water bodies, as recognized by Seo et al. (2001), Li et al. (2015), and Kitan and Nang (2020). The intensity of the effects varied depending on the nature of the water body. In lentic systems, precipitation resulted in the dilution of nutrients within the system and the runoff of nutrients from surrounding areas. Besides, in lotic systems, precipitation increased flow rates and contributed additional nutrients during water flow.

Wayanad experienced excess rainfall for half the year and deficiency in rainfall for four months in 2019 (Figure 2). In 2020, six months had excess rainfall, while three months were rainfall deficient (Figure 3). In 2021, all months except March received excess rainfall (Figure 4).

Rainfall patterns in Wayanad have become increasingly asymmetric, influenced by significant climate changes, as noted by Madhu (2021). The typical seasonal trends in the parameters of lentic and lotic water bodies were disrupted by heavy pre-monsoon and post-monsoon showers and reduced monsoon rainfall. The consequences of heavy rains and floods in August 2019 and 2020 significantly influenced and altered expected outcomes. Future simulations predicted similar heavy summer rainfall in Wayanad in the coming years (Riya et al., 2022).

These climatic changes affected water quality and algal diversity in water bodies as observed by Xia et al. (2015). The massive floods of Kerala had a profound impact on the parameters and algal flora of water bodies in the study area, as previously documented by Jayalakshmi and John (2019) and Shenoy et al. (2019).

5.2.1.2 Temperature

The temperature of a water body is influenced by factors such as altitude, flow rate, precipitation, and the surrounding canopy. The seasonal and spatial variation in temperature observed during the study was significant. As the study site is a high-altitude district, the temperature ranged from 22.8˚C to 33.33˚C, reflecting a cool and pleasant climate. A similar temperature range of 23.9˚C to 33.2˚C was reported in the ponds of Wayanad by Krupa et al. (2020). Pre-monsoons exhibited the highest mean temperatures due to increased sunlight, whereas monsoons recorded the lowest mean temperatures in both years of the study (Figure 6), consistent with observations by Jithesh and Radhakrishnan (2020) and Rajan and Keerthitha (2021).

Site-specific variations were also noted, with Pookode Lake exhibiting the lowest mean temperature among all study sites (Figure 7). This high-altitude lake, surrounded by evergreen forests and abundant aquatic plants and weeds, experienced reduced water temperatures due to shading and limited sunlight penetration. The lowest temperature recorded during the study occurred in the post-monsoon season at the Papanasini River (Figure 8), where precipitation and the increased flow rate significantly lowered the temperature. The river, originating in the high altitudes of the Brahmagiri Hills and flowing through dense forests, remained cooler than other water bodies. In contrast, Heart Lake experienced the highest temperatures among the study sites due to its exposure to direct sunlight at the highest altitude of the study area. Surrounded by tropical shola grasslands and rocky terrains, the lake absorbed significant heat from direct sunlight. The highest temperature was recorded during the post-monsoon period at Heart Lake (Figure 8), as reduced precipitation led to a further rise in temperature.

Precipitation significantly influenced water temperature. In Heart Lake and Karapuzha Dam, the post-monsoon season exhibited the highest temperatures due to reduced precipitation during this period. The temperature in Karapuzha Dam ranged between 29.2˚C and 33.3˚C, with the lowest temperatures recorded during the monsoon and the highest during the pre-monsoon season. However, the overall seasonal variation in temperature has decreased, now ranging from 24.5˚C to 29.3˚C (Panikkar et al., 2024).

In Pookode Lake, the temperature range previously reported as 14.6˚C to 26.7˚C (Nirmala et al., 1991) has increased to 24.5˚C to 28.3˚C in the present study. The earlier trend of low temperatures in the pre-monsoon and elevated temperatures in the post-monsoon (Nirmala et al., 1991) has now shifted to lower temperatures in the post-monsoon and higher temperatures in the pre-monsoon. In Pookode Lake, Banasurasagar Dam, and Kuruva Islands, pre-monsoon temperatures were the highest due to minimal rainfall. Monsoon rains subsequently reduced the elevated pre-monsoon temperatures. The post-monsoon temperature either decreased or increased depending on the amount of precipitation received during the season.

A different trend was observed in the Papanasini River. In the first year of the study, the monsoon season exhibited the highest temperature, attributed to delayed monsoon rains in 2019 (Figure 2). In the second year, the highest temperature was recorded during the pre-monsoon season, which declined through the monsoon and post-monsoon periods due to increased precipitation and flow rates during these seasons (Figure 4).

Temperature showed a significant positive correlation with electrical conductivity (Figure 5), consistent with the findings of Kondulkar et al. (2015). This relationship occurred because higher temperatures enhanced ion mobility, thereby increasing the water's ability to conduct electrical charges (Dewangan et al., 2023).

5.2.1.3 pH

The pH of a water body determines its suitability for aquatic life and drinking purposes. It was found to be influenced by temperature, precipitation, and the presence of organic matter. A reduction in carbon dioxide levels due to plant and algal utilization and evaporation during elevated temperatures increased the pH. In contrast, an increase in carbon dioxide levels due to precipitation, organic matter decomposition, and respiration reduced the pH.

The water bodies of Wayanad exhibited an alkaline nature, with most pH values above 7. The study found pH levels ranging between 6.13 and 9.53, consistent with a similar range of 6.32 to 8.26 reported in the groundwater of Wayanad by Richard et al. (2016). Significant seasonal variations in pH were observed, with the monsoon season recording the lowest mean pH and the pre-monsoon season the highest (Figure 9). The low pH during the monsoon was also noted by Ajayan et al. (2013) and was attributed to acid leaching from rainwater, as observed in Karapuzha Dam (Panikkar et al., 2024). The high pre-monsoon pH was linked to elevated temperatures and minimal precipitation, resulting in nutrient concentration. Similar findings were reported by Kaushik and Suksena (1999), Nazneen et al. (2019), Rao et al. (2019), and Ghildyal and Chaudhary (2023).

Monsoon rains typically lowered the elevated pre-monsoon pH. However, heavy rainfall could increase the pH of water bodies. Unusual heavy rains and floods during the study period altered this trend, increasing the pH of water bodies. This phenomenon was consistent with the post-flood pH elevation observed by Saha et al. (2020). For instance, the pH of Karapuzha Dam, previously reported in the range of 6.7 to 9.1, increased to 7 to 8.4 (Panikkar et al., 2024). Karapuzha Dam exhibited the lowest mean pH among the study sites (Figure 10). The Karapuzha River and nearby streams introduced organic acids and nutrients into the dam, contributing to a lower pH. The pH decreased during the monsoon of the first year but increased during the monsoon and post-monsoon of the second year due to the excess rainfall and flooding in August 2020 (Figure 3). The pre-monsoon and monsoon seasons of the first year were found to be alkaline and exceeded the permissible limits of WHO (1999).

Lentic water bodies had higher pH levels than lotic ones, due to the elevated photosynthesis rates of algae (Salem, 2021). Heart Lake recorded the highest mean pH among the sites, attributed to reduced carbon dioxide levels caused by elevated temperatures and decreased atmospheric pressure. These conditions reduced the dissolution of carbon dioxide, thereby increasing the pH. Additionally, algae and aquatic plants utilized dissolved carbon dioxide, further elevating pH levels. The highest pH was observed in the post-monsoon season at Heart Lake (Figure 11), where high evaporation rates concentrated nutrients and released carbon dioxide, rendering the lake more alkaline. The post-monsoon pH at Heart Lake in the first year also exceeded WHO (1999) limits.

At Pookode Lake, the pH range, previously reported as 6 to 7.1 (Nirmala et al., 1991), increased to 6.1 to 8.56 in the study. The earlier trend of the lowest pH in the pre-monsoon and highest in the monsoon (Nirmala et al., 1991) shifted to the lowest in the monsoon and highest in the pre-monsoon. The minimum pH (6.13) was recorded during the monsoon at Pookode Lake (Figure 11), falling below WHO (1999) limits. Historically, Pookode Lake exhibited an acidic nature with a mean pH of 5.6 due to organic acids from surrounding forests and spring water intrusion (Das et al., 2021). During the monsoon, runoff from nearby fields and forests introduced nutrients and organic acids into the lake, lowering the pH. Organic matter from sources such as leaf debris, weeds, and algae on decomposition, released carbon dioxide, which further decreased the pH. Invasive weed *Cabomba furcata* were present throughout the study period, along with *Lantana camara* and *Eichornia* sp. along the banks. In Banasurasagar Dam, the heavy rains of August 2019 (Figure 2) caused floods in parts of Wayanad, mixing organic acids and nutrients into the dam and temporarily increasing the pH during the monsoon. In the second year, pH levels declined during the monsoon and post-monsoon seasons.

In lotic water bodies, precipitation significantly impacted pH by increasing the flow rate. For example, Kuruva Islands and Papanasini River exhibited high pH levels during the pre-monsoon season, which decreased during the monsoon and post-monsoon seasons due to accelerated flow and the introduction of minerals and nutrients along their courses, reducing the pH.

5.2.1.4 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) values indicate the concentration of dissolved substances in water. In the study area, TDS ranged between 5.6 ppm and 100 ppm, well within the permissible limits established by WHO (1999). Monsoon rains diluted the water bodies, resulting in the lowest mean TDS values during the monsoon season (Figure 9). Conversely, the pre-monsoon season recorded the highest mean TDS values due to reduced water levels, minimal precipitation, and higher nutrient concentrations. These findings align with observations by Priju et al. (2016), Jithesh and Radhakrishnan (2020), and Kannan and Joseph (2022).

Lotic water bodies exhibited higher TDS levels compared to lentic ones, primarily due to surface runoff containing ionic substances (Salem, 2021). High silicate content and electrical conductivity in lotic systems also contributed to elevated TDS levels. TDS, composed of dissolved solids, directly influences the electrical conductivity of water, as noted by Sharma and Chhipa (2013), Rusydi (2018), and Jothivenkatachalam et al. (2010). Minerals such as silicate significantly contribute to TDS values, as reported by Day and Nightingale (1984), Thirumalini and Joseph (2009), and Khan et al. (2015). These associations resulted in a significant positive correlation between TDS, electrical conductivity (EC), and silicate (Figure 5).

TDS exhibited substantial spatial variation across the study area. Heart Lake, situated at a high altitude with minimal pollutants and minerals, recorded the lowest mean TDS values among all sites (Figure 13). Banasurasagar Dam displayed the lowest TDS value during the post-monsoon season (Figure 14), indicating that the dam is primarily freshwater with limited salt or substance mixing from external sources. In contrast, Kuruva Islands recorded the highest mean TDS values among all sites (Figure 13), due to nutrient accumulation as it is the confluence point of tributaries of Kabini. The sandy bottom, rich in silica, further contributed to elevated TDS levels. The highest TDS value within the study area was recorded during the pre-monsoon season at Kuruva Islands (Figure 14), where minimal dilution led to the concentration of salts and minerals.

Lentic water bodies, such as Pookode Lake, Banasurasagar Dam, and Heart Lake, exhibited lower TDS values compared to lotic systems like Kuruva Islands and Papanasini River, which had higher EC and silicate levels along with TDS. In lentic systems, precipitation diluted nutrients, resulting in reduced TDS levels, particularly during the monsoon season. However, in Heart Lake, TDS increased during the monsoon and decreased in the post-monsoon season, due to mineral inflows caused by precipitations.

The Karapuzha Reservoir exhibited TDS values ranging from 47.33 ppm to 61.66 ppm, which were later reported to have increased to 53.8 ppm to 138.9 ppm by Panikkar et al. (2024). Unlike other lentic water bodies, Karapuzha Dam showed an increase in TDS during the monsoon due to nutrient inflow. The first year’s monsoon season experienced a slight TDS increase due to deficient rainfall, while in the second year, TDS decreased during the monsoon but rose again in the post-monsoon season.

In Pookode Lake, TDS values decreased from 11.66 ppm to 27 ppm, compared to an earlier range of 17.73 ppm to 32.8 ppm reported by Nirmala et al. (1991).

Lotic water bodies such as Kuruva Islands and Papanasini River experienced TDS increases during the monsoon season due to elevated flow rates and the accumulation of salts and silicates. However, during the second year, both sites exhibited reduced TDS levels during the monsoon season, influenced by variations in rainfall intensity and nutrient runoff.

5.2.1.5 Electrical conductivity (EC)

Electrical conductivity (EC) indicated the presence of electrolytes in water and its ability to conduct electricity. In the study area, EC ranged from 6.66 µmho/cm to 135.66 µmho/cm. EC exhibited significant spatial variation. EC was lowest during the monsoon season, due to dilution of nutrients by monsoon rains, and highest during the pre-monsoon season, when minimal precipitation led to higher concentrations of minerals and salts, exacerbated by elevated temperatures and evaporation (Figure 15). Similar seasonal trends in EC had been reported by Sheetal et al. (2017) and Kumari and Sinha (2023). A positive correlation between EC and temperature, further supported this observation.

Sites such as Kuruva Islands and Papanasini River, which exhibited high TDS, also had high EC, demonstrating the strong positive correlation between EC and TDS in natural waters, as noted by Jothivenkatachalam et al. (2010), Sharma and Chhipa (2013), and Rusydi (2018). Additionally, EC showed significant positive correlations with temperature, TDS, and silicate (Figure 5), consistent with the findings of Day and Nightingale (1984). As temperature increased, ion mobility also increased, which enhanced the conducting capacity of water (Dewangan, 2023; Gaur et al., 2022). Since TDS included conducting ions, an increase in TDS naturally corresponded to an increase in EC. Silicate, being a non-conductor, did not contribute directly to EC but increased it when combined with other conducting ions.

Spatially, Heart Lake exhibited the lowest mean EC (Figure 16). The lowest EC during the monsoon season at Heart Lake could be attributed to limited water intrusion and low temperatures, both of which reduced conductivity. Karapuzha Dam, in contrast, had the highest mean EC among all sites (Figure 16), due to the influx of ions from Karapuzha River and nearby streams, which elevated EC levels. The maximum EC value in the study area was recorded during the pre-monsoon season at Kuruva Islands in the first year (Figure 17). The site’s high silicate and TDS content which concentrated in pre-monsoon contributed to the increased EC.

In lentic water bodies such as Pookode Lake, Banasurasagar Dam, Heart Lake, and Karapuzha Dam, precipitation diluted the nutrients, resulting in lower EC values. This decline during the monsoon season was often compensated for in the post-monsoon season, especially when rainfall was minimal. At Pookode Lake, EC ranged from 12.66 µmho/cm to 30.33 µmho/cm, showing a decrease from the range reported by Nirmala et al. (1991). In Banasurasagar Dam, EC decreased during the monsoon in the first year but increased during the second-year monsoon. TDS values were higher during pre-monsoon, but the electrical conductivity was lower, due to the pre-monsoon showers of the second year, which reduced EC. In Karapuzha Dam, reduced rainfall during the first year’s monsoon led to higher EC, which dropped with the post-monsoon rains. In Heart Lake, post-monsoon precipitation in the second year led to an increase in EC during the monsoon, followed by a decrease in post-monsoon of Banasurasagar Dam.

Lotic water bodies like Kuruva Islands and Papanasini River exhibited increased EC during the monsoon season, primarily due to higher flow rates and the accumulation of salts and silicates. However, in the first year at Kuruva Islands, heavy monsoon rains and floods led to a decrease in EC. Similarly, in the second year, a slight reduction in EC was observed during the monsoon in Papanasini, due to the pre-monsoon rains.

5.2.1.6 Dissolved Oxygen (DO)

Dissolved oxygen (DO) indicated the water quality and its ability to support aquatic organisms. DO was influenced by temperature, the presence of organic matter, and the flow rate of water bodies. In the study area, DO ranged from 3.8 mg/L to 7.5 mg/L. A similar range of DO between 4.84 mg/L and 7.75 mg/L (Richard et al., 2016) and 3.6 mg/L to 9.1 mg/L (Krupa et al., 2020) had been previously recorded from Wayanad. DO exhibited minimal variation across seasons but showed significant spatial variation in the study area. The range of DO was narrower in the second year. While monsoon seasons typically increased the DO of water bodies, sudden growth of aquatic plants, floods, and nutrient runoff could reduce DO. The pre-monsoon season had the lowest mean DO among seasons, a trend also observed by Krupa et al. (2020) and Panikkar et al. (2024) in Wayanad. The low DO during the pre-monsoon season was attributed to increased water temperature (Kaushik & Saksena, 1999; Garg et al., 2010). The post-monsoon season had the highest mean DO, as reported by Panikkar et al. (2024) in a study at Karapuzha Dam of Wayanad. Elevated temperatures during the pre-monsoon season reduced DO, while high oxygen dissolution in water resulted in high DO during post-monsoon (Hassan et al., 2017).

Lotic water bodies exhibited higher DO levels in the study, owing to increased aeration and turbulence from the flow of water. The minimum mean DO was recorded at Karapuzha Dam, while the maximum was found at Papanasini River (Figure 19). At Karapuzha Dam, DO ranged from 3.8 mg/L to 7.3 mg/L which increased recently between 5.9 mg/L and 7.88 mg/L (Panikkar et al., 2024). The minimum DO was observed during the pre-monsoon season at Karapuzha Dam (Figure 20). A key factor influencing DO was temperature. Elevated temperatures at the dam during the pre-monsoon season facilitated the escape of dissolved gases, such as oxygen, thereby reducing DO. Additionally, the stagnant nature of the dam water, combined with insufficient aeration, allowed consumption of available oxygen for the decomposition of aquatic plants and algae. Although DO increase during the monsoon season in both years, the excessive accumulation of nitrates and phosphates at Karapuzha Dam resulted in nutrient accumulation, which further hindered DO levels. The elevated levels of EC and TDS were indicative of nutrient-rich inflows, which, while contributing to high species richness at the site, also led to reduced oxygen levels in the water. Only the post-monsoon season in both years had DO within permissible limits at Karapuzha Dam.

Papanasini River showed a high mean value of DO (Figure 19), with maximum DO record during the pre-monsoon season (Figure 18). The river originated from the virgin forests of Brahmagiri Hills, which reduced water temperature and limited the mixing of chemicals. The flowing water was naturally aerated, contributing to elevated DO levels. However, during the monsoon season, DO decreased as monsoon rains mixed cremated ashes with the water body, lowering DO levels in both years. Despite this, only the post-monsoon period of the first year recorded DO levels outside permissible limits.

Typically, high precipitation and low temperatures during the monsoon season enhanced DO levels in water bodies. However, nutrient runoff during monsoons could sometimes lower DO levels. At Pookode Lake, DO ranged from 6.27 mg/L to 7.35 mg/L (Nirmala et al., 1991), and later changed between 4.03 mg/L and 6.99 mg/L (Das et al., 2017). In this study, DO ranged from 5.06 mg/L to 6.08 mg/L, showing a decrease over the years. Except for the pre-monsoon and post-monsoon of the second year, all seasons at Pookode Lake had DO levels within permissible limits. DO at Pookode Lake decreased during the monsoon season, primarily due to the rapid growth of aquatic plants fostered by increased rainfall. These numerous aquatic plants, along with fish, leaf litter, and other organic matter, consumed DO from the water. Additionally, nutrient runoff from nearby fields contributed to a decrease in DO during the monsoon. Pookode Lake, being nutrient-rich, had the highest number of cells. Organic matter, such as leaf litter, required oxygen for decomposition, which further reduced DO levels. The lake also had elevated levels of phosphate, a limiting nutrient that impacted its productivity. Low nitrate content corresponded to the demand for nitrate by algae, aquatic plants, and invasive species. The high dependence of various amphibians and plants on DO further lower DO levels in the lake.

Banasurasagar Dam experienced low DO during the first-year monsoon due to nutrient inflows. During post-monsoon, nutrient runoff from the monsoon season became concentrated, further reducing DO levels. In the second year, DO increased during the monsoon. In Banasurasagar Dam, only the pre-monsoon of the first year and the monsoon of the second year had DO levels within permissible limits. In Heart Lake, DO increased during the first-year monsoon but decreased in the second-year monsoon. During the first-year pre-monsoon and post-monsoon, as well as the second-year monsoon, DO levels exceeded permissible limits. At Kuruva Islands, DO decreased during the first-year monsoon, but showed a slight increase in the second-year monsoon. At Kuruva Islands, only the first-year monsoon and the second-year post-monsoon had DO levels not within permissible limits.

5.2.1.7 Nitrate

Nitrate was one of the most widespread pollutants in water bodies, entering primarily through agricultural or wastewater runoff. The main sources of nitrate in water bodies were fertilizers and sewage (Panikkar et al., 2024). Nitrate accelerated the decomposition of organic matter in water bodies (Bulseco, 2019), which was converted into ammonia and subsequently into nitrates. A range between 0.002 mg/L and 0.13 mg/L of nitrate is found in the study area. In the Sulthan Bathery block of Wayanad, high nitrate values from fertilizers and pesticides were found in groundwater, ranging from 0.09 mg/L to 20.37 mg/L (Richard et al., 2016).

Significant seasonal variation was observed in nitrate levels. The lowest nitrate values were recorded during the post-monsoon season of the second year, while the highest were found in the pre-monsoon of the second year (Figure 21). In both years, post-monsoon showed lower nitrate values, as observed by Kaushik and Saksena (1999). During the first year, nitrate increased in the monsoon due to nutrient inflows but decreased during post-monsoon. In the second year, pre-monsoon showers caused an influx of nutrients, thereby increasing nitrate during pre-monsoon. This elevated level of nitrate was reduced during monsoon and post-monsoon periods through the uptake of plants and nutrient cycling. The lowest mean nitrate value was found at Pookode Lake, where nitrate was readily consumed by aquatic weeds, plants, and algae. Heart Lake exhibited a higher mean nitrate level among the sites (Figure 22), even though the minimum nitrate value was recorded during the pre-monsoon of the first year at the same site (Figure 23). Heart Lake showed high variability in nitrate values, and the presence of high organic matter in the lake contributed to the elevated nitrate levels. The highest nitrate value was recorded during the pre-monsoon at Kuruva Islands (Figure 23), where the confluence of the Panamaram and Mananthavady Rivers carried nutrients that raised nitrate levels.

At Pookode Lake, a range of 0.002 to 0.004 mg/L was noted by Nirmala et al. (1991), with nitrate increasing during the monsoon season. Das et al. (2017) found nitrate levels ranging between 1.2 mg/L and 1.9 mg/L at Pookode Lake, showing an increase in nitrate levels over the years. Nitrate levels between 0.007 mg/L and 0.09 mg/L, with nitrate decreasing during both monsoon seasons was recorded in this study from Pookode. Pre-monsoon rains caused nitrate inflow, which was reduced during monsoon by the uptake of growing aquatic plants and weeds. In Banasurasagar Dam, nitrate levels decreased due to flooding during the first-year monsoon, but an increase was observed in the second-year monsoon, which was attributed to nutrient inflow. In Kuruva Islands, heavy precipitation during the monsoon increased dilution, thus decreasing nitrate content. At Karapuzha Dam, nitrate levels ranged from 2.3 mg/L to 16 mg/L, with high values in the post-monsoon season, as reported by Panikkar et al. (2024). This differed from the findings of this study.

Nitrate increased during the monsoon at Heart Lake, Karapuzha Dam, and Papanasini River, as sampling was conducted before the floods, showing a similar trend of increased nitrate levels in the first-year monsoon due to nutrient mixing. However, in the second year, monsoon rains led to a reduction in nitrate levels due to dilution. Overall, nitrate content in the study area was low, and all nitrate values remained within permissible limits.

5.2.1.8 Phosphate

Phosphate was considered as the primary limiting nutrient in algal growth. Primary productivity in freshwater bodies was associated with phosphate levels (Wetzel, 2001). Phosphate typically settled in the sediments at the bottom of nutrient-rich lakes. During the summer or flooding, these sediments mixed with the water, increasing phosphate levels. Groundwater samples from the Sulthan Bathery block of Wayanad recorded phosphate levels between 0.025 mg/L and 4.5 mg/L (Richard et al., 2016), which exceeded permissible limits, indicating contamination from pesticides. However, phosphate in the study area ranged from 0.01 mg/L to 0.2 mg/L within permissible limits.

The lowest mean phosphate values were noted during the post-monsoon season of the second year (Figure 24). The highest phosphate levels were observed in the pre-monsoon season of the first year (Dhinamala et al., 2015). This trend was also observed in the phosphate levels of Pookode Lake (Nirmala et al., 1991). The release of inorganic phosphates from waters in the summer season was a contributing factor, as increased water temperatures could promote phosphate release (Cheng et al., 2020). In the second year, phosphate increased during the monsoon season and decreased in post-monsoon.

Phosphate exhibited significant spatial variation in the study area. In Pookode Lake, phosphate ranged from 0.02 mg/L to 0.08 mg/L (Nirmala et al., 1991), which later increased to a range of 0.087 mg/L to 0.66 mg/L (Das et al., 2017). In the present study, phosphate levels ranged from 0.01 mg/L to 0.19 mg/L in Pookode Lake. Pookode Lake exhibited the lowest mean phosphate value among the study sites

(Figure 25). Phosphate concentrations were typically low in a well-oxygenated lake like Pookode, with the lowest values during the monsoon due to dilution (Figure 26). Karapuzha Dam had the highest mean phosphate value among the sites (Figure 25), attributed to the contributions from Karapuzha River and other nutrient-rich streams. The highest phosphate value was observed in the pre-monsoon season of Papanasini River (Figure 24). The elevated phosphate levels in Papanasini River were associated with the ashes released during rituals and offerings in this religiously significant river, contributing to phosphate accumulation. Animal waste and leaching from rocks and soils during water flow could also contribute to increased phosphate levels in the water body.

The flood of 2019 caused a decrease in phosphate content in lentic water bodies during the monsoon season of the first year. In Pookode Lake, Banasurasagar Dam, Heart Lake, and Karapuzha Dam, heavy monsoon rains reduced phosphate levels in the first year. In the second year, phosphate levels increased during the monsoon due to nutrient inflows. In Pookode Lake, phosphate levels were low in both years' monsoons as plants and invasive weeds utilized the available phosphate for their growth. In Karapuzha Dam, phosphate ranged from 0.11 mg/L to 0.20 mg/L, but this range later increased to 1.6 mg/L to 12.27 mg/L (Panikkar et al., 2024).

In lotic water bodies, monsoons typically increased phosphate content. In the Kuruva Islands, no such increase was observed during the first year due to floods which also affected Kuruva's water. Nevertheless, the phosphate value during the monsoon remained stable and did not increase. In the second year, phosphate levels in Papanasini River were lower during the monsoon. Cremated ashes from religious ceremonies were the main source of phosphate in the river. The sampling period during the second-year monsoon was limited due to COVID-19 restrictions, resulting in lower phosphate levels during that season. Phosphate levels were found to be low and within permissible limits across the study sites.

5.2.1.9 Silicate

Silicate, a natural compound found in sand, is the primary nutrient utilized by diatoms for their growth. The presence of silicate in water bodies results from the geological rock formations beneath them. Elevated temperatures and heavy rainfall can accelerate the weathering process (Amrish et al., 2022). During weathering, rocks release silicate, which then enters water bodies through the course of flow. In the study area, silicate concentrations ranged from 0.005 mg/L to 1.23 mg/L.

The study revealed significant seasonal and spatial variation in silicate levels. The pre-monsoon season exhibited the lowest mean values, while the post-monsoon season had the highest (Figure 27). Monsoon rains contributed to the mixing of silicates released by sand through weathering, which became concentrated during the post-monsoon, leading to high silicate values (Anushmali & Ramanathan, 2007; Deka et al., 2015). The lowest mean silicate value was observed at Banasurasagar Dam (Figure 28), a lentic freshwater body with a limited course of flow. In Banasurasagar Dam, diatoms utilized the available silica, dominating other algae classes, which resulted in low silicate values in the water. A similar observation was noted by Zhang et al. (2019) in a reservoir dominated by diatoms. Rao and Madhyastha (1990) also recognized low silicate content associated with an increase in diatom populations. The lowest silicate value was observed in the pre-monsoon season of Heart Lake (Figure 29), a lentic freshwater body at high altitudes, where the silicate content was naturally low.

Silicate content in water bodies was found to correlate directly with total dissolved solids (TDS) and electrical conductivity (EC) (Figure 5). Salts such as silica contribute to TDS, which in turn affects the conductivity of water (Day & Nightingale, 1984). The Papanasini River exhibited a high mean value of silicate (Figure 28), as its sandy bottom, composed of silica, released silicate into the water during weathering. The highest silicate value was recorded during the post-monsoon season at the Kuruva Islands. The water temperature in post-monsoon conditions accelerated weathering, leading to the highest silicate concentration in the Kuruva Islands (Figure 29).

In lentic water bodies like Pookode Lake, Banasurasagar Dam, Heart Lake, and Karapuzha Dam, silicate levels increased during the monsoon. In Banasurasagar Dam, silicate levels decreased during the first year of the monsoon, due to the heavy rainfall and flooding of 2019, which may have diluted the silicate concentrations. In lotic water bodies, such as the Kuruva Islands, silicate levels decreased during the monsoon, as monsoon water diluted the natural silicate content. A different trend was observed in the Papanasini River, where silicate levels increased during the monsoon due to the mixing of silicates by precipitation and increased flow rate. All silicate values in the study area were found to be within permissible limits (WHO, 1999).

5.2.2 Quantitative analysis

5.2.2.1 Number of algal cells

Seasonal and spatial analyses of algal cells were evaluated in Tables 30 and 31, respectively. The seasonal distribution revealed that the highest number of algal cells occurred in the post-monsoon season of first year (Figure 30). This finding was consistent with the results of Kumar et al. (2012b) and Rao (2024). In contrast, studies by Sebastian and Thomas (2016), Gogoi et al. (2019), and Dhakal et al. (2022) had reported a greater number of algal cells in the pre-monsoon season. The heavy monsoon rains and the 2019 floods in Wayanad led to the mixing of nutrients, which subsequently stabilized, fostering an increase in algal growth during the post-monsoon season. The lowest number of algal cells was recorded during the monsoon, which was attributed to high turbidity, lower temperatures, and reduced sunlight penetration, all of which inhibited algal growth. Comparable results, with the lowest number of cells observed during the monsoon, were noted by Sebastian and Thomas (2016), Aravinth et al. (2023), and Rao (2024). In the first year, the number of algal cells increased during the monsoon, and the post-monsoon season exhibited the highest cell count. In the second year, the highest number of cells was observed in the pre-monsoon season, while the monsoon precipitation led to a reduction in algal cells during both the monsoon and post-monsoon season.

Spatial analysis of algal cells indicated that Pookode Lake hosted the highest number of cells (Figure 31). This natural high-altitude freshwater lake, surrounded by forests, provided a favourable climate and abundant organic matter. The decay of tree leaves in the lake contributed nutrients, while nutrient runoff from nearby areas, including paddy fields, further promoted nutrient accumulation, which facilitated algal growth. Meanwhile, Kuruva Islands exhibited the lowest number of algal cells. This island, with its sandy bottom (Yoswaty et al., 2021), had limited organic matter. High TDS and EC levels were also observed at the site due to increased silicate concentrations, which reduced sunlight penetration. Additionally, the high flow rate during the monsoon season may have contributed to the lower number of cells compared to other sites.

Lentic water bodies in the study area showed a higher number of algal cells than the lotic water bodies. This result contrasted with the findings of Al-Saeedi et al. (2022), where lotic water bodies supported a higher number of algal cells.

5.2.2.2 Class-wise analysis of algae

The class-wise distribution of algae in the study area indicated that Chlorophyceae contributed the most, followed by Bacillariophyceae (Figure 32). Chlorophyceae was reported as the dominant class in the studies by Kumar and Rai (2005), Srivastava et al. (2018), and Jose and Xavier (2022). Diatom dominance over Chlorophyceae typically requires high silicate and temperature levels (Zhang et al., 2017). The limited availability of silicate in the study area may have contributed to the dominance of Chlorophyceae. Classes such as Cyanophyceae, Dinophyceae, and Chrysophyceae were represented at similar levels in the study area. The lower representation of Cyanophyceae could be attributed to the abundance of desmids, which might have reduced the population of Cyanophyceae (Lefevre et al., 1952). Xanthophyceae was the least represented class, as these algae are not abundant in nature, a pattern also observed in the algal flora of Idukki (John, 2008).

The seasonal distribution of algal classes revealed that, in most seasons, including the pre-monsoon season of the first year, the monsoon season of both the first and second years, and the post-monsoon season of the second year, Chlorophyceae was dominant (Figure 33). However, Bacillariophyceae dominated during the pre-monsoon of the second year and the post-monsoon of the first year. The growth of Bacillariophyceae is often limited by the availability of silicate in water bodies. High silicate content resulting from nutrient runoff during monsoon rains led to the concentration and accelerated growth of diatoms. This resulted in Bacillariophyceae dominance during the pre-monsoon of the second year and post-monsoon of the first year. The diatom dominance in the post-monsoon of the first year carried over into the pre-monsoon of the second year. Diatoms were found to be abundant in the post-monsoon season and pre-monsoon season by Ajayan et al. (2013) also.

Bacillariophyceae was most abundant in the post-monsoon season, where elevated temperatures and nutrient concentrations were observed. The influx of nutrients led to the highest numbers of Chlorophyceae, Cyanophyceae, and

Dinophyceae in the monsoon season. Euglenophyceae was most abundant in the pre-monsoon season, owing to high light intensity, water temperature, and nutrient content. A similar observation of Euglenophytes was noted in freshwater bodies of Goa (Sawaiker & Rodrigues, 2023). Seenayya (1971) also reported a rise in Euglenophytes during the summer season. Chrysophyceae, represented by the genus *Dinobryon*, was most abundant in the pre-monsoon season (Sharma & Sharma, 2021). *Dinobryon* thrives in waters with a high nitrate-to-phosphate ratio (Pearsall, 1932). The pre-monsoon of the second year exhibited a high nitrate-to-phosphate ratio with fewer precipitations, which attracted the genus *Dinobryon*. This also relates to *Dinobryon*'s ability to thrive in high TDS environments (Roka et al., 2022). Xanthophytes, which prefer elevated temperatures and less disturbed waters (Gogoi et al., 2019), were most abundant in the pre-monsoon and post-monsoon seasons.

Spatial distribution of algal classes showed that all classes, except Bacillariophyceae and Dinophyceae, were most abundant in Pookode Lake (Figure 34). The organic matter from the lake, along with nutrient leaching from adjacent farmlands, contributed to the excessive algal growth in the lake. Chlorophyceae was dominant in Pookode Lake, Heart Lake, and Karapuzha Dam, all of which are lentic systems receiving ample sunlight that fostered the proliferation of green algae. Previous studies have also found Chlorophyceae to be dominant in lentic water bodies, including Pookode Lake (Nirmala et al., 1991) and Karapuzha Reservoir (Panikkar et al., 2024), as well as in reservoirs of the Western Ghats (Palaniswamy et al., 2015). In contrast, Bacillariophyceae was the dominant class in Banasurasagar Dam, Kuruva Islands, and Papanasini River. The high silicate content in these lotic water bodies supported the dominance of diatoms over other algal classes.

Bacillariophyceae and Dinophyceae were most abundant in Banasurasagar Dam, a site with the high nitrate content. Large reservoirs, such as Banasurasagar, were also found to favour Dinophycean members like *Peridium* and *Ceratium* (Bustamante et al., 2023). Dinophyceae prefer waters with low TDS, which contributed to their abundance in Banasurasagar Dam, a correlation also noted in previous studies (Mohammed & Mahran, 2022). The consumption of silicate by diatoms and Dinophyceae in the dam depleted the silicate levels, which were low in the dam despite the high abundance of diatoms (Rao & Madhyastha, 1990; Zhang et al., 2019). In Heart Lake, Bacillariophyceae and Chlorophyceae were equally abundant, suggesting evenness in this natural water body.

5.2.3 Community structure and diversity analysis

5.2.3.1 Frequent and dominant algal genera

Gomphonema and *Navicula* were the most frequent genera found in the study area (Table 6). Both genera are large genera of diatoms and were present in all the samples collected throughout the study, making them common. Diatoms are capable of surviving in a wide range of habitats, which contributes to their greater frequency compared to other algal groups. *Gomphonema* is typically found attached to submerged plants in flowing waters and rivers. Both *Gomphonema* and *Navicula* are known to be pollution-tolerant (Palmer, 1969) and can thrive under various environmental stressors. Diatoms were reported as the most frequent class in high-altitude wildlife sanctuaries (Toppo et al., 2016). *Cosmarium*, which is more frequent in clean and natural freshwater bodies, was the third most frequent genus in the study area (Table 6). It is the most common and largest desmid genus, found abundantly in freshwater lakes and dams. *Cosmarium* was the dominant genus from study area, which is also reported in the high-altitude lake, Naini Tal (Rao et al., 1982). *Navicula*, the next most dominant genus after *Cosmarium*, which is one of the largest, most cosmopolitan, and common diatom genera. Chlorophycean members were the dominant group, while diatoms were the most frequent group. This observation was also recorded in the high-altitude lake of Shillong (Rai & Muniyandi, 1981).

Seasonal distribution and dominance of algae were noted (Table 7). In the first year, the pre-monsoon season was characterized by algal genera from diverse groups such as Chlorococcales, desmids of Chlorophyceae, Bacillariophyceae, and Euglenophyceae. During the monsoon season, these genera were replaced by diatoms and the desmid *Cosmarium*. In the post-monsoon season, diatoms, along with *Cosmarium*, became the most frequent genera. *Cosmarium* was frequent in all seasons of the first year. In the second year, diatoms were frequent across all seasons. In all seasons except the pre-monsoon and post-monsoon of the first year, *Cosmarium* was the dominant algal genus. In the pre-monsoon season, *Trachelomonas* was dominant, while *Navicula* was the dominant genus in the post-monsoon season.

Spatial distribution of algal genera at each site was specified (Table 8). Six algal genera from diverse groups, including Chlorococcales and desmids of Chlorophyceae, Bacillariophyceae, and Euglenophyceae, were frequent in Pookode Lake. A previous limnological study at Pookode Lake (Nirmala et al., 1991) noted *Ankistrodesmus* and *Navicula* as major algae. In Banasurasagar Dam, seven algal genera were frequent, comprising three desmids and four diatoms. Diatoms *Gomphonema* and *Navicula* were frequently observed in the Kuruva Islands. In Heart Lake, seven genera, including Chlorococcales, desmids of Chlorophyceae, diatoms, and Euglenophyceae, were frequent. Karapuzha Dam had six algal genera, with one from Chlorococcales, two desmid genera, and three diatoms. *Gomphonema* was frequently found in the Papanasini River. *Cosmarium* was dominant in Pookode Lake and Karapuzha Dam, while *Navicula* dominated in the Kuruva Islands, Heart Lake, and Papanasini River. *Staurastrum* was dominant in Banasurasagar Dam.

The altitude of the study site influences the community structure of algae (Barinova & Barkatullah, 2013). Heart Lake, at the highest altitude in the study area (1412 msl), exhibited a diverse algal flora. All twelve frequent genera, except *Melosira* and *Euglena*, had been previously reported from high-altitude water bodies in India (Rao et al., 1982; Nautiyal et al., 1999; Das & Keshri, 2012; Kumar et al., 2012b; Patil et al., 2015; Toppo et al., 2016; Sharma & Singh, 2018). The frequent distribution of *Melosira* and *Euglena* across all seasons in Heart Lake indicates their adaptability to high-altitude environments, a characteristic not previously noted.

A total of sixteen genera were found in all sites across the study area. Most of these frequent genera, except *Melosira, Euastrum, Bulbochaete, Euglena,* and *Staurodesmus*, had been previously reported as frequent in other high-altitude water bodies of India. This suggests that the algal flora of Wayanad shares similarities with other high-altitude regions in India.

5.2.3.2 Algal genera exclusive to seasons and sites

Algae exclusive to seasons and sites were listed. The monsoon season of the first year exhibited the highest number of exclusive algal genera for the season. The pre-monsoon season of the first year, as well as the monsoon and post-monsoon seasons of the second year, each had a single genus exclusive to the respective season. Karapuzha Dam was found to have the highest number of algal genera exclusive to the site. In contrast, Kuruva Islands had no algae exclusive to the site. The monsoon season and Karapuzha Dam, with their higher numbers of exclusive algal genera, contributed the most to the species richness of the study area. The unique habitat specificity provided by the monsoon season and Karapuzha Dam facilitated the presence of rare algal species.

5.2.3.3 Diversity analysis

High algal diversity was recognized in the study area, which varied across seasons and sites. Different diversity indices, including species dominance, richness, evenness, and a combined index, depicted the seasonal and spatial variation in diversity across the study area (Table 11). In the first year at Pookode Lake, the late monsoon and post-monsoon rains resulted in high algal diversity during the monsoon season. The monsoon season of the first year exhibited the highest number of genera and cells. The pre-monsoon season of the first year showed the highest dominance and the lowest richness index, leading to the lowest diversity index. The limited nutrient inflow in this season created intense nutrient competition in the lake, resulting in a high dominance index and an overall low diversity index. The monsoon season of the first year exhibited the highest richness index, but the dominance of algae resulted in the lowest evenness index, reducing overall diversity. The post-monsoon season of the second year displayed the least dominance and the highest evenness, making it the most diverse season at this site.

At Banasurasagar Dam, the highest number of genera, richness index, and diversity index were observed during the monsoon of the second year. The post-monsoon of the second year had the least number of genera, cells, and the highest dominance index, which resulted in the lowest richness index and diversity index. The highest number of cells was recorded in the pre-monsoon of the second year, due to good sunlight and nutrient accumulation, which promoted algal proliferation. The post-monsoon season of the first year exhibited the lowest dominance index, resulting in the highest evenness index.

In the Kuruva Islands, the highest number of algal genera were observed in the monsoon of the first year, accompanied by the lowest dominance, highest species richness, and the highest diversity index. The post-monsoon season of the second year had the lowest number of genera and cells, resulting in the highest dominance and evenness indices, which led to the lowest richness index and diversity index. The highest number of cells was recorded in the post-monsoon of the first year. The highest dominance index was observed in the pre-monsoon of the first year, where the lowest evenness index was also found.

In Heart Lake, the monsoon of the first year exhibited the highest number of genera, leading to the highest species richness index. The monsoon of the second year had the least number of genera, the highest dominance, the lowest richness index, and consequently the lowest diversity index. The post-monsoon of the first year recorded the highest number of cells, the lowest dominance index, and the highest evenness index, contributing to the highest diversity index. The pre-monsoon of the second year had the least evenness index.

At Karapuzha Dam, the monsoon of the first year showed the highest number of genera and cells. The lowest dominance index and the highest richness index contributed to the highest diversity index in this season. The monsoon of the second year had the lowest number of genera and cells, along with the highest evenness index, but also the lowest richness index, which resulted in the lowest diversity index for the site. The post-monsoon of the second year had the lowest number of cells and the highest dominance index. The pre-monsoon of the second year showed the lowest evenness index.

At the Papanasini River, the post-monsoon of the first year exhibited the highest number of genera and cells, along with the highest richness index. The monsoon of the second year had the least number of genera and cells, resulting in the highest dominance index and the lowest richness index, which in turn led to the lowest diversity index. The monsoon of the first year showed the lowest dominance index, making this season the most diverse. The highest evenness index was observed in the post-monsoon of the second year, with the least in the post-monsoon of the first year, making the season more species rich.

The seasonal and spatial analysis of the Shannon-Weiner diversity index indicated trends in diversity (Figure 35). A high Shannon diversity index was observed during the monsoon season at most sites, except Heart Lake. This observation contradicted the typical high diversity seen in post-monsoon seasons. Changes in rainfall were the main factors driving high monsoon algal diversity. Late monsoon rains led to increased nutrient concentrations early in the monsoon season, contributing to high algal diversity during this period at Pookode Lake, Karapuzha Dam, and Papanasini River. During the first year of the study, algal diversity decreased in the post-monsoon season at most sites, except Banasurasagar Dam and Heart Lake, due to rainfall. At Banasurasagar Dam, diversity increased during both monsoon and post-monsoon seasons, with the highest diversity occurring in post-monsoon. The dam, as a collection of water from different streams, contained more minerals and nutrients due to heavy rainfall and monsoon runoff, facilitating the growth of diatoms, the dominant group, during post-monsoon. In Heart Lake, the diversity index remained the same during pre-monsoon and monsoon seasons but increased during post-monsoon, reaching the highest index value. In other sites, diversity increased during the monsoon season but decreased during post-monsoon due to post-monsoon rains in the first year. Banasurasagar Dam and Kuruva Islands exhibited increased diversity during both monsoon seasons of the second year. However, Heart Lake showed no increase in diversity during the monsoon seasons, due to nutrient dilution. In the second year, diversity increased during the monsoon at Banasurasagar Dam and Kuruva Islands, whereas all other sites experienced a decrease in diversity during monsoon, with high diversity observed during post-monsoon. These sites received insufficient nutrient inflow during the monsoon season compared to other areas. Late monsoon rains introduced nutrients that increased diversity in the post-monsoon season. Heart Lake, which received sufficient rainfall during both years, had high algal diversity in both post-monsoon seasons. This attribute may be related to the lake's high altitude and minimal pollution, contributing to higher rainfall. Lakkidi, which receives the second-highest rainfall in the state, is in proximity to Heart Lake.

The seasonal variation of diversity was studied in the study area (Table 12). Seasonal variation in diversity was primarily driven by nutrient influx during the monsoon. A greater number of genera and cells were present during the monsoon of the first year. Sharma et al. (2024) also observed an increase in algal numbers during the monsoon season. High richness was observed during the monsoon of the first year, as more genera were present in this season, making it more diverse according to the Shannon-Weiner index. A high richness index during the monsoon season was also reported by Pandiammal et al. (2017). Delayed and insufficient monsoon rains concentrated nutrients, promoting algal growth. High algal diversity during the monsoon season was also observed by Shrivastava et al. (2014), Agrawal (2018), Ray et al. (2020), Parakkandi et al. (2021), Roka et al. (2022), and Bishnoi and Khan (2024). Desmids, the most dominant algal group in the study, favour the monsoon season (Barman et al., 2015). Pre-monsoon of the first year and post-monsoon of the second year were less diverse due to high dominance. Delayed monsoon showers reduced the diversity in both post-monsoon and pre-monsoon samples. High dominance was observed during the pre-monsoon of the first year. The reduced dilution during this period may have contributed to the dominance of competitive species. Nutrient availability increased the evenness index during the monsoon of the second year. Heavy rainfall enhanced nutrient availability and promoted algal growth, as observed by Li et al. (2015).

The spatial variation of diversity (Table 13) revealed that Heart Lake had the highest diversity index. As a natural high-altitude lake situated at the highest altitude among the study sites, Heart Lake is located within a deep shola forest and has limited human intervention due to restricted access. Consequently, this high algal diversity was expected at the lake. Heart Lake displayed the least dominance and the highest evenness index, making it the most diverse site. Lentic water bodies exhibited greater diversity and species richness than lotic water bodies. After Heart Lake, Karapuzha Dam and Banasurasagar Dam had higher diversity. Karapuzha Dam contributed the highest number of genera. Sites such as Karapuzha Dam, with intermediate disturbances, can foster high species richness (Connell, 1978). However, this site had higher dominance and lower evenness, making it less diverse than Heart Lake. Sites with high human intervention exhibited a high dominance index. The highest number of algal cells was observed at Pookode Lake, but the site had the highest dominance index and the lowest evenness index, reducing its diversity. It was the least diverse site in the study. The Kuruva Islands recorded the lowest number of cells and had the least richness index. Species in poor communities, such as those in Kuruva Islands, tend to be less stable (Elton, 1958). Banasurasagar Dam had a high number of genera and cells, with lower dominance and higher evenness, contributing to an intermediate richness and diversity. Papanasini River had fewer algal genera and cells, with high dominance and low evenness, resulting in lower richness and diversity. This diversity analysis highlighted that, despite the presence of more genera and cells, evenness played a crucial role in determining the diversity of an area. Sites with lower dominance among algae were found to be more diverse.

5.2.3.4 Hierarchical Cluster Analysis (HCA)

Hierarchical Cluster Analysis (HCA) of seasonal collections (Figure 36) resulted in two distinct groups. The first group included the monsoon and post-monsoon of the second year, as well as the pre-monsoon of the first year. Within this group, the monsoon and post-monsoon of the second year were more similar, while the pre-monsoon of the first year is an outgroup. The algal flora of the post-monsoon season closely resembled that of the monsoon season of the second year due to their continuous nature and minimal variation in the factors affecting algal flora between these seasons. The pre-monsoon of the first year, while sharing similarities in algal composition, was not continuous with this group. The second group comprised the monsoon and post-monsoon of the first year, along with the pre-monsoon of the second year. These three seasons were close and continuous, with the monsoon of the first year acting as an outgroup. The post-monsoon of the first year and the pre-monsoon of the second year showed greater similarity to each other than to the monsoon of the first year. These two seasons were close, exhibiting less variation in algal composition.

Spatial similarity in algal composition was studied using HCA (Figure 37), resulting in two groups. The first group consisted of the Kuruva Islands, Papanasini River, and Heart Lake. These three sites contributed the similar number of genera and had similar values for the evenness and richness indices. Despite their low species richness compared to other sites, Kuruva Islands and Papanasini River were most similar, with Heart Lake acting as the outgroup. Both Kuruva Islands and Papanasini River were lotic water bodies, with Bacillariophyceae being the dominant algal class. The diversity indices of Kuruva Islands and Papanasini River were also similar. Heart Lake, while having an algal composition resembling that of Kuruva Islands and Papanasini River, exhibited unique characteristics. Located at Chembra Peak, the highest altitude in the district, Heart Lake had similar levels of Chlorophyceae and Bacillariophyceae.

The second group included Banasurasagar Dam, Karapuzha Dam, and Pookode Lake. These three sites had a high number of algal genera and cells in the study and exhibited high richness indices. They were all connected to the Panamaram River. Banasurasagar Dam and Karapuzha Dam were most similar, with Pookode Lake serving as the outgroup. Banasurasagar Dam and Karapuzha Dam shared similar habitats and exhibited comparable Shannon diversity indices. Pookode Lake was considered an outgroup due to its distinct habitat, characterized by high dominance and low evenness among the algae, which resulted in lower diversity.

5.2.3.5 Non-metric multidimensional scaling (NMDS) analysis

Non-metric Multidimensional Scaling (NMDS) analysis was conducted to assess similarities in algal composition between seasons (Figure 38). The results indicated that each season was distinct, as the points were not clustered together. In both years, the algal flora of the monsoon and post-monsoon seasons demonstrated similarities in composition, whereas the pre-monsoon flora remained distinct. This differentiation was attributed to the nutrient influx during the monsoon, while the distinctiveness of the pre-monsoon season was influenced by elevated temperatures and limited precipitation.

The spatial variation of algal flora (Figure 39) revealed that Heart Lake exhibited unique and distinct characteristics. Situated at the highest altitude within the study area and located in a less-disturbed tropical shola forest, this water body was identified as a valuable and unique site. Heart Lake also represented the most diverse location within the study area. Another distinctive algal flora was observed at Pookode Lake, a natural high-altitude freshwater lake that recorded a high number of algal genera and the highest cell count. However, the high dominance in Pookode Lake resulted in lower overall diversity. This lake exhibited the highest abundance of algae across all classes except Bacillariophyceae and Dinophyceae.

Banasurasagar Dam and Karapuzha Dam, both characterized by high species richness, were found to share similar algal flora, habitats, and Shannon diversity indices. Similarly, Kuruva Islands and the Papanasini River displayed comparable algal compositions. Both lotic water bodies were dominated by diatoms and exhibited similarities in their diversity indices.

Scatter plots with convex hulls demonstrated that Pookode Lake, Banasurasagar Dam, and Karapuzha Dam shared similar algal flora, while Kuruva Islands, Heart Lake, and the Papanasini River formed another comparable group

(Figure 40). Furthermore, Banasurasagar Dam and Karapuzha Dam exhibited greater similarity in algal composition, while Kuruva Islands and the Papanasini River shared common algal species. The findings from the NMDS analysis corroborated the results obtained through Hierarchical Cluster Analysis (HCA).

5.2.4 Correlation Analysis

5.2.4.1 Canonical Correspondence Analysis (CCA)

The seasonal correlation of algae with environmental parameters was illustrated using the Canonical Correspondence Analysis (CCA) plot (Figure 41). pH exhibited a significant negative correlation with nitrate (Dadgar & Payandeh, 2017) and a positive correlation with phosphate (Chhatwal, 1998). On Axis 1, pH, phosphate, electrical conductivity (EC), silicate, and temperature were positively correlated with the pre-monsoon of the first year, as well as the monsoon seasons of the first and second years. These parameters showed a positive relationship with genera such as *Spirogyra*, *Peridinium*, *Euglena*, *Trachelomonas*, *Staurodesmus*, *Melosira*, and *Scenedesmus*. The high eigenvalue of phosphate indicated its strong influence on Axis 1.

The pre-monsoon of the first year exhibited a strong correlation with elevated levels of phosphate, EC, and pH. *Spirogyra* displayed an affinity for high phosphate, pH, and EC (Hainz et al., 2009), leading to its abundance during this season. Its growth was suppressed under low pH conditions (Simons & Van Beem, 1990), highlighting its pH specificity. The genus was found in waters with high EC, as increased EC enhanced the number of pyrenoids in *Spirogyra* (Wongsawad & Peerapornpisal, 2015). Previous observations by Rao and Madyastha (1990) also noted the abundance of *Spirogyra* during the pre-monsoon season. *Melosira* was most abundant in the pre-monsoon of the first year, coinciding with high EC (23.33) and pH (8) values (Kilham & Kilham, 1975). This genus, considered as pollution-tolerant (Palmer, 1969), thrived in nutrient-rich waters, particularly those with elevated phosphate levels (Arumugham et al., 2023).

Genera such as *Peridinium* and *Trachelomonas* demonstrated an affinity for high phosphate and pH, resulting in their abundance during the pre-monsoon of the first year. *Peridinium* could directly assimilate organic phosphate using alkaline phosphatases and maintained high growth rates under elevated pH (Lindstrom, 1984).

Euglena species were most abundant in waters with high phosphate concentrations (Seenayya, 1971), aligning with the observed abundance of *Trachelomonas* during the pre-monsoon season. Although *Trachelomonas* tolerated a wide pH range, it was most diverse at high pH (Poniewozik, 2016). These algae thrived under conditions of low precipitation (Philipose, 1988) and high phosphate levels (Kim & Boo, 2001; Rahman & Khan, 2007).

The order Chlorococcales exhibited a significant positive correlation with EC (Purushothama et al., 2011; Narayana, 2016). *Scenedesmus* showed a strong association with EC and was most abundant during the monsoon of the first year, when EC was elevated. Genera such as *Cylindrospermum*, *Cyclotella*, *Euglena*, *Staurastrum*, and *Closterium* were most abundant in the monsoon of the first year. *Staurodesmus* reached its peak abundance in the monsoon of the second year when temperatures were lower (approximately 25˚C). Elevated temperatures above 30˚C caused structural changes and abnormal growth in desmids (Coesel & Wardenaar, 1990).

On Axis 2, algal genera such as *Sphaerozosma*, *Cylindrospermum*, *Cosmarium*, *Staurastrum*, *Gomphonema*, *Achnanthes*, *Synedra*, *Cyclotella*, *Euastrum*, *Pleurotaenium*, *Ankistrodesmus*, *Actinotaenium*, *Closterium*, and *Cocconeis* were positively correlated. Dissolved oxygen (DO), total dissolved solids (TDS), and nitrate emerged as the most influential parameters, with DO serving as the primary factor. The pre-monsoon of the second year, along with the monsoon seasons of both years and the post-monsoon of the second year, exhibited positive correlations with Axis 2.

In Axis 2, the pre-monsoon season of the second year showed a positive correlation with nitrate and total dissolved solids (TDS). *Gomphonema* was abundant during the pre-monsoon of the second year, where high TDS, high nitrate, and low DO levels were observed. *Gomphonema* is recognized as pollution-tolerant algae capable of thriving in turbid and oxygen-deficient waters. This genus was reported as abundant in water bodies with high nitrate and TDS levels and low oxygen concentrations (Hansika & Yatigammana, 2019). It was noted that living diatoms absorb and store nitrate, while dead organisms release this stored nitrate (Stief et al., 2022) increasing nitrate levels.

The highest number of diatoms, including *Synedra*, *Achnanthes*, *Cocconeis*, and *Gomphonema*, was recorded during the pre-monsoon season of the second year when high nitrate levels were observed. In this study, desmids such as *Actinotaenium* and *Sphaerozosma* were abundant during the pre-monsoon of the second year and were influenced by high nitrate levels (0.09 mg/L). While desmids are generally diverse in waters with low nitrate, certain genera were found to associate with high nitrate levels (Shetty & Gulimane, 2022). Algal genera like *Sphaerozosma* were reported in mesotrophic water bodies by Coesel and Meesters (2007). *Ankistrodesmus* demonstrated an affinity for the high DO levels observed during the pre-monsoon of the second year (Sharma & Tiwari, 2018).

Diatoms such as *Neidium*, *Eunotia*, *Navicula*, *Nitzschia*, *Surirella*, *Frustulia*, and *Pinnularia*, along with Chlorococcales, including *Pediastrum*, were most abundant during the post-monsoon season of the first year. These algal genera exhibited negative correlations in both axes, suggesting that their niche preferences extended beyond the parameters considered. The post-monsoon of the second year was associated with low TDS levels, and in most sites, this season recorded the lowest TDS values. *Pleurotaenium* exhibited a preference for environments with the highest DO (7.2 mg/L) (Roka et al., 2022) and high nitrate (0.11 mg/L) (Shetty & Gulimane, 2022), conditions observed during the post-monsoon season of the second year.

Euastrum displayed an affinity for high DO levels (Ngearnpat & Peerapornpisal, 2007) and was found to be abundant during the monsoon of the second year. Algal genera such as *Cylindrospermum*, *Cosmarium*, *Closterium*, *Staurastrum*, *Euglena*, *Cyclotella*, *Ankistrodesmus*, and *Closterium* showed positive correlations with both axes. The parameters considered in the analysis collectively influenced the niches of these organisms. The monsoon seasons of both years had positive eigenvalues on both axes and were impacted by all the parameters examined.

The spatial correlation of algae with environmental parameters was also analysed using the CCA plot (Figure 42). On Axis 1, genera such as *Sphaerozosma*, *Trachelomonas*, *Cosmarium*, *Staurastrum*, *Eunotia*, *Ankistrodesmus*, *Actinotaenium*, and *Closterium* were positively correlated. Pookode Lake and Karapuzha Dam showed positive correlations with this axis. The highest abundance of *Trachelomonas*, *Actinotaenium*, *Cosmarium*, *Staurastrum*, and *Eunotia* was observed at Pookode

Lake, where these genera were identified as indicator genera. *Sphaerozosma* is exclusive to Pookode Lake and is strongly correlated in axis one. *Closterium* is most abundant in Karapuzha Dam. CCA also established the correlation of Pookode Lake, Banasurasagar Dam and Karapuzha Dam by the floral similarity observed from the results of HCA and NMDS.

On Axis 2, parameters such as TDS, EC, silicate, phosphate, and DO were positively correlated. Sites like Kuruva Islands, Heart Lake, and the Papanasini River were strongly influenced by these parameters. According to HCA and NMDS, these sites shared similar algal compositions, which was further validated by the CCA analysis. The Papanasini River exhibited a strong affinity for phosphate and dissolved oxygen (DO). The genera *Cocconeis* and *Achnanthes* demonstrated an affinity for phosphate and were most abundant in the Papanasini River, which recorded the highest phosphate levels. *Spirogyra* was abundant in the Papanasini River at locations where prominent levels of DO and phosphate concentrations were observed. The pollution-tolerant algal genera *Navicula* and *Gomphonema* were also found to be most abundant in this river.

Kuruva Island displayed a strong correlation with DO, maintaining high DO levels across all seasons except during the monsoon of the first year. Pollution-tolerant algal genera such as *Navicula*, *Pinnularia*, *Gomphonema*, and *Nitzschia* were the most abundant taxa observed at Kuruva Island. Among these, *Nitzschia* was most abundant in areas where silicate levels were highest, while phosphate concentrations were minimized due to the rapid uptake by diatoms such as *Nitzschia*. This genus demonstrated a high capacity for utilizing available phosphate in aquatic environments and has been employed in wastewater treatment systems (Su et al., 2012; Al-Hassany et al., 2021). Furthermore, it exhibited substantial growth under conditions of elevated silicate levels (Jiang et al., 2014).

The Banasurasagar Dam was identified as the site where *Melosira*, *Frustulia*, *Euastrum*, *Staurodesmus*, and *Cyclotella* were most abundant. Heart Lake, a small natural freshwater lake situated on the high-altitude Chembra peak, experienced elevated temperatures during the post-monsoon season. In Heart Lake, temperature and pH were identified as the key determinants of algal diversity. The highest abundances of *Euglena*, *Scenedesmus*, *Surirella*, and *Neidium* were recorded at this site.

5.2.4.2 Indicator analysis

The indicator algal genera for various seasons were depicted in Figure 43. *Trachelomonas* and *Peridinium* were identified as indicator genera for the pre-monsoon of the first year. The CCA plot across seasons revealed that both genera were sensitive to pH and were most abundant during the pre-monsoon of the first year at Pookode Lake. *Peridinium* was present during the pre-monsoon of the first year across all sites except the Papanasini River, establishing its role as an indicator genus for the season. *Gomphonema*, *Cymbella*, and *Synedra* were most abundant during the pre-monsoon of the second year at Karapuzha Dam, while *Achnanthes* dominated during the same period at the Papanasini River due to their high sensitivity to nitrate levels. This identified them as indicators of the pre-monsoon of the second year. For the monsoon of the first year, *Euglena* and *Cyclotella*, associated with the high pH of Heart Lake and Banasurasagar Dam respectively, were identified as indicator genera for the season. Both genera exhibited their highest abundance during this period. *Navicula* and *Pinnularia* were most abundant during the post-monsoon of the first year at Karapuzha Dam and the Papanasini River, respectively, correlating with the elevated temperatures characteristic of the season. *Frustulia* had its highest abundance during the post-monsoon of the first year at Banasurasagar Dam, coinciding with the highest recorded nitrate levels. Although *Cymbella* was an indicator genus for the pre-monsoon of the second year, it also exhibited a significant presence during the post-monsoon of the first year at Karapuzha Dam, where nitrate levels were high. Thus, *Navicula*, *Pinnularia*, *Cymbella*, and *Frustulia* were established as indicator genera for the post-monsoon of the first year.

Indicator genera specific to individual sites were examined in Figure 44. *Trachelomonas*, *Cosmarium*, *Staurastrum*, and *Eunotia* were most abundant at Pookode Lake. The highest abundance of *Trachelomonas* occurred during the pre-monsoon of the first year, correlating with the highest EC levels at Pookode Lake. During the monsoon of the first year, low EC levels at Pookode Lake likely influenced the proliferation of *Cosmarium*. An unknown parameter, not accounted for in this study, may have also contributed to the proliferation of these algal genera.

Melosira, *Frustulia*, *Peridinium*, and *Cyclotella* were most abundant during low-nitrate seasons at Banasurasagar Dam, establishing them as indicator genera for the site. *Euglena* thrived under low-temperature conditions during the monsoon of the first year, while *Scenedesmus* preferred higher temperatures and exhibited its highest abundance during the same season at Heart Lake. *Melosira* was associated with low nitrate levels during the post-monsoon of the first year at Heart Lake. These findings identified *Melosira*, *Euglena*, and *Scenedesmus* as indicator genera for Heart Lake. *Gomphonema* was abundant during the pre-monsoon of the second year at Karapuzha Dam, where the lowest phosphate levels were observed. *Synedra* exhibited its highest abundance during the same season at Karapuzha Dam, where both low DO and phosphate levels were recorded. *Cymbella* was positively influenced during the pre-monsoon of the second year at Karapuzha Dam by elevated temperatures and low DO. Although *Cosmarium* was an indicator genus for Pookode Lake, it was also abundant at Karapuzha Dam during low EC seasons. These observations identified *Cosmarium*, *Gomphonema*, *Cymbella*, and *Synedra* as indicator genera for Karapuzha Dam. *Achnanthes* exhibited its highest abundance during the pre-monsoon of the second year at the Papanasini River, correlating with the highest observed phosphate levels, establishing it as the indicator genus for the site. The indicator analysis effectively narrowed the range of algae specific to seasons and sites and substantiated the results of the HCA and NMDS analyses.

The genus *Trachelomonas*, as an indicator genus, suggested that Pookode Lake was advancing toward organic pollution. The abundance of this genus has been associated with high levels of organic matter and pollution (Wolowski & Walne, 2007). A similar observation was reported in the wetlands of the Bhagalpur district (Rahman & Choudhary, 2024). Increased bacterial populations and the presence of coliforms were previously detected in Pookode Lake (Das et al., 2021), confirming the necessity of monitoring the lake and its catchment area. If appropriate actions are not taken, there is a risk of the lake advancing toward eutrophication. Similar observations were previously reported by Das et al. (2017).

5.2.5 Pollution analysis

Different indices were calculated to find the indication of pollution in study area. The results revealed no pollution in the study area.

5.2.5.1 Nutrient Pollution Index (NPI)

The calculations of the Nutrient Pollution Index (NPI) substantiated that no significant nutrient pollution was observed in the study area. Nutrient pollution was found to be least during the post-monsoon season (Table 15). Nutrients diluted during the monsoon season were further diluted by post-monsoon showers, resulting in lower nutrient content in water bodies. Conversely, the pre-monsoon season exhibited higher nutrient content due to minimal or no precipitation, leading to concentrated nutrient levels during this period.

Heart Lake exhibited the lowest nutrient pollution, likely due to limited human intervention in the area (Table 16). In contrast, Karapuzha Dam recorded a higher NPI index value, attributed to elevated nitrate and phosphate levels. These elevated nutrient levels correlated with the high species richness index observed at the site. The inflow of water from various regions contributed to the increased nutrient concentrations in the dam.

5.2.5.2 Palmer’s Pollution Index

Palmer’s Pollution Index identified PRE2 and PO1 as the most polluted seasons, while the remaining seasons recorded zero index values (Table 17). PRE2 and PO1, as consecutive seasons, were characterized by the presence of only a few algae tolerant to pollution and water scarcity. Among the study sites, Banasurasagar Dam and Karapuzha Dam exhibited the highest pollution levels, whereas Pookode Lake and Kuruva Islands recorded zero index values (Table 18). Despite this, both Banasurasagar Dam and Karapuzha Dam may have accumulated pollutants due to water being collected from various areas and retained for extended periods. Pookode Lake and Kuruva Islands had fewer pollution-tolerant genera, indicating relatively lower pollution levels. *Gomphonema* and *Navicula* were identified as the only pollution-tolerant genera within the study area.

5.2.5.3 Boyd’s Diversity Index

According to Boyd’s Diversity Index, the most polluted season was PO2, while the least polluted season was MO1 (Table 19). The calculated index indicated that Kuruva Islands were the most polluted site, whereas Karapuzha Dam was the least polluted site (Table 20). The high number of genera and algal cells contributed to lower pollution levels based on Boyd’s index, explaining the lower pollution values during the monsoon season and at Karapuzha Dam. The smaller number of genera and cells in Kuruva Islands and during the post-monsoon season resulted in a higher pollution index.

The pollution analysis conducted using various indices confirmed that no severe pollution was present at the study sites. However, when nutrient concentrations and the presence of pollution-tolerant algae were considered, Karapuzha Dam emerged as comparatively the most polluted site. In contrast, Boyd’s Diversity Index classified Karapuzha Dam as the least polluted site due to its higher number of genera and cells.

In oligotrophic lakes, phosphate is often the limiting nutrient. An increase in phosphate concentrations can elevate productivity, causing nitrate to become the limiting nutrient (Wetzel, 2001). This scenario was observed in the Papanasini River. At Karapuzha Dam, however, both phosphate and nitrate levels were elevated, promoting algal proliferation and potentially advancing the water body toward eutrophication. This condition was accurately reflected in the Nutrient Pollution Index and Palmer’s Pollution Index.

The monsoon season exhibited lower levels of nutrients and fewer pollution-tolerant algal genera. As per Boyd’s Diversity Index, the monsoon season was the least polluted, despite having the highest number of genera and algal cells. Nutrient concentration analyses indicated higher pollution levels during the pre-monsoon season, while the presence of pollution-tolerant algae suggested that both the pre-monsoon and post-monsoon seasons were more polluted. Boyd’s Diversity Index, however, classified the post-monsoon season as the most polluted.

Chapter 6

Summary and Conclusion

The study attempts to reveal the hidden freshwater algal diversity of the Wayanad district. Algae from puddles, paddy fields, ponds, streams, brooks, canals, temple ponds, quarries, tea plantations, and rock crevices were collected. The study enumerated 106 genera , 392 species and 442 taxa of algae belonging to seven classes. Twelve new reports to India and 119 new reports to Kerala were recorded as a part of the work. Chlorophyta was the most contributed division with 224 taxa followed by Bacillariophyta with 150 species. Out of 12 new reports to India, only one belongs to Bacillariophyceae and others belong to the Chlorophyceae family.

Asymmetric and unpredictable rainfall patterns influenced the seasonal algal variation in water bodies. Algae were found to be highly variable in relation to the physicochemical properties of water. A significant positive correlation was observed between EC and temperature, TDS and EC, TDS and silicate, and EC and silicate. The temperature of the water bodies was influenced by altitude, flow rate, precipitation, and the surrounding canopy. The monsoon seasons experienced the lowest temperatures, while the pre-monsoon seasons recorded the highest temperatures. The lowest mean temperature was observed at Pookode Lake, whereas Heart Lake recorded the highest mean temperature.

The seasonal variation of pH was found to be significant, as it was influenced by temperature, precipitation, and the organic matter present in the water body. The monsoon season exhibited the lowest mean pH, while the pre-monsoon season recorded the highest mean pH. Among the study sites, Karapuzha Dam had the lowest mean pH, whereas Heart Lake had the highest mean pH. The minimum pH value was recorded during the monsoon of the second year at Pookode Lake, while the maximum value was observed during the post-monsoon of the first year at Heart Lake. The pre-monsoon and monsoon seasons of Karapuzha Dam in the first year, as well as the post-monsoon season at Heart Lake in the first year, were found to be alkaline and exceeded the permissible limits set by WHO. In contrast, the monsoon season at Pookode Lake was acidic and fell below the permissible limit of WHO.

The lowest mean TDS value was recorded during the monsoon season, while the highest was observed in the pre-monsoon season. TDS showed significant variation across sites, with the lowest mean TDS recorded at Heart Lake and the highest at Kuruva Islands. The minimum TDS value was observed during the post-monsoon season of the second year at Banasurasagar Dam, whereas the highest value occurred during the monsoon season of the second year at Kuruva Islands. All TDS values were within the permissible limits prescribed by WHO.

Electrical conductivity (EC) was positively influenced by temperature, TDS, and silicate. A significant positive correlation of EC with temperature, TDS, and silicate was noted. The lowest mean EC was recorded during the monsoon season of the first year, while the highest mean EC occurred in the pre-monsoon season of the first year. Significant spatial variation in EC was observed, with Heart Lake showing the lowest mean EC and Karapuzha Dam recording the highest. The minimum EC value was observed during the monsoon season of the second year at Heart Lake, while the maximum value was recorded during the pre-monsoon season of the first year at Kuruva Islands. All EC values were within the permissible limits prescribed by WHO.

Dissolved oxygen (DO) was influenced by temperature, the presence of organic matter, and the flow rate of water bodies. The mean DO was lowest during the pre-monsoon season and highest during the post-monsoon season, with significant spatial variation observed across the study sites. Karapuzha Dam recorded the lowest mean DO, while Papanasini River showed the highest. The minimum DO value occurred during the pre-monsoon season of the second year at Karapuzha Dam, and the maximum value was recorded during the pre-monsoon season of the first year at Papanasini River. Most seasons recorded DO values within permissible limits, except for certain seasons. At Pookode Lake, DO values exceeded permissible limits during the pre-monsoon and post-monsoon seasons of the second year. At Banasurasagar Dam, only the pre-monsoon season of the first year and the monsoon season of the second year were within limits. At the Kuruva Islands, the monsoon season of the first year and the post-monsoon season of the second year were beyond limits. At Heart Lake, the pre-monsoon and post-monsoon seasons of the first year, as well as the monsoon season of the second year, recorded values exceeding permissible limits. At Karapuzha Dam, only the post-monsoon seasons of both years had DO values within permissible limits. At Papanasini River, the post-monsoon season of the first year recorded DO values beyond permissible limits.

Nutrients such as nitrate, phosphate, and silicate were analysed in the laboratory. Nitrate, which is related to organic matter, is introduced into water bodies through nutrient runoff containing sewage or fertilizers. Significant seasonal variation in nitrate levels was observed. The mean nitrate concentration was lowest during the post-monsoon season of the second year and highest during the pre-monsoon season of the second year. Among the study sites, Pookode Lake recorded the lowest mean nitrate value, while Banasurasagar Dam had the highest. The minimum nitrate value was observed during the pre-monsoon season of the first year at Heart Lake, while the maximum value was recorded during the pre-monsoon season of the second year at Kuruva Islands.

Phosphate levels were also found to vary significantly across seasons and sites. The lowest mean phosphate value occurred during the post-monsoon season of the second year, while the highest mean value was recorded during the pre-monsoon season of the first year. Pookode Lake showed the lowest mean phosphate concentration, whereas Karapuzha Dam had the highest. The minimum phosphate value was recorded during the monsoon season of the second year at Pookode Lake, while the maximum value was observed during the pre-monsoon season of the second year at Papanasini River. All phosphate values recorded were within the permissible limits set by WHO.

Silicate, which occurs naturally in the sandy bottoms of lotic water bodies, also exhibited significant seasonal and spatial variation. The lowest mean silicate concentration was recorded during the pre-monsoon season of the second year, while the highest mean concentration was observed during the post-monsoon season of the first year. Banasurasagar Dam had the lowest mean silicate value, whereas Papanasini River recorded the highest. The minimum silicate value was noted during the pre-monsoon season of the second year at Heart Lake, while the maximum value occurred during the post-monsoon season of the first year at Kuruva Islands.

Due to water stability and sunlight penetration, the lowest number of algal cells was observed during the monsoon season, while the highest number was recorded in the post-monsoon season. Among the study sites, Pookode Lake had the highest number of algal cells, whereas the Kuruva Islands had the least. Seven out of the eleven algal classes were represented in the study, with Chlorophyceae being the most abundant and Xanthophyceae the least. Chlorophyceae, Cyanophyceae, and Dinophyceae were more prevalent during the monsoon season, while Euglenophyceae and Chrysophyceae peaked during the pre-monsoon season. Xanthophyceae exhibited higher abundance in both the pre-monsoon and post-monsoon seasons.

The nutrient-rich Pookode Lake supported all classes of algae except Bacillariophyceae and Dinophyceae, with Chlorophyceae being the most dominant. Class Chlorophyceae was also dominant in lentic water bodies such as Pookode Lake, Heart Lake, and Karapuzha Dam. In contrast, Bacillariophyceae was the dominant class in the lotic water bodies, including Banasurasagar Dam, Kuruva Islands, and Papanasini River. Dinophyceae and Bacillariophyceae were abundant in Banasurasagar Dam. In Heart Lake, Chlorophyceae and Bacillariophyceae had nearly equal representation, indicating a high degree of evenness in the algal distribution within the water body.

Diatoms such as *Gomphonema* and *Navicula* were the most frequently observed genera, while Chlorophytes like *Cosmarium* were the most dominant genera in the study area. During the pre-monsoon season, frequent algal genera were primarily diatoms, while *Cosmarium* became prominent in the post-monsoon season of the first year. In the second year, diatoms were consistently frequent across all seasons. *Cosmarium* was the dominant genus in all seasons except during the pre-monsoon season, where *Trachelomonas* dominated, and the post-monsoon season, where *Navicula* was dominant.

The richness of algal genera varied across sites. Pookode Lake exhibited frequent algal genera from different classes, indicating high species richness. Desmids and diatoms were frequently observed in Banasurasagar Dam, while diatoms were prominent in the Kuruva Islands and Papanasini River. In Heart Lake, 12 algal genera were frequent and present throughout all seasons. Karapuzha Dam displayed frequent genera from diverse algal classes. Regarding dominance, *Cosmarium* was dominant in Pookode Lake and Karapuzha Dam, while *Navicula* dominated the Kuruva Islands, Heart Lake, and Papanasini River. In Banasurasagar Dam, *Staurastrum* was the dominant genus. A total of sixteen algal genera were frequently observed across all sites. The algal genera frequent in water bodies of high-altitude areas were also represented in this study.

The monsoon season of the first year recorded the highest number of algal genera exclusive to that season owing to the effect of flood. Karapuzha Dam had the largest number of algal genera exclusive to its site, which correlated with the high species richness of the site and the unique habitat characteristics of the dam.

Algal diversity varied with changes in rainfall patterns and across water bodies. In the first year, all sites except Banasurasagar Dam and Heart Lake experienced decreased algal diversity during the post-monsoon season. In the second year, algal diversity declined during the monsoon season across most sites, except at Banasurasagar Dam and Kuruva Islands, where diversity increased during the monsoon of both years. Notably, only Heart Lake received sufficient rainfall in both years, resulting in consistently high algal diversity during both post-monsoon seasons.

Lentic water bodies exhibited higher species richness compared to lotic water bodies. Water bodies situated at higher altitudes with limited human access, such as Heart Lake, showed greater diversity. Heart Lake had the highest evenness and the lowest dominance index, making it the most diverse among the study sites. In contrast, the nutrient-rich Pookode Lake had the highest number of algal cells; however, due to high dominance and low evenness, it was the least diverse study site. The Kuruva Islands, characterized by a flowing nature and low organic content, had the lowest number of algal cells and species richness. Similarly, Papanasini River displayed low diversity due to a high dominance index.

The similarity in algal flora across seasons and sites was analysed using Hierarchical Cluster Analysis and Non-metric Multidimensional Scaling Analysis, based on Bray-Curtis Similarity index. These analyses revealed that the monsoon and post-monsoon floras were similar, while the pre-monsoon flora was distinct. Spatial similarity indicated a unique algal flora in Pookode Lake and Heart Lake, while Kuruva Islands and Papanasini River, as well as Banasurasagar Dam and Karapuzha Dam, shared similar algal floras.

Canonical Correspondence Analysis (CCA) revealed the relationships between physicochemical parameters and algae across seasons and sites. Algae in the pre-monsoon of the first year, and the monsoons of both years, were strongly influenced by pH, phosphate, electrical conductivity (EC), silicate, and temperature. Algae in the pre-monsoon of the second year, the monsoons of both years, and the post-monsoon of the second year were strongly influenced by dissolved oxygen (DO), total dissolved solids (TDS), and nitrate. Spatial variation in the correlation between algae and physicochemical parameters was also observed. CCA further indicated the similarity of Pookode Lake, Banasurasagar Dam, and Karapuzha Dam along Axis 1, while Kuruva Islands, Heart Lake, and Papanasini River clustered along Axis 2. TDS, EC, silicate, phosphate, and DO were positively correlated with Kuruva Islands, Heart Lake, and Papanasini River.

Indicator analysis identified specific algal genera as indicators for each season and site. *Trachelomonas* and *Peridinium* were the indicator genera for the pre-monsoon of the first year. For the pre-monsoon of the second year, *Gomphonema*, *Cymbella*, *Achnanthes*, and *Synedra* were identified as indicators. The monsoon of the first year was marked by *Euglena* and *Cyclotella*, while the post-monsoon of the second year was characterized by *Navicula*, *Pinnularia*, *Cymbella*, and *Frustulia*.

Regarding specific water body indicators, *Trachelomonas*, *Cosmarium*, *Staurastrum*, and *Eunotia* were identified for Pookode Lake. *Melosira*, *Peridinium*, *Frustulia*, and *Cyclotella* served as indicators for Banasurasagar Dam. The Kuruva Islands did not have any significant indicator genera. *Melosira*, *Euglena*, and *Scenedesmus* were identified as indicators for Heart Lake, while *Cosmarium*, *Gomphonema*, *Cymbella*, and *Synedra* were indicators for Karapuzha Dam. *Achnanthes* was identified as the indicator genus for Papanasini River.

Pollution levels in the study area were evaluated using the Nutrient Pollution Index, Palmer's Pollution Index, and Boyd's Pollution Index. All three indices indicated that the study area did not experience significant pollution.

Chapter 7

Recommendations

- To develop a taxonomic key for the identification of algae at the species level.
- To provide elaborated morphological descriptions for each identified algae species.
- To investigate the distribution, ecological conditions, and habitat preferences of each algal species.
- To conduct an in-depth study on the altitude specificity of various algae species in the study area.
- To prepare a distribution map of algae in Wayanad district using GIS tools for documentation.
- To evaluate water quality using the Water Quality Index and check for presence of *E.coli* in samples to assess levels of water pollution.

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Appendices

Appendix 1. Table showing details of collection sites of the study area.

COLLECTION NUMBER	HABITAT	LATITUDE	LONGITUDE
COLLECTION NO 1	Tea Plantation	11.5500064	76.1133188
COLLECTION NO 2	Puddles	11.620407	76.168863
COLLECTION NO 3	Paddy Fields	11.62046	76.1688312
COLLECTION NO 4	Puddles	11.6226422	76.16994
COLLECTION NO 5	Stream	11.6227245	76.1698459
COLLECTION NO 6	Lake	11.54055556	76.02666667
COLLECTION NO 7	Lake	11.54083333	76.02666667
COLLECTION NO 8	Island	11.82222222	76.09444444
COLLECTION NO 9	Lake	11.54083333	76.02694444
COLLECTION NO 10	Quarry	11.622634	76.170005
COLLECTION NO 11	Paddy Fields	11.772902	76.085896
COLLECTION NO 12	Lake	11.54083333	76.02722222
COLLECTION NO 13	Mountain Lake	11.54805556	76.08361111
COLLECTION NO 14	Mountain Lake	11.54833333	76.08388889
COLLECTION NO 15	Lake	11.54166667	76.02777778
COLLECTION NO 16	Tea Plantation	11.5501515	76.1136298
COLLECTION NO 17	Lake	11.540811	76.0274331
COLLECTION NO 18	Lake	11.5407565	76.0272709
COLLECTION NO 19	River	11.9130927	75.9940923
COLLECTION NO 20	River	11.9112825	75.9957688
COLLECTION NO 21	Temple Pond	11.91222222	75.99472222
COLLECTION NO 22	Temple Pond	11.91194444	75.995
COLLECTION NO 23	Temple Pond	11.91222222	75.995
COLLECTION NO 24	Rock Crevices	11.55166667	76.08472222
COLLECTION NO 25	Forest Stream	11.55305556	75.085
COLLECTION NO 26	Rock Crevices	11.54555556	76.07833333
COLLECTION NO 27	Puddles	11.7975	75.90527778
COLLECTION NO 28	Canal	11.66611111	76.3325
COLLECTION NO 29	Puddles	11.68305556	76.07805556
COLLECTION NO 30	Puddles	11.726304	76.195758
COLLECTION NO 31	Stream	11.726335	76.195745
COLLECTION NO 32	Stream	11.726323	76.195818
COLLECTION NO 33	Lake	11.772927	76.085733
COLLECTION NO 34	Lake	11.540753	76.027257
COLLECTION NO 35	Lake	11.54194444	76.02805556
COLLECTION NO 36	Dam	11.67083333	75.95
COLLECTION NO 37	River	11.91333333	75.99583333
COLLECTION NO 38	River	11.9130408	75.9940032
COLLECTION NO 39	Dam	11.67027778	75.95055556

COLLECTION NUMBER	**HABITAT**	**LATITUDE**	**LONGITUDE**
COLLECTION NO 40	Dam	11.67083333	75.94972222
COLLECTION NO 41	Lake	11.54194444	76.02777778
COLLECTION NO 42	Lake	11.54166667	76.0275
COLLECTION NO 43	Island	11.82194444	76.09444444
COLLECTION NO 44	Island	11.82138889	76.09444444
COLLECTION NO 45	Lake	11.5408059	76.0273652
COLLECTION NO 46	Lake	11.5425	76.02611111
COLLECTION NO 47	Lake	11.54194444	76.02694444
COLLECTION NO 48	Dam	11.67083333	75.95
COLLECTION NO 49	Dam	11.67055556	75.95
COLLECTION NO 50	Dam	11.67083333	75.95
COLLECTION NO 51	Dam	11.67055556	75.95055556
COLLECTION NO 52	Dam	11.67027778	75.95055556
COLLECTION NO 53	Dam	11.67111111	75.94972222
COLLECTION NO 54	Island	11.8163987	76.0933948
COLLECTION NO 55	Island	11.8218104	76.0897921
COLLECTION NO 56	Island	11.8218745	76.0900516
COLLECTION NO 57	Island	11.8225	76.09555556
COLLECTION NO 58	Island	11.82222222	76.09416667
COLLECTION NO 59	Dam	11.6675	75.96055556
COLLECTION NO 60	Dam	11.66666667	75.96111111
COLLECTION NO 61	Dam	11.66805556	75.95138889
COLLECTION NO 62	Dam	11.6707833	75.9504976
COLLECTION NO 63	Mountain Lake	11.55055556	76.08611111
COLLECTION NO 64	Mountain Lake	11.55083333	76.08638889
COLLECTION NO 65	Mountain Lake	11.55111111	76.08666667
COLLECTION NO 66	Dam	11.6708061	75.9504337
COLLECTION NO 67	Dam	11.67083333	75.95
COLLECTION NO 68	Dam	11.67055556	75.95027778
COLLECTION NO 69	Dam	11.67027778	75.95027778
COLLECTION NO 70	Dam	11.67111111	75.94972222
COLLECTION NO 71	Island	11.82166667	76.09444444
COLLECTION NO 72	Island	11.82138889	76.09444444
COLLECTION NO 73	Island	11.8163987	76.0933948
COLLECTION NO 74	Island	11.83333333	76.08666667
COLLECTION NO 75	Mountain Lake	11.54722222	76.08277778
COLLECTION NO 76	Mountain Lake	11.54722222	76.08277778
COLLECTION NO 77	Mountain Lake	11.5475	76.08305556
COLLECTION NO 78	Dam	11.61694444	76.16638889
COLLECTION NO 79	Dam	11.61722222	76.16611111

COLLECTION NUMBER	HABITAT	LATITUDE	LONGITUDE
COLLECTION NO 80	Dam	11.61805556	76.1675
COLLECTION NO 81	Mountain Lake	11.54777778	76.08333333
COLLECTION NO 82	Mountain Lake	11.54861111	76.08416667
COLLECTION NO 83	River	11.91361111	75.99555556
COLLECTION NO 84	River	11.91333333	75.99527778
COLLECTION NO 85	River	11.91305556	75.99555556
COLLECTION NO 86	River	11.91361111	75.99555556
COLLECTION NO 87	Mountain Lake	11.54888889	76.08444444
COLLECTION NO 88	Mountain Lake	11.54916667	76.08472222
COLLECTION NO 89	Mountain Lake	11.54944444	76.085
COLLECTION NO 90	Island	11.83472222	76.08666667
COLLECTION NO 91	Island	11.82194444	76.09416667
COLLECTION NO 92	Island	11.82194444	76.09416667
COLLECTION NO 93	Island	11.82222222	76.09388889
COLLECTION NO 94	Mountain Lake	11.54972222	76.08527778
COLLECTION NO 95	Mountain Lake	11.55	76.08555556
COLLECTION NO 96	Mountain Lake	11.55166667	76.08722222
COLLECTION NO 97	Dam	11.59916667	76.21472222
COLLECTION NO 98	Dam	11.61694444	76.16638889
COLLECTION NO 99	Dam	11.61666667	76.16666667
COLLECTION NO 100	Dam	11.61888889	76.17527778
COLLECTION NO 101	Dam	11.61694444	76.16638889
COLLECTION NO 102	Dam	11.6175	76.17361111
COLLECTION NO 103	Lake	11.5425	76.02861111
COLLECTION NO 104	Lake	11.54111111	76.02722222
COLLECTION NO 105	Lake	11.54166667	76.02694444
COLLECTION NO 106	Lake	11.54194444	76.02694444
COLLECTION NO 107	Dam	11.61722222	76.17333333
COLLECTION NO 108	Dam	11.61666667	76.17083333
COLLECTION NO 109	Dam	11.61611111	76.16694444
COLLECTION NO 110	Dam	11.61694444	76.16611111
COLLECTION NO 111	River	11.91361111	75.99555556
COLLECTION NO 112	River	11.91333333	75.99527778
COLLECTION NO 113	Island	11.82222222	76.09444444
COLLECTION NO 114	Island	11.82222222	76.09416667
COLLECTION NO 115	River	11.91305556	75.99555556
COLLECTION NO 116	River	11.91333333	75.99583333
COLLECTION NO 117	River	11.91333333	75.995
COLLECTION NO 118	Dam	11.61611111	76.17027778
COLLECTION NO 119	Dam	11.6171284	76.1710336

COLLECTION NUMBER	HABITAT	LATITUDE	LONGITUDE
COLLECTION NO 120	Dam	11.6171932	76.1710078
COLLECTION NO 127	Dam	11.6171482	76.170982
COLLECTION NO 128	Dam	11.61638889	76.16694444
COLLECTION NO 129	River	11.91305556	75.99527778
COLLECTION NO 121	River	11.91333333	75.99527778
COLLECTION NO 122	River	11.91333333	75.99555556
COLLECTION NO 123	Mountain Lake	11.55027778	76.08583333
COLLECTION NO 124	Mountain Lake	11.55138889	76.08694444
COLLECTION NO 125	River	11.91361111	75.99527778
COLLECTION NO 126	River	11.91305556	75.99583333

Appendix 2. Table showing number of algal cells of each genera in each season of six sites

	S1						S2						S3						S4						S5						S6					
GENUS	PRE1	PRE2	MO1	MO2	PO1	PO2	PRE1	PRE2	MO1	MO2	PO1	PO2	PRE1	PRE2	MO1	MO2	PO1	PO2	PRE1	PRE2	MO1	MO2	PO1	PO2	PRE1	PRE2	MO1	MO2	PO1	PO2	PRE1	PRE2	MO1	MO2	PO1	PO2
Achnanthes	0	0	500	0	0	0	0	1500	0	0	1500	0	0	1500	0	1500	1000	0	0	0	0	0	0	0	0	0	0	0	0	1000	0	12500	500	1500	0	3000
Actinastrum	2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	7000	0	0	0	0	0	500	0	0	0	0	0	500	0	0	0
Actinocyclus	0	0	0	0	500	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1000	0	1500	0	0	0	0	500	500	0	0	0
Actinotaenium	0	15000	500	1000	1500	5000	0	0	2500	2000	0	0	0	0	0	0	0	0	0	0	0	0	4000	0	0	0	0	0	0	1000	0	0	0	0	0	500
Amphora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	3000	0	0	0	0	0	0	0	0	0	0
Ankistrodesmus	1000	6500	3500	1500	3000	3500	1500	0	1000	500	500	1000	500	0	0	0	0	0	2000	10000	6000	0	2000	500	500	500	4500	500	2000	1000	500	0	500	0	1500	500
Aphanocapsa	0	1500	3000	0	1000	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	500	500	0	0	0	0	0	500	0	0	0
Aphanothece	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0	0
Astasia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0
Asterococcus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	500	500	1000	2000	0	0	0	0	0	0	0
Botryococcus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	500	0	1500	0	0	0	0	0	0	0
Bulbochaete	0	0	500	0	0	0	0	0	0	0	500	0	0	0	500	0	0	0	500	0	0	0	2000	0	500	1500	500	0	0	1500	0	0	0	0	3000	0
Caloneis	0	0	0	0	0	0	0	1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Centritractus	500	500	1000	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0
Ceratium	0	0	0	0	0	0	0	0	0	500	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetophora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0
Chaetosphaeridium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1000	0	0	0	0	500	0	0	0	0	0	0
Chlorococcum	2000	1000	500	0	0	0	1000	0	0	500	0	0	0	500	1000	500	1000	0	0	0	1000	0	0	0	0	0	1500	0	0	0	0	0	500	0	500	0
Chroococcus	0	0	2500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2500	0	0	0	0	0	0	0	0	0
Closterium	0	2000	3000	0	500	1000	500	1000	0	500	0	0	0	0	3500	0	0	500	0	0	0	2500	0	1000	1500	2500	3500	0	2500	1500	0	0	500	0	500	0
Cocconeis	0	0	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6000	0	1000	0	2000
Coelastrum	2000	0	2000	1000	3000	3500	1500	0	0	0	0	0	500	2000	0	0	1000	0	0	0	0	0	0	0	0	0	0	0	2500	1000	0	0	0	0	0	0
Coelosphaerium	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	500	0	500	0
Coenochloris	500	0	0	0	0	0	0	0	0	1000	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1500	0	0	0	0	0	0	0	0	0
Coenocystis	0	0	1500	0	0	0	500	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1000	0	0	0	0	0	500	0	1000	0
Coleochaete	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1000	0	0	0	0	0	0	0	0	0	0
Cosmarium	29000	51500	52000	22000	25500	20500	1500	12500	15500	6500	11500	18500	500	0	4500	1000	2000	0	1500	2500	1000	2500	1000	2500	14500	40000	46000	3000	29000	21500	500	500	1500	0	10000	1000
Crucigenia	500	0	0	0	0	0	0	0	0	0	0	0	1000	500	0	0	0	0	0	0	0	0	0	0	0	0	1500	0	0	0	0	0	0	0	0	0
Cyclotella	0	0	4000	0	0	0	5000	1500	21000	6000	4000	6500	500	0	1500	0	0	0	500	0	0	0	0	0	2500	0	4500	8000	1000	0	0	0	0	0	0	0
Cylindrospermum	0	0	0	0	0	500	0	0	0	0	0	0	0	0	500	0	0	0	0	0	1500	0	0	0	0	0	11500	0	0	0	0	0	0	0	0	0
Cymbella	0	10000	1500	2000	2000	1000	0	6000	3000	0	2500	0	0	2000	2000	1000	4000	0	1000	2500	1000	1000	2500	1000	1500	8000	3500	500	11500	2000	500	1500	500	0	3000	0
Desmidium	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosphaerium	1500	1000	500	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	1500	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimorphococcus	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinobryon	0	0	3000	1000	5000	0	500	0	0	4500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0
Elakatothrix	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epithemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0
Euastrum	0	4000	2000	1000	0	2500	3500	3000	5500	8000	2500	4500	500	500	500	0	1000	0	500	1000	500	0	3500	1000	1000	2000	1000	0	2000	1000	0	0	0	0	1000	0
Euglena	0	0	1000	0	0	0	3000	0	0	2000	0	500	9000	500	4000	500	1000	0	1000	2500	10000	3500	8500	2500	500	0	2000	2000	0	0	0	0	3000	0	500	0
Eunotia	0	4000	18000	3500	1500	500	0	1000	3500	0	2000	0	0	500	1000	0	0	0	0	500	500	2000	4500	0	500	1000	500	0	0	500	0	3000	0	0	14000	0
Eutetramorus	500	1500	2000	0	1000	3500	0	0	0	1500	500	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	1000	0	0	0	0	0	500	0	0	0
Frustulia	500	0	500	0	500	500	0	20000	1500	2000	7500	0	0	0	500	0	0	0	0	0	500	0	10000	0	0	0	0	0	0	0	0	0	0	0	2000	0
Geminella	0	0	3000	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1500	0
Glaucocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	500	0	2000	0	0	0	0	0	0
Gloeocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0
Golenkinia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1000	500	6500	0	5000	0	0	0	0	0	0	0	0	0	500	0	500	0
Gomphonema	0	10500	5000	3000	8500	3500	500	8500	20000	500	8000	16500	3500	3500	2000	3000	8000	1500	2000	1500	500	500	1500	1500	6500	25000	5000	4000	9500	20000	2500	16500	500	500	19000	2500
Gonatozygon	0	0	500	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	2500	0	0	0	0	0	0	0	0	0
Gongrosira	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groenbladia	0	1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Gyrosigma	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hantzschia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	500	0
Kirchneriella	1500	500	1500	0	500	500	0	0	0	1500	0	0	0	0	0	0	0	0	0	0	1000	0	0	0	0	0	500	0	500	0	0	0	0	0	0	0
Lepocinclis	4500	1500	0	500	0	500	500	0	0	0	0	0	0	0	1000	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2500	0
Melosira	4500	4000	4000	1500	2000	500	15500	9500	1500	7500	6000	3000	1000	0	1500	1000	1500	500	2500	3500	9500	2000	10000	2500	0	1000	3000	500	0	0	0	0	0	0	2500	500
Merismopedia	0	0	0	0	0	0	0	0	0	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	500	0	0	0	0	0	1000	0	0	0
Micrasterias	0	1500	1000	0	500	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1000	0	0	1500	0	0	0	0	0	0
Monomorphina	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	3000	0	0	0	0	0	0	0	0	0	0	0	0	0
Mougeotia	0	0	0	0	0	0	0	0	3000	0	0	0	0	0	500	0	0	0	0	0	0	0	3000	0	0	0	2000	0	0	0	0	0	0	0	0	0
Navicula	1500	18500	5500	3000	1500	8500	9000	12500	10500	4000	10500	2500	2000	5500	14500	6500	15500	2000	7000	17000	8000	2500	13500	5500	3500	4500	9000	1000	37500	1500	1000	15500	0	4500	28000	4000
Neidium	0	0	0	500	0	500	0	1000	0	0	0	0	0	500	500	500	2500	500	3000	1500	2000	8500	3000	2500	500	0	500	0	500	0	500	0	500	0	4500	0
Nephrocytium	0	0	0	0	0	0	0	0	0	3000	0	1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Netrium	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0
Nitzschia	0	0	3000	0	0	0	500	3000	1500	1500	2500	0	0	1500	4000	3000	9500	500	0	0	0	0	0	0	1500	500	6000	0	2000	0	0	500	0	0	6000	0
Nostoc	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1500	0	0	0	0	0	0	0	0	0
Oedogonium	0	1000	5500	0	0	0	0	500	2000	0	1500	500	0	0	0	0	0	0	0	0	1000	0	0	0	1500	3000	3000	0	1000	500	0	0	1500	0	1000	0
Oocystis	0	500	500	0	1000	1500	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	500	0	500	500	0	0	0	0	0	0	0	0	0
Oscillatoria	0	500	1500	0	0	500	0	500	1000	500	1500	0	0	0	1500	0	500	0	0	0	0	0	0	0	0	0	500	0	2000	0	0	0	0	0	0	0
Pandorina	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pediastrum	0	1000	500	0	1000	500	0	0	0	0	0	0	1000	0	0	0	0	0	2500	3000	2000	1000	8000	3500	0	0	0	0	500	0	0	0	0	0	3500	0
Penium	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0
Peridinium	7000	0	3000	500	0	0	6500	500	1500	1500	2500	0	3000	0	0	0	0	0	500	0	7500	0	3500	0	1500	0	1500	0	0	0	0	0	0	0	0	0
Phacus	0	2000	2000	0	500	0	0	0	0	0	0	0	500	0	0	0	500	0	0	1000	500	0	1000	0	0	500	0	0	0	0	0	0	500	0	2500	0
Pinnularia	0	5500	500	1500	5500	2000	1500	12000	2500	2000	8000	0	0	1000	9000	3500	7000	1500	5500	1000	5000	7500	9000	500	2000	4500	1000	500	13000	0	1500	3500	1000	500	22500	0
Pleurosigma	0	0	0	0	0	0	0	0	0	0	0	0	500	1500	0	1000	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pleurotaenium	0	0	0	0	0	0	0	500	0	500	0	500	0	0	0	0	0	0	0	500	0	4000	0	6000	0	1000	0	0	500	1000	0	0	0	0	1000	0
Pseudanabaena	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhopalodia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	500	0	0	0	0	500	500	3000	500	0	0	0	0	0	0	0	0
Scenedesmus	1000	0	1000	0	1000	1000	0	0	0	0	0	0	7500	3500	0	1500	4000	0	3500	9000	16000	500	8000	1500	0	0	5500	0	1500	0	0	0	1000	0	7000	0
Schroederia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Selenastrum	1500	1500	1000	0	2000	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sorastrum	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerocystis	0	0	0	0	0	0	500	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1000	0	0	0	0	0	0	0
Sphaerozosma	0	5500	4500	0	3500	2500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spirogyra	0	0	0	0	0	0	0	0	500	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0	2000	0	0	0	0	4500	0	0	0	0	0
Spirulina	0	500	0	0	500	0	0	0	500	0	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0
Spondylosium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	3000	0	0	0	0	0	0	0	0	0
Staurastrum	8000	31000	64500	6000	32500	6000	10000	14500	4000	20500	11000	22500	0	0	0	0	500	500	4500	0	6000	0	3500	0	1000	2500	12000	1500	5500	1500	0	0	500	500	0	500
Staurodesmus	0	1500	2000	1000	500	0	1500	1000	1500	6500	0	500	0	0	0	0	0	500	0	0	0	0	3500	0	500	500	1000	0	1500	500	0	0	0	0	1000	0
Stauroneis	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	500	0	0	500	500	0	500	0	0	0	0	0	0	0	0	0	500	0	0	0	0
Strombomonas	0	0	0	0	0	0	500	0	0	0	0	0	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surirella	0	0	0	0	0	0	0	0	0	0	1000	0	1000	0	2500	1500	3000	500	3000	4000	3000	4000	8000	2500	500	0	500	0	1000	0	0	0	0	0	3000	500
Synedra	0	500	1500	0	0	2000	0	1000	3000	0	0	0	1000	1000	3000	2500	3000	0	4000	2500	2500	1500	3000	1000	3500	12500	2000	0	3000	3500	0	1000	500	500	2000	2000
Tetraedron	0	500	1000	0	500	500	500	0	0	3000	0	0	500	0	0	0	0	0	500	0	0	0	0	0	0	0	6000	0	0	0	0	0	0	0	0	0
Tetrastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas	45500	40000	20000	5000	12000	7000	28000	1500	0	5500	500	2000	10000	0	2500	2000	0	500	500	7000	15000	0	1000	1000	3500	7500	0	4500	0	4000	3500	0	4500	0	20000	0
Triceratium	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triplastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	0	0	0	0	1000	0	1500	0	0	2500	0	0	0	0	0	0
Xanthidium	0	2000	1000	0	0	1500	0	1500	3500	1500	1500	3000	0	0	500	0	0	0	0	0	0	0	0	0	0	1000	0	0	0	500	0	0	0	0	0	0

Appendix 3. Table showing physicochemical parameters studied in each season of six sites

TEMP	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
PRE 1	28.2 ±0.10	30.53 ±0.30	31.73 ±0.20	31.8 ±0.34	31.3 ±0.26	28.16 ±0.15
PRE 2	28.33 ±0.15	31.06 ±.010	31.83 ±0.28	31.83 ±0.28	31.86 ±0.11	28.16 ±0.15
MO 1	25.33 ±0.11	26.96 ±0.11	27.7 ±0.10	27.13 ±0.11	29.23 ±0.20	29.43 ±0.11
MO 2	28 ±0.52	24.26 ±0.25	25.6 ±0.40	28.03 ±0.75	29.8 ±0.17	23.96 ±0.25
PO 1	24.53 ±0.35	26.56 ±0.40	31 ±0.20	32.86 ±1.0	32.96 ±0.41	29.53 ±0.28
PO 2	25.13 ±0.11	25.93 ±0.05	24.4 ±0.36	33.33 ±0.57	33.36 ±0.11	22.8 ±0.17
PH						
PRE 1	8.16 ±0.11	8.03 ±0.05	8.2 ±0.26	7.73 ±0.15	9.13 ±0.25	7.96 ±0.25
PRE 2	8.56 ±0.20	7.83 ±0.35	7.63 ±0.05	7.6 ±0.1	6.7 ±0.1	7.7 ±0.1
MO 1	7.83 ±0.15	8.16 ±0.05	8 ±0.1	8.36 ±0.23	8.86 ±0.05	7.5 ±0.1
MO 2	6.13 ±0.20	7 ±0.1	7.03 ±0.05	7.43 ±0.35	7.16 ±0.11	7.26 ±0.15
PO 1	7.86 ±0.11	7.63 ±0.15	7.73 ±0.05	9.53 ±0.15	7.03 ±0.05	7.6 ±0.1
PO 2	7.53 ±0.15	6.9 ±0.05	6.7 ±0.05	8.46 ±0.50	7.8 ±0.3	7.66 ±0.25
TDS						
PRE 1	15.33 ±1.52	11 ±0.5	61.33 ±9.8	7.33 ±0.57	58.66 ±0.57	24.33 ±1.15
PRE 2	13.66 ±0.57	22.33 ±1.5	100 ±1	9 ±1.73	61.66 ±4.04	21.66 ±0.57
MO 1	13 ±1.73	10.33 ±0.5	61 ±1	10.66 ±1.15	59.33 ±0.57	38.66 ±6.02
MO 2	27 ±1	11.33 ±0.5	40.33 ±0.5	14 ±0	50.33 ±0.57	20.66 ±0.57
PO 1	12.33 ±0.57	9 ±0	45 ±1	5.66 ±0.57	47.33 ±0.57	36.66 ±0.57
PO 2	11.66 ±0.57	5.6 ±0.36	64.33 ±1.15	6 ±0	55.33 ±2.08	17.66 ±1.52
EC						
PRE 1	30.33 ±0.57	23.33 ±0.57	135.66 ±8.50	17 ±1	122.66 ±0.57	78 ±3.6
PRE 2	29.33 ±1.15	10.33 ±0.57	47.66 ±0.50	19 ±3.6	129.66 ±8.62	45.66 ±0.57
MO 1	28 ±3.46	21.66 ±1.15	29 ±0	23.33 ±2.30	125 ±1	82 ±12.53
MO 2	12.66 ±0.57	22.66 ±0.57	83.66 ±0.577	6.66 ±0.57	104 ±1	44.66 ±0.57
PO 1	26.66 ±1.15	20.33 ±0.57	94.33 ±2.08	12.33 ±1.52	98.66 ±1.15	79.33 ±0.57
PO 2	25.33 ±1.15	20.33 ±0.57	30.33 ±0.57	12.66 ±0.57	115.66 ±4.16	39.33 ±0.57
DO						
PRE 1	5.66 ±0.05	6.8 ±0.17	6.7 ±0.36	5.03 ±0.15	5.43 ±0.05	7.5 ±0.2
PRE 2	6.53 ±0.35	6.43 ±0.20	6.66 ±0.41	6.9 ±0.26	3.8 ±0.1	6.7 ±0.1
MO 1	5.06 ±0.11	6.23 ±0.15	5.6 ±0.26	6.8 ±0.1	6.4 ±0.4	7.33 ±0.15
MO 2	6 ±0.43	6.76 ±0.05	6.76 ±0.05	6.23 ±0.15	5.73 ±0.05	6.56 ±0.11
PO 1	6.46 ±0.25	5.46 ±0.41	7.03 ±0.25	5.8 ±0.26	7.3 ±0.1	5 ±0.2
PO 2	6.86 ±0.11	5.6 ±0.36	6.46 ±0.45	7.2 ±0.1	6.5 ±0.1	6.9 ±0.45
NITRATE						
PRE 1	0.03 ±0.03	0.04 ±0.120	0.04 ±0.01	0.002 ±0.001	0.006 ±0.002	0.03 ±0.003
PRE 2	0.09 ±0.01	0.10 ±0.006	0.13 ±0.01	0.10 ±0.008	0.08 ±0.007	0.04 ±0.001
MO 1	0.02 ±0.004	0.02 ±0.01	0.03 ±0.03	0.05 ±0.05	0.05 ±0.04	0.05 ±0.01
MO 2	0.04 ±0.03	0.11 ±0.02	0.02 ±0.01	0.03 ±0.03	0.07 ±0.05	0.06 ±0.002
PO 1	0.01 ±0.01	0.01 ±0.007	0.03 ±0.005	0.005 ±0.005	0.03 ±0.01	0.02 ±0.009
PO 2	0.007 ±0.001	0.008 ±0.002	0.01 ±0.002	0.11 ±0.01	0.01 ±0.003	0.01 ±0.001
PHOSPHATE						
PRE 1	0.19 ±0.005	0.18 ±0.004	0.19 ±0.002	0.19 ±0.002	0.20 ±0.004	0.05 ±0.14
PRE 2	0.09 ±0.01	0.06 ±0.05	0.16 ±0.18	0.05 ±0.006	0.11 ±0.005	0.21 ±0.01
MO 1	0.18 ±0.02	0.14 ±0.05	0.19 ±0.002	0.02 ±0.12	0.19 ±0.004	0.18 ±0.007
MO 2	0.01 ±0.002	0.17 ±0.01	0.18 ±0.002	0.16 ±0.01	0.18 ±0.004	0.11 ±0.02
PO 1	0.17 ±0.008	0.12 ±0.02	0.07 ±0.002	0.18 ±0.009	0.18 ±0.004	0.15 ±0.007
PO 2	0.08 ±0.01	0.09 ±0.01	0.09 ±0.006	0.05 ±0.02	0.13 ±0.004	0.18 ±0.005
SILICATE						
PRE 1	0.09 ±0.13	0.11 ±0.01	0.74 ±0.17	0.16 ±0.01	0.13 ±0.04	0.30 ±0.06
PRE 2	0.01 ±0.001	0.07 ±0.04	0.17 ±0.004	0.005 ±0.001	0.07 ±0.01	0.41 ±0.19
MO 1	0.16 ±0.02	0.01 ±0.006	0.74 ±0.07	0.21 ±0.02	1.07 ±0.1	0.68 ±0.02
MO 2	0.19 ±0.04	0.19 ±0.008	0.16 ±0.01	0.24 ±0.005	0.07 ±0.02	0.75 ±0.20

PO 1	0.02 ±0.002	0.11 ±0.02	1.23 ±0.13	0.16 ±0.012	0.77 ±0.01	0.96 ±0.06
PO 2	0.23 ±0.02	0.15 ±0.01	0.16 ±0.002	0.38 ±0.03	0.23 ±0.07	0.02 ±0.009

Appendix 4. Table showing results of season wise ANOVA of temperature

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	245.2252	17	14.42501	1.81169	0.038338	1.737467
Within Groups	716.5967	90	7.962185			
Total	961.8219	107				

Appendix 5. Table showing results of site wise ANOVA of temperature

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	370.433	5	74.08659	12.77811	1.2E-09	2.303493
Within Groups	591.3889	102	5.79793			
Total	961.8219	107				

Appendix 6. Table showing results of season wise ANOVA of pH

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	18.59519	17	1.093834	2.853757	0.0007	1.737467
Within Groups	34.49667	90	0.383296			
Total	53.09185	107				

Appendix 7. Table showing results of site wise ANOVA of pH

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.978519	5	0.995704	2.110886	0.070054	2.303493
Within Groups	48.11333	102	0.471699			
Total	53.09185	107				

Appendix 8. Table showing results of season wise ANOVA of TDS

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1933.1	17.0	113.7	0.2	1.0	1.7
Within Groups	56070.3	90.0	623.0			
Total	58003.3	107.0				

Appendix 9. Table showing results of site wise ANOVA of TDS

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	48241	5	9648.2	100.8075	7.36E-38	2.303493
Within Groups	9762.338	102	95.70919			
Total	58003.34	107				

Appendix 10. Table showing results of season wise ANOVA of EC

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8381.963	17	493.0566	0.267766	0.998274	1.737467
Within Groups	165723.3	90	1841.37			
Total	174105.3	107				

Appendix 11. Table showing results of site wise ANOVA of EC

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	136934.2	5	27386.84	75.1513	1.26E-32	2.303493
Within Groups	37171.11	102	364.4227			
Total	174105.3	107				

Appendix 12. Table showing results of season wise ANOVA of DO

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.09963	17	0.182331	0.242904	0.999071	1.737467
Within Groups	67.55667	90	0.75063			
Total	70.6563	107				

Appendix 13. Table showing results of site wise ANOVA of DO

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.74963	5	1.549926	2.513127	0.034495	2.303493
Within Groups	62.90667	102	0.616732			
Total	70.6563	107				

Appendix 14. Table showing results of season wise ANOVA of Nitrate

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.069098658	17	0.004064627	4.099566794	5.41E-06	1.73746672
Within Groups	0.089232946	90	0.000991477			
Total	0.158331604	107				

Appendix 15. Table showing results of site wise ANOVA of Nitrate

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00529015	5	0.00105803	0.705162286	0.620849408	2.303493035
Within Groups	0.153041454	102	0.001500406			
Total	0.158331604	107				

Appendix 16. Table showing results of season wise ANOVA of Phosphate

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.109042	17	0.006414	2.88595	0.000617	1.737467
Within Groups	0.200031	90	0.002223			
Total	0.309073	107				

Appendix 17. Table showing results of site wise ANOVA of Nitrate

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.034522	5	0.006904	2.565126	0.031444	2.303493
Within Groups	0.274551	102	0.002692			
Total	0.309073	107				

Appendix 18. Table showing results of season wise ANOVA of Silicate

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.510367	17	0.147669	1.449355	0.132872	1.737467
Within Groups	9.169718	90	0.101886			
Total	11.68009	107				

Appendix 19. Table showing results of site wise ANOVA of Silicate

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.460764	5	0.692153	8.589466	8.08E-07	2.303493
Within Groups	8.219321	102	0.080582			
Total	11.68009	107				

Appendix 20. Table showing correlation matrix of parameters

Parameters	Temperature	pH	TDS	EC	DO	Nitrate	Phosphate	Silicate
Temperature		0.32	0.31	0.36	-0.05	0.15	0.00	0.19
pH	0.32		-0.12	0.04	0.07	0.27	0.24	0.06
TDS	0.31	-0.12		0.68	-0.07	0.12	0.23	0.35
EC	0.36	0.04	0.68		-0.06	0.22	0.29	0.46
DO	-0.05	0.07	-0.07	-0.06		0.26	-0.20	0.19
Nitrate	0.15	0.27	0.12	0.22	0.26		0.10	0.27
Phosphate	0.00	0.24	0.23	0.29	-0.20	0.10		0.11
Silicate	0.19	0.06	0.35	0.46	0.19	0.27	0.11	

Appendix 21. Table showing axes and eigen values of season wise CCA analysis

Axis	Eigenvalue	%
1	0.12	39.42
2	0.07	24.27
3	0.06	22.21
4	0.03	9.84
5	0.01	4.24

Appendix 22. Table showing axes and eigen values of each algae of season wise CCA analysis

	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
SPI	4.36	-1.56	4.45	0.22	-0.16
STD	0.02	-0.21	-1.22	-3.32	3.24
SPH	-0.92	1.19	-0.03	1.94	-1.00
CYL	2.11	3.22	-4.52	4.91	-0.20
TRA	1.51	-0.68	1.44	0.06	0.18
COS	0.05	0.83	-0.03	0.24	-0.44
NAV	-0.71	-0.74	-0.03	0.04	-0.01
MEL	0.83	-0.36	0.39	-0.80	0.60
STA	0.27	0.87	-0.78	0.03	0.13
PER	3.30	-0.82	0.54	0.53	-0.51
GOM	-0.91	0.39	0.73	0.05	-1.44
EUG	1.72	0.26	-0.99	-0.32	0.61
PIN	-0.68	-1.82	-0.69	-0.34	0.22
SCE	0.53	-0.74	-0.70	1.42	-0.63
CYM	-1.05	-0.48	0.36	1.15	1.47
ACH	-1.95	1.75	2.44	0.42	3.58
FRU	-1.66	-1.40	0.45	1.31	1.80
SYN	-0.14	0.69	0.68	0.01	-0.37
CYC	1.50	1.62	-1.97	-1.28	1.46
EUN	-0.51	-0.92	-1.80	1.05	0.35
NEI	-0.13	-0.89	-0.83	-3.62	1.18
EUA	-0.11	0.72	-0.01	-1.86	0.17
NIT	-0.29	-1.31	-1.84	0.46	0.03
PLE	-1.38	2.44	0.39	-6.33	-3.65
ANK	0.03	0.81	0.28	1.13	-0.09
ACT	-1.60	1.41	1.29	-0.25	0.47
SUR	-0.20	-1.16	-0.78	-1.56	-0.96
PED	-0.60	-1.65	-0.13	-0.57	-3.30
CLO	0.31	1.49	-0.91	0.34	0.08
COC	-1.87	2.37	2.52	0.15	2.85
PRE 1	0.76	-0.20	0.38	-0.04	-0.03
PRE 2	-0.31	0.10	0.28	0.13	0.10
MO 1	0.27	0.23	-0.33	0.16	0.01
MO 2	0.04	0.11	-0.19	-0.46	0.22
PO 1	-0.22	-0.37	-0.14	0.00	-0.06
PO 2	-0.22	0.45	0.15	-0.20	-0.24
TEMP	0.11	-0.61	0.66	0.62	-0.05
PH	0.52	-0.38	0.18	0.80	-0.37
TDS	-0.07	0.16	0.32	0.64	0.37

EC	0.79	-0.75	0.29	0.31	0.04
DO	-0.28	0.75	-0.01	-0.56	-0.51
NITRATE	-0.38	0.26	0.20	0.19	0.60
PHOSPHATE	0.82	-0.67	-0.15	0.18	0.24
SILICATE	0.11	-0.46	-0.73	0.24	-0.09

Appendix 23. Table showing axes and eigen values of site wise CCA analysis

Axis	Eigenvalue	%
1	0.25	45.85
2	0.14	24.92
3	0.10	17.87
4	0.06	11.37
5	0.00	0.00

Appendix 24. Table showing axes and eigen values of each alga of site wise CCA analysis

	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
SPI	-0.90	3.72	2.16	-2.75	0.06
STD	-0.34	-0.81	0.20	-0.50	1.51
SPH	3.14	-0.67	1.01	1.48	-2.00
CYL	-0.08	1.76	-4.65	-2.76	0.65
TRA	0.98	-0.10	0.86	0.52	-0.65
COS	1.08	0.39	-1.04	-0.43	0.12
NAV	-0.65	0.64	0.09	0.32	-0.11
MEL	-0.75	-1.55	0.54	-0.26	0.95
STA	1.16	-0.87	0.59	0.49	0.34
PER	-0.27	-1.42	0.08	0.20	0.26
GOM	-0.38	1.22	-0.21	-0.33	0.83
EUG	-1.50	-0.91	-0.61	1.35	-1.17
PIN	-0.82	0.57	0.48	0.24	-0.09
SCE	-1.36	-0.68	-0.59	0.36	-1.69
CYM	-1.36	-0.68	-0.59	0.36	-1.69
ACH	-1.19	3.54	3.85	-0.93	-0.29
FRU	-1.33	-1.85	1.30	-0.56	2.56
SYN	-0.70	0.79	-1.79	-0.17	-0.28
CYC	-0.87	-0.67	-0.16	0.06	3.23
EUN	0.67	0.63	1.92	-0.88	-0.85
NEI	-1.48	-1.13	0.43	-1.38	-1.71
EUA	-0.51	-0.99	0.30	0.19	1.82
NIT	-1.04	1.47	-0.47	4.74	0.04
PLE	-1.33	-1.74	-0.85	-3.74	-0.83

ANK	0.23	-0.96	-0.38	-1.75	-0.95
ACT	1.77	-0.99	0.78	0.41	-0.98
SUR	-1.61	-1.22	-0.47	-0.02	-1.70
PED	-1.07	-1.75	0.17	-3.05	-1.89
CLO	0.11	0.73	-1.95	0.38	-0.23
COC	-0.71	4.52	5.52	-4.14	-0.86
S1	0.74	-0.11	0.10	0.05	-0.06
S2	-0.03	-0.24	0.17	0.07	0.67
S3	-0.70	0.23	-0.13	0.52	-0.36
S4	-0.69	-0.53	-0.08	-0.20	-0.59
S5	0.11	0.38	-0.53	-0.11	0.19
S6	-0.41	0.75	0.58	-0.19	-0.23
TEMP	-0.36	-0.18	-0.80	-0.22	-0.22
PH	-0.25	-0.57	-0.31	-0.58	-0.49
TDS	-0.21	0.60	-0.53	0.54	-0.09
EC	-0.22	0.59	-0.53	0.53	-0.10
DO	-0.67	0.29	0.71	0.22	-0.49
NITRATE	-0.29	-0.74	-0.56	-0.13	-0.24
PHOSPHATE	-0.24	0.57	-0.56	0.51	-0.11
SILICATE	-0.22	0.59	-0.53	0.53	-0.10

Appendix 25. Table showing result of season wise Indicator analysis

SEASON	TRA	COS	NAV	MEL	STA	PER	GOM	EUG	PIN	SCE	CYM	ACH	FRU	SYN	CYC	EUN
PRE1	0.02	0.71	0.93	0.35	0.72	0.01	0.97	0.24	0.94	0.45	0.99	1.00	0.93	0.79	0.34	0.99
PRE2	0.37	0.28	0.10	0.53	0.56	0.96	0.04	0.91	0.25	0.60	0.00	0.04	0.34	0.04	0.93	0.23
MO1	0.50	0.09	0.65	0.33	0.16	0.05	0.57	0.03	0.52	0.10	0.39	0.88	0.43	0.18	0.03	0.05
MO2	0.84	0.89	0.96	0.61	0.76	0.80	0.98	0.47	0.64	0.92	0.95	0.44	0.79	0.94	0.40	0.75
PO1	0.62	0.37	0.00	0.26	0.17	0.55	0.13	0.50	0.00	0.06	0.02	0.52	0.05	0.47	0.71	0.12
PO2	0.82	0.65	0.94	0.85	0.52	1.00	0.27	0.92	1.00	0.91	0.98	0.35	0.93	0.64	0.76	0.97

Appendix 26. Table showing result of site wise Indicator analysis

SITES	TRA	COS	NAV	MEL	STA	PER	GOM	EUG	PIN	SCE	CYM	ACH	FRU	SYN	CYC	EUN
S1	0.00	0.00	0.66	0.31	0.00	0.22	0.75	0.98	0.76	0.78	0.28	0.88	0.48	0.96	0.87	0.02
S2	0.45	0.50	0.45	0.00	0.06	0.04	0.13	0.72	0.41	1.00	0.77	0.44	0.01	0.98	0.00	0.59
S3	0.87	1.00	0.51	0.91	1.00	0.85	0.82	0.11	0.54	0.21	0.75	0.27	0.93	0.37	0.87	0.94
S4	0.66	0.99	0.36	0.04	0.91	0.18	0.99	0.00	0.22	0.00	0.54	1.00	0.31	0.11	0.96	0.45
S5	0.80	0.02	0.30	0.98	0.55	0.75	0.02	0.76	0.57	0.77	0.02	0.85	1.00	0.03	0.14	0.78
S6	0.78	0.99	0.54	1.00	1.00	1.00	0.34	0.89	0.33	0.76	0.91	0.02	0.78	0.71	1.00	0.40

Paper presentations

- Paper presented on topic ‘Desmids in Banasurasagar Dam, Wayanad’ in International seminar on Plant science Research organized by Department of Botany, Mahatma Gandhi College, Thiruvanthapuram on 3rd and 4th March of 2022 and got first in paper presentation competition.
- Poster presented on topic ‘Diversity of desmids in Karapuzha Dam, Wayanad’ in International Symposium on “Biodiversity, Biology and Biotechnology of Algae (ISBBBA-20)” by Centre for Advanced Studies in Botany, University of Madras, Chennai on, January 8th –10th of 2020.
- Presented paper on ‘Biomonitoring of Pookode Lake using phytoplanktons’ in National seminar ‘Species the Passion V’ of Department of Botany, St. Thomas College, Thrissur on June 26th and 27th of 2019.
- Presented paper on ‘Diversity of phytoplanktons in two dams of Wayanad district’ in National conference on Bioprospecting of Algae: - Resources, Conservation and Utilization, Central university of Kerala, 1st & 2nd August of 2019.
- Paper presented on topic on ‘Phytoplankton assessment of Heart Lake, Chembra Peak, Wayanad’ in National seminar, ‘Species the Passion 7’ of Department of Botany, St. Thomas College, Thrissur on March 9th of 2022.
- Paper presented on topic ‘Algae of Kuruva Islands, Wayanad, Kerala’ in National seminar ‘Species the Passion 8’ of Department of Botany, St. Thomas College, Thrissur on February 3rd of 2023.
- Paper presented on topic on ‘Diversity and seasonal distribution of phytoplankton in Pookode Lake, Wayanad’ in National seminar, ‘Species the Passion 9’ of Department of Botany, St. Thomas College, Thrissur on December 15th of 2023.

Paper Publications

- Dhanya Jose, Ignatius Antony, P.V. Anto, & Tessy Paul (2022). Taxonomy and distribution of desmids in Karapuzha Dam, Western Ghats, Kerala. *Feddes Repertorium*, *133*(2), 89–102.
- Dhanya Jose, Ignatius Antony, P.V. Anto, (2022). Phytoplankton assessment of Heart Lake, Western Ghats, Kerala, Proceedings of the national seminar ‘Species the Passion 7’, ISBN 978-93-91691-01-1.

Papers Accepted

- Dhanya Jose, P.V. Anto, Seena K.K., Ignatius Antony, & Tessy Paul (2025), New records of algae to the Indian Subcontinent from Wayanad, the Western Ghats, Kerala, India in International Journal on Algae.
- Dhanya Jose, P.V. Anto, Seena K.K., Ignatius Antony, & Tessy Paul (2025), New records of freshwater algae to Kerala from Wayanad, Western Ghats, India in International Journal on Algae.

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4.	Department/Institution	DEPARTMENT OF BOTANY, ST. THOMAS COLLEGE, THRISSUR-680005.	
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