WATER QUALITY ASSESSMENT AND MICROPHYTE DIVERSITY OF SATYAWATI LAKE, LUMBINI PROVINCE, NEPAL

A THESIS

SUBMITTED FOR THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE MASTER'S DEGREE IN BOTANY

Submitted to

Department of Botany

Amrit Campus

TRIBHUVAN UNIVERSITY

Kathmandu, Nepal

Submitted by

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26th July 2023

DECLARATION

I, Nabina Reshmi, hereby declare that the work enclosed here is entirely my own, except where states otherwise by reference or acknowledgement, and has not been published or submitted elsewhere, in whole or in part, for the requirement of any other degree or professional qualification. Any literature, data or work done by others and cited within this thesis has been acknowledged and listed in the reference section.

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RECOMMENDATION

This is to recommend that the master's thesis entitled **"Water Quality assessment and Microphyte Diversity of Satyawati Lake, Lumbini Province, Nepal"** is carried out by **Nabina Reshmi** under our supervision. The entire work is based on original scientific investigation and has not been submitted for any other degree in any institutions. We, therefore, recommend this thesis work to be accepted for the partial fulfilment of M.Sc. Degree in Botany.

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LETTER OF APPROVAL

The thesis work submitted by **Nabina Reshmi** (T.U. Registration No.: 5-2-49-300-2012) entitled **"Water Quality assessment and Microphyte Diversity of Satyawati Lake, Lumbini Province, Nepal"** to Department of Botany, Amrit Campus, Tribhuvan University has been accepted for the partial fulfilment of the requirement for master's degree in Botany.

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Nabina Reshmi

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
APHA	American Public Health Association
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DOF	Department of Forest
EC	Electrical Conductivity
EDTA	Ethylenediaminetetraacetic Acid
IUCN	International Union for Conservation of Nature
Mg/l	Milligram per liter
MOFSC	Ministry of Forest and Soil Conservation
pH	Potential of Hydrogen
SD	Standard Deviation
SPSS	Statistical Package for Social Science
TA	Total Alkalinity
TDS	Total Dissolved Solid
Temp	Temperature
TH	Total Hardness
WHO	World Health Organization

ABSTRACT

Understanding seasonal variation in water quality is one of the most important aspects for conserving and protecting water resources. This study aims to analyze seasonal variation in physicochemical parameters of water and its impact on microphytes (algae) in Satyawati Lake, Lumbini Province, Palpa, Nepal. Altogether thirty samples of water were collected from the littoral zone of the lake and from the same points algae were sampled. The parameters of water such as temperature, pH, Alkalinity, total dissolved solids (TDS), total hardness, electrical conductivity (EC), dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD) were analyzed. A total of 62 algal species belonging to 7 Phyla, 10 Classes, 27 Orders and 30 Families were reported. The algal class Bacillariophyceae was found dominant with 23 genera, followed by 16 genera of Zygnematophyceae, 10 genera of Chlorophyceae, 4 genera of Cyanophyceae, 3 genera of Xanthophyceae, 2 genera of Ulvophyceae and one genus of each Coscinodiscophyceae, Trebouxiophyceae, Glaucophyceae and Euglenophyceae. Study shows that the seasons have significant impact on algal species composition. TDS, Alkalinity, EC and total hardness have supported for high frequency of Bacillariophyceae. The study showed the present status of the Satyawati Lake, Nepal regarding water quality and microphyte (algae) relationship. It also provides useful information for decision makers for conservation and sustainable management of this wetland.

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CHAPTER – I

INTRODUCTION

1.1 Background

Nepal has a diverse climate and ecosystems that features both terrestrial and wetland ecosystems with big water supply approximately 6,000 rivers, 5358 lakes, and more than 1,000 ponds (CBS, 2008). In Nepal, wetlands make up 0.42 million hectares, or 5% of the country's total land area (CBS, 2008). Wetlands in Nepal include perennial rivers, intermittent streams, high-altitude glacial lakes, marshes and swamps, paddy fields, reservoirs, and ponds. According to the Ministry of Forest and Soil Conservation, Nepal the wetlands are described as transitional lands between terrestrial and aquatic systems where the water table is typically at or near the surface or as land that is submerged in shallow water (MOFSE, 2002). The Ramsar Convention (1997) defines wetlands as 'Areas of marsh, fen, peat land or water, whether natural or artificial, permanent, or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water the depth of which at low tide does not exceed six meters. In Nepal, there are 240 ecologically significant wetland habitats with a diverse range of flora and wildlife, including several threatened species (BPP, 1995). Wetlands support the regulation of ecosystem components and processes. Numerous biotic and abiotic elements make up wetland ecosystems, which interact with one another and offer a range of functions to the surrounding people (BPP, 1995).

One of the world's most productive ecosystems are wetlands and other lake environments. In Nepal, there are more than 5000 lakes with an area of more than 1 hectare, and 10 of those are recognized as the Ramsar sites (DNPWC, 2016). According to Siwakoti (2006) the wetlands in Nepal are exclusively freshwater in nature and occupy approximately 5% of the total area of the country mainly in the form of river, lakes, reservoirs, village ponds, paddy fields and marshes. Both rural and urban residents use the water from these ecosystems for drinking and domestic purposes. Also, they play a significant part in the ecological processes that promote biodiversity and protect the ecological integrity of the environment. Wetland water quality is a key factor in both conservation and development because it affects the spatiotemporal dynamics of aquatic organisms.Water quality is an important factor for the diversity, distribution, growth and development of wetland flora and fauna. Several factors such as growth of invasive species on lakes, seasonal fluctuation of water level, eutrophication, lack of efficient inlet and outlet are the major threats to the wetlands (Burlakoti et al., 2004). Due to the significance of water, particularly in biological growth and reproduction, water quality monitoring has recently attracted more attention (Baral et al., 2015). Also, the water quality directly affects land use as well as the soil and vegetation characteristics (Batzer et al., 2000; Montgomery et al., 2008).

1.2 Aquatic microphytes

Aquatic plants are commonly recognized as indicators of environmental changes in lakes and aid in maintaining the structure and functionality of lakes. Wetlands contain both macroscopic and microscopic species called aquatic macro- and microphytes, commonly referred to as algae, ferns, mosses, and angiosperms (Burlakoti et al., 2004). The most significant biotic component of the littoral zone in a lake environment is represented by aquatic macrophytes, which can take on various growth forms and both the littoral, limnetic and profundal zones are occupied by microphytes specially algae (Burlakoti and Karmacharya, 2004).

Algae are a diverse group of microorganisms that can range in size from tiny blue-green algae to enormous, intricate seaweeds that can reach a few meters in length. Most algae are aquatic, basic photosynthetic thalloid organisms without organized tissue systems that show a wide range of thalli organization, from microscopic unicellular to enormous macroscopic sea weeds (Rai and Ghimire, 2020). Algae may flourish in almost any habitats, rivers, lakes, ponds, hypersaline lagoons, and freshwater springs. They could grow on animals (like turtles, sloths, and crabs) as well as plants like (tree trunks, water plants, aquatic plants, and macroalgae) (Rai and Ghimire, 2020). They are regarded as the base of the aquatic food chain because they are the main producers and provide oxygen to other aquatic life to utilize in place of excess carbon dioxide from the environment (Shrestha and Rai, 2017). Nepal has a diverse range of algae because to its varied temperature, topography, and altitudinal changes. Desmids flourish luxuriantly in the Terai's hot and humid environment, whereas diatoms predominate in the cool, ice-fed streams (Rai et al., 2008).

Algae has long been utilized as a water quality indicator. Algae react to environmental change fast due to their limited lifespans. Some species have also been linked to poisonous blooms, which can occasionally produce hazardous conditions or offensive tastes and odors (Rao and Rao, 2016).

In the case of an algal bloom, algae may trigger the mass extinction of other organisms, but they also produce vital industrial products like food, medicine, and fertilizer that are necessary for human survival (Shrestha and Rai, 2017).

The algae are significantly affected by different parameters of water quality. Regarding the relationship between water quality parameters and algae, there are several studies carried out throughout the world. However, such studies in context of Nepal are rare. The notable exploration on algae in Nepal began after the first and second Himalayan expeditions to Mount Manaslu. Although, studies regarding algae from different wetlands have been carried out by several national and international researchers. The history of algal exploration in Nepal revealed that numerous phycologists from nation and international were involved, and most of the research were conducted periodically at various points in time and only in certain locations. For example, Hirano (1955) identify 271 species of algae, played a significant role in popularizing the study of algae in Nepal. After that, Joshi (1979), Upadhyaya (1979), Nakano and Watanabe (1988), Haga (1988), Bando et al. (1989) made contribution to the algal flora of Nepal (Rai and Ghimire 2020). After that large number of algal species including new reports and new species have been reported by number of algologists till the date in Nepal. According to Rai et al. (2010), Prasad (2011), and Necchi et al. (2016) the total number of algal species of Nepal is 998. Among them there are 29 species of algae endemic to Nepal (Rai and Ghimire, 2020)

1.3 Physicochemical characteristic of water

In general, "water quality" refers to the element of water that must be present for aquatic creatures to develop as best they can (Verma and Khan, 2015). The physical, chemical, and biological properties of water are referred to as its quality. The interaction of water's physical and chemical qualities has a significant impact on the composition, distribution, and abundance of aquatic communities. The physicochemical study may be useful in understanding the structure and use of a particular body of water in connection to its habitants. An abundance of one element may indicate the type of organism that may be present as well as an indication of an ecologically unstable or unfavorable ecosystem, which may have an impact on the population either negatively or favorably. For example, a high concentration of nitrate or phosphate indicates eutrophication (Adedeji et al., 2019)

According to Wiegand et al. (2013), lakes are an essential component of the hydrological cycle and significant water supplies for irrigation, domestic water supply, transportation, fishing, biodiversity protection, and environmental balance. There are different physicochemical parameters available for the analysis of water quality and parameters are selected depending on the purpose of use. Some of the important physicochemical parameters under study are temperature, total dissolved solid (TDS), pH, alkalinity, total hardness, electric conductivity (EC), dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD). Temperature is a significant factor as it affects the chemical and biological reaction that takes place in water. According to Trivedi and Goel (1986) a rise in temperature of water speeds up the chemical reaction, reduces the solubility of gases and increases odour. The distribution of plankton and the stratification of lakes are significantly influenced by physical factors such as temperature, light permeability, and water velocity. Because of the major biological and physicochemical characteristics of the surrounding water, DO is also a significant indicator of the quality of the water (Trivedi and Goel, 1986).

1.4 Justification

Algae are important biotic components of the lake ecosystem and biological diversity. Also, the diversity and distribution of aquatic biota including algae are affected by the changes in water chemistry (Deshkar et al., 2010). Algae are good indicators of water quality as their composition, abundance and diversity are altered with change in water quality. In Nepal, most of the scientific efforts have been focused on Ramsar listed wetlands, but many of other wetlands have been ignored which are vulnerable to the degradation and anthropogenic disturbances (Neupane et al., 2011). A religious lake, the Satyawati Lake located in Palpa district of Lumbini Province, Nepal is one of such ignored lakes regarding documentation of water quality and its biological components. The lake has good potential for internal and external tourism and hence their conservation is important. This study was carried out in the lake for assessment of seasonal variation of water quality and its impact on algae. Understanding the seasonal variation, characteristics and trends in water quality is one of the most important aspects for protecting and conserving lakes.

1.5 Research questions

Following are the research question of this study:

- What is the status of water quality in the Satyawati Lake, Lumbini Province, Nepal?
- What is the diversity of algae in the Satyawati Lake, Lumbini Province, Nepal?
- What are the relationships between water quality to the algal components of the lake?

1.6. Objectives

The overall objective of the study is to measure the lake water quality and their impacts on the algae in the Satyawati lake, Lumbini Province, Nepal. Following are the specific objectives:

- To analyze the seasonal changes in physicochemical characters of the lake water.
- To document seasonal influence on algal species richness and composition in the lake.
- To analyze the effects of physicochemical parameters of water with algal species diversity, richness, and distribution in the lake.

1.7 Limitations

- Study was carried out only in two seasons for water quality analysis and algae documentation.
- For the physicochemical parameters of water only the parameters like pH, temperature, alkalinity, electric conductivity (EC), total hardness, total dissolved solute (TDS), dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD) were measured.

Chapter – II

Literature Review

2.1 Physicochemical parameters of water

Many scientists and researchers have conducted various studies on the physicochemical features of water in the past. Bhattrai (2008) conducted the water quality analysis and watershed management at Sundarijal in three different seasons and found that the overall water quality of the study site was natural and was within the WHO and EC guidelines. The study also showed that the reservoir is still in good condition with the documentation of 11 species of phytoplankton and absence of macrophytes.

Neupane et al. (2011) studied lake water quality and surrounding vegetation in the Mudka, Bedkot and Jhilmila lakes of Kanchanpur in far western Nepal during pre-monsoon and post-monsoon and recorded a significant variation in the physiochemical properties of the lake. They have also documented number of plant species in the surrounding vegetation of these lakes.

Baral et al. (2015) studied the water quality of Jagadispur Reservoir of Lumbini Province (Kapilvastu), Nepal and their results showed that the value of pH, electrical conductivity, total dissolved solid, nitrate, phosphate, bicarbonate, and chemical oxygen demand were in permissible range.

Pant and Adhikari (2015) analyzed the major physico-chemical parameters and the water quality assessment of Phewa lake of Gandaki Province (Pokhara), Nepal and found that temperature, pH, electrical conductivity, free $CO_{2,}$ total hardness, and chloride content were found within the satisfactory level. Also, eutrophication was found to be a major problem due to increased concentration of nitrate-nitrogen and phosphate from agricultural seepage from surrounding agricultural fields.

Pandey and Devkota (2016) conducted an extensive investigation of physicochemical parameters of water samples of Tinau River at Butwal, Nepal. They compared the observed values of different physicochemical parameters like pH, temperature, turbidity, total hardness (TH) Chloride, total dissolved solid (TDS), total alkalinity (TA), dissolved oxygen (DO), total phosphorus, total nitrogen, electrical conductivity of samples with standard values recommended by world health organization (WHO) and found that all the physicochemical parameters except turbidity and pH within the standard for drinking water.

Chaudhary and Devkota (2018) also evaluated the limnological status of low altitude lake Jagadishpur Reservoir of Kapilvastu district. They found that the water quality in the reservoir was less favourable to aquatic organisms with low pH, low transparency, low dissolved oxygen (DO) and high nutrient concentration (nitrogen). The reservoir was found eutrophic in nature by nitrogen concentration.

Adhikari et al. (2020) carried out geochemical and multivariate assessment of water quality of the Rajarani lake in Dhankuta and found that the basic pH (8.71), EC (54 µS/cm), and lowest TDS (32.15 mg/l). It concluded that chemical parameters of the water were below the guidelines of WHO for drinking water and mostly meet the guidelines of National water quality guidelines for aqua culture.

Bhusal and Devkota (2020) studied physicochemical characteristics pH, temperature, dissolved DO, total alkalinity, EC, TH, nitrate, inorganic phosphorus total solid matter and free CO_2 of the lakes of the Chitwan National Park. Study revealed that higher nitrate in the Beeshazari Lake with higher inorganic phosphorus. The study concluded that the lakes were hyper-eutrophic based on the nitrate and phosphorus concentration. In terms of DO, Tamor Lake, Kingfisher Lake and Athaieshazar Lake had good water quality in the lake cluster.

Pant et al. (2019) studied the water quality of Betkot Lake of Sudurpaschim Province, Nepal. They analyzed the water parameters and found that the water quality of the lake met the guideline of Nepal's drinking water quality guideline; however, some parameters like concentration of DO, biological oxygen demand (BOD), chemical oxygen demand (COD) and ammonia did not meet the guidelines for aqua culture in some sampling locations.

2.2 Algal studies in Nepal

Rai (2005) reported the diatoms from Maipokhari lake of Ilam district, Koshi Province, Nepal and found 10 taxa belonging to 5 genera of Bacillariophyceae. Out of these, 8 taxa were being reported for the first time from Nepal. Similarly, Rai and Rai (2005) investigated some Bacillariophycean algae from Biratnagar, Nepal during September to November and reported 12 taxa belonging to

10 genera of Bacillariophycean algae of which *Synedra ulna* var. *amphirhynchns, Navicula perrotetti*, *Gomophonema garcile* var. *lanceolata*, *Gomphonema parvulum* var. e*xilissima* and *Nitzschia intermedia* were reported for the first time in Nepal.

Rai (2006) investigated freshwater diatoms from the eastern terai region of Nepal and explained about the distribution of 17 freshwater diatom species (Bacillariophyceae) belonging to 11 genera of which *Cyclotella*, *Gomphonema*, *Cymbella*, *Epithemia* and *Hantzschia*. Furthermore, 5 diatom species were newly reported in this area and 5 diatom species were new to the country.

Rai et al. (2008a) studied freshwater algae from running streams of Gajurmukhi, Illam, Nepal. They had reported altogether 18 taxa of freshwater algae. Rai et al. (2008b) also reported collected samples from Beeshazaar lake, Chitwan, Nepal and reported 36 taxa belonging to 7 genera of desmids. Out of which 11 taxa were recorded for the first time in the country.

Rai and Mishra (2010) studied the freshwater cyanophycean of eastern Nepal and found 51 algal taxa of Cyanophycean belonging to 28 genera from different lotic and lentic freshwater bodies of east Nepal. Out of these, 19 taxa were new additions to the cyanophycean flora of Nepal and 39 were new records for the study area.

Rai (2011) studied algal flora of Betana wetland of Morang, eastern Nepal. He enumerated planktonic algae belonging to the classes Cyanophyceae, Chlorophyceae and Bacillariophyceae. The diatom taxa reported were *Gomphonema parvulum* var. *lagenula*, *Rhopalodia gibba* var. *ventricosa*, *Nitzschia amphibia* and *Surirella tenera* var. *Ambigua* were the new records for the country. Rai (2012) reported 5 species of genus *Oedogonium* which were new to Nepal. They were *Oedogonium leave, O. peripingense, O. pisanum, O.plagiostomum* and *O. undulatum*.

Rajopadhyaya and Rai (2018) explored Baghjoda wetland of Morang, Nepal and found 8 cyanophycean algae under 6 genera. They were Anabaena, Aphanocapsa, Chroococcus, Oscillatoria, Phormidium and Spirulina. Two species *Anabaena affinis* and *Anabaena subcylindrical* were new records for Nepal.

Shrestha et al. (2013) studied the algae of Itahari Municipality and its adjoining area, eastern Nepal, and a total of 52 algal taxa belonging to three classes and 21 families were recorded. Most species collected from lentic and lotic habitat with some from soil and epiphyte showed that the

Chlorophyceae were rich with 36 taxa followed by 9 species of Cyanophyceae and 7 species of Bacillariophyceae.

Rai and Paudel (2019) also investigated algal flora of Jagadishpur Reservoir, Kapilvastu, Nepal and found a total of 124 algae belonging to 58 genera and 9 classes. Some of the rare and interesting algae were also reported from this reservoir. They also concluded that this reservoir is rich and diverse and needs further study for documentation and conservation.

Dhakal et al. (2020) studied algal flora of Gajedi Lake at Rupandehi, Nepal. They reported 33 taxa belonging to 10 orders, 14 families, 5 classes and 18 genera from their study. Chlorophyta with 15 taxa was found to be the dominant phylum of algae followed by Charophyta, Cyanophyta, euglenophyta and Glaucophyta.

2.3 Relationship between physicochemical characteristics of water and algal species composition

Bhattarai et al. (2008) conducted water analysis and watershed management in four sites at Sundarijal, Kathmandu, Nepal by investigating different physicochemical parameters, heavy metals and microbiological (TC and FC) characteristics in three different seasons. He found that all the tested physicochemical parameters were under WHO guidelines in the absence of phosphorus and carbonates. The result showed that Bagmati River is a little bit polluted as the value of heavy metal parameters was found highest. Algal documentation was also done at Sundarijal reservoir and 11 species of phytoplankton were recorded and suggested that streams and reservoir of water are in good condition.

Ghosh et al. (2012) conducted the investigation on diversity and seasonal variation of the phytoplankton community in Santraganchi lake, West Bengal, India. They observed that density of phytoplankton was higher when temperature and nutrients increased and found a total of 29 phytoplankton taxa belonging to Chlorophyta, Cyanobacteria, Charophyta, Bacillariophyta and Euglenozoa. They concluded that bioindication showed a low diverse community in the monsoon period with better water quality in pre- and post-monsoon.

Shrestha and Rai (2017) carried out the seasonal distribution of algal flora of Rajarani Lake, Dhankuta, Nepal and found that there was changing number and type of algae with physicochemical parameters in different seasons. They reported maximum number of algae in summer followed by winter and rainy seasons with few of the common algae in all seasons.

Zaky and Okpanachi (2019) concluded that organic pollution in the water body supports growth and development of algal species. Pokhrel et al. (2021) studied the seasonal variation of algal diversity with reference to water quality in Jagadishpur Reservoir, Kapilvastu, Nepal during dry and wet seasons and found that higher number of algal species was recorded in the dry season rather than in the wet season. They reported that algal diversity was positively correlated with the increase of alkalinity, electric conductivity and TDS, while negatively correlated with free CO_2, hardness, concentration of phosphates and nitrates, DO, pH and temperature. Shannon–Weiner diversity index value was higher during the dry season than in the wet season.

In Beeshazari Lake - Chitwan, Roka et al. (2022) analyzed the seasonal variation of algal diversity in response to physicochemical parameters of lakeshore water during monsoon and winter season. They concluded that Chlorophyceae are dominant group in both seasons. They observed that value of pH, DO, TDS and conductivity were recorded highest during winter while highest temperature was recorded during monsoon season. The species like *Glaucocystis* and *Closterium* sp. were more frequent, whereas *Gomphonema* sp. was more common during the monsoon. They also found that *Dictyosphaerium* sp., *Anabaena* sp., *Pinnularia* sp. and *Closterium* sp. showed high abundance with high EC but *Cymbella* sp., *Ulnaria* sp. and *Pleurotaenium* sp. seemed concentrated towards high DO.

2.4 Research gap

Many studies have been carried out for the analysis of water quality previously by many scientists and researchers based on the physicochemical characteristics on different sources of water such as rivers, lakes, ponds, and wells. Most of the studies are confined in and around Kathmandu valley, the Himalayan regions and western Nepal. Literature survey concludes that there are no assessments related to the water quality, status of physicochemical parameters and their impacts on algal species composition of Satyawati Lake, Lumbini Province, Nepal. Hence, the present study aims to investigate the seasonal variation of algal species composition with physicochemical parameters of Satyawati Lake, Lumbini Province, Nepal.

Chapter – III

Materials and Methods

3.1 Study area

The study was conducted in Satyawati Lake of Palpa district, Lumbini Province, Nepal. It is a natural rain feed lake with geographic latitude 27.7º 55.3' 59.5" N and longitude 83.5º 54.1' 21.1" E that lies in Tinau Rural Municipality, Ward no. 4. The lake occupies an area of five hectares at an elevation of 1000m. The lake is around 35 kilometers far from Tansen, the district headquarters of Palpa district. The lake partially dries up during mid- April to mid- June. When the water is sufficient in the lake some migratory birds spend a few days in this area. Location map of study area, showing position of Palpa district and Tinau Rural Municipality is shown below (Figure 1).

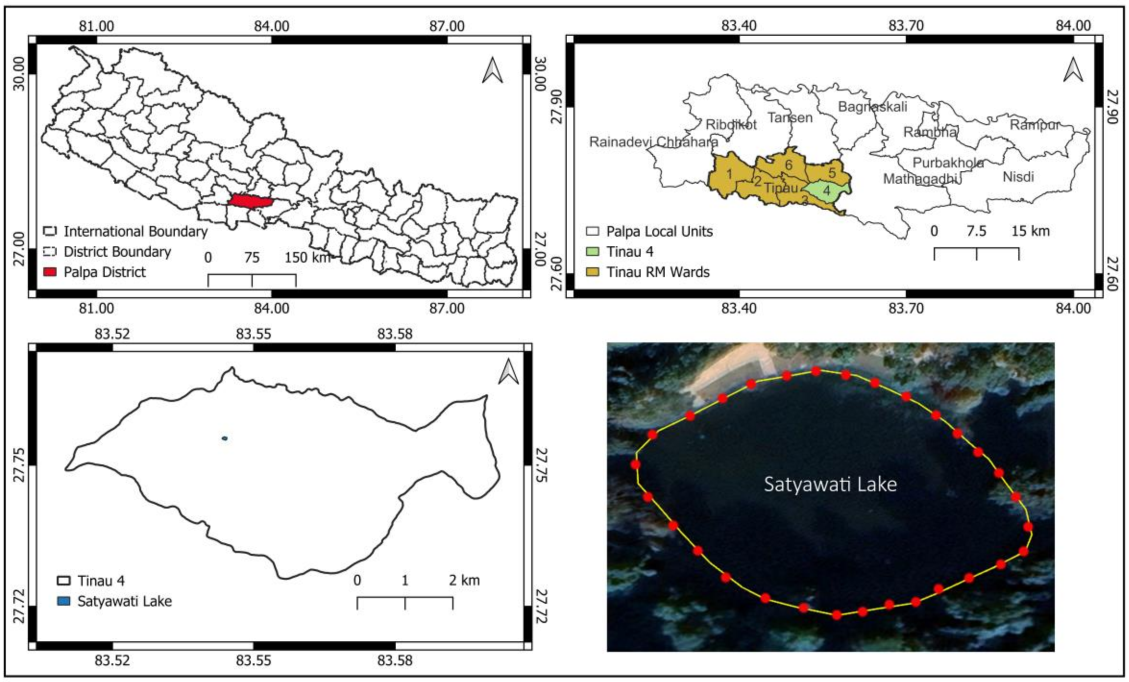


Figure 1: Map of study area (a) Nepal map showing Palpa district (b) Palpa district map showing Tinau Rural Municipality (c) Tinau Rural Municipality with Satyawati lake d) Satyawati lake showing sampling points.

3.2 Climate

Since, the study area belongs to churiya region the climate of the study area is tropical type. Typically, four seasons are found in this region viz. pre-monsoon from March to May, monsoon from June to September, post-monsoon from October to November and winter from December to February. Climate data from the nearest meteorological station revealed the minimum temperature 5.48° in January and the maximum temperature of 27.68° in July. The average annual precipitation is 121.23mm and maximum precipitation is 437.85 mm. All the meteorological data were recorded in Tansen station from the year 2010-2020 (Figure 2).

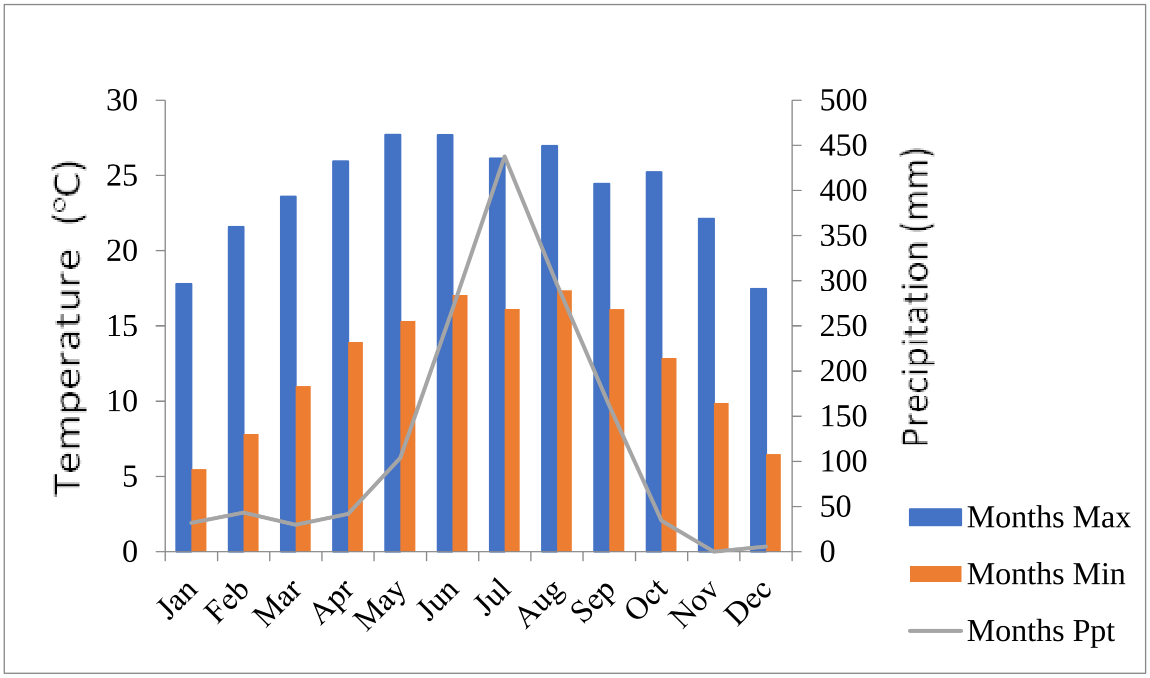


Figure 2: Ten years (2010-2020) average monthly minimum, maximum temperature and rainfall recorded at Tansen weather Station (Station that is nearest to the study area). (Source: Department of Hydrology and Meteorology, Babarmahal, Kathmandu, Nepal, 2020).

The dominant forest type around the Satyawati lake area is *Shorea robusta* forest and mixed hardwood forest like *Terminalia alata*, *Lagerstroemia parviflora*, *Aegle marmelos* etc. at lower altitude and *Pinus roxburghii* and *Schima-Castonopsis* Forest at higher altitude (DFO, 2007).

3.3 Sampling design and data collection

The preliminary study about the study area was carried out on January 2020. To determine the physiochemical parameters and algal diversity, the samples were collected during two seasons. For collection of water and algal samples, the study area was first visited on winter season (February 2020) and second field visit was on post-monsoon (November 2020) seasons.

3.4 Physicochemical parameters and analysis of water

Altogether 30 quadrats of size 1m × 1m were sampled from the littoral zone covering all sites of lake with distance between two quadrat 20m each. From each quadrat, water sample was collected in a 1L clean plastic bottle of mineral water. Water samples were collected from surface of lake and before collecting water, plastic bottles were first rinsed with lake water of each site for three times. Water was collected from surface and its mouth was unlocked to fill water and again cap was locked under water before taken out from water. Each water bottle cap was coded with a sampling site. Geographic location i.e., latitude and longitude of each quadrat were recorded using Global Poisoning System (GPS) in each quadrat.

In each season, water samples were taken from the same location. Temperature was measured on the spot by using a mercury thermometer. Likewise, pH, total dissolved solids (TDS), electrical conductivity (EC), total hardness, alkalinity, biological oxygen demand (BOD), dissolved oxygen (DO) and chemical oxygen demand (COD) were analyzed in the laboratory. Water samples were brought to the laboratory of Central Department of Environment Science, Tribhuvan University, Kritipur, Kathmandu. All the samples were kept in refrigerator at 4°C. in the laboratory, and before analysis samples were allowed to gain normal water temperature.

3.5 Algae sampling

Along with the water samples, the epilithic forms (present as a slippery coating on stones) of algae were collected using a toothbrush, the epipelic forms (residing on sand/mud at the edge) were collected using a dropper, and the epiphytic forms (dwelling on the surfaces of other plants) were collected by squeezing aquatic macrophytes. Each sample was assigned with collection number starting from S1, S2, S3, ………S30 and then preserved in 4% formaldehyde solution in airtight plastic bottle and brought to the Research laboratory, Department of Botany, Amrit Campus, Tribhuvan University, Kathmandu, Nepal.

3.6 Analysis of physicochemical parameter

3.6.1 Temperature

The temperature of the water sample was measured on the spot by using a mercury thermometer. The bulb of the thermometer was dipped in the bottle containing water sample and reading was noted after two minutes.

3.6.2 pH

The pH of water sample was recorded in the laboratory by the help of electric pH meter (ORION model 210A) where buffer solute ions of pH 4 and pH 7 were used for calibration of pH meter.

3.6.4 Total dissolved solid (TDS) and Electrical conductivity (EC)

TDS and EC of water samples were recorded in the laboratory by electric TDS and EC meter (HANNA/ Combo HI 98129).

3.6.5 Dissolved oxygen (DO)

Dissolved oxygen of water samples was measured by using a digital DO meter (AZ8403) in the laboratory.

3.6.6 Total Hardness

Total Hardness was measured by EDTA trimetric method as described by Trivedi and Goel (1986). Total hardness was determined by taking 50ml sample in a clean conical flask in which 2ml of ammonia buffer was added and 200mg of Erichrome Black as indicator was added to it and shaken well. Then the sample was titrated against standard EDTA solution of 0.01 N till the color changed from wine red to blue. The volume of EDTA consumed was noted. Three readings were taken, and mean was carried out to convert total hardness as mg/l by following equation:

$$\text{Total hardness (as } CaCo_3\text{, mg/l)} = \frac{\text{volume of EDTA used}}{\text{Volume of sample taken}} \times 1000$$

3.6.7 Total Alkalinity

Total alkalinity was determined by taking 100ml of sample in a conical flask and 2 drops of Phenolphthalein indicator were added to it. The sample remains colorless which indicated that the Phenolphthalein alkalinity was zero. Immediately 2 or 3 drops of methyl orange were added to the same sample and titrated against HCL (0.1 N) until the yellow color changed to pink at the end. The volume of HCL consumed was noted which gave the total alkalinity. Three readings were taken, and the mean was taken out to convert total alkalinity later as mg /liter by using the following equation:

$$\text{TA as } CaCo_3 \text{ (mg/l)} = \frac{(B\times \text{Normality of Hcl})\times 1000\times 50}{\text{volume of sample taken (ml)}}$$

Where, B = ml of total Hcl used with Phenolphthalein and Methyl orange.

TA =Total Alkalinity

Whenever the color changed to pink after addition of Phenolphthalein it was titrated with

0.1 Hcl until the color disappeared. PA alkalinity was calculated by the following equation:

$$\text{PA as } CaCo_3 = \frac{(A\times \text{Normality of Hcl})\times 1000\times 50}{\text{volume of sample taken (ml)}}$$

Where, A = ml of Hcl used with Phenolphthalein

PA = Phenolphthalein Alkalinity

3.6.8 Chemical oxygen demand (COD)

COD was measured as described by Trivedi and Goel (1986) and calculated by using following formula:

$$\text{COD (mg/l)} = \frac{(b-a)\times \text{Normality of ferrous ammonium sulphate} \times 8 \times 1000}{\text{volume of sample taken}}$$

Where, a = volume of titrant with sample

b = volume of titrant with blank.

3.6.9 Biological oxygen demand (BOD)

BOD was measured as described by Trivedi and Goel (1986) and using the following formula:

$$\text{BOD (mg/l)} = (D_0 - D_5)\times \text{dilution factor}$$

Where, D_0 = Initial DO in the sample

D_5 = DO after 5-days.

3.7 Identification of algae

The temporary slides of each sample were prepared and examined under different magnification of compound microscope. Taxa were identified consulting various literatures and monographs (Prescott, 1951; Prescott and Scott, 1952; Vurren et al., 2006; Rai, 2012; Bhakta and Adhikari, 2014; Rosen and Amand, 2015; Dhakal et al, 2020; Rai and Paudel, 2019; Shrestha and Rai, 2017). Nomenclature, as well as classification follows Algae Base (2022). The species richness and frequency of algae species in both seasons were calculated.

3.7 Statistical analysis

Multivariate analyses were performed to test the effect of seasons and physicochemical parameters on the composition of algal species in the study area. In Detrended Correspondence Analysis (DCA), the length of the first axis in the data was found to be 5.367 and the data thus were analyzed using unimodal techniques. Then canonical correspondence analysis (CCA) was performed and tested the effect of seasons and physicochemical parameters on algal species composition. To test the significance of relationships, Monte-Carlo simulation tests were also done. All tests were carried out using software R. In all the multivariate tests, species with less than two occurrences were not included. Also, Principal Component Analysis (PCA) was applied to extract significant principal components (PCs) to explain the correlation between physicochemical parameters of water. Water quality analysis between two seasons were compared using t- test. These analyses were carried out using SPSS version 25.

CHAPTER – IV

RESULTS

4.1. Algal species richness and composition

Altogether a total of 62 algal species belonging to seven phyla, 10 classes, 27 orders, 30 families and 35 genera were recorded during winter and post-monsoon seasons in study site (Table 1). Twenty-four genera belonging to phylum Bacillariophyta were recorded, followed by 16 genera of Charophyta, 13 genera of Chlorophyta, 4 genera of Cyanobacteria, 3 genera of Ochrophyta and one genus of Glaucophyta and Euglenozoa each.

Among the classes, Bacillariophyceae was found dominant with 23 genera, followed by 16 genera of Zygnematophyceae, 10 genera of Chlorophyceae, 4 genera of Cyanophyceae, 3 genera of Xanthophyceae, 2 genera of Ulvophyceae and one genus of each Coscinodiscophyceae, Trebouxiophyceae, Glaucophyceae and Euglenophyceae (Figure 3).

Thirty-seven algal species were recorded in winter season and forty-five algal species were recorded during post monsoon seasons. Class wise distribution showed that Bacillariophyceae (23) has maximum number of species which was followed by Zygnematophyceae (16) and Chlorophyceae (10) (Figure 4). In average, a greater number of Zygnematophycean and Chlorophycean species was found during Winter season while Bacillariophycean was found dominant during post-monsoon season. One genus of each Euglenophycean (*Trachelomonas* sp.) and Trebouxiophycean (*Dictyosphaerium* sp.) algal species was found during post-monsoon season but absent in Winter season. The common algal species which were found on both seasons were *Ankistrodesmus* sp., *Aulacoseira* sp., *Cladophora* sp., *Euastrum germanicum, Eunotia* sp., *Glaucocystis* sp., *Gomphonema* sp., *Navicula exigua, N. gracilis, N. radiosa, Oedogonium leave, Oedogonium* sp.1, *Oscillatoria* sp., *Pinnularia* sp., *Pleurotaenium* sp., *Rhopalodia* sp., *Spirogyra rhizopus, Staurastrum* sp., *Synedra ulna* and *Vaucheria sessilis.*

Table 1. Algal species, their name abbreviation, kingdom, phylum, class, order, family and seasons.

S.N.	Name of species	Abbrev.	Kingdom	Phylum	Class	Order	Family	Season	
								Winter	Post monsoon
1	*Achnanthes* sp.	Ach.sp	Chromista	Bacillariophyta	Bacillariophyceae	Achnanthales	Achnanthaceae	-	+
2	*Achnanthidium minutissium*	Ach.min	Chromista	Bacillariophyta	Bacillariophyceae	Achnanthales	Achnanthidiaceae	-	+
3	*Amphora* sp.1	Amp.sp1	Chromista	Bacillariophyta	Bacillariophyceae	Thalassiophysales	Catenulaceae	+	-
4	*Amphora* sp.2	Amp.sp2	Chromista	Bacillariophyta	Bacillariophyceae	Thalassiophysales	Catenulaceae	+	-
5	*Amphora* sp.3	Amp.sp3	Chromista	Bacillariophyta	Bacillariophyceae	Thalassiophysales	Catenulaceae	+	-
6	*Ankistrodesmus* sp.	Ank.sp	Plantae	Chlorophyta	Chlorophyceae	Sphaeropleales	Selenastraceae	+	+
7	*Aulacoseira* sp.	Aul.sp	Chromista	Bacillariophyta	Coscinodiscophyceae	Aulacoseirales	Aulacoseiraceae	+	+
8	*Cladophora* sp.	Cla.sp	Plantae	Chlorophyta	Ulvophyceae	Cladophorales	Cladophoraceae	+	+
9	*Closterium ehrenbergii*	Clo.ehr	Plantae	Charophyta	Zygnematophyceae	Desmidiales	Desmidiaceae	+	-
10	*Closterium* sp.	Clo.sp	Plantae	Charophyta	Zygnematophyceae	Desmidiales	Desmidiaceae	-	+
11	*Cosmarium lundelli*	Cos.lun	Plantae	Charophyta	Zygnematophyceae	Desmidiales	Desmidiaceae	+	-
12	*Diatoma hyemale*	Dia.hye	Chromista	Bacillariophyta	Bacillariophyceae	Rhabdonematales	Tabellariaceae	-	+
13	*Dictyosphaerium* sp.	Dic.sp	Plantae	Chlorophyta	Trebouxiophyceae	Chlorellales	Chlorellaceae	-	+
14	*Euastrum germanicum*	Eua.ger	Plantae	Charophyta	Zygnematophyceae	Desmidiales	Desmidiaceae	+	+
15	*Euastrum pectinatum*	Eua.pec	Plantae	Charophyta	Zygnematophyceae	Desmidiales	Desmidiaceae	+	-
16	*Eunotia* sp.	Eun.sp	Chromista	Bacillariophyta	Bacillariophyceae	Eunotiales	Eunotiaceae	+	+
17	*Fragillaria crotonensis*	Fra.cro	Chromista	Bacillariophyta	Bacillariophyceae	Fragilariales	Fragilariaceae	-	+
18	*Fragillaria* sp.	Fra.sp	Chromista	Bacillariophyta	Bacillariophyceae	Fragilariales	Fragilariaceae	-	+
19	*Glaucocystis* sp.	Gla.sp	Plantae	Glaucophyta	Glaucophyceae	Glaucocystales	Glaucocystaceae	+	+
20	*Gomphonema* sp.	Gom.sp	Chromista	Bacillariophyta	Bacillariophyceae	Cymbellales	Gomphonemataceae	+	+
21	*Hyalotheca dissiliens*	Hya.dis	Plantae	Charophyta	Zygnematophyceae	Desmidiales	Desmidiaceae	+	-
22	*Merismopedia* sp.	Mer.sp	Eubacteria	Cyanobacteria	Cyanophyceae	Synechococcales	Merismopediaceae	-	+
23	*Navicula bory*	Nav.bor	Chromista	Bacillariophyta	Bacillariophyceae	Naviculales	Naviculaceae	-	+
24	*Navicula exigua*	Nav.exi	Chromista	Bacillariophyta	Bacillariophyceae	Naviculales	Naviculaceae	+	+

25	*Navicula gracilis*	Nav.gra	Chromista	Bacillariophyta	Bacillariophyceae	Naviculales	Naviculaceae	+	+
26	*Navicula gregaria*	Nav.gre	Chromista	Bacillariophyta	Bacillariophyceae	Naviculales	Naviculaceae	-	+
27	*Navicula radiosa*	Nav.rad	Chromista	Bacillariophyta	Bacillariophyceae	Naviculales	Naviculaceae	+	+
28	*Navicula* sp.	Nav.sp	Chromista	Bacillariophyta	Bacillariophyceae	Naviculales	Naviculaceae	-	+
29	*Nitzschia obtuse*	Nit.obt	Chromista	Bacillariophyta	Bacillariophyceae	Bacillariales	Bacillariaceae	-	+
30	*Oedogonium hindustanaceae*	Oed.hin	Plantae	Chlorophyta	Chlorophyceae	Oedogoniales	Oedogoniaceae	-	+
31	*Oedogonium boscii*	Oed.bos	Plantae	Chlorophyta	Chlorophyceae	Oedogoniales	Oedogoniaceae	+	-
32	*Oedogonium leave*	Oed.lae	Plantae	Chlorophyta	Chlorophyceae	Oedogoniales	Oedogoniaceae	+	+
33	*Oedogonium peipingense*	Oed.pei	Plantae	Chlorophyta	Chlorophyceae	Oedogoniales	Oedogoniaceae	+	-
34	*Oedogonium plagiostomum*	Oed.pla	Plantae	Chlorophyta	Chlorophyceae	Oedogoniales	Oedogoniaceae	+	-
35	*Oedogonium* sp.1	Oed.sp1	Plantae	Chlorophyta	Chlorophyceae	Oedogoniales	Oedogoniaceae	+	+
36	*Oedogonium* sp.2	Oed.sp2	Plantae	Chlorophyta	Chlorophyceae	Oedogoniales	Oedogoniaceae	+	-
37	*Oscillatoria* sp.	Osc.sp	Eubacteria	Cyanobacteria	Cyanophyceae	Oscillatoriales	Oscillatoriaceae	+	+
38	*Pinnularia* sp.	Pin.sp	Chromista	Bacillariophyta	Bacillariophyceae	Naviculales	Pinnulariaceae	+	+
39	*Pinnularia viridis*	Pin.vir	Chromista	Bacillariophyta	Bacillariophyceae	Naviculales	Pinnulariaceae	+	-
40	*Pleurotaenium ehrenbergii*	Ple.ehr	Plantae	Charophyta	Zygnematophyceae	Desmidiales	Desmidiaceae	+	-
41	*Pleurotaenium* sp.	Ple.sp	Plantae	Charophyta	Zygnematophyceae	Desmidiales	Desmidiaceae	+	+
42	*Rhopalodia* sp.	Rho.sp	Chromista	Bacillariophyta	Bacillariophyceae	Rhopalodiales	Rhopalodiaceae	+	+
43	*Scenedesmus ecornis*	Sce.eco	Plantae	Chlorophyta	Chlorophyceae	Sphaeropleales	Scenedesmaceae	-	+
44	*Spirogyra corrugate*	Spi.cor	Plantae	Charophyta	Zygnematophyceae	Spirogyrales	Spirogyraceae	-	+
45	*Spirogyra chungkingensis*	Spi.chu	Plantae	Charophyta	Zygnematophyceae	Spirogyrales	Spirogyraceae	+	-
46	*Spirogyra hopeiensis*	Spi.hop	Plantae	Charophyta	Zygnematophyceae	Spirogyrales	Spirogyraceae	+	-
47	*Spirogyra Rhizopus*	Spi.rhi	Plantae	Charophyta	Zygnematophyceae	Spirogyrales	Spirogyraceae	+	+
48	*Spirogyra* sp.	Spi.sp	Plantae	Charophyta	Zygnematophyceae	Spirogyrales	Spirogyraceae	-	+
49	*Spirulina nodosa*	Spi.nod	Eubacteria	Cyanobacteria	Cyanophyceae	Spirulinales	Spirulinaceae	-	+

50	*Spirulina* sp.	Spi.sp	Eubacteria	Cyanobacteria	Cyanophyceae	Spirulinales	Spirulinaceae	+	-
51	*Surirella euigepta*	Sur.eui	Chromista	Bacillariophyta	Bacillariophyceae	Surirellales	Surirellaceae	-	+
52	*Surirella splendida*	sur.spl	Chromista	Bacillariophyta	Bacillariophyceae	Surirellales	Surirellaceae	-	+
53	*Staurastrum manfeldtii*	Sta.man	Plantae	Charophyta	Zygnematophyceae	Desmidiales	Desmidiaceae	-	+
54	*Staurastrum* sp.	Sta.sp	Plantae	Charophyta	Zygnematophyceae	Desmidiales	Desmidiaceae	+	+
55	*Synedra ulna*	Syn.uln	Chromista	Bacillariophyta	Bacillariophyceae	Fragilariales	Fragilariaceae	+	+
56	*Trachelomonas* sp.	Tra.sp	Protozoa	Euglenozoa	Euglenophyceae	Euglenida	Euglenidae	-	+
57	*Tetraedron kutzing*	Tet.kut	Plantae	Chlorophyta	Chlorophyceae	Sphaeropleales	Hydrodictyaceae	-	+
58	*Ulothrix zonata*	Ulo.zon	Plantae	Chlorophyta	Ulvophyceae	Ulotrichales	Ulotrichaceae	-	+
59	*Vaucheria sessilis*	Vau.ses	Chromista	Ochrophyta	Xanthophyceae	Vaucheriales	Vaucheriaceae	+	+
60	*Vaucheria* sp.1	Vau.sp1	Chromista	Ochrophyta	Xanthophyceae	Vaucheriales	Vaucheriaceae	-	+
61	*Vaucheria* sp.2	Vau.sp2	Chromista	Ochrophyta	Xanthophyceae	Vaucheriales	Vaucheriaceae	-	+
62	*Zygnema* sp.	Zyg.sp	Plantae	Charophyta	Zygnematophyceae	Zygnematales	Zygnemataceae	+	-

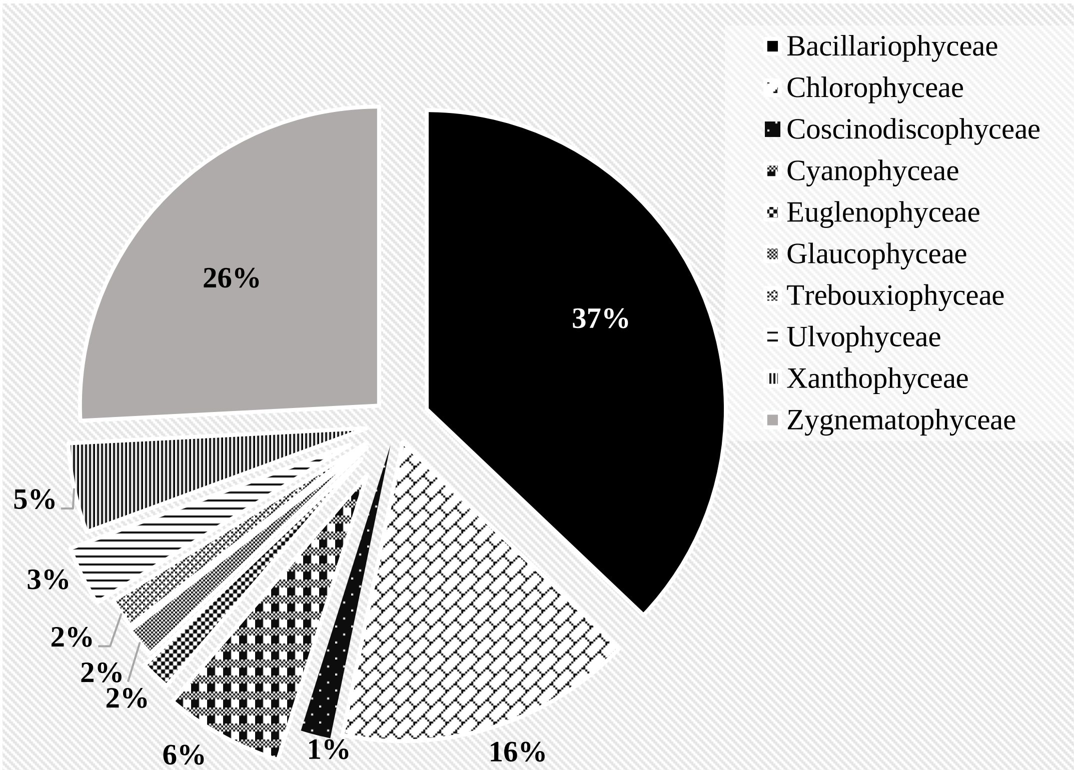


Figure 3: Class-wise representation of total algal species

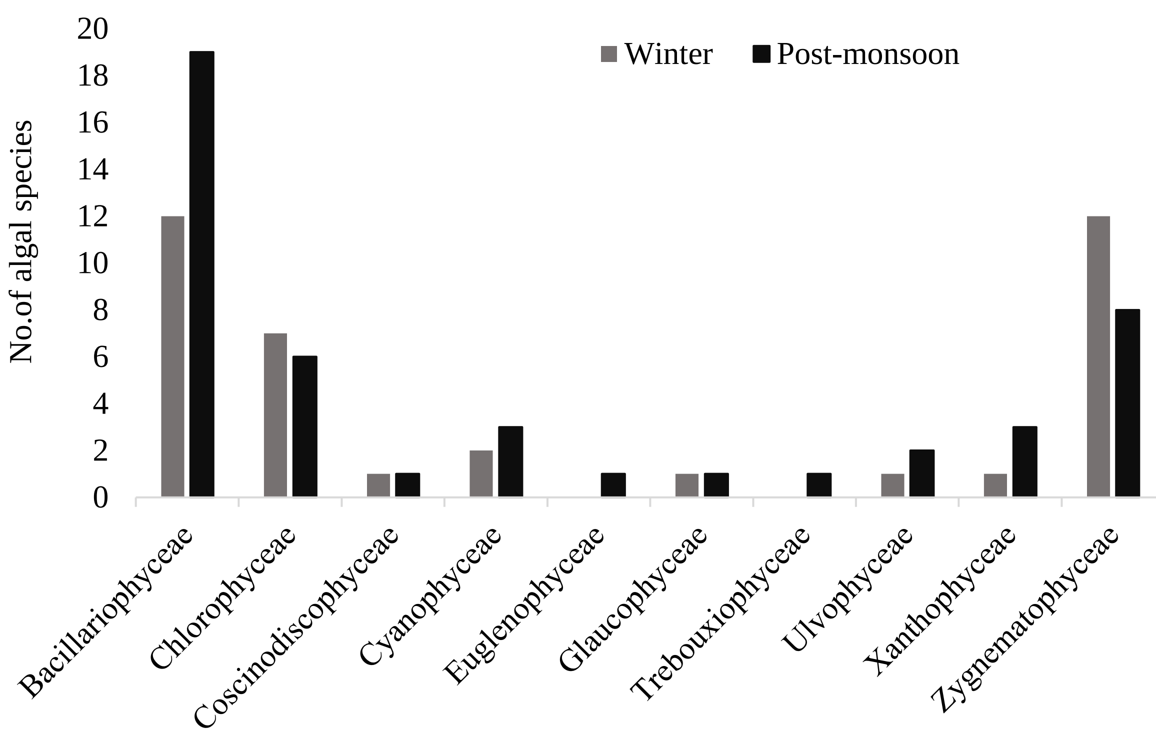


Figure 4: Class-wise distribution of algal species in two different seasons

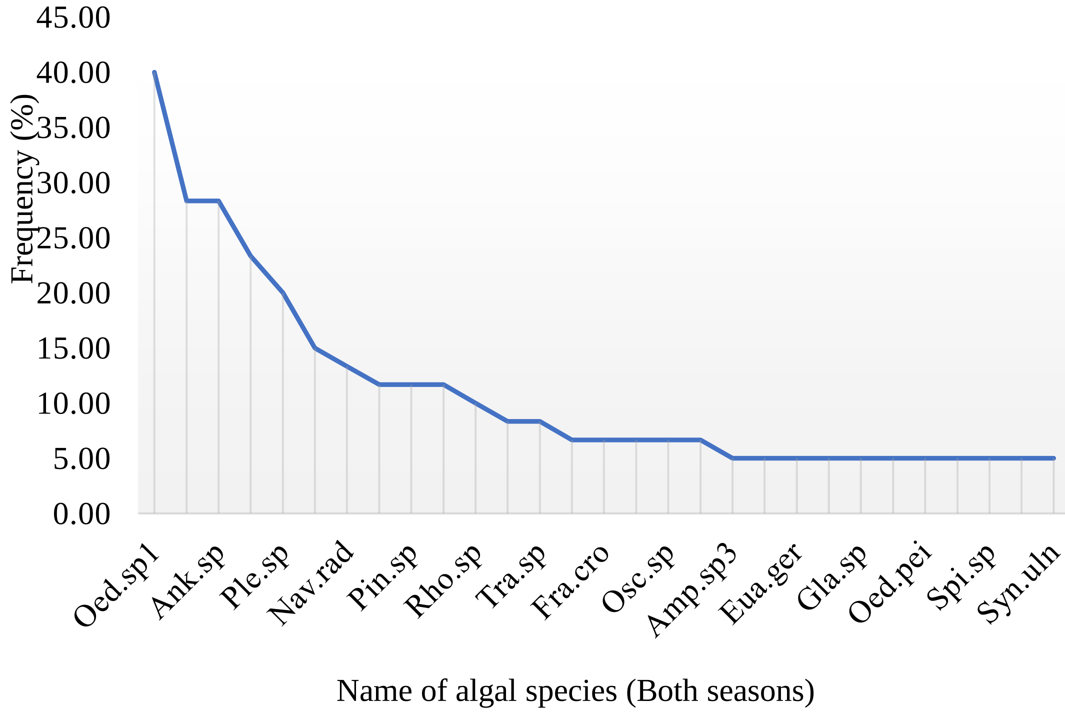
4.2. Algal Frequency

The graph (Figure 5) shows the frequency curve of algal species found in winter season, post monsoon season and found in both seasons. *Oedogonium* sp.1 had the highest frequency in both seasons followed by *Achnanthes* sp. and *Ankistrodesmus* sp. *Pleurotaenium ehrenbergii, Pleurotaenium* sp. *Surirella euigepta, Navicula radiosa, Navicula exigua, Pinnularia* sp., *Vaucheria* sp. 1, *Rhopalodia sp., Closterium* sp. *Trachelomonas* sp., *Aulacoseira* sp., *Fragillaria crotonensis, Hyalotheca dissiliens, Oscillatoria* sp., *Spirogyra* sp., *Amphora sp.3 Closterium ehrenbergii, Euastrum germanicum, Eunotia* sp., *Glaucocystis* sp., *Oedogonium leave, Oedogonium peipingense, Pinnularia viridis, Spirulina* sp., *Staurastrum* sp., *Synedra ulna.*

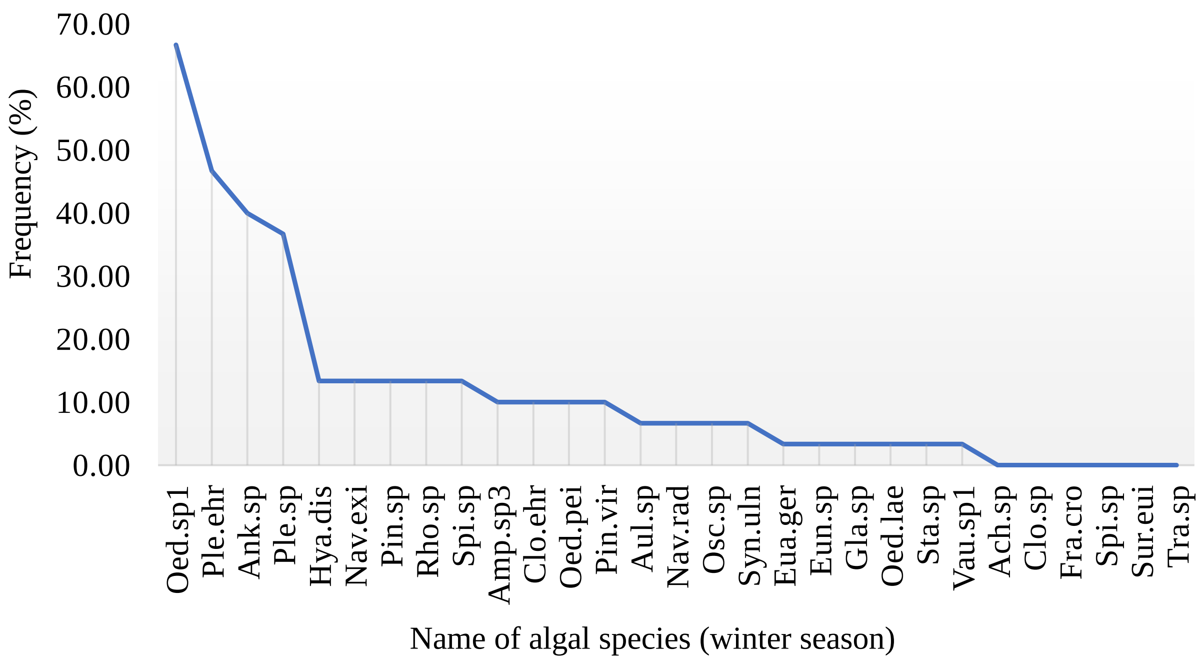
Similarly, in Winter season the most frequent algal species was *Oedogonium* sp.1 followed by *Pleurotaenium ehrenbergii, Ankistrodesmus* sp., *Pleurotaenium* sp., *Hyalotheca dissiliens, Navicula exigua, Pinnularia* sp., *Rhopalodia* sp, *Spirogyra* sp., *Amphora* sp.3, *Closterium ehrenbergii, Oedogonium peipingense, Pinnularia viridis, Aulacoseira* sp., *Navicula radiosa, Oscillatoria* sp., *Synedra ulna, Euastrum germanicum, Eunotia* sp., *Glaucocystis* sp., *Oedogonium leave, Staurastrum* sp., *Vaucheria* sp. 1.

Likewise, the most frequent species was *Achnanthes* sp. followed by *Surirella euigepta, Navicula radiosa, Vaucheria* sp. 1, *Ankistrodesmus* sp., *Closterium* sp. *Trachelomonas* sp., *Fragillaria crotonensis, Oedogonium* sp.1, *Navicula exigua, Pinnularia* sp., *Spirogyra* sp., *Aulacoseira* sp., *Euastrum germanicum, Eunotia* sp., *Glaucocystis* sp., *Oedogonium leave, Oscillatoria* sp., *Rhopalodia* sp., *Staurastrum* sp., *Pleurotaenium* sp., *Synedra ulna* during post monsoon season.

(**A**)


45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Frequency (%)
Oed.sp1
Ank.sp
Ple.sp
Nav.rad
Pin.sp
Rho.sp
Tra.sp
Fra.cro
Osc.sp
Amp.sp3
Eua.ger
Gla.sp
Oed.pei
Spi.sp
Syn.uln
Name of algal species (Both seasons)

(B)


70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Frequency (%)
Oed.sp1
Ple.ehr
Ank.sp
Ple.sp
Hya.dis
Nav.exi
Pin.sp
Rho.sp
Spi.sp
Amp.sp3
Clo.ehr
Oed.pei
Pin.vir
Aul.sp
Nav.rad
Osc.sp
Syn.uln
Eua.ger
Eun.sp
Gla.sp
Oed.lae
Sta.sp
Vau.sp1
Ach.sp
Clo.sp
Fra.cro
Spi.sp
Sur.eui
Tra.sp
Name of algal species (winter season)

(C)

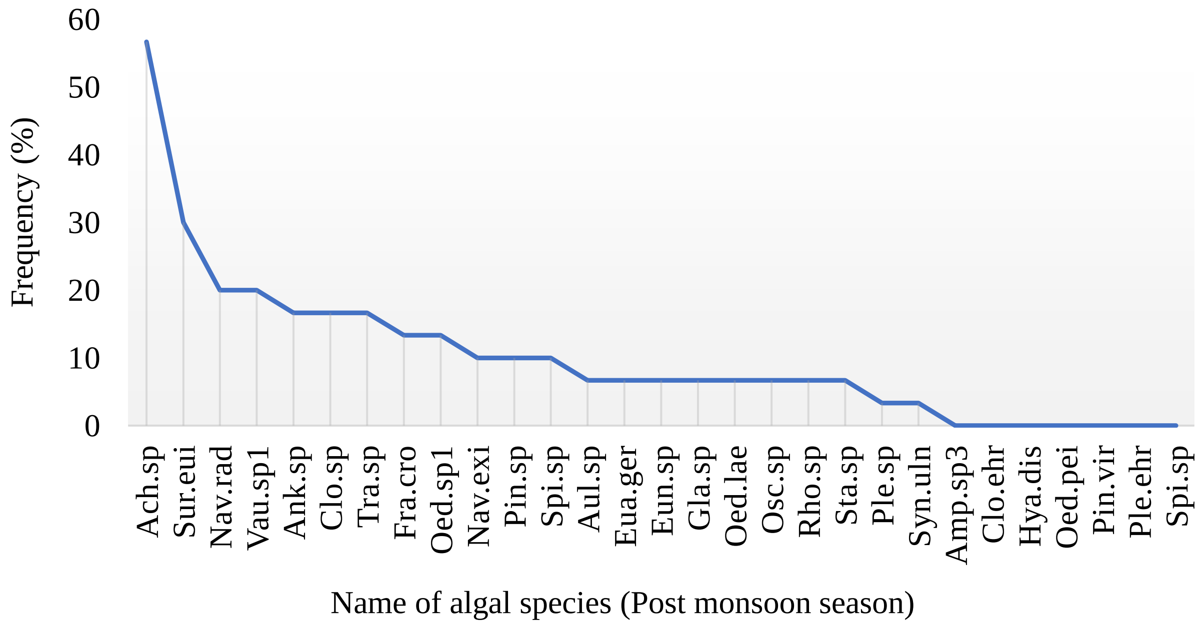


Figure 5: Frequency curve of algal species found in both seasons (A), Winter season (B) and Post-`monsoon season (C). The full forms of species are given in Table 1.

4.3. Seasonal effect on algal species composition

Two seasons showed a significantly different relationship with algal species composition (p=0.001). From the CCA analysis, the season explained 7.5% of total variation in the data set of algal species composition explained by two ordination axis (Figure 6).

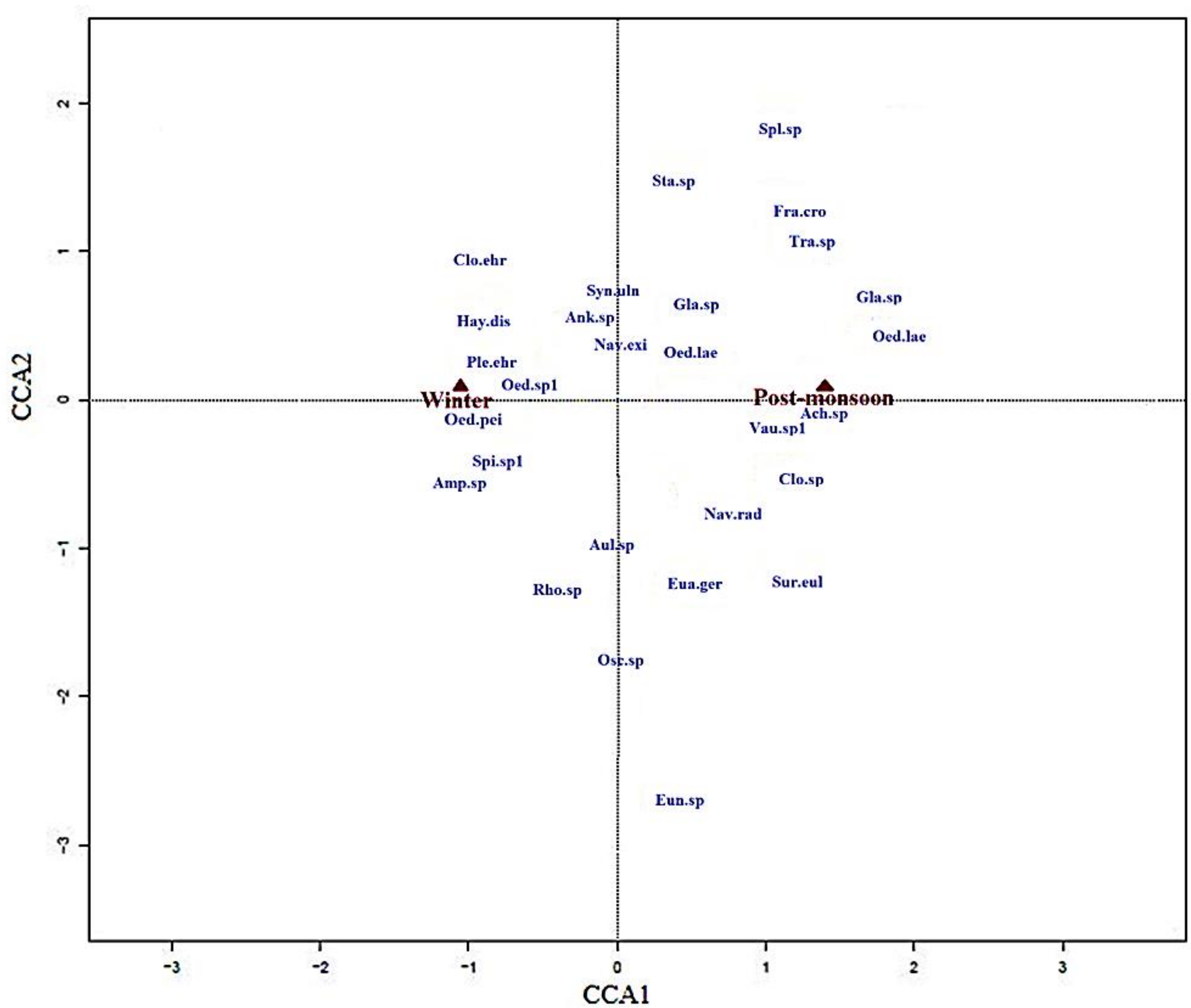


Figure 6. Results of the CCA analysis showing the effect of two seasons on algal species composition. Seasons explained 7.5% of total variation in dataset. Full names and abbreviations are given in Table 1.

4.4. Water quality parameters

The physicochemical parameters (Mean ± SD) of the lake water are shown in Table 2. In the present study the mean value of pH, total dissolved solids (TDS), alkalinity, electric conductivity (EC), total hardness and biological oxygen demand (BOD) were higher in winter seasons than in post monsoon whereas temperature, chemical oxygen demand (COD) and dissolved oxygen (DO) were higher in post monsoon seasons. These differences were significant for all the parameters except pH ($P < 0.05$). The highest mean value for temperature was observed during post monsoon

(16.10±0.14°C) and lowest winter season (14.83±0.14°C). For pH, the mean highest value was recorded in winter season (6.95±0.28) and lowest during post monsoon (6.94±0.11). Similarly, TDS was found higher during winter season (23.60±2.39 mg/l) than in rainy season (21.33±1.40 ppm).

For Alkalinity, the highest mean value was observed during winter season (53.00±12.64 mg/l) and lowest during post monsoon season (44.00±9.68 mg/l). Similarly, the highest mean value of EC was observed during winter season (47.10±5.56 µS/cm) and lowest during post monsoon season (41.07±2.75 µS/cm). In the same way, the mean value of total hardness was found highest at winter season (25.40±3.83 mg/l) and lowest during post monsoon (21.07±4.78 mg/l) (Table 2).

But the highest mean value of chemical oxygen demand (COD) was found highest at post monsoon (26.09± 9.54 mg/l) and lowest during winter season (16.19± 5.21mg/l). In the same way, the highest mean value of the dissolved oxygen (DO) was observed during post monsoon (3.47±0.98 mg/l) and lowest during winter season (2.76±0.41 mg/l). For biological oxygen demand (BOD), the highest mean value was observed during winter season (10.47±2.76 mg/l) and lowest during post monsoon season (4.21±2.09 mg/l).

Table 2. Physicochemical parameters of water in winter and post monsoon season (independent sample t test)

Parameter	**Seasons**	**Mean ± SD**	**Min. Value**	**Max. Value**	**P value**
Temperature(°C)	Winter	14.83±0.14b	14.30	15.10	<0.001
	Post-monsoon	16.10±0.14a	15.80	16.30	
pH	Winter	6.95±0.28	6.50	7.60	0.435
	Post-monsoon	6.94±0.11	6.65	7.20	
TDS (mg/l)	Winter	23.60±2.39a	21.00	29.00	

	Post-monsoon	21.33±1.40b	20.00	26.00	<0.001
Alkalinity (mg/l)	Winter	53.00±12.64	35.00	80.00	0.003
	Post-monsoon	44.00±9.68	30.00	75.00	
EC(µS/cm)	Winter	47.10±5.56a	41.00	58.00	<0.001
	Post-monsoon	41.07±2.75b	35.00	49.00	
Total Hardness (mg/l)	Winter	25.40±3.83a	20.00	34.00	<0.001
	Post-monsoon	21.07±4.78b	14.00	32.00	
COD (mg/l)	Winter	16.19±5.22b	8.57	25.71	<0.001
	Post-monsoon	26.09±9.54a	8.57	45.71	
DO (mg/l)	Winter	2.76±0.41	2.08	3.52	0.021
	Post-monsoon	3.47±0.98	2.23	5.40	
BOD (mg/l)	Winter	10.47±2.76a	3.31	16.53	<0.001
	Post-monsoon	4.21±2.09b	3.16	9.47	

(Note, SD- Standard Deviation; Min- Minimum; Max- Maximum; TDS- Total Dissolved solids; EC- Electrical Conductivity; DO- Dissolved oxygen; COD- Chemical Oxygen Demand; BOD- Biological Oxygen Demand. The letters “a”, “b” after SD indicates significant differences at the level $p < 0.05$).

4.5 PCA component analysis of water quality parameters

PCA provides information on the key characteristics of an entire dataset, enabling data reduction with the least amount of original data loss (Helena et al. 2000; Singh et al. 2005). Figure 7 displays the results of the PCA for the temperature, pH, BOD, total hardness, total dissolved solids, electrical conductivity, alkalinity, and DO. The validity of PCA was tested before to analysis using the Kaiser-Meyer-Olkin (KMO) and Bartlett's sphericity tests. Table 2 displays the PCA findings for the chosen variables and lists the leading PCs along with the loading values for each parameter. Strong, moderate, and weak loading levels are defined as values > 0.75, 0.75- 0.50, and 0.50-0.30, respectively (Pant et al. 2021).

KMO value more than 0.5 is acceptable. The KMO value is 0. 718, and the Bartlett's Test of sphericity yields a significant P value (P <0.05). For PCA analysis, the dataset is suitable. Three principal components (PCs) with eigenvalues greater than one accounted for around 74.35% of the total variances. Specifically, PC1 demonstrated a substantial positive loading on TDS, EC, and total hardness and accounts for 33.54% of the total variance. Due to the direct link between EC and TDS, these variables also have a significant correlation. A significant portion of the variance, or 24.15 % is accounted for by PC2, which strongly influenced temperature and BOD while strongly influencing DO. PC3 has a strongly positive pH loading and accounts for 16.66% of the total variance.

Table 3. Varimax rotated component matrix of physicochemical parameters of the Satyawati Lake, Nepal**.**

Parameter	Component		
	1	2	3
Temp	0.392	0.750	0.277
pH	-0.172	0.066	0.752
TDS	0.922	0.183	0.010
EC	0.915	0.239	0.062
Alk	0.440	-0.003	0.683
TH	0.687	0.274	-0.005
DO	-0.068	-0.776	0.373
BOD	0.378	0.773	0.284
% Of variance	33.54%	24.15%	16.66%
Cumulative %	33.54%	57.69%	74.35%

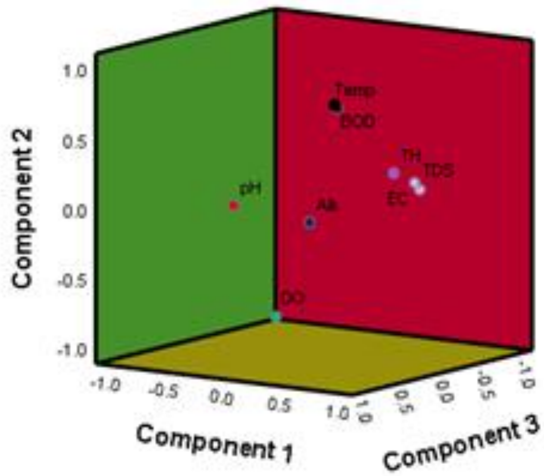


Figure 7: Principal component analysis of the physicochemical parameters of the Satyawati Lake, Nepal. (Temp- Temperature; TH- Total Hardness; Alk- Alkalinity; TDS- Total Dissolved solute; EC- Electrical Conductivity; DO- Dissolved oxygen; BOD- Biological Oxygen Demand).

4.6. Effect of water quality parameters on algal species composition

All the physical parameters of water except the pH ($p=0.335$) showed significant effect on algal species composition ($p<0.005$) where it explained 13.27% of the total variation in algal species composition (Figure 8). Species such as *Pinnularia viridis, Hyalotheca dissiliens, Synedra ulna, Amphora* sp3, *Pleurotaenium ehrenbergii*, *Oedogonium* sp.1, *Oedogonium peipingense, Ankistrodesmus* sp, were found to be more concentrated towards physical parameters. The CCA diagram showed that *Pinnularia viridis, Hyalotheca dissiliens* and *Synedra ulna* are corresponded to Electrical Conductivity (EC) whereas *Pleurotaenium ehrenbergii* is corresponded more to temperature and *Amphora* sp3, *Oedogonium* sp.1 are corresponded more to pH and temperature.

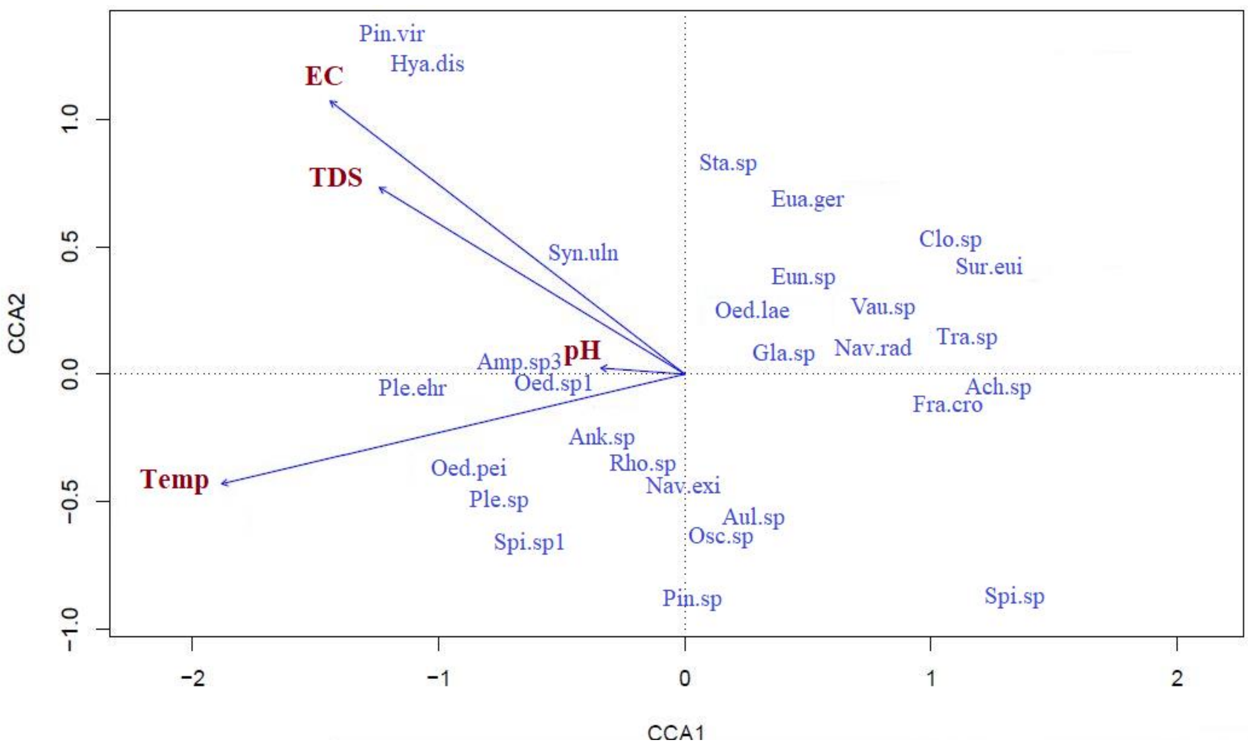


Figure 8. Results of the CCA analysis showing the effect of physical parameters of water on algal species composition. Physical parameters explained 13.27% of total variation in dataset. Full names and abbreviations are given in Table 1.

All the chemical parameters of water except the Total Hardness (p=0.028) showed significant effect on algal species composition (p<0.005) where it explained 13.15% of the total variation in algal species composition (Figure 9). The CCA diagram showed that *Ankistrodesmus* sp., *Oedogonium* sp.1, *Pleurotaenium* sp., *Synedra ulna*, *Navicula exigua* were more associated towards Total Hardness whereas *Hyalotheca dissiliens* and *Pleurotaenium ehrenbergii* corresponded to BOD. *Ankistrodesmus* sp and *Amphora* sp3, were associated more towards Alkalinity. *Spirogyra* sp.1, *Vaucheria* sp., *Staurastrum* sp. and *Glaucocystis* sp. were corresponded to DO.

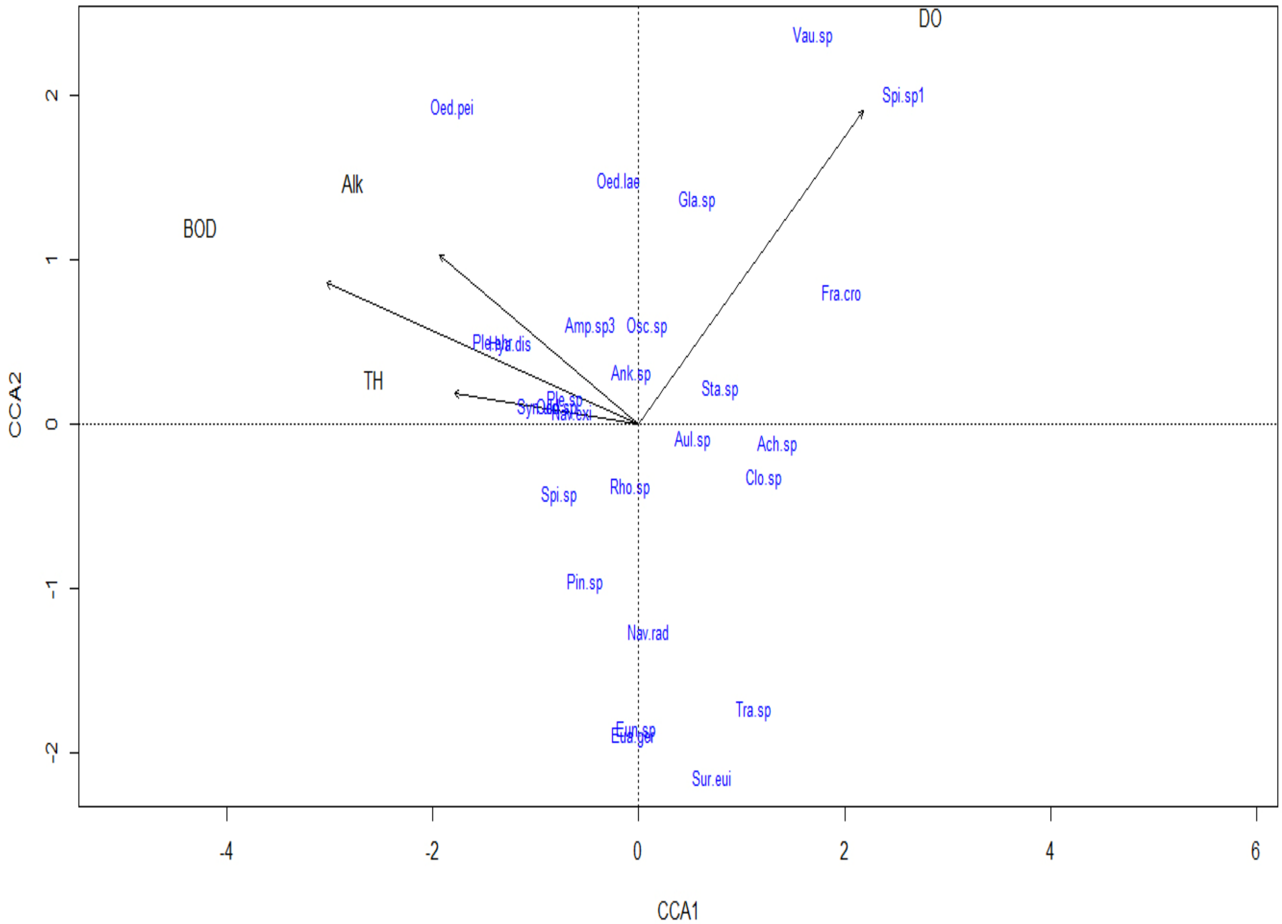


Figure 9. Results of the CCA analysis showing the effect of chemical parameters of water on algal species composition. Chemical parameters explained 13.15% of total variation in dataset. Full names and abbreviations are given in Table 1

CHAPTER - V

DISCUSSION

5.1. Algal species richness and composition

The biological, chemical, physical, and algal population dispersion features are used to evaluate the quality of freshwater bodies. A total of 62 genera of algae belonging to 10 classes were recorded in Winter and Post-monsoon season where, the Bacillariophyceae was found dominant with 23 genera, followed by 16 genera of Zygnematophyceae, 10 genera of Chlorophyceae, 4 genera of Cyanophyceae, 3 genera of Xanthophyceae, 2 genera of Ulvophyceae and one genus of each Coscinodiscophyceae, Trebouxiophyceae, Glaucophyceae and Euglenophyceae.

Class Bacillariophyceae showed the most dominant group in the study. These findings are also supported by Sharma et al. (2007); Shrestha et al (2013); Rai (2014). Bacillariophyceae was also found dominant in hill stream of Chandrabhaga of Garhwal Himalaya (Sharma et al., 2007), Semara Taal of Uttar Pradesh (Verma and Prakash, 2020), in four freshwaters of Turkey (Atici and Tokatli, 2014). According to Hulyal and Kaliwal (2009) diatoms typically bound in alkaline water and can achieve high levels of biodiversity there. High temperature and pH may be favorable for the diatoms to became maximum in summer than in other seasons (Shrestha and Rai, 2017). The capability of the Bacillariophyceae group of Phytoplankton's species to survived in unfavourable condition and to adjust with the environment might be the reason for the occurrence of this group and they can also be used as an indicator of organic pollution in river (Matta et al., 2015).

Along with the Bacillariophyceae other dominant groups were Zygnematophyceae, Chlorophyceae and Cyanophyceae. Shrestha and Rai (2017) also reported maximum number of Chlorophyceae followed by Bacillariophyceae and Cyanophyceae in Rajarani lake, Dhankuta. Pokhrel et al. (2021) also showed similar results in Jagadishpur reservoir of Kapilvastu district. Chlorophyceae was also found the dominant group in Beeshazari Lake of Chitwan district (Roka et al., 2022). In the Rewada reservoir of Andrapradesh, India Kaparapu and Rao (2013) found Chlorophyceae as dominant group followed by Bacillariophyceae and Cyanophyceae.

The algal species Cyanophyceae and Bacillariophyceae were dominant when compared to other groups of algae like Coscinodiscophyceae, Trebouxiophyceae, Glaucophyceae and Euglenophyceae. The majority of phytoplankton are included in Cyanophyceae. Because even at low concentrations, blue-green algae are often quite good at absorbing nutrients (Aleena and Chitra, 2022). Rahman et al. (2007) in fishpond of Bangladesh observed that cell density of euglenophytes increased at acidic environment and showed a declining trend at alkaline condition (pH > 7.0) with lower nutrient concentrations. In the present study the lake water contains only one genus of Euglenophyceae.

Thirty-seven algal species were recorded in winter season and forty-five algal species were recorded during post monsoon seasons. Similar result was supported by Roka et. al (2022); Jose and Xavier, (2022). This may be due to the maximum deposition of organic matter and prevailing suitable temperature favors for algal growth. Similar results were also supported by Shrestha and Rai, (2017) where maximum algal species were observed during the summer (59%) followed by the winter (50%) and rainy seasons (31%).

Comparing two seasons Bacillariophyceae was dominating during the post-monsoon period which was also found in ponds of Kerala, India (Aleena and Chitra, 2022). According to Barman (2015) seasonal diversity of diatoms and desmids favor the monsoon season by occurring with the greatest number of species diversity. The presence of a large variety of desmid and diatom species indicates that the water body has poor nutrition level. Though winter season is not suitable for algal growth, Chlorophyceae prefer this season for their growth and reproduction (Barman, 2015) which was similar to the present study.

Out of documented sixty-two algal species, twenty species were found on both winter and post monsoon seasons which may be of their resilient and tolerating abilities to both severe and favorable environments (changing seasons) for their growth and reproduction. Species like *Ankistrodesmus* sp., *Navicula radiosa, Oedogonium* sp., *Staurastrum* sp. were reported in both seasons which was also reported in both dry and wet season by Shrestha and Rai (2017), Pokhrel et al. (2021). The common algae present throughout the study period were *Ankistrodesmus*, *Euastrum germanicum, Eunotia*, *Glaucocystis*, *Navicula exigua, Oedogonium*, s*taurastrum* sp, which was reported in Jagadishpur reservoir by Rai and Poudel (2019). In this study, the post-monsoon period is dominated by the supply of Bacillariophyceae which was also reported in ponds of Kerala, India (Aleena and Chitra, 2022).

5.2. Seasonal effect on algal species composition

In the present study area two seasons showed a significantly different relationship with algal species composition (Figure 4). Similar results were also observed in Rajarani lake (Shrestha and Rai, 2017), Beeshazari lake (Roka et al., 2022), Jagadishpur Tal (Rai and Poudel, 2019), Mansagar Lake of Jaipur (Singh et al. 2010), Jagadishpur Reservoir (Pokhrel et al. 2021). Species like *Achnanthes* sp, *Surirella euigepta, Navicula radiosa* were most frequent species during post monsoon season similar species like *Navicula* sp., *Pinnularia* sp., *Closterium* sp., and *Achnanthes* sp. were also recorded in Sundarijal reservoir (Bhattrai et al., 2008) during this season. The species *Gomphonema* sp., *Closterium* sp. and *Glaucocystis* sp. which belongs to Bacillariophyceae class showed maximum frequency during monsoon in Beeshazari taal (Roka et al. 2022) which was like present study. *Oedogonium* sp.1 followed by *Pleurotaenium ehrenbergii*, *Ankistrodesmus* sp, *Pleurotaenium* sp., were the most frequent species during winter season. Tiwari and Chauhan (2006) observed chlorophyceae being the most dominant during winter, followed by Bacillariophyceae in Kitham Lake, Agra. According to Tiwari and Chauhan (2006) winters are favorable for Bacillariophyceae and Chlorophyceae.

5.3. Water quality parameters

The distribution, variety and abundance of aquatic species in freshwater habitats vary widely depending on water quality and other physical environmental conditions. According to Dar et al. (2014) the distribution of species appears to be most strongly influenced by the availability of light and temperature. In the present study the mean value of water temperature was higher in the post monsoon season (16.10± 0.14°C) than in the winter season (14.83± 0.14°C) which was also supported by the result published by Roka et al. (2022); Thapa and Saund (2012); Pokhrel et al. (2021); Mandal et al. (2016). The differences in water temperature may be contributed due to different collection times, the influence of the season, and the impact of air temperature (Thapa and Saund, 2012). The seasonal variation also causes fluctuation in water temperatures and because of their location, exposure to sunlight, or shadow from surrounding trees. The warmer water generally increases the rate of growth of plants and algae and their interactions with many aquatic animals (Pant et al., 2019) which also supports the present study.

The average value of pH was (6.944±0.11) during post monsoon season and (6.95±0.28) during the winter season. There was no significant difference in pH between the two seasons. The average pH values on the sites were neutral which was alike to Sundarijal reservoir (Bhattrai et al., 2008). According to Pandey et al. (2014), pH of aquatic systems is a key sign of the level of pollution and the quality of the water in watershed areas. The pH of water changes as a result of factors like air temperature (Manjare et al., 2010), CO_2 balance, liberation of ions and buffering capacity of water (Bhattrai et al., 2008). According to the Pant and Adhikari (2015) the minimum value of pH in Phewa lake is due to runoff from agricultural land as the site was near to agricultural field similar maybe with the present study as the site is surrounded by forest.

The total content of all compounds dissolved in water either inorganic or organic is expressed as Total dissolved solids (TDS). The mean value of TDS was highest during winter season and lowest during post monsoon season. During the monsoon season, high inflow from the forest and high rainfall may have decreased the TDS, while low rainfall and a drop in lake level during the winter may have increased the TDS which was also observed in Jagadishpur Reservoirs (Pokhrel et al., 2021), Beeshazari lake (Roka et al., 2022). According to Bhattrai et al. (2008) water becomes diluted because of the heavy recharge in the form of surface runoff and direct precipitation that causes low TDS during the monsoon season which is also found in the present study.

Alkalinity of water is its capacity to neutralize a strong acid and is characterized by the presence of hydroxyl (OH^-) ions capable of combining with hydrogen (H^+) ions. Alkalinity is directly related to the productivity of water bodies because it regulates the pH and free carbon dioxide of the water bodies. Bicarbonates and carbonates in most natural water is responsible for alkalinity (Verma and Prakash, 2020). The alkalinity in the present study was only due to bicarbonates where the carbonates were nil. According to Jhingran (1975) the pH value ranged from 4.5 to 8.3 has practically no carbonates, which supported the present study. In the present study the total alkalinity was maximum during the winter season (53.00± 12.64) and minimum during the post monsoon season (44.00±9.68). Similar results were also observed in Jagadishpur Reservoir (Thapa and Saund, 2012; Pokhrel et al. 2021), Sundarijal reservoir (Bhattrai et al., 2008), Nagdaha Lake

(Pant, 2013), Tinau river (Pandey and Devkota 2016). Due to less water volume the winter may have the greatest alkalinity value than other seasons (Bhattrai et al., 2008). The low alkalinity during autumn may be due to dilution of water (Trivedy and Goel, 1984) which may be the cause of having maximum alkalinity during winter and minimum alkalinity at post monsoon season.

Conductivity depends on the presence of ions, their total concentration, mobility, valences and on the temperature of measurement (APHA, 1999). Mostly, lake water temperature has a significant proportional relation with conductivity values as the conductivity values. Generally, when the conductivity values of water increase by 2-3%, there is an increase of 1°C lake water temperature (Pant et al., 2019). Due to low salinity and mineral contents, the EC values of lake water were discovered to be in the lower range as recommended by WHO standards which was also similar to Rupa and Begnas lake (Pant et al., 2019). The Electrical conductivity (EC) was maximum in winter season and minimum in post monsoon season. Similar result was also reported by Thapa and Saund (2012); Roka et al. (2022). According to Ibrahim et al. (2015), the Electric conductivity (EC) value is proportionally dependent with the TDS value, with high EC values suggesting high salt content in water which supports present study. Highest electrical conductivity was observed in winter season than in post monsoon season which may be due to the dilution of water during heavy rainfall. Similar result was also reported in Mansagar lake of Jaipur (Singh et al., 2010).

The total hardness in water is due to the sum of concentrations of alkaline earth metal ions. Total hardness of water is primarily controlled by calcium and magnesium concentration, which mostly combine with bicarbonates and carbonates (temporary hardness) as well as with sulphate, chlorides and other anions of minerals (permanent hardness) (Singh et al., 2010). The average value of hardness was highest in winter (25.40±3.83) and lowest in post monsoon (21.07±4.78) which was alike to Pant (2013). The increase in hardness during winter may be due to the decrease in water volume and increase in high loading organic substances, detergent and other polluted (Rajgopal et al., 2010) while the decrease in water volume is also observed in present study. The water of these rivers and reservoir can be regarded as soft water as described by ENPHO (1996) and the value was far below the WHO standard of 500mg/l.

Oxygen is one of the most important components necessary for a normal aquatic community. Concentration of DO indicates water quality and its relation to the distribution and abundance of various algal species (Singh et al., 2010). Dissolved oxygen (DO) measures the amount of oxygen dissolved naturally in water. The mean value of DO was found slightly higher in post-monsoon than in winter season which was also observed in Jagadishpur reservoir (Pokhrel et al., 2021). According to Chia and Bako (2008) DO was higher in the wet season possibly because of wind action that enhances mixing of atmospheric oxygen with water which may be the cause of having low DO during the winter season in present study.

The amount of dissolved oxygen that is used by the microorganisms, or the degradable organic material, present in the water sample under aerobic circumstances is measured by the BOD. The present study showed the highest mean value of BOD during winter season (10.47±2.76mg/l) and lowest mean value during post monsoon season (4.21±2.09 mg/l) which was also supported by the result of Nirula et al. (2010). Almost the same value of BOD was reported in Nagdaha lake (Pant 2013).

COD indicates the pollution level of water body as it is related to the organic matter present in the lake (WQM Report 1999). The mean value of COD was maximum during post monsoon season (26.09±9.54 mg/l) and minimum during winter season (16.19±5.22 mg/l) similar as in Sundarijal reservoir (Bhattrai et al. 2008). The maximum COD value in post monsoon season may be due to the high amount of organic waste in study area from nearby forest area.

5.4. Effect of water quality parameters on algal species composition

According to CCA analysis *Pinnularia viridis, Hyalotheca dissiliens, Synedra ulna, Amphora* sp.3, *Pleurotaenium ehrenbergii*, *Oedogonium* sp.1, *Oedogonium peipingense*, *Ankistrodesmus* sp. were found to be more concentrated towards physical parameters like pH, Temperature, TDS and EC. *Oedogonium* sp.1, *Oedogonium peipingense*, *Ankistrodesmus* sp. belongs to the Chlorophyceae class which was also found in lake of Assam (Devi et al. 2015). According to Devi et al. (2015) Chlorophyceae species are associated with increase in EC, total alkalinity, BOD which corresponds to present study. According to Sahoo and Seebach (2015) high total dissolved solute (TDS) support high freqeuency for Bacillariophyceae. Similar trend was found in present study. *Staurastrum* sp., *Surirella euigepta, Trachelomonas* sp, *Oedogonium leave, Navicula radiosa, Closterium* sp., *Glaucocystis* sp., *Eunotia* sp., *Euastrum germanicum, Achnanthes* sp., were found against high concentration of some of the physical parameters it might be due to their physiological adaptation to low temperature, pH, TDS and conductivity value of lake water.

Ankistrodesmus sp., *Oedogonium* sp.1, *Pleurotaenium* sp., *Synedra ulna, Spirogyra* sp.1, *Navicula exigua, Hyalotheca dissiliens, Pleurotaenium ehrenbergii, Ankistrodesmus* sp *Amphora* sp3, *Oscillatoria* sp., *Staurastrum* sp., *Glaucocystis* sp. *Aulacoseira* sp., *Closterium* sp. were positively correlated with alkalinity, High BOD and COD value and total hardness. These species may be useful indicators for High alkalinity, BOD and COD of water and can be used for the phycoremediations.

CHAPTER - VI

CONCLUSION AND RECOMMENDATIONS

6.1. Conclusions

Altogether 62 algal species belonging to 10 classes, 27 orders, 30 families and 35 genera were recorded during two seasons in the study site. Thirty-seven algal sp. were recorded in winter season and forty-five algal species in post monsoon season. The distribution, variety and abundance of aquatic species in freshwater habitat also depends upon water quality and other physical environmental conditions. Water quality parameters like total dissolved solute (TDS), alkalinity, electric conductivity (EC), total hardness and biological oxygen demand (BOD) was found higher in winter season while temperature, chemical oxygen demand (COD) and dissolved oxygen (DO) was found higher in post- monsoon season. The majority of the species like *Ankistrodesmus* sp., *Aulacoseira* sp., *Cladophora* sp., *Euastrum germanicum*, *Eunotia* sp., *Glaucocystis* sp., *Gomphonema* sp., *Navicula exigua*, *Navicula gracilis*, *Navicula radiosa*, *Oedogonium leave*, *Oedogonium* sp.1, *Oscillatoria* sp., *Pinnularia* sp., *Pleurotaenium* sp., *Rhopalodia* sp., *Spirogyra rhizopus*, *Staurastrum* sp., *Synedra ulna* and *Vaucheria sessilis* have been discovered in both seasons because of being resilient and tolerate to both severe and favorable environments for their growth and reproduction. Bacillariophyceae was found dominant with 23 genera, followed by 16 genera of Zygnematophyceae, 10 genera of Chlorophyceae, 4 genera of Cyanophyceae, 3 genera of Xanthophyceae, 2 genera of Ulvophyceae and one genus of each Coscinodiscophyceae, Trebouxiophyceae, Glaucophyceae and Euglenophyceae. Class Bacillariophyceae showed the most dominant group in the study as high total dissolved solids (TDS), Alkalinity, electric conductivity (EC) and total hardness also support for high frequency of Bacillariophyceae.

6.2. Recommendations

- Algae are showing response to high total dissolved solids (TDS), Alkalinity, electrical conductivity (EC) and total hardness.Hence, can be used to purify polluted water which has high parameters.
- The study of other physicochemical parameters like Nitrogen, Phosphorus content of water is recommended.
- Research related to ecosystem services should be conducted which will be beneficial for conservation of aquatic species.

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APPENDICES

Appendix I: Algal species in water bodies of Satyawati Lake.

S.N.	Name of species	Abbreviation	Season	
			Winter	Post monsoon
1	*Achnanthes* sp.	Ach.sp	-	+
2	*Achnanthidium minutissium*	Ach.min	-	+
3	*Amphora* sp.1	Amp.sp1	+	-
4	*Amphora* sp.2	Amp.sp2	+	-
5	*Amphora* sp.3	Amp.sp3	+	-
6	*Ankistrodesmus* sp.	Ank.sp	+	+
7	*Aulacoseira* sp.	Aul.sp	+	+
8	*Cladophora* sp.	Cla.sp	+	+
9	*Closterium ehrenbergii*	Clo.ehr	+	-
10	*Closterium* sp.	Clo.sp	-	+
11	*Cosmarium lundelli*	Cos.lun	+	-
12	*Diatoma hyemale*	Dia.hye	-	+
13	*Dictyosphaerium* sp.	Dic.sp	-	+
14	*Euastrum germanicum*	Eua.ger	+	+
15	*Euastrum pectinatum*	Eua.pec	+	-
16	*Eunotia* sp.	Eun.sp	+	+
17	*Fragillaria crotonensis*	Fra.cro	-	+
18	*Fragillaria* sp.	Fra.sp	-	+
19	*Glaucocystis* sp.	Gla.sp	+	+
20	*Gomphonema* sp.	Gom.sp	+	+

21	*Hyalotheca dissiliens*	Hya.dis	+	-
22	*Merismopedia* sp.	Mer.sp	-	+
23	*Navicula bory*	Nav.bor	-	+
24	*Navicula exigua*	Nav.exi	+	+
25	*Navicula gracilis*	Nav.gra	+	+
26	*Navicula gregaria*	Nav.gre	-	+
27	*Navicula radiosa*	Nav.rad	+	+
28	*Navicula* sp.	Nav.sp	-	+
29	*Nitzschia obtuse*	Nit.obt	-	+
30	*Oedogonium hindustanaceae*	Oed.hin	-	+
31	*Oedogonium boscii*	Oed.bos	+	-
32	*Oedogonium leave*	Oed.lae	+	+
33	*Oedogonium peipingense*	Oed.pei	+	-
34	*Oedogonium plagiostomum*	Oed.pla	+	-
35	*Oedogonium* sp.1	Oed.sp1	+	+
36	*Oedogonium* sp.2	Oed.sp2	+	-
37	*Oscillatoria* sp.	Osc.sp	+	+
38	*Pinnularia* sp.	Pin.sp	+	+
39	*Pinnularia viridis*	Pin.vir	+	-
40	*Pleurotaenium ehrenbergii*	Ple.ehr	+	-
41	*Pleurotaenium* sp.	Ple.sp	+	+
42	*Rhopalodia* sp.	Rho.sp	+	+
43	*Scenedesmus ecornis*	Sce.eco	-	+
44	*Spirogyra corrugate*	Spi.cor	-	+
45	*Spirogyra chungkingensis*	Spi.chu	+	-

46	*Spirogyra hopeiensis*	Spi.hop	+	-
47	*Spirogyra Rhizopus*	Spi.rhi	+	+
48	*Spirogyra* sp.	Spi.sp	-	+
49	*Spirulina nodosa*	Spi.nod	-	+
50	*Spirulina* sp.	Spi.sp	+	-
51	*Surirella euigepta*	Sur.eui	-	+
52	*Surirella splendida*	sur.spl	-	+
53	*Staurastrum manfeldtii*	Sta.man	-	+
54	*Staurastrum* sp.	Sta.sp	+	+
55	*Synedra ulna*	Syn.uln	+	+
56	*Trachelomonas* sp.	Tra.sp	-	+
57	*Tetraedron kutzing*	Tet.kut	-	+
58	*Ulothrix zonata*	Ulo.zon	-	+
59	*Vaucheria sessilis*	Vau.ses	+	+
60	*Vaucheria* sp.1	Vau.sp1	-	+
61	*Vaucheria* sp.2	Vau.sp2	-	+
62	*Zygnema* sp.	Zyg.sp	+	-

Appendix II: Frequency of algal species in Winter season

S.N.	Name of species	Winter Season
1	*Oedogonium* sp.1	66.67
2	*Pleurotaenium ehrenbergii*	46.67
3	*Ankistrodesmus* sp.	40.00
4	*Pleurotaenium* sp.	36.67
5	*Hyalotheca dissiliens*	13.33
6	*Navicula exigua*	13.33
7	*Pinnularia* sp.	13.33
8	*Rhopalodia* sp	13.33
9	*Spirogyra* sp.	13.33
10	*Amphora* sp.3	10.00
11	*Closterium ehrenbergii*	10.00
12	*Oedogonium peipingense*	10.00
13	*Pinnularia viridis*	10.00
14	*Aulacoseira* sp.	6.67
15	*Navicula radiosa*	6.67
16	*Oscillatoria* sp.	6.67
17	*Synedra ulna*	6.67
18	*Euastrum germanicum*	3.33
19	*Eunotia* sp.	3.33
20	*Glaucocystis* sp.	3.33
21	*Oedogonium leave*	3.33
22	*Staurastrum* sp.	3.33
23	*Vaucheria* sp.1	3.33

Appendix III: Frequency of algal species in post-monsoon season.

S.N.	Name of species	post monsoon
1	*Achnanthes* sp.	56.67
2	*Surirella euigepta*	30.00
3	*Navicula radiosa*	20.00
4	*Vaucheria* sp.1	20.00
5	*Ankistrodesmus* sp	16.67
6	*Closterium* sp.	16.67
7	*Trachelomonas* sp	16.67
8	*Fragillaria crotonensis*	13.33
9	*Oedogonium* sp.1	13.33
10	*Navicula exigua*	10.00
11	*Pinnularia* sp.	10.00
12	*Spirulina* sp.	10.00
13	*Aulacoseira* sp.	6.67
14	*Euastrum germanicum*	6.67
15	*Eunotia* sp.	6.67
16	*Glaucocystis* sp.	6.67
17	*Oedogonium leave*	6.67
18	*Oscillatoria* sp.	6.67
19	*Rhopalodia* sp	6.67
20	*Staurastrum* sp.	6.67
21	*Pleurotaenium* sp.	3.33
22	*Synedra ulna*	3.33

Appendix IV: CCA ordination summary of seasonal effect on algal species composition

	Inertia	Proportion	Df	Chi Square	F value	P value
Total	7.505	1				
Constrained	0.560	0.075	1	0.566	4.67	0.001
Unconstrained	6.945	0.925				

Appendix V: CCA ordination summary of effect of physical parameters of water on algal species composition.

	Inertia	Proportion	Df	Chi Square	F value	P value
Total	7.505	1				
Constrained	0.9958	0.1327	4	0.9958	2.1034	0.001
Unconstrained	6.5092	0.8673				

Biplot scores for constraining variables

	CCA1	CCA2	CCA3	CCA4	Df	Chi Square	F value	P value
Temp	-0.971	-0.222	-0.007	-0.091	1	0.541	4.502	0.001
pH	-0.145	0.010	-0.989	0.013		0.142	1.116	0.335
TDS	-0.527	0.311	0.180	0.770		0.234	1.864	0.006
EC	-0.612	0.455	0.156	0.628		0.293	2.354	0.001

Accumulated constrained eigenvalues

	CCA1	CCA2	CCA3	CCA4
Eigenvalue	0.562	0.213	0.133	0.089
Proportion Explained	0.564	0.214	0.133	0.089
Cumulative Proportion	0.564	0.778	0.911	1

Appendix VI: CCA ordination summary of effect of chemical parameters of water on algal species composition.

	Inertia	Proportion	Df	Chi Square	F value	P value
Total	7.505	1				
Constrained	0.9867	0.1315	5	0.9867	1.6348	0.001
Unconstrained	6.5183	0.8685				

Biplot scores for constraining variables

	CCA1	CCA2	CCA3	CCA4	CCA5	Df	Chi Square	F value	P value
Alk	-0.552	-0.347	-0.737	-0.126	-0.126		0.240	1.919	0.005
TH	-0.532	-0.078	0.389	-0.549	-0.508		0.199	1.577	0.028
COD	0.577	0.324	-0.358	0.177	-0.635	1	0.218	1.732	0.008
DO	0.575	-0.811	-0.052	-0.080	-0.059		0.307	2.473	0.001
BOD	-0.864	-0.230	0.117	0.395	-0.176		0.377	3.071	0.001

Accumulated constrained eigenvalues

	CCA1	CCA2	CCA3	CCA4	CCA5
Eigenvalue	0.4604	0.2337	0.128	0.1149	0.04964
Proportion Explained	0.4666	0.2369	0.1297	0.1165	0.05032
Cumulative Proportion	0.4666	0.7035	0.8332	0.9497	1

Appendix VII: PCA analysis of physicochemical parameters of water

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.718
Bartlett's Test of Sphericity	Approx. Chi-Square	306.067
	Df	28
	Sig.	.000

PHOTOPLATES

Photo 1: Satyawati Lake

Photo 2: Collecting algal sample.

Photo 3: Collection of water sample

Photo 4: COD test

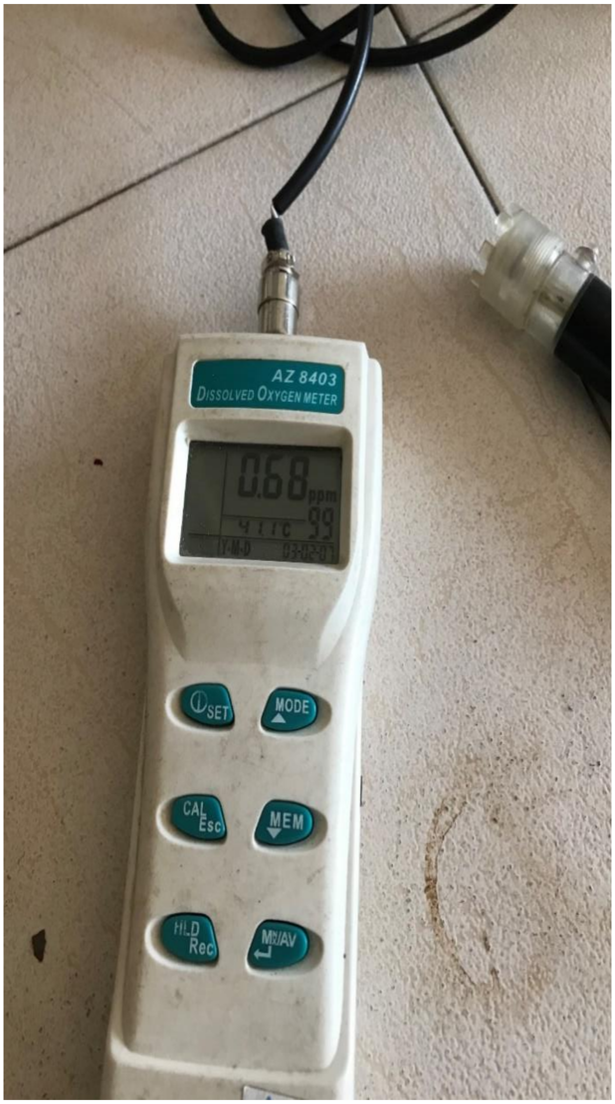

Photo 5: measurement of DO

Photo 6: Measurement of Alkalinity

Photo 7: Measuring pH of water.

Photo 8: Identification of Algae

Photo 9: water stored on BOD incubator.

Photo 10: Measuring COD of water.

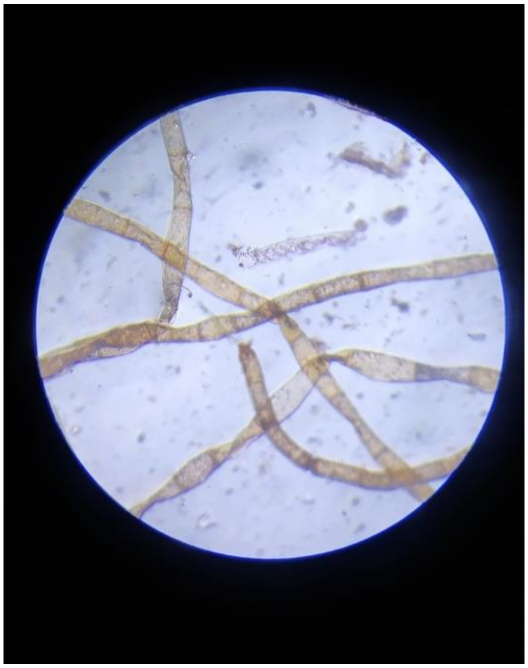

Photo 11: *Oedogonium* sp. and *Spirogyra* sp.

Photo 12: *Oedogonium peipingense*

Photo 13: *Pleurotaenium ehrenbergii*

Photo 14: *Vaucheria* sp.

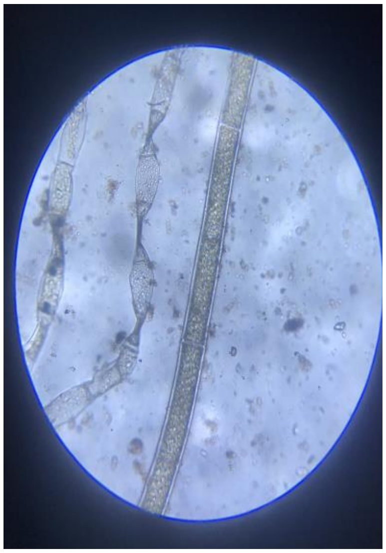

Photo 15: *Oedogonium* sp and *Spirogyra chungkingensis*

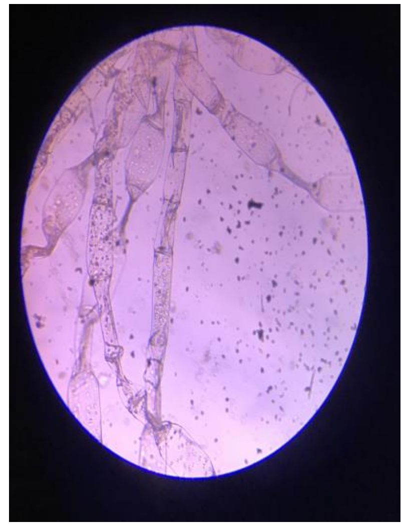

Photo 16: *Oedogomium* sp.

Photo 17: *Euastrum germanicum*

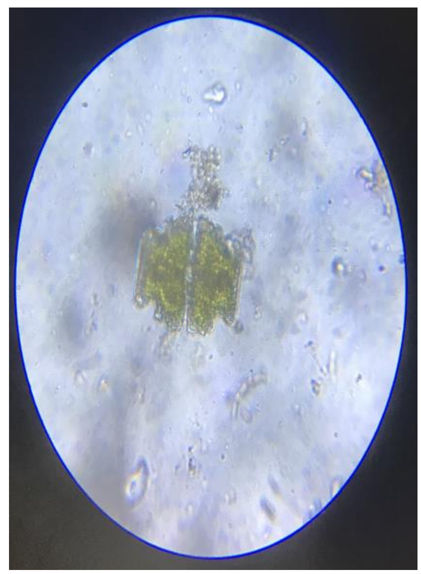

Photo 18: *Euastrum pectinatum*

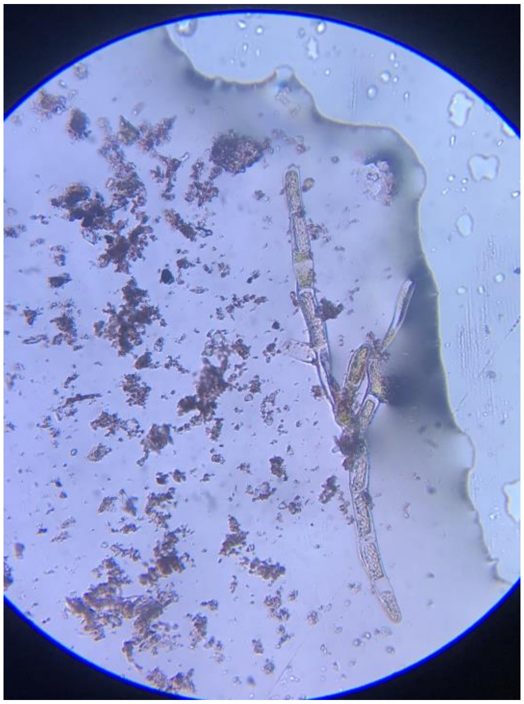

Photo 19: *Cladophora* sp.

Photo 20: *Hyalotheca dessiliens* and *Navicula radiosa*

Photo 21: *Oedogonium laeve*