SEASONAL DYNAMICS OF WETLAND FLORA IN RESPONSE TO PHYSICO-CHEMICAL PARAMETERS OF PRAVAS WETLAND, PALPA, NEPAL

A dissertation submitted for partial fulfillment of the requirement for Master's Degree in Botany

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RECOMMENDATION

I hereby certify that thesis entitled "**Seasonal dynamics of wetland flora in response to physico-chemical parameters of Pravas wetland, Palpa, Nepal**" has been completed out by Ms. Pooja Ghimire under my guidance and supervision. This work has been completed through the candidate's own research on the basis of original research based on field visit and lab work. To the best of my knowledge, the work has not been submitted for any other academic degree or qualification. I recommend this dissertation work to be accepted as a partial fulfillment for the Master's Degree of Science in Botany (Ecology and Resource Management Unit).

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LETTER OF APPROVAL

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DECLARTAION

I hereby affirm that I am the author of this dissertation and it is entirely my original work. I have not previously submitted it, either in its entirety or in part, for the purpose of obtaining a degree at any other academic institution. The opinions and perspectives presented in this dissertation are solely the responsibility of the author and don't necessarily reflect those of any other institution.

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ABSTRACT

The wetland plant communities are effective indicators of wetland status. The fluctuations in seasonal environmental factors and water quality exert a significant influence on the growth and proliferation of aquatic species in freshwater ecosystems. The relationships between the seasonal variation of physico-chemical parameters and the diversity of plant species were investigated in Pravas wetland using correlation analysis and CCA. Seven water quality parameters were selected and analyzed from different 32 sampling points. A wooden framed quadrat of sized (1m×1m) was laid down for species sampling. The presented flora was evaluated by species composition, species richness and the ecological indices. Total of 73 plant species were recorded with the dominancy of emergent species, Poaceae was the dominant family followed by Cyperaceae and Asteraceae in two seasons. Shannon- Weiner Index was high during post-monsoon season than pre-monsoon. *Digitaria* species was dominant during the post-monsoon and *Cynodon dactylon* was dominant during pre-monsoon season. Among all studied characteristics, temperature and phosphorous were the most responsible characters affecting the species abundance during both post and pre-monsoon season. The physico-chemical characteristics of the water (temperature and dissolved oxygen) exhibited significant variations between the seasons with the change in species composition. The post-monsoon season was found to be more favourable for macrophyte growth due to the flushing of nutrients through high rainfall. It was revealed that the wetland plant diversity was changed accordance with the season with the change in nutrient level in the water quality. The prevalence of emergent indicates an escalation in increasing productivity of the lake ecosystem.

ABBREVIATIONS AND ACRONYMS

°C	degree Celsius
μS/cm	micro Siemens per centimeter
APHA	American Public Health Association
CCA	Canonical Correspondence Analysis
CO_2	Carbon-dioxide
DCA	De-trended Correspondence Analysis
DO	Dissolved oxygen
EC	Electrical Conductivity
GN	Government of Nepal
KATH	National Herbarium and Plant Laboratories
Km^2	square kilometer
mg/L	milligram per liter
MFSC	Ministry of Forest and Soil Conservation
NO_3^-	Nitrate
p	level of significance
PO_4^-	Phosphate
ppm	Parts Per Million
QGIS	Quantum Geographic Information System
r	correlation coefficient
RFL	Rooted- Floating Leaves
S.E	Standard Error
sp	species
SPSS	Statistical Package for Social Science

TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorous
WQI	Water Quality Index

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CHAPTER 1: INTRODUCTION

1.1 Background

Wetland refers to lands that are in between terrestrial and aquatic ecosystems and frequently have waterlogged soil, water tables are typically close to the surface or where the land is immerged in shallow depth of water (Podder et al., 2001). According to Ramsar Convention on Wetlands (2010), wetlands are defined as "areas of marsh, fen, peatland, 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 whose depth at low tide does not exceed six meters."

Wetlands are termed as the kidneys of the landscape as they act as the receivers downstream, accumulating both waste and water from both various sources, including both natural processes natural and human activities (Roy & Behera, 2003). They help to stabilize water supply, reducing floods and droughts. They have been proven to clean polluted waters, protect shorelines, and replenish groundwater aquifers (Boyer & Polasky, 2004; Shafiq et al., 2019). Wetlands have additionally been dubbed as "nature's supermarkets" due to the extensive food chain and diverse biodiversity that they endorse (Mitsch & Gosselink, 1993).

Nepal has a diverse range of wetland ranging from mountain conditions near the Himalayas in the north to tropical conditions in the south. Wetlands are estimated to cover 382,700 hectare of Nepal's total land area, accounting for approximately 2.6 percent of the country's total land area (GN/MFSC, 2009). Nepal has over 5000 lakes with an area of more than one hectare. Nepal has a vast area of land with a range of wetlands even though it only has freshwater wetlands (Rijal et al., 2021). The wetlands of Nepal are threatened by both natural and anthropogenic interferences as a result the livelihoods of many communities that depend on wetlands are negatively impacted (Pant et al., 2020). The disruption, degradation and depletion of wetlands result in the elimination of native plant species, encroachment of non-native species and a decrease in the ecological and socioeconomic value of wetlands (Kassahun et al., 2014).

Seasonal dynamics refers to the patterns, changes and fluctuation that occur natural processes or phenomenon over the course of a year. The seasonal dynamics of wetland flora refers to the change and patterns in plant life within wetland ecosystems over the course of a year. Wetland plants have evolved specialized adaptations to grow in environments that lack oxygen, water or soils that remains flooded or saturated for extended periods of time, making it an ideal place for their growth (Crawford, 2003). The species may be floating, floating-leaved, submerged, or emergent (Sculthorpe, 1967). Wetland vascular plants are classified based on their growth form based on physical relationship to the water and soil. Emergent plants possess submerged basal portions that extend below the water surface, while their leaves, stems and reproductive organs are aerial. All photosynthetic tissues are normally underwater in submerged species (Cook, 1996). The terminal portion of the plant does not usually reach the water's surface though it may lie horizontally just beneath it. The leaves of floating-leaved species remain buoyant on the water's surface, while their roots are securely anchored in the underlying substrate. The leaves and stems of floating species float on the surface of the water. Wetland plant communities are valuable indicators of wetland status because they encompass species with diverse capabilities to thrive in the different environmental conditions and are recognized as crucial components of wetlands' biological integrity (Asefa et al., 2016). Aquatic plant species have the ability to influence alternations in water quality and are utilized as a bio-indicator of pollution due to their sensitivity to environmental changes (Mahaney, 2004; Sass et al., 2010). However, macrophytes play a role in modifying water quality and are employed as indicators of pollution, reflecting their ability to respond to changes in their environment (Tripathi & Shukla, 1991).

The understanding of macrophyte community features relies on knowledge of the species composition, diversity and primary productivity of the community (Han et al., 2018; Wang et al., 2019). The role of macrophytes in lake ecosystem depends on their species richness, species composition, distribution, abundance and diversity which in turn are influenced by a number of environmental variables such light, water temperature, substrate composition, disturbance and lake water quality (Wetzel, 1983; Barko & Smart, 1986; Duarte, Kalff & Peters, 1986; Jafari et al., 2003).

Quantitative parameters are measured as frequency, density, coverage, and importance value index (IVI). The measuring of these parameters is crucial because it reveals information about a community's homogeneity or heterogeneity, species dominance and species distribution patterns (Burlakoti, 2004). Several environmental factors control the distribution and abundance of macrophyte species such as hydrological regime, nutrient status and water quality (Lacoul & Freedman, 2006).

Water quality refers to the physical, chemical and biological properties of water and is determined by assessing how well it meets the need of both general and specific organisms. In time series data, seasonality refers to the occurrence of consistent and periodic variations at regular intervals shorter than a year, such as weekly, monthly. Surface water quality undergoes continuous fluctuations in response to daily, seasonal and climatic patterns, as it relies on maintaining a balance between the physical, chemical and biological properties of the surrounding environment. The surface water quality is constantly changing in response to daily, seasonal and climatic rhythms because it depends on the equilibrium between the physical, chemical and biological characteristics of the environment. A number of environmental variables pronounced seasonal variation and have an impact on the growth of aquatic macrophytes (Manolaki & Papastergiadou, 2013; Xie et al., 2018; Wang et al., 2019). One of the most crucial aspects of the aquatic environment is the temperature as it controls both the physico-chemical and biological processes. The chemical processes in lakes are also impacted by an increase in water temperature, with an increase in pH (Psenner & Schmidt, 1992). pH is another critical water parameter which has a significant impact on biotic life in both lentic and lotic environments. The amount of oxygen dissolved naturally in water is measured as dissolved oxygen, which is also affected by the physico-chemical and biological activities of water bodies. It is a primary source of oxygen for aquatic plants. The ability of an aqueous solution to carry an electric current is known as electrical conductivity (EC), which is a measure of ionic strength. It is influenced by the ions' presence, total concentrations, mobility, and temperature. Total dissolved solids (TDS) are dissolved ions that can affect the pH of a body of water, which further affects the overall health of many aquatic species. Another essential nutrient for the growth of plants are phosphorus and nitrogen, which are typically present in lakes as PO_4^-, NO_3^-, NO_2^- (Pant et al., 2019).

The deterioration of water quality is pronounced as a result of human activity than environmental factors. A few anthropogenic factors that have an impact on water quality are those related to agriculture, the use of fertilizers, manures, and pesticides, animal husbandry, ineffective irrigation techniques, the deforestation of forests, aquaculture, pollution from domestic and industrial sewage, mining, disposal of pollutants and recreational purposes (Peters & Meybeck, 2000; Buck et al., 2004; Alam et al., 2006; Zhang et al., 2007; Hussain et al., 2008).

1.2 Research questions

1. Are there any significant changes in physico-chemical characteristics of water in the lake during two seasons?
2. How does the abundance and diversity of plant species vary with different physico-chemical conditions of water?
3. What are the key environmental factors that influence the distribution of aquatic macrophyte in the Pravas Lake?

1.3 Objectives of the study

Though qualitative information exists in Nepal, but the well-enough information on quantitative relationship study has not taken place.

The broader objective of the research was to observe the impacts of seasonal variation in physico-chemical parameters of water on the distribution and diversity of plant communities within Pravas wetland.

The specific objectives were:

- To analyze the quantitative characteristics of water and assess the diversity of wetland flora during two seasons.
- To assess the seasonal fluctuation of physico-chemical parameter of the lake.
- To observe the relationship between physico-chemical parameters of the lake and species richness.
- To identify the predominant environmental factors influencing the distribution of wetland flora.

1.4 Justification

The wetland plant species play an important role in maintaining the ecology of aquatic ecosystems by providing habitats, food, and shelter for aquatic organisms. The establishment of macrophytes are directly correlated with the physico-chemical characteristics of water. The distribution and diversity of macrophytes varies between seasons due to the seasonal fluctuations in the physico-chemical parameters. Therefore, the study of wetland species and their relationship with physio-chemical parameters of water is significant in understanding the functioning of aquatic ecosystems. The effects of environmental factors on aquatic macrophyte growth have been studied, however limited systematic investigations have been carried out regarding the relationship between seasonal variation of the aquatic plant species and the environmental factors of water. Pravas lake was selected as a target lake in this work as it encompasses species with significant economic value and carries immense religious importance. Additionally, it plays a pivotal role in preserving the ecological equilibrium of the area while also supplying essential natural resources to the local population. The studies can contribute to filling this gap in knowledge and provide valuable information for future management and conservation efforts of Pravas Lake and other aquatic ecosystems in Nepal. The physico-chemical parameters of water such as temperature, pH, dissolved oxygen, and nutrients are important indicators of water quality. Therefore, the study can provide valuable information on the seasonal variation of water quality in Pravas Lake. The presence and absence of certain species can indicate the overall status of the aquatic ecosystem. Moreover, the taxonomic documentation of these species is necessary to add and update the database of aquatic biodiversity.

1.5 Limitation of the study

Though the current work initiated new discussion in the field of limnological study in Pravas lake, has following limitations:

1. The entire research based is limited only with two seasons hence all the seasonal variation could not be explained by the work.
2. There has been some lag between the collection of water, water samples and their analysis in the laboratory.

CHAPTER 2: LITERATURE REVIEW

2.1 Aquatic flora

The exploration of aquatic flora in Nepal commenced through the efforts of Hamilton and Wallich, who conducted botanical surveys across various regions of the country, documenting plant species, including wetland species. There has been a progressive increase in research works onwards in the field of aquatic macrophytes (Shrestha, 1994).

The quantitative analysis of macrophytes in Beeshazar Tal, Chitwan, Nepal, conducted by Burlakoti & Karmacharya (2004) revealed that there were distinct seasonal variations in the distribution of macrophytes. The highest species diversity was found in the summer, followed by the winter, and concluded that the dominance of emergent growth forms indicated the encroachment of littoral vegetation.

The distinct seasonal variation was observed in the species richness and family diversity of the plant species. Altogether 41 plant species were collected during the rainy season, 28 plant species during the winter season, and 54 plant species during the summer season from Chimdi Lake, Sunsari, Nepal by Mandal et al. (2010). The species belonging to the Poaceae family showed dominance, followed by Cyperaceae and Asteraceae during all the seasons.

Lamsal et al. (2014) documented aquatic and terrestrial riparian biodiversity in an anthropogenically disturbed site, the Ghodagodi Lake, and illustrated altogether 45 species of aquatic macrophytes. Among the macrophytes, floating-leaved species (21) were found to be dominant, followed by submerged species (9), and free-floating species (9). The *Nelumbo nucifera*, *Trapa bispinosa*, *Nymphaea nouchali,* and *Potamogeton natans* were the major anchored leaf-floating species, whereas *Hydrilla verticillata*, *Ceratophyllum demersum,* and *Potamogeton* sp. were the major submerged species, and *Azolla imbricate*, *Lemna minor,* and *Wolffia globosa* were the major free-floating species found in the lake.

The highest density values, area coverage, and genus richness of macrophytes were observed during the post-monsoon than during the pre-monsoon season from the oxbow lake ecosystem in the Ganga River basin. The IVI value indicated that the emergent were more dominant followed by free-floating, submerged and rooted- floating leaved genus. Among the emergent genus, *Cynodon* sp. was observed to be dominant during both seasons. Among free- floating genus *Eichhornia* sp. was highly dominant throughout the year. Likewise, among the submerged genus *Hydrilla* sp. was found to be the most dominant throughout the season by Gosh & Biswas (2015) and concluded that the low richness of species, dominancy of water hyacinth may be correlated with the quality of water.

The Pravas Lake covered altogether 45 macrophytes with endangered species, the species belonging to the Poaceae family showed the dominancy during all three seasons (winter, summer and rainy) reported by Ghimire (2016). The site is also important for genetic reservoir supporting wild rice *Oryza rufipogon* (Siwakoti & Tiwari, 2007). The emergent macrophytes were dominant in both monsoon and winter seasons, macrophytes diversity and Shannon Weiner diversity index value of species was higher during winter than monsoon in Beeshazari Lake and revealed that macrophytes were correlated with the water parameters (Ghimire et al., 2016).

Sharma & Singh (2017) found altogether 45 macrophytes species in Himalayan Lake, Dodi Tal with the dominancy of emergent among other growth form and the high diversity of macrophytes exists during summer season than winter season. *Renunculus letua* and *Myriophyllum verticillatum* were dominant during all three seasons. It was revealed that the huge growth of macrophytes during spring and summer seasons, correlated with high influx of tourists.

Sharma et al. (2019) documented the flora of three wetlands of Rupendehi district and altogether 115 species belonging to 45 families were recorded with the dominancy of Poaceae family followed by Cyperaceae, Malvaceae. The highest number of species were represented by Dicotyledons. 33 species were alien and 12 species invaded the area as invasive species and the observation claimed that the wetland flora were in threatened condition.

Overall, 58 species of macrophytes were recorded from Jagadispur reservoir where the maximum number of aquatic macrophytes were observed during the rainy season (57), compared to the winter (54) and summer (46) seasons by Chaudhary & Devkota (2021). The emergent species were observed to be the most abundant among all the growth forms during the study period. The quantitative and diversity analyses revealed that there was a distinct seasonal variation in the distribution of macrophytes but lacked the responsible factors.

2.2 Physico-chemical parameters

An examination of surface water quality data collected in Nepal in 1985 revealed significant differences in the ionic composition compared to other global regions. These distinctions include the prevalence of bicarbonates, the absence of sulfates, calcium dominance as a major anion and frequently observed N:P ratios below 10 (Jones et al., 1989).

According to broad consensus regarding Nepal's water quality, nutrients like Nitrogen and Phosphorous are higher in the dry season due to low flow and decreased dilution, while organic materials are more abundant during the wet season (Kannel et al., 2007).

Kunwar & Devkota (2012) studied the macrophytes production of Rupa Lake Kaski, Nepal and found that the highest biomass of aquatic macrophytes was observed during post-monsoon with the dominance of emergent species and lowest biomass was observed by submerged species and also categorized lake as eutrophic. They also concluded that the temperature during pre-monsoon was 23.24 ±1.20 °C and that of post-monsoon was 21.90 ±2.10°C. The pH value was 5.67 ± 0.25 and 6.29 ±0.16 during pre-monsoon and post-monsoon respectively. The DO was 4.16 ±1.10 mg/l and 7.68 ±1.50 mg/l respectively.

The value of temperature was observed higher during summer, while higher value of conductivity, DO, TDS, pH, nitrate, and phosphate was observed during winter in Jagdishpur reservoir by Thapa & Soudh (2012). The temperature was positively correlated with pH, EC, TDS, PO_4^- where pH showed positive correlation with Mg^{2+} and TH and EC showed high correlation with TDS (Pant et al., 2020).

Xu et al. (2019) on determining the seasonal variation in River basin, observed DO was highest during winter and lowest during summer with the mean values of 10.29 mg/L and 7.99 mg/L wherever pH did not show significant variation, EC was lowest during summer, Low NN concentration were frequent during the summer and Total phosphorous were higher during the spring. Thus, it was concluded that nitrate nitrogen and total phosphorous were responsible for the water pollutants.

According to Xu et al. (2022), the contents of TN and TP in winter were significantly higher in winter than in summer season. The correlation analysis showed that the correlation between temperature, DO, pH was relatively high where the correlation between TN and TP was negatively low. The variation in temperature was major factor for influencing the water quality. The seasonal variation of physico-chemical parameters was linked with the climate change, anthropogenic activity as well as the urbanization (Sankar et al., 2018).

2.3 Relationship between physico-chemical parameters and wetland flora

Tamire & Mengistou (2013) concluded that level of nutrient brings significant change in the abundance of species and observed the abundance of *Cyperus articulates*, *Pistia stratiotes* had a positive correlation with nitrate also the increase in temperature, pH negatively affects the abundance of *Cyperus papyrus*, *Nymphoides indica* and *Schoenoplectus corymbous.* Similarly, the abundance of *Potamogeton schweinfurthii* was affected negatively with the increasing concentration of nitrate and nitrite.

Based on the observation of relationship between aquatic macrophytes and environmental factors in different season of Baiyangdian lake, China Yang et al. (2020) revealed that the environmental factors and the total biomass of aquatic macrophytes of the lake changed significantly in different seasons. Hence, NO_3-N and total nitrogen were the major chemical factors that influenced the aquatic macrophytes. Physical parameters, pH, DO and conductivity play significant role in water quality. From correlation analysis DO, TOC, NO_2-N exhibited strong correlation with other water environmental factors in spring and summer seasons. Among all the parameters observed, NO_2-N, TOC and $PO_4{}^{3}$- exhibited great influenced on aquatic macrophyte growth during autumn hence it was concluded that each macrophytes was distinctly influenced by environmental factors in different seasons.

Kassa et al. (2021) concluded that the variation in season has effect in the distribution of macrophytes. The density of *Azolla pinnata*, *Ceratophyllum dermusum*, *Cyperus alopecuroides*, *Digitaria milanjiana*, *Pycerus coerula* were positively correlated with pH, TP whereas *Ipomoea aquatic*, *Amaranthus hypochondriaus*, *Cyperus papyrus* were negatively associated with these variables but positively correlated with $NO_3{}^{-}$N. Similarly, *Leersia hexandria* was negatively associated with pH and TP.

Upadhyay et al. (2022) recorded 39 macrophyte species from Setikhola watershed, belonging to 29 families with the dominancy of emergent species and revealed that conductivity was found most important influencing factor for causing variations in species composition of macrophyte among all the water characteristics studied.

CHAPTER 3: MATERIAL AND METHODS

3.1 Study area

3.1.1 Location

Pravas Lake is a freshwater lake lies in Palpa, district, Lumbini Province, tropical zone of Nepal. It is extended from 27º 50' 45.75"N longitude and 83º 32' 53.97"E latitude. The wetland is situated at an elevation of 900m above sea level. The lake covered about an area of 8 hectare and average depth is about 4-5 meter also 45% of wetland is covered by water. The wetland is surrounded by the community forest in the Southern side and Lumbini Medical College, hospital in the Northern side. The eastern part of this station is occupied by agricultural lands mainly paddy cultivation. The lake is well-known for its spiritual significance. During the last decades, lake has begun to show reduction in its water level because of wetland defragmentation. The (figure 1) below shows the location of study area and sampling sites.

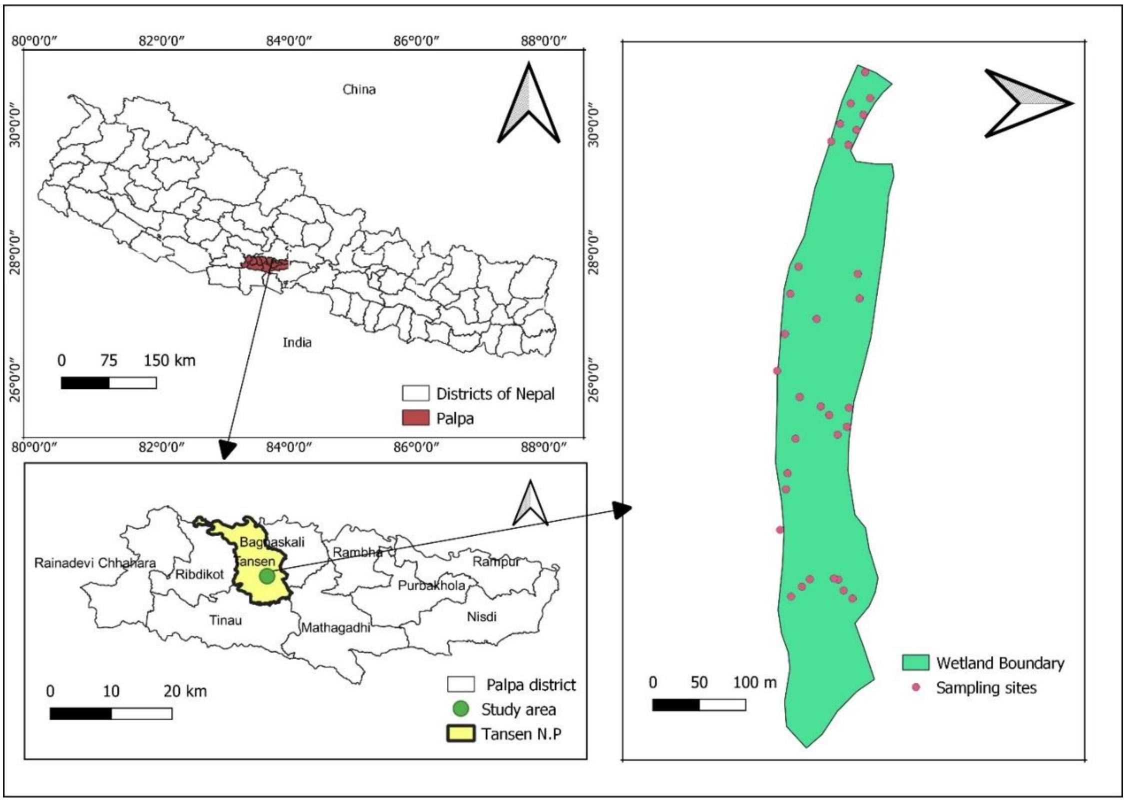
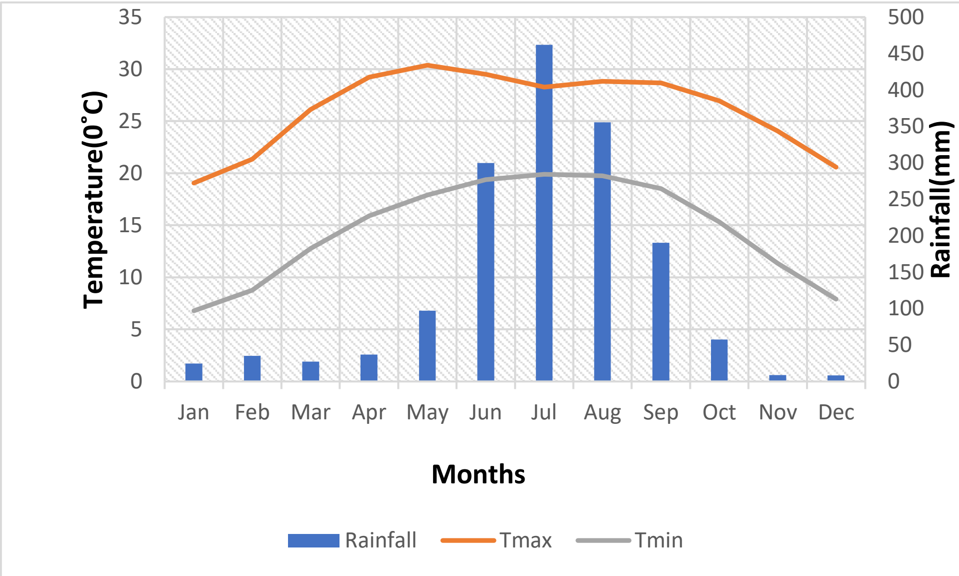


Figure 1: Study area showing the Palpa district within the Map of Nepal, the location of the study area and the sampling sites through QGIS.

3.1.2 Climate

The tropical climate exhibits marked seasonal variation in terms of hydrological regimes. It consists of four seasons: monsoon, post-monsoon, winter-monsoon and pre-monsoon. Monsoon lies from mid-June to mid-October, post-Monsoon lies from mid-October to December, winter-monsoon lies from January to March and pre-monsoon lies between April and May. Mainly the water in the lake is fed by atmospheric precipitation.



Source: Department of Hydrology and Meterology, (GON),2022

Figure 2: Monthly pattern of temperature and rainfall of Tansen station (1991-2021)

The meterological data indicated that mean maximum temperature was 30.37ºC and mean minimum temperature is 6.78 ºC of the Tansen station, Palpa district. The highest total rainfall was occurred in the month of July i.e 461.83 mm month^{-1} followed by August i.e 355.73 mm month^{-1} and the minimum rainfall occurred during December i.e 8.30 mm month^{-1}. There was gradual increase in rainfall and temperature from May to August and declining from August to December (Figure 2).

3.1.3 Vegetation and Flora

The tropical temperature and heavy monsoon rainfall allow vigorous growth of numerous plants, with a rich variety of both evergreen and deciduous plants. *Schima wallichi, Castanopsis indica, Shorea robusta* are the predominant trees around the Pravas area. The wetland is densely vegetated by submerged with succession stage along with the patches of floating species holding high economic values. Among the aquatic species, species of *Pistia*, *Potamogeton*, *Nelumbo* were mainly distributed in the water bodies. The lake was mostly invaded by the invasive species mainly *Pistia stratiotes* and other invasive herbs.

3.2 Study Design

The compilation of primary and secondary data was involved during the field study. Field survey (Nov-Dec 2021 and April- May 2022) and laboratory analysis were the primary methods used to obtain data. Secondary data for the study was retrieved from a variety of published and unpublished academic journals, publications, and websites. Descriptive and explanatory research methods were used in this study.

Reconnaissance visit was done in October 2021 to study the general site features and to further develop study strategy. The lake was visibly distinct. This produced the idea that there are certain regulating variables that influence the attributes of the lake, necessitating the study of lake.

Table 1: Methods of measurement and model of instruments used for physico-chemical parameters of water.

S.N	Parameters	Methods of measurement	Model of Instruments
1	Temperature(°C)	Thermometric	Mercury Thermometer
2	Ph	Electrometric	pH meter (H198108)
3	DO (mg/L)	Electrometric	DO meter (EcoSense DO200A)
4	Electrical conductivity(µS/cm)	Electrometric	Conductivity meter (Pro Quatro)
5	Total Dissolved solids(ppm)	Electrometric	Conductivity meter (Pro Quatro)
6	Nitrate(mg/L)	Spectrophotometry (Phenol Disulphonic Acid)	Spectrophotometer (Milton Roy Spectronic 21)
7	Phosphate (mg/L)	Stannous chloride	Spectrophotometer (Milton Roy Spectronic 21)

3.2.1 Sampling, Preservation and Identification of species

Quantitative parameters of Pravas Lake were studied in the littoral zone of four different sites during two seasons i.e post- monsoon and pre- monsoon. Standard quadrat method was applied (Ghosh & Biswas, 2015). Species were collected from 32 sampling units by using quadrat (1m×1m) and stratified random sampling were used. The quadrat size was determined by species area curve method as mentioned in Zobel et al. (1987). Eight quadrats on each transect of four sites were taken. The lake was categorized by four different sites (site A joined by paddy field, site B excessive growth of aquatic macrophytes, site C dominancy of invasive species and site D joined by road side with open area) for sampling as representative of the entire lake system. Macrophytes were categorized according to their growth forms and morphology, emergent as a plant that grow in shallow water or wetlands with stems and leaves that extend above the water surface, herbs as a non-woody plant with a soft stem that grows above the ground. Similarly, submerged as a plant that grow entirely underwater, with leaves and stems that remain below the water surface, free-floating as a plant that float freely on the water surface without being anchored to the bottom, rooted floating leaves as a plant that float on the water surface but are anchored to the bottom by their roots and shrubs were characterized as a woody plant with multiple stems that are less than 10 meters in height. The collected species from the study area were tagged, pressed and dried by standard herbarium specimen preparation technique. Herbarium of collected specimens were identified and labelled in herbarium sheet. Identification was done by consulting relevant literatures (Annotated Checklist of the Flowering Plants of Nepal) (Press et al., 2000). Besides, taxonomists were also consulted and cross checking of specimens with the herbarium specimen's house in the National Herbarium and Plant Laboratories (KATH) and TUCH of Central Department of Botany was also done.

3.2.2 Quantitative analysis of species

Simpson's Diversity Index (D)

It provides higher weightage to dominant species in the sample the value of this index also ranges between 0 and 1 was computed as (Simpson, 1949)

$D = 1 - \sum (pi) 2 si = 1$

Where, "pi" is the proportion of individuals in the "ith" taxon of the community and "s" is the total number of taxa in the community.

D is the Simpson diversity index

Σ is the sum over all species present in the sample.

Shannon-Wiener Index (H')

This is a widely used method of calculating biotic diversity in aquatic and terrestrial ecosystems and is expressed as (Shannon & Weiner, 1963):

$H' = - \Sigma i^{s}[(pi) * \ln(pi)]$

where,

H' = index of species diversity

s= number of species,i=1

Pi= proportion of individual species in the ith species

ln = natural logarithm

This diversity index aids in the assessment of species relative abundance. A higher value of H signifies increased diversity, which is also influenced by a larger number of species and/ or a more even distribution among them. The index values range between 0 and 5, where higher index values demonstrate higher diversity, while low index values are considered to indicate pollution. The Shannon index takes account of species richness as well as abundance. Diversity is maximum when all species that made up the community are equally abundant (i.e., have a similar population sizes)

Pielou evenness (J)

This is relative distribution of individuals among taxonomic groups within a community and is expressed as (Pielou, 1969):

J= H'/ln(S),

where,

H' = Shannon –Wiener diversity index, and ln = natural logarithms (S defined as **Species Richness**) recorded.

It is used for the degree to which the abundances are equal among the groups present in a sample or community.

IVI (Importance Value Index) was computed as a sum of relative density, relative frequency and relative abundance of macrophytes (Bhadra & Pattanayak, 2016). The calculation of each metric was performed using a specific formula:

$$\text{Density}= \frac{\text{Total number of individuals of a species present in all quadrat}}{\text{Total number of quadrats studied}}$$

$$\text{Frequency (\%)} = \frac{\text{Number of quadrats of species occurrence}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species present in all quadrats}}{\text{Total no of quadrats of species occurred}}$$

$$\text{Relative density} = \frac{\text{Density of a species}}{\text{Sum of density of all species}} \times 100$$

Relative frequency = $\frac{\text{Frequency of a species}}{\text{Sum of frequency of all species}} \times 100$

Relative abundance = $\frac{\text{Abundance of a species}}{\text{Sum of abundance of all species}} \times 100$

3.2.3 Water Sampling, Collection and Preservation

For the lab analysis, altogether 32 water samples were taken from water bodies at a depth of 0.5m. Prior to collection, the samples were rinsed with clean water and one-litre plastic bottles were filled with lake water. Samples of water were acquired by avoiding floating objects. To guard against contamination from outside sources, the sample bottle's stoppers were carefully sealed. The bottle was labeled with the name of the sampling site, sampling point, date, and time of sampling. The water temperature, dissolved oxygen (DO), total dissolved solids (TDS) and conductivity were measured on the spot using a portable water analysis kit. Nitrate as inorganic nitrogen and inorganic phosphorus were determined in the laboratory of Central Department of Botany. The samples were sent to a laboratory and placed in a refrigerator at 4˚C for chemical analysis.

3.2.4 Physico-chemical analysis of water

Temperature (˚C)

For the determination of temperature, water was collected in a beaker from sampling site. Mercury filled Celsius thermometer was inserted into the beaker and the reading was noted.

pH

For the measurement of pH, the electronic pre-calibrated pH meter was used. pH was determined by dipping the pH meter in a beaker containing water sample.

DO (mg/L)

Dissolved oxygen was measured by using DO meter by dipping the meter on a sample which was collected on a bottle.

Electrical conductivity (µS/cm), Total Dissolved solids (ppm)

For the measurement of electrical conductivity and total dissolved solids, sample was taken in a clean beaker and the conductivity meter was dipped and the reading shown in the instrument was recorded.

Nitrate (mg/L)

The nitrate in the form of nitrate was determined by Phenol Disulphonic Acid method (APHA, 2005). A 50 mL of filtrated water sample was taken in a conical flask. An equivalent amount of silver solution was added to remove chlorides (1 mg/L Cl= 1 mL of silver sulphates). Then the mixture was slightly heated to filter the precipitation of AgCl. With the absence of precipitation, filtrated sample was evaporated to dryness in a porcelain basin. The residue was cooled and dissolved in 2 mL phenol disulphonic acid and the contents were diluted to 50 mL then 6 mL of liquid ammonia was added to developed a yellow color. The absorbance of the color was measured by using a spectrophotometer at 410 nm using distilled water blank with the same amount of chemicals. The concentration of N equivalent to the observed absorbance of the sample was determined by using a calibration curve. The result was expressed as mg nitrate as N per liter of sample. The obtained value was multiplied by 4.43 to express in terms of nitrate.

Phosphate (mg/L)

Phosphate as inorganic phosphorous was determined by using Ammonium Molybdate Stannous Chloride Solution method (APHA, 2005). A 50mL of filtrate sample was taken in a beaker and 2mL of ammonium molybdate was added in it. After that 5 drops of stannous chloride were added. The color changed into blue and the absorbance was measured on a spectrophotometer at 690nm after 5minutes within 12minutes timeframe. The concentration of phosphate in the water sample was determined by using calibration curve of phosphate.

Weighted Arithmetic Water Quality Index Method

The water quality was classified based on its level of purity using the commonly measured water quality variables through the application of the Weighted Arithmetic water quality index method (Brown et al., 1972). The calculation of WQI was performed by using the following equation.

$$WQI = \Sigma\, QiWi / Wi$$

The quality rating scale (Qi) for each parameter is calculated by using this expression:

$$Qi = 100[(Vi\text{-}Vo/Si\text{-}Vo)]$$

where, Vi is estimated concentration of ith parameter in the analyzed water

Vo is the ideal value of this parameter in pure water Vo = 0 (except pH =7.0 and DO = 14.6 mg/l) Si is recommended standard value of ith parameter The unit weight (Wi) for each water quality parameter was calculated by using the following formula:

Wi = K / Si

Where, K = proportionality constant and can also be calculated by using the following equation:

K= 1/ Σ(1/Si)

3.3 Statistical Analysis

3.3.1 Descriptive analysis

The normality in data distribution of different physio-chemical parameters and aquatic flora were tested by SPSS Statistics version 23. Shapiro-Wilk significant value was used to test the normality of the data. If the obtained value was $p \geq 0.05$ the data distribution considered as normal but when the value showed $p < 0.05$, the data distribution was considered significantly different from the normal distribution. This test was conducted to assess the data's adherence to a normal distribution (Mishra et al., 2019).

t-test

Mann- Whittney test was performed to compare the medians of two independent groups whether there is significant difference between species richness and ecological indices between two different seasons (post-monsoon and pre-monsoon). Also, the test was performed to see the significant difference among the physio-chemical parameters of two seasons both for parametric and non-parametric data.

Correlation analysis

The Spearman rank-order correlation coefficient (Spearman's correlation) is a nonparametric measure of strength and direction of association that exists between two variables (Hauke & Kossowski, 2011). R programme was used to analyze the correlation between physico -chemical parameters of water with species richness.

3.3.2 Multivariate analysis

An analysis was conducted using a direct gradient approach to examine how environmental factors relate to the abundance of different species. As the first axis length of detrended correspondence analysis (DCA) was greater than 3 for both seasons, canonical correspondence analysis (CCA) was performed (ter Braak & Smilauer, 2002). All statistical analyses were carried out in R studio version 1.2.1335 (R Core Team, 2019).

CHAPTER 4: RESULTS

4.1 Species composition, abundance and distribution

A total of 73 plant species belonging to 34 families and 66 genera were recorded during the study period. Maximum number of species belonged to emergent (36 species) followed by herbs (25), submerged (9 species), free-floating (2 species) and only 1 species from rooted-floating leaves and shrub were found during the study period (Appendix 2). The plant family having the greatest diversity was of Poaceae with 14 species during post-monsoon season and 11 during pre-monsoon season followed by Cyperaceae with 12 species during post-monsoon and 8 during pre-monsoon season, Asteraceae with 6 species during post-monsoon and 7 during pre-monsoon seasons. No species of rooted-floating leaves was recorded in post-monsoon season. The emergent (53%) species were observed more in pre-monsoon season than in post-monsoon season (50%) where the herbs (32%) was observed more in post-monsoon than pre-monsoon season (28%) (Fig 4 & 5).

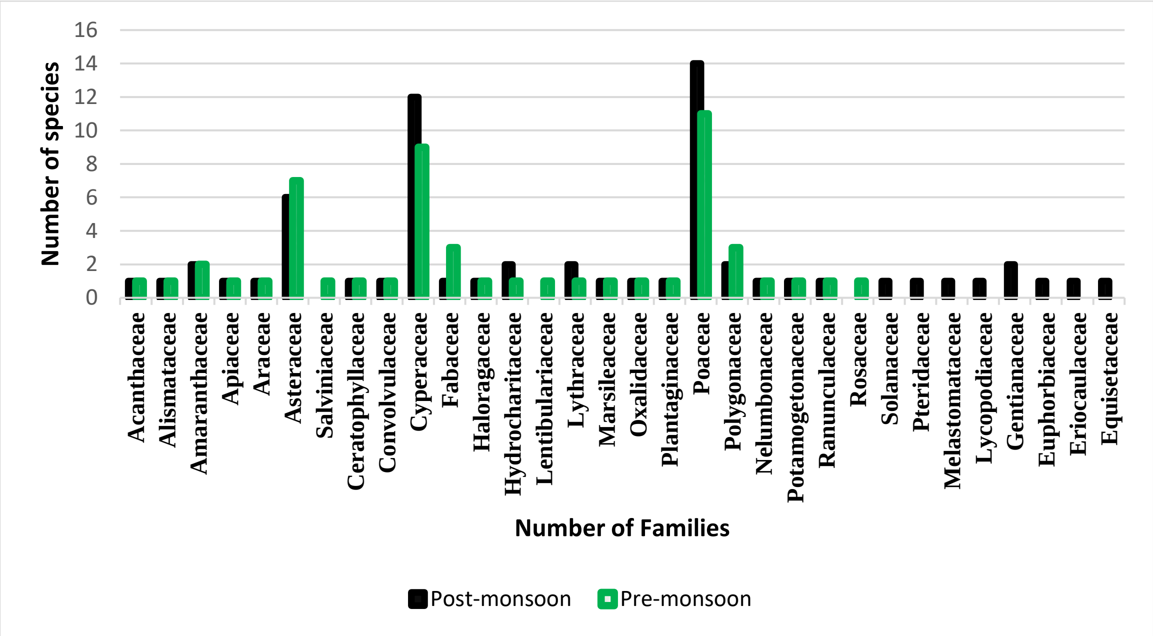


Figure 3: Graph showing families of recorded wetland flora of two seasons

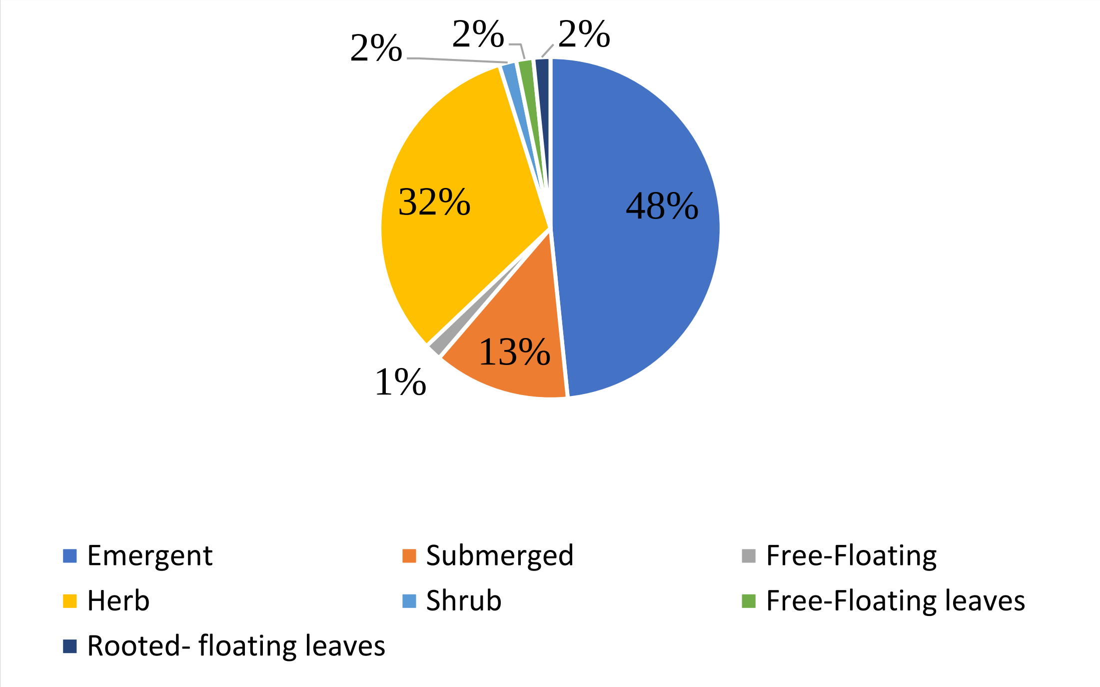


Figure 4: Percentage composition of different growth form of wetland flora during post-monsoon season

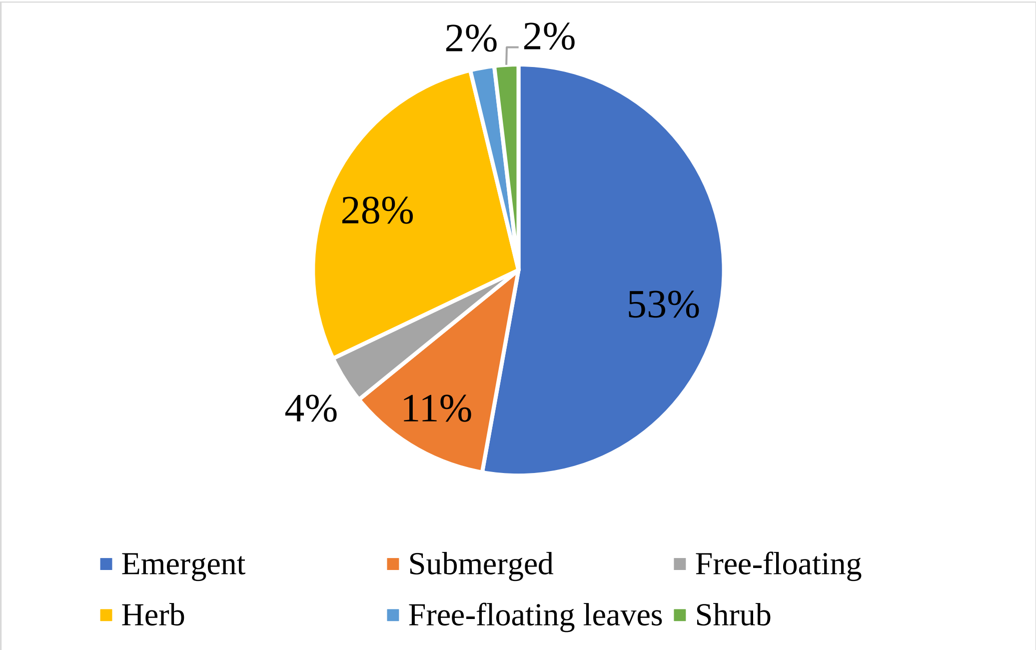


Figure 5: Percentage composition of different growth form of wetland flora during pre-monsoon season

The dominance of species by growth forms on the basis of IVI value is presented in (Appendix 2). Emergent were the most dominant form and free-floating leaves species were the least dominant throughout the seasons. The IVI of the species indicated that the study area was highly dominated by the emergent (159.18) followed by herbs

(86.75), submerged (34.27), free-floating (9.23), rooted-floating leaves (4.00), shrub (1.31) in post-monsoon and emergent (165.75), followed by herbs (78.40), submerged (28.83), free-floating (14.04), free-floating leaves (4.28) in pre-monsoon. Comparatively, in post-monsoon the most frequent species were *Digitaria* (34.37%) followed by *Cyperus difformis*, *Cyperus imbricatus*, *Bothriochloa pertusa* with 28.12% individually, *Kyllinga brevifolia* and *Paspalum distichum* with 21.87%. Other species accounted less than 20% of frequency. The most frequent species recorded in the study area were *Leersia hexandra* (28.12%), followed by *Cynodon dactylon* (28.12%), *Persicaria barbata*, *Pistia stratiotes*, *Imperata cylindrica* with 18.75% during pre-monsoon season. Similarly, the highest density among the species were recorded by *Digitaria* (10.34) followed by *Bothriochloa pertusa* (5.34), *Imperata cylindrica* (3.96), *Leersia hexandra* (3.50), *Pistia stratiotes* (3.40) during post-monsoon and in pre-monsoon the highest density was recorded by *Potamogeton natans* (3.15) followed by *Imperata cylindrica* (2.87), *Cyperus difformis* (2.59), *Pistia stratoites* (2.71). The other species accounted less than those species.

The highest species diversity index (H=3.69) for the entire community was found in the post-monsoon, as compared to the pre-monsoon (H=3.46) (Table 2). The data on evenness calculated for the plant species in study wetland and found to be maximum (J=0.89) in post-monsoon season and minimum in pre-monsoon season (J=0.87).

Table 2: Ecological indices of two seasons

S.N	**Season**	**Shannon-Weiner Index(H)**	**Pielou’s evenness (J)**
1	Post-monsoon	3.69	0.89
2	Pre-monsoon	3.46	0.87

Overall, significant variation was observed in species diversity metrices ($p<0.05$) between two seasons (Table 3).

Table 3: Significant test of species richness and ecological indices between two seasons.

Test variables	**S.E**	**Mann Whitney U test value (z)**	**p-value**
Species-richness	73.791	-3.063	**0.002**
Species-abundance	74.463	-5.969	**0.000**
Shannon - Weiner Index	74.476	-3.290	**0.001**
Simpson's Diversity Index	74.476	-3.309	**0.002**
Evenness	74.476	-2.068	**0.039**

5% Level of significance

Statistical differences in the value of Importance Value Index (IVI) of macrophytes between seasons was also tested. The difference between the seasons were found statistically insignificant in different growth forms. (emergent, p=0.77, submerged, p=0.75, herbs, p=0.92, free-floating, p=0.55, shrub, p=0.98, free-floating leaves, p=0.98 and rooted-floating leaves, p=0.31 and shrub, p= 0.31) (Table 4).

Table 4: Significant test of IVI of different plant species based on growth form between two seasons.

Growth-form	**S.E**	**Mann Whitney U test value (z)**	**p-value**
Emergent	88.52	-0.282	0.77
Submerged	59.55	-0.319	0.75
Herb	82.00	-0.091	0.92
Free-floating	30.74	-0.586	0.55
Shrub	25.27	-0.02	0.98
Free-floating leaves	0.02	-0.02	0.98
Rooted-floating leaves	18.00	-1.00	0.31

4.2 Seasonal fluctuations of physico-chemical parameters

The water samples collected during post-monsoon and pre-monsoon period were analyzed through physico-chemical parameters and the mean value with standard error were calculated (Appendix 3). The temperature value was 17.364 ± 0.202 during post-monsoon season and high value of temperature observed (29.507 ± 0.223) during pre-monsoon season. pH was found to be alkaline in nature during the study period. The high value of pH observed during pre-monsoon season (7.449± 0.107) and lower (7.375 ±0.202) during post-monsoon season. The high value of DO was recorded (7.595 ± 0.105) during post-monsoon season and low (5.801 ± 0.173) during pre-monsoon season. The high value of Total Dissolved Solids was recorded (146.984 ± 2.938) during post-monsoon season and low (135.468 ±2.84) during pre-monsoon season. Likewise, the value of conductivity was recorded 282.439 ± 5.708 during post- monsoon season and the value of conductivity raised (292.000 ± 4.966) during pre-monsoon. The concentration of nitrate value was observed high (0.226 ± 0.017) during post-monsoon season (0.226 ± 0.017) and the concentration value of phosphate was observed high during pre-monsoon season (0.048 ± 0.006) than post- monsoon season (0.047 ± 0.008) (Figure 6).

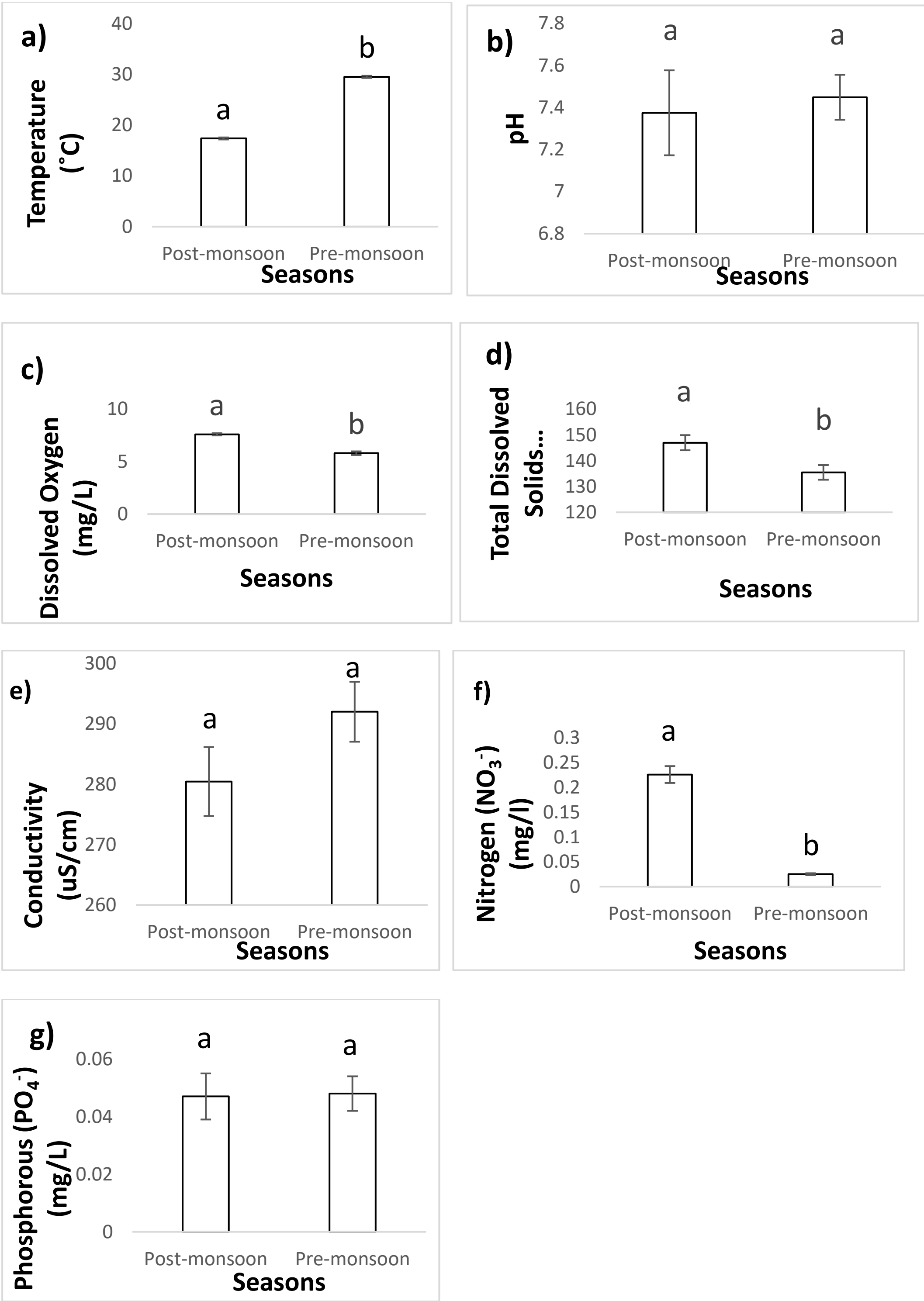


Figure 6: Variation in mean value with standard error of physico-chemical parameters of two seasons a) temperature b) pH c) Dissolved oxygen d) Total Dissolved Solids e) Conductivity f) Nitrogen g) Phosphorous

The following table shows the WQI of lake during two seasons where the estimated WQI of the lake during post-monsoon was 47.10 and during pre-monsoon WQI was 48.52The determination of the Water Quality Index (WQI) was based on the recommended drinking water quality standard set by the World Health Organization (WHO, 2017).

Table 5: Water Quality Index of lake during two seasons

Parameters	**Post- monsoon**			**Pre- monsoon**		
	Wi	**Qi**	**WQI**	**Wi**	**Qi**	**WQI**
pH (pH unit)	0.01	50.	47.10	0.01	59.87	48.52
DO (mg/L)	0.02	72.97		0.02	91.66	
TDS (ppm)	0.00	14.70		0.00	13.55	
Conductivity (uS/cm)	0.00	28.04		0.00	29.20	
NO_3^-(mg/L)	0.01	2.26		0.01	0.25	
PO_4^-(mg/L)	0.96	47		0.96	48	

The test shows that the mean value of Temperature, DO and Nitrate were significantly different in two different seasons with the p -value < 0.05, whereas, the value of pH, conductivity, phosphorous were not significantly different in post-monsoon and pre-monsoon seasons with the p- value > 0.05 (Table 6).

Table 6: Statistical tests of physico-chemical parameters between two seasons.

Parameters	Test	Test-Statistics	p-value
Temperature	Mann-Whitney U	0.000	**0.000**
pH	Mann-Whitney U	384.000	0.086
DO	Mann-Whitney U	48.000	**0.000**
TDS	t-test	2.817	**0.006**
Conductivity	t-test	-1.528	0.132
Nitrate	Mann-Whitney U	0.000	**0.000**
Phosphorous	Mann-Whitney U	434.500	0.294

Spearmann's correlation coefficient were determined among seven physico-chemical parameters of water samples and with species richness (Table 6 and Table 7). For post-monsoon season, species richness exhibited a weak positive correlation with conductivity (r = 0.160), TDS (r = 0.117) and the significant negative relationship with phosphorous (r = -0.447) and weak negative correlation with nitrate (r = -0.215). Temperature showed significantly weak negative correlation with TDS (r= -0.357) and DO (r = -0.354), negative correlation with conductivity (r = -0.282). The correlation coefficients of pH with nitrate (0.380), phosphorous (r = 0.299) were observed positive and significant negative relationship with conductivity (r = -0.541). DO showed weak positive relationship with phosphate (r = 0.226). A significant positive relationship was shown by TDS with conductivity (r = 0.827). Conductivity showed the significant negative correlation with phosphorous (r = -0.360) likewise phosphorous and nitrate were significantly positively correlated (r = 0.636) (Table 7).

Table 7: Relationship between species richness and water parameters through correlation matrix during post-monsoon season.

	Sp.rich	Temp	pH	DO	TDS	Cond	Nitrate	Phos
Sp.rich	1							
Temp	-0.042	1						
pH	-0.092	0.041	1					
DO	0.018	**-0.354**	0.012	1				
TDS	0.117	**-0.357**	**-0.342**	0.027	1			
Cond	0.160	-0.282	**-0.541**	-0.116	**0.827**	1		
Nitrate	-0.215	-0.098	**0.380**	0.212	**0.115**	-0.149	1	
Phos	**-0.447**	0.043	0.299	0.226	-0.222	**-0.360**	**0.636**	1

(Bold: Correlation is significant at $p < 0.05$)

Sp.rich: Species richness, Temp: Temperature, DO: Dissolved Oxygen, TDS: Total Dissolved Solids, Cond: Conductivity, Phos: Phosphorous

For the pre-monsoon season, species richness showed positive correlation with temperature (r = 0.250), pH (r = 0.270), DO (r = 0.253) and weak negative correlation with TDS (r= -0.041), nitrate (r = -0.210) and phosphorous (r= -0.104).

Positive relationship was showed by temperature with phosphorous (r = 0.194) but the significant negative correlation with nitrate (r = -0.431), conductivity (r = -0.396) and insignificant with TDS (-0.318). pH showed a significantly weak positive relationship with TDS (r = 0.478), DO (r = 0.317), phosphorous (r = 0.250) and weak negative relationship with nitrate (r = -0.27). DO showed a significant positive relationship with TDS (r = 0.432) and conductivity (0.390). Similarly, conductivity was significantly positively correlated with nitrate (r = 0.374) (Table 8).

Table 8: Relationship between species richness and water parameters during pre-monsoon season

	Sp.rich	Temp	pH	DO	TDS	Cond	Nitrate	Phos
Sp.rich	1							
Temp	0.250	1						
pH	0.270	-0.108	1					
DO	0.253	-0.055	0.317	1				
TDS	-0.041	-0.318	**0.478**	**0.432**	1			
Cond	0.003	**-0.396**	-0.069	**0.390**	0.125	1		
Nitrate	-0.210	**-0.431**	-0.272	0.182	0.059	**0.374**	1	
Phos	-0.104	0.193	0.250	0.168	-0.072	-0.240	-0.043	1

(Bold: Correlation is significant at p< 0.05)

Sp.rich: Species richness, Temp: Temperature, DO: Dissolved Oxygen, TDS: Total Dissolved Solids, Cond: Conductivity, Phos: Phos

4.3 Multivariate analysis between species distribution and physico-chemical parameters of water

For post-monsoon season, value of CCA showed that the first canonical variate (CCA1) has the highest eigenvalue of 0.545, which explained the most variance among all the canonical variates considered. Likewise, CCA 1, explained 26.2% of the total variation in the data, while CCA 2 explained 18.1% (Appendix 7). The cumulative proportion of variance showed that the first three canonical variates explain 60.1% of the total variation. First canonical variate, CCA1 value showed a significant predictor of the species with the p-value of 0.017, which is less than significance level 0.05 (Appendix 8). The p value of temperature (0.023) and phosphorous (0.016) indicated the significant predictor for species distribution (Appendix 9).

Species abbreviations represent concatenated forms of first three letters of generic name and specific epithet, as presented in (Appendix 1). *Lipocarpha chinensis*, *Ipomoea carnea*, *Persicaria hydropiper*, *Cynodon dactylon*, *Alternanthera sessilis* showed positive affinity with temperature. *Ageratum houstonianum*, *Digitaria* sp. showed positive affinity with nitrate. *Ageratum conyzoides* showed positive affinity with DO.

Panicum sp., *Osbeckia nepalensis* showed positive affinity with nitrate. *Oryza rufipogon*, *Pistia stratoites*, *Paspalum distichum*, *Leersia hexandra*, *Canscora diffusa* showed positive affinity with phosphorous. Species like *Solanum xanthocarpum*, *Chrysopogon aciculatus*, *Cyperus imbricatus*, *Ceratophyllum dermesum* showed strong negative affinity with pH and phosphorous. *Senna occidentalis*, *Grangea maderaspatana*, *Oryza sativa*, *Kyllinga brevifolia*, *Fimbristylis dactylon*, *Schoenoplectus mucronatans*, *Carex filicina* showed strong positive affinity with TDS and conductivity (Figure 7).

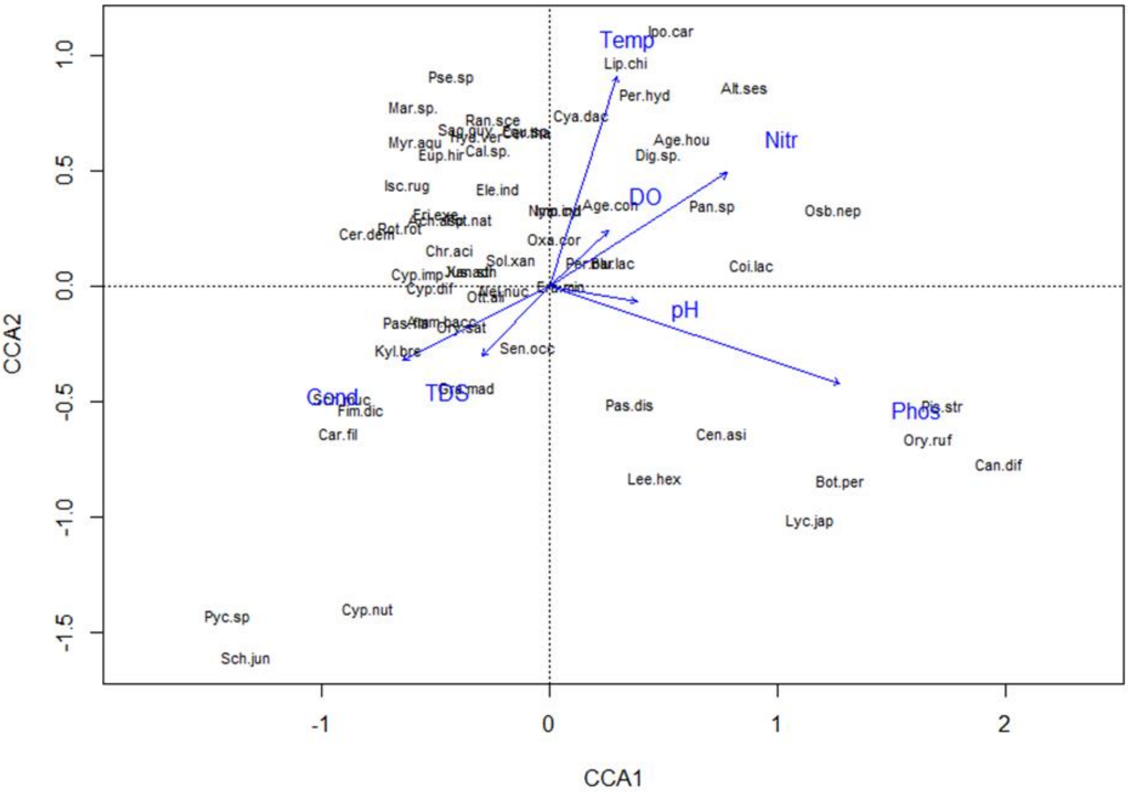


Figure 7: CCA plot of species distribution constrained by environmental variables during post-monsoon season

For pre-monsoon season, the table of CCA showed that the first CCA axis had the highest eigenvalue (0.6199), explaining 25.66% of the total variance. The second CCA axis had an eigenvalue of 0.5303, explaining an additional 21.95% of the variance. Together, the first two CCA explain 47.61% of the variance. The first and second canonical variate, (CCA1 and CCA2) were the significant predictor of the species with the p-value of 0.001 and 0.045 respectively which is less than significance level 0.05.

The ANOVA table showed that the significant predictor is temperature, DO and Phosphorous with p- values 0.017, 0.003 and 0.026 respectively (Appendix 10).

Senna occidentalis, *Mimosa pudica* showed strong positive affinity with temperature. *Pistia stratoites*, *Bothriochola pertusa*, *Vernonia cinera* showed strong positive affinity with phosphorous. *Persicaria hydropiper*, *Ottelia alishmoides*, *Desmodium trifolium* and *Coix lachryma* showed positive affinity with pH and TDS. Likewise, *Ceratophyllum demersum*, *Rumex* sp. showed positive affinity with DO and conductivity. The species of *Cyperus difformis*, *Saggitaria guyanensis*, *Fimbristylis dichotoma*, *Utricularia aurea*, *Marsilea* sp., *Carex filicina*, *Schoenoplectus mucronatans* showed positive affinity with nitrate where *Fragaria nubicola*, *Justicia adhatoda*, *Kyllinga brevifolia*, *Oxalis corniculata*, *Centella asiatica* showed strong negative affinity with pH and TDS (Figure 8).

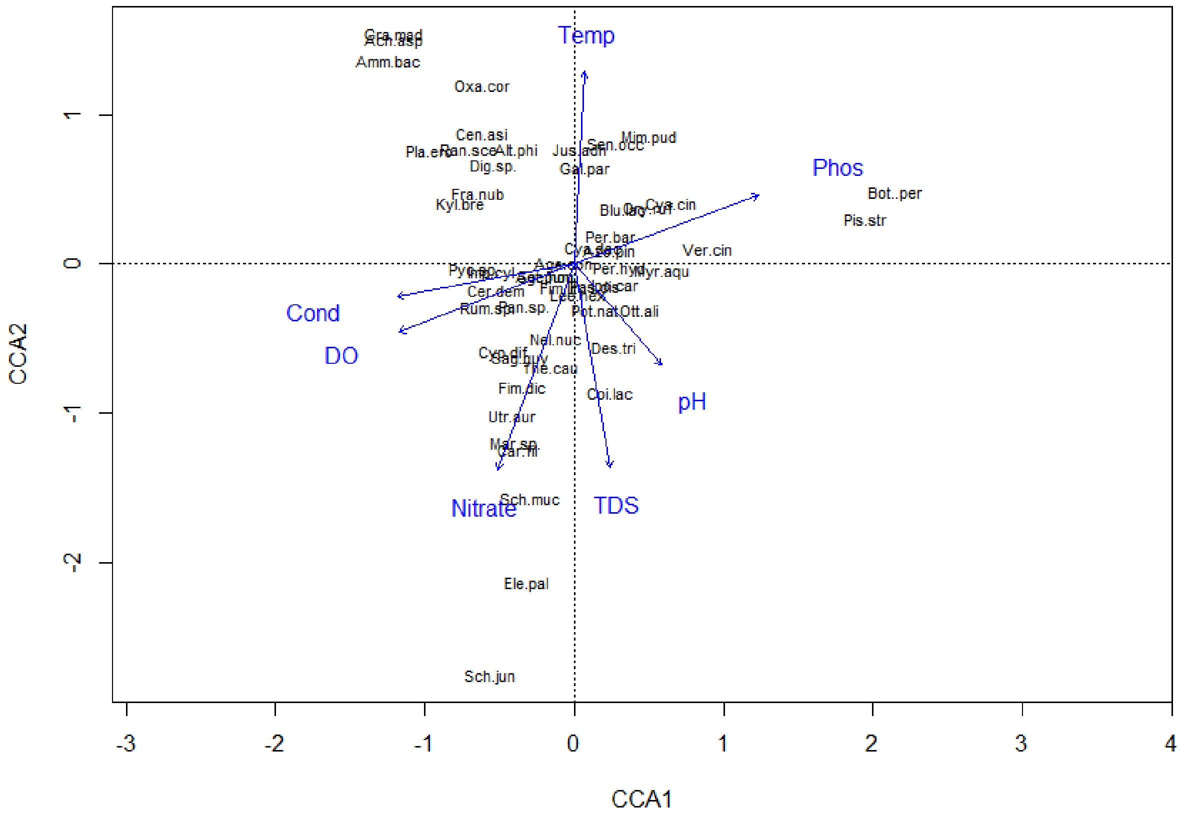


Figure 8: CCA plot of species distribution constrained by environmental variables during pre-monsoon season

CHAPTER 5: DISCUSSION

5.1 Species composition

The community as a whole showed a highest species richness and diversity during post-monsoon compared to pre-monsoon and the result was similar with Kunwar & Devkota (2012) of Rupa lake Kaski, Nepal. Post- monsoon is characterized by increased rainfall, with the increase of water level hence flushing of nutrients from the surrounding landscape may support for ideal growing of macrophyte species (Badra et al., 2022). Yet, nutrition availability is typically only one of numerous factors influencing macrophyte richness (Grimaldo et al., 2016). Aquatic plants could use carbon dioxide and release oxygen throughout photosynthesis effectively during the post-monsoon sunlight than during the pre-monsoon (Manjare et al., 2010). In this study, the ecological indices (species richness, Shannon index, Simpson's index and evenness) showed a significant differences between post monsoon season and pre-monsoon season (t-test, $p< 0.05$) and the result is contractory to Saluja & Garg (2017) in Bhindawas wetland (India). The differences may be attributed to the significant changes in environmental variables that occur during different season (Tamire & Mengistou, 2012).

Estimating the IVI values, it was found that the emergent were dominant followed by herbs, submerged, free-floating, free-floating leaves, rooted-floating leaves and shrubs in both seasons. The IVI of emergent was high in post-monsoon than the pre-monsoon which is similar to the result to Ghosh & Biswas (2015). Although the ecology and life history of the aquatic macrophytes are influenced by the distribution and amount of rainfall but the emergent species are capable of surviving in extreme-tropical conditions (Pereira et al., 2012). As lakes become eutrophic, emergent species tend to grow very densely, while the presence of emergent macrophytes becomes more prominent over that of floating leaf species due to rising of alkalinity levels (Makela et al., 2004).The lake was characterized by the decrease in water level hence the submerged aquatics predominate in the deepest water, floating-leaf type macrophytes prevalent in deeper water, and emergent plant species predominate in shallower water (Reshi et al., 2021).

Among, emergent species, *Digitaria* species was dominant during the post-monsoon season may be due to the ability to grow rapidly in response to favourable moisture conditions and nutrient availabilty where as *Cynodon dactylon* was found dominant during the pre-monsoon season (Ghosh & Kumar, 2015). *Cynodon dactylon*, was primarily found in open, dry, and highly disturbed areas that were also associated with lower water levels (Dinerstein, 1974). Among the submerged species, *Potamogeton natans* showed the dominance during both the season. *Potamogeton natans* are well known for their higher relative growth rate and proven resistance to various abiotic stresses (Devi & Prasad 1998; Bernez et al., 2004). Although only a few floating species was observed in the study area, hence the IVI value of *Pistia stratiotes* indicate invasive nature also preference for hyper-eutrophic and stagnant water preference (Saluja & Garg, 2017). The growth and distribution of species, as well as the presence of pollution- tolerant species, are influenced by the physio-chemical characteristics (Naryana & Someshekar, 2002). Only one species of rooted floating leaved species was observed during post-monsoon but absence in pre-monsoon. In general, the dense proliferation of the rooted floating leaved species may be attributed to their better adaptation to water turbidity (Burlakoti & Karmacharya, 2004). Most of the sites was observed dry and with low level of water hence the high diversity of emergent species and low diversity of free-floating species signifies the increament in species richness at the same level decreases the level of water (Sharma & Singh, 2017).

The species belonging to Poaceae was found the high diversity followed by Cyperaceae and Asteraceae during both seasons (Dongol et al., 2014; Pathak et al., 2020; Ghimire et al., 2022). This may imply that the environment conditions of Pravas were favourable for these families. The dominance of the Asteraceae family may be related to species mostly with light weights, which expedites the seed dispersal mechanism. Most of the species within the family exhibit invasive tendencies, and the herbaceous plants outnumber the shrubby ones (Rastogi et al., 2015).

5.2 Characteristics of physico-chemical parameters during two seasons

The variation of physico-chemical water quality parameter during two seasons were investigated. Relatively more variation in mean values of physio-chemical parameters between the seasons was observed for temperature and DO. The study showed that the mean concentration of temporal variation in temperature, pH, DO and nitrate were significantly different between two seasons. The lower mean temperature values were recorded during post-monsoon (17.66˚C) and higher values during pre-monsoon

(29.50˚C). The trends in value of temperature between the season was consistent with the findings of Loryue et al. (2018). The temperature of the water body was believed to have been infuenced by the intensity of sunlight and change in atmosphere (Kundanger et al., 1996). pH was found to be alkaline in nature in most of the samples as the value of pH was observed acidic in previous studies in the same lake ecosystem (Ghimire, 2016). The value of pH variations in post monsoon (7.37) and pre monsoon (7.44) could be attributed to the precipitation of calcium carboante by planktons (Bastola, 1995) also might be due to the combined impact of temperature, carbon dioxide levels, release of ions, and the water's ability to buffer changes (Chaudhary & Devkota, 2018).

Dissolved Oxygen is one of the most important factor for determining the health of aquatic ecosystem. The DO values showed a significant variations between two seasons as higher during post-monsoon than the pre-monsoon season as that of Rupa Lake, Kaski, Nepal (Kunwar & Devkota, 2012). The optimum value for good water quality to support the aquatic life is 4 to 6mg/l (Burden et al., 2002). The increased level of dissolved oxygen (DO) might be due to the release of oxygen through photosynthesis into the water, and it gradually decreases as the organic matter begins to decompose during the pre-monsoon season (Panigrahi et al., 2007). DO showed a significant negative correlation with temperature during both seasons. Similar result was obtained by Gautam & Bhattarai (2008) in Jagadishpur reservior. The decline in concentration of dissolved oxygen during pre-monsoon might be attributed to increased water temperature, the vigorous decomposition of autochthonous and allochthnous organic matter introduced by inflowing streams, microbial respiration (Badge & Verma, 1985; Kafle, 2000) and high metabolic rate of an organisms (Munawar 1970; Tara et al., 2011; Pathak & Mankodi, 2013).

The significant variation in mean values was observed for TDS as the highest mean value was observed during post- monsoon (146.984 ppm) than pre-monsoon season. The notable escalation in the concentration of ions during post-monsoon might be due stemming from both the leaching of salts from the soil and the influence of anthropogenic activity (Venugopal et al., 2009). Heavy inflow of organic and inorganic fertilizers, pollutants directly or indirectly from the canals and paddy fields may leads to the increasement of TDS during post-monsoon season. Electrical conductivity and TDS were positively correlated during both post-monsoon and pre-monsoon seasons which signified that the conductivity increases as the concentration of all dissolved constituents/ions increases (Batabyal & Chakraborty, 2015). The highest mean value of conductivity during post- monsoon attributed to significant anthropogenic activities such as improper waste disposal, household waste, and the runoff of chemicals from the nearby hospital (Kangabam et al., 2017).

The seasonal variation of nitrate can be related to the volume of drainage (Beck et al., 1985). The increase in nitrate value during the post-monsoon season might be due to the agricultural activity and the massive growth of aquatic macrophytes (Jinwal & Dixit, 2008).The high influx of water resulting from land drainage during the post-monsoon period might lead to elevated nitrate concentrations in the water (Mahmood et al. 2014).The addition of phosphorous and nitrogen to the lake might occured through the draingae from sewage waste and water – run off during the early month of paddy cultivation seasons during post-monsoon (Lodh et al., 2014).

Hence the value of nutrient concentration was very low in comparison to previous study (Ghimire, 2016) as the lake overall showed the oligotrophic status. Water quality index is employed to assess the condition of various attributes of the water table, including the range of the index values and their corresponding status. The estimated WQI value during post-monsoon seasons and pre-monsoon season revealed that the lake was in good conditions throughout the season and also suitable for the growth of aquatic macrophytes (Chatterji & Raziuddin, 2002).

5.3 Influence of seasonal variation in physico-chemical characteristics on wetland flora

The distribution and composition of macrophytes in lakes are influenced by the interactions between various environmental variables such as abiotic, biotic factors (Rolon & Maltchik, 2006; Rolon et al., 2008) and anthropogenic factors (Minggagud & Yang, 2013). The massive growth and distribution of macrophytes in wetlands during post-monsoon season might be influenced by low pH value, high concentration of nitrogen, and high dissolved oxygen levels (Woodcock et al., 2005; La Toya et al., 2013).

During post-monsoon season species like *Lipocarpha chinensis*, *Cynodon dactylon*, *Persicaria hydropiper*, *Digitaria* sp, *Coix lachryma*, *Paspalum distichum* was associated with temperature and concentration of nitrogen (NO_3^-). The low temperature and high concentration of nitrogen favours the distribution of those species. Similarly, *Pistia stratiotes, Paspalum distichum*, *Centella asiatica*, *Oryza rufipogon*, *Leersia hexandra* were positively associated with phosphorous which also suggests that if the phosphate concentrations in the lake surpass a specific threshold, it has the potentail to facilitate the rapid growth and spread of these species.

Ottelia alishmoides, *Oryza sativa*, *Alternanthera sessilis*, *Kyllinga brevifolia*, *Schoenoplectiella juncoides*, *Fimbristylis dichotoma*, *Carex filicina* species were restricted to those sites where there was higher concentration of conductivity and TDS which suggested that these species need or can indicate those nutrient levels (conductivity, TDS) of lake water. Similarly, during pre-monsoon season *Mimosa pudica*, *Blumea laciniata*, *Oryza rufipogon*, *Persicaria barbata*, *Bothriochloa pertusa*, *Pistia stratiotes*, *Vernonia cinera* were positively correlated with temperature and phosphorous which suggests that species have the potential to thrive in environments with elevated nutrient concentrations. *Persicaria hydropiper*, *Myriophyllum aquaticum*, *Ipomoea carnea*, *Potamogeton natans*, *Ottelia alishmoides*, *Desmodium triflorum*, *Coix lachryma* showed positive affinity with pH and TDS. The level of DO and conductivity of water supported the distribution of *Imperata cylindrica*, *Pycerus* sp, *Rumex* sp, *Cyperus difformis*, *Nelumbo nucifera*, *Themeda caudata*, *Sagittaria guyanensis*, *Fimbristylis dichotoma*, *Utricularia aurea*, *Marsilea* sp, *Schoenoplectus mucronatans* species. Overall, each macrophyte was distinctly influenced by environmental factors in different seasons. Even though there were some instances of overlapping effects found in two seasons, the infuencing variables exert their influence on the specific aquatic macrophytes during both seasons. This occurrence may be due to changes in both seasonal factors and the growth patterns of aquatic species during those seasons.

Phosphorous and temperature were the main influencing chemical parameter for the abundance of macrophytes during post-monsoon season. The top parameters temperature, DO and phosphorous exerted a great influence for the macrophyte growth during pre-monsoon season (Saluja & Garg, 2017). The abundance of invasive species were mostly correlated with the Temperature (*Ipomoea carnea*, *Ageratum houstonianum*, *Ageratum conyzoides*). The rise in temperature affects the composition, phenology, abundance, productivity and distribution of the species (Pisaric & Smol, 2005). *Pistia stratiotes* were most invasive species to the lake which was associated with phosphorous. *Pistia stratiotes* exerts a significant influence on reservior metabolism due to its high biomass and rapid decomposition process, which leads to the liberation of phosphorous (Mazzeo et al., 1995). *Pistia stratiotes* might able to absorb and utilize the concentration of those nutrients quickly.

CHAPTER 6: CONCLUSION

The high species diversity was observed during post-monsoon. Altogether 63 species was found during post- monsoon season and 53 found during pre-monsoon season. The abundance and distribution of macrophytes in a wetland ecosystem were influenced by various environmental factors such as rainfall, nutrient availability, sunlight and physico-chemical parameters of the water. The post-monsoon season was found to be more favourable for macrophyte growth due to the increased nutrients.

The dominancy of species belonging to Poaceae, Cypaeraceae and Asteraceae family showed during both the seasons. Emergent species were found to be dominant in both seasons, with *Digitaria* species being dominant during the post-monsoon and *Cynodon dactylon* during the pre-monsoon season. The prevalence of emergents, the most prolific communities of macrophytes in the lake indicated that the lake is evolving at rapid pace, indicating an escalation in increasing productivity of the lake ecosystems.

The physico-chemical parameters of the water also varied significantly between the two seasons,with temperature and dissolved oxygen showing the highest variation. The temperature and phosphorous were the main predictors during post-monsoon season and in addition Dissolved oxygen were the main predictors during pre-monsoon season determining the of distribution of species.

Similarly, increased invasive species abundance affects water quality by exploiting nutrients and blocking light penetration, making it unsuitable for the growth of other, notably native macrophytes, creating major ecological impact in wetlands by endangering biodiversity and sustainability.

The findings highlight the importance of nutrient levels for the distribution of species. The monitoring and management of wetland ecosystems is necessity to ensure the conservation and sustainable use of macrophytes and their associated biodiversity. This study may be used as a baseline for future work, particularly in the context of the ecosystem services, sustainable wetland monitoring and conversation programmers.

CHAPTER 7: RECOMMENDATIONS

- Consistent and periodic assessment of physico-chemical parameters of water should be conducted.
- The invasive species from the wetland should strictly be removed to maintain the ecological integrity.
- The anthropogenic effect should be monitored.

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APPENDICES

Appendix 1

List of wetland flora of Pravas wetland

Name of plant species	Family	Abbreviation
Achyranthes aspera L.	Amaranthaceae	Ach.asp
Ageratum conyzoides L.	Asteraceae	Age.con
Ageratum houstonianum Mill.	Asteraceae	Age.hou
Alternanthera sessilis (L.) DC.	Amaranthaceae	Alt.ses
Ammannia baccifera L.	Lythraceae	Amm.bac
Azolla pinnata subsp. *asiatica* R.M.K. Saunders & K. Fowler	Salviniaceae	Azo.pin
Blumea laciniata (Roxb.) DC.	Asteraceae	Blu.lac
Bothriochloa pertusa Linn.	Poaceae	Bot.per
Callitriche sp.	Plantaginaceae	Cal.sp
Canscora diffusa (Vahl) R. Brown	Gentianaceae	Can.dif
Carex filicina Nees	Cyperaceae	Car.fil
Centella asiatica (L.) Urban	Apiaceae	Cen.asi
Ceratophyllum demersum L.	Ceratophyllaceae	Cer.dem
Ceratopteris thalictroides (L.) Brongn.	Pteridaceae	Cer.tha
Chrysopogon aciculatus (Retz.) Trin.	Cyperaceae	Chr.aci
Coix lachryma L.	Poaceae	Coi.lac
Cyanthillium cinereum (L) H.Rob.	Asteraceae	Cya.cin
Cynodon dactylon (L.) Pers.	Poaceae	Cyn.dac
Cyperus difformis L.	Cyperaceae	Cyp.dif
Cyperus imbricatus Retz.	Cyperaceae	Cyp.imb
Cyperus nutans Vahl.	Cyperaceae	Cyp.nut
Desmodium triflorum (L.) DC.	Fabaceae	Des.tri
Digitaria sp.	Poaceae	Dig.sp
Eleocharis palustris (L.)	Cyperaceae	Ele.pal
Eleusine indica (L.) Gaertn.	Poaceae	Ele.ind
Equisetum sp.	Equisetaceae	Equ.sp.
Eragrostis minor (Host) Kuntze	Poaceae	Era.min

Name of plant species	**Family**	**Abbreviation**
Eriocaulon exertum L.	Eriocaulaceae	Eri.exe
Euphorbia hirtra L.	Euphorbiaceae	Eup.hir
Fimbristylis dichotoma (L.) Vahl	Cyperaceae	Fim.dic
Fimbristylis littoralis Gaudich.	Cyperaceae	Fim.lit
Fragaria nubicola (Hook.f.) Lindl.	Rosaceae	Fra.nub
Galinsoga parviflora Cav.	Asteraceae	Gal.par
Grangea maderaspatana (L.) Poir.	Asteraceae	Gra.med
Hydrilla verticillata (L.f.) Royle	Hydrocharitaceae	Hyr.ver
Imperata cylindrica (L.) Raeusch.	Poaceae	Imp.cyl
Ipomoea carnea subsp. *fistulosa*	Convolvulaceae	Ipo.car
Ischaemum rugosum Salisb.	Poaceae	Isc.rug
Justicia adhatoda L.	Acanthaceae	Jus.adh
Kyllinga brevifolia Rottb.	Cyperaceae	Kyl.bre
Leersia hexandra Swartz	Poaceae	Lee.hex
Lipocarpha chinensis (Osbeck) Kern	Cyperaceae	Lip.chi
Lycopodium japonicum Thunb.	Lycopodiaceae	Lyc.jap
Marsilea sp.	Marsileaceae	Mar.sp
Mimosa pudica L.	Fabaceae	Mim.pud
Myriophyllum aquaticum (Vell.) Verdc.	Haloragaceae	Myr.aqu
Nelumbo nucifera Gaertn.	Nelumbonaceae	Nel.nuc
Nymphoides indica (L.) Kuntze	Gentianaceae	Nym.ind
Oryza sativa L. subsp. rufipogon (Griffith)	Poaceae	Ory.ruf
Oryza sativa L.	Poaceae	Ory.sat
Osbeckia nepalensis Hook. f.	Melastomataceae	Osb.nep
Ottelia alismoides (L.) Pers.	Hydrocharitaceae	Ott.ali
Oxalis corniculata L.	Oxalidaceae	Oxa.cor
Panicum sp	Poaceae	Pan.sp
Paspalum distichum L.	Poaceae	Pas.dis
Paspalum flavidium (Retz)A.Camus	Poaceae	Pas.fla
Persicaria barbata (L.) H.Hara	Polygonaceae	Per.bar
Persicaria hydropiper (L.) Delarbre	Polygonaceae	Per.hyd

Name of plant species	**Family**	**Abbreviation**
Pistia stratiotes L.	Araceae	Pis.str
Platango major L.	Plantaginaceae	Pla.ero
Potamogeton natans L.	Potamogetonaceae	Pot.nat
Pseudognaphalium sp	Asteraceae	Pse.sp
Pycerus sp	Cyperaceae	Pyc.sp
Ranunculus sceleratus L.	Ranunculaceae	Ran.sce
Rotala rotundifolia (Buch. -Ham. ex Roxb.) Koehne	Lythraceae	Rot.rot
Rumex sp.	Polygonaceae	Rum.sp
Sagittaria guyanensis Kunth.	Alismataceae	Sag.guy
Schoenoplectiella juncoides (Roxb.) Lye	Cyperaceae	Sch.jun
Schoenoplectus mucronatus (L.) palla	Cyperaceae	Sch.muc
Senna occidentalis (L.) Link	Fabaceae	Sen.occ
Setaria pumila (Poir.) Roem. & Schult.	Poaceae	Set.pum
Solanum xanthocarpum Schrad. & Wendl.	Solanaceae	Sol.xan
Themeda caudata (Nees) A. Camus	Poaceae	The.cau
Utricularia aurea Lour.	Lentibulariaceae	Utr.aur
Vernonia cinera L.	Asteraceae	Ver.cin
Xanthium strumarium L.	Asteraceae	Xan.str

Appendix 2

Importance value index (IVI) during post-monsoon and pre-monsoon season

Seasons	Post-monsoon				Pre-monsoon			
Name of species	**RD**	**RF**	**RA**	**IVI**	**RD**	**RF**	**RA**	**IVI**
A	**Emergent**							
Achyranthes aspera	0.596	1.694	0.649	2.940	1.038	2.247	2.370	5.655
Alternanthera sessilis	1.258	1.271	1.827	4.357	2.975	3.370	1.240	7.587
Carex filicina	1.721	2.118	1.500	5.341	0.968	0.561	0.635	2.165
Ceratopteris thalictroides	0.298	0.423	1.298	2.020	0	0	0	0
Coix lachryma	0.231	0.847	0.505	1.584	0.207	0.561	2.963	3.732
Cynodon dactylon	1.754	2.118	1.529	5.403	9.826	5.056	0.563	15.446
Cyperus difformis	3.509	3.813	1.699	9.023	5.743	4.494	0.856	11.095
Cyperus imbricatus	2.847	3.813	1.378	8.040	0	0	0	0
Cyperus nutans	2.152	2.118	1.876	6.147	0	0	0	0
Digitaria sp.	10.960	4.661	4.342	19.963	5.813	4.494	0.846	11.154
Eleocharis palustris	0	0	0	0	2.214	1.123	0.555	3.893
Euphorbia hirtra	0.927	1.694	1.010	3.632	0	0	0	0
Fimbristylis dichotoma	2.781	2.542	2.020	7.344	0.761	1.123	1.616	3.501
Fimbristylis littoralis	0	0	0	0	0.484	1.123	2.540	4.148
Imperata cylindrica	4.205	2.118	3.665	9.989	6.366	3.370	0.579	10.317
Ipomoea carnea	0.231	1.694	0.252	2.179	0.484	2.247	5.080	7.811
Kyllinga brevifolia	3.443	2.966	2.144	8.553	0.553	1.123	2.222	3.899
Leersia hexandra	3.708	2.118	3.232	9.059	8.166	5.056	0.678	13.900
Mimosa pudica	0	0	0	0	0.138	0.561	4.445	5.145
Oryza rufipogon	1.357	1.694	1.479	4.531	0.761	1.123	1.616	3.501
Oryza sativa	0.662	1.694	0.721	3.078	0	0	0	0
Oxalis corniculata	0.993	1.271	1.443	3.707	1.038	2.247	2.370	5.655
Panicum sp	2.516	1.694	2.741	6.953	1.176	1.685	1.568	4.430
Paspalum distichum	2.019	2.966	1.257	6.243	0.553	1.685	3.333	5.572

Seasons	Post-monsoon				Pre-monsoon			
Name of species	**RD**	**RF**	**RA**	**IVI**	**RD**	**RF**	**RA**	**IVI**
Paspalum flavidium	1.026	2.118	0.894	4.039	0	0	0	0
Persicaria barbata	1.920	2.542	1.395	5.857	2.768	3.370	1.333	7.472
Persicaria hydropiper	1.688	1.694	1.839	5.223	1.799	2.247	1.367	5.414
Pycerus sp	0.562	0.847	1.226	2.637	0.899	1.123	1.367	3.390
Ranunculus sceleratus	2.748	2.966	1.711	7.425	2.214	4.494	2.222	8.931
Schoenoplectiella juncoides	2.086	1.271	3.030	6.387	0.830	0.561	0.740	2.133
Schoenoplectus mucronatans	2.947	1.694	3.210	7.852	2.283	1.685	0.808	4.777
Senna occidentalis	0.066	0.423	0.288	0.778	0.138	0.561	4.445	5.145
Setaria pumila	0	0	0	0	0.415	0.561	1.481	2.458
Themeda caudata	0	0	0	0	0.899	2.247	2.735	5.882
Xanthium strumarium	0.033	0.423	0.144	0.601	0	0	0	0
B	**Submerged**							
Callitriche sp.	1.192	1.271	1.731	4.194	0	0	0	0
Ceratophyllum demersum	0.794	0.847	1.731	3.373	0.692	0.561	0.889	2.142
Hydrilla verticillata	1.721	0.847	3.752	6.321	0	0	0	0
Marsilea sp.	1.125	0.847	2.453	4.426	0.968	1.123	1.270	3.362
Myriophyllum aquaticum	0.298	0.423	1.298	2.020	0.346	0.561	1.778	2.685
Ottelia alishmoides	0.894	1.271	1.298	3.464	1.314	1.123	0.935	3.374
Potamogeton natans	3.907	2.118	3.405	9.431	6.989	2.808	0.440	10.238
Rotala rotundifolia	2.019	1.271	2.934	6.225	0	0	0	0
Sagittaria guyanensis	0.728	1.271	1.058	3.057	1.937	1.685	0.952	4.575
Utricularia aurea	0	0	0	0	0.138	0.561	4.445	5.145
C	**Free-floating**							
Azolla pinnata	0	0	0	0	1.314	1.685	1.403	4.404
Pistia stratiotes	3.609	1.694	3.932	9.236	6.020	3.370	0.613	10.004

Seasons	Post-monsoon				Pre-monsoon			
Name of species	**RD**	**RF**	**RA**	**IVI**	**RD**	**RF**	**RA**	**IVI**
D	**Free- floating leaves**							
Nelumbo nucifera	1.158	2.118	1.010	4.287	1.384	3.370	2.667	7.421
E	**Rooted- floating leaves**							
Nymphoides indica	0.993	0.847	2.164	4.005	0	0	0	0
F	**Herb**							
Ageratum conyzoides	0.463	1.694	0.505	2.663	0.761	2.247	3.232	6.241
Ageratum houstonianum	0.430	0.847	0.938	2.215	0.207	0.561	2.963	3.732
Ammannia baccifera	0.629	1.271	0.913	2.814	2.352	2.808	1.307	6.469
Blumea laciniata	0.331	0.847	0.721	1.900	0.276	1.123	4.445	5.845
Bothriochloa pertusa	5.662	3.813	2.741	12.217	3.875	1.123	0.317	5.316
Canscora diffusa	0.463	0.847	1.010	2.321	0	0	0	0
Centella asiatica	0.761	1.271	1.106	3.139	1.660	2.247	1.481	5.389
Chrysopogon aciculatus	3.145	2.966	1.958	8.070	0	0	0	0
Cyanthillium cinereum	0	0	0	0	0.415	1.123	2.963	4.502
Desmodium triflorum	0	0	0	0	1.176	1.123	1.045	3.345
Eleusine indica	0.927	1.271	1.346	3.545	0	0	0	0
Equisetum sp.	0.264	0.423	1.154	1.843	0	0	0	0
Eragrostis minor	0.629	1.271	0.913	2.814	0	0	0	0
Eriocaulon exertum	2.086	2.542	1.515	6.143	0	0	0	0
Fragaria nubicola	0	0	0		1.384	2.808	2.222	6.415
Galinsoga parviflora	0	0	0	0	1.107	1.685	1.666	4.459
Grangea maderaspatana	0.960	0.847	2.092	3.900	1.522	2.247	1.616	5.386
Ischaemum rugosum	1.721	1.694	1.876	5.292	0	0	0	0
Lipocarpha chinensis	0.198	0.847	0.432	1.479	0	0	0	0
Lycopodium japonicum	0.099	0.423	0.432	0.956	0	0	0	0
Osbeckia nepalensis	0.463	0.423	2.020	2.907	0	0	0	0
Platango erosa	0	0	0	0	0.484	0.561	1.270	2.316

Seasons	**Post-monsoon**				**Pre-monsoon**			
Name of species	**RD**	**RF**	**RA**	**IVI**	**RD**	**RF**	**RA**	**IVI**
Pseudognaphalium sp	1.092	1.271	1.587	3.951	0	0	0	0
Rumex sp.	0	0	0	0	0.899	1.685	2.051	4.636
Solanum x*anthocarpum*	0.099	0.847	0.216	1.163	0	0	0	0
Vernonia cinera	0	0	0	0	1.245	1.123	0.987	3.357
G	**Shrub**							
Justicia adhatoda	0.165	0.423	0.721	1.310	0.138	0.561	4.445	5.145

Appendix 3

Descriptive statistics of physico-chemical parameters of water

Physio-chemical parameters	**Post-monsoon (Mean±SE)**	**Pre-monsoon (Mean±SE)**
Temperature(˚C)	17.364±0.202	29.507±0.223
pH (pH unit)	7.375±0.202	7.449±0.107
DO (mg//L)	7.595±0.105	5.801±0.173
TDS (ppm)	146.984±2.938	135.468±2.84
Conductivity (uS/cm)	280.439±5.708	292.000±4.966
Nitrogen (NO_3^-) (mg/L)	0.226±0.017	0.025±0.002
Phosphorous (PO_4^-) (mg/L)	0.047±0.008	0.048±0.006

Appendix 4

Water Quality Index (WQI) and status of water quality (Chatterji & Raziuddin, 2002)

WQI Value	**Rating of water quality**
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very-poor
Above	Unsuitable

Appendix 5

Normality of data distribution of Species richness and diversity metrices test by using SPSS statistics.

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Species-richness	.100	64	.184	.950	64	.011
Species-abundance	.146	64	.002	.927	64	.001
Shannon	.146	64	.002	.950	64	.011
Simpson	.199	64	.000	.820	64	.000
Evenness	.147	64	.002	.912	64	.000
a. Lilliefors Significance Correction						

Appendix 6

Normality of data distribution of physio-chemical characteristics by using SPSS statistics

Tests of Normality						
	Kolmogorov-Smirnov[a]			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Temp	.241	64	.000	.799	64	.000
pH	.107	64	.068	.928	64	.001
DO	.127	64	.012	.919	64	.000
TDS	.098	64	.200*	.969	64	.112
Cond	.077	64	.200*	.985	64	.611
Nitrate	.215	64	.000	.842	64	.000
Phos	.191	64	.000	.844	64	.000
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

Appendix 7

DCA ordination summary (length of axis, eigen values and total inertia)

Seasons	Length of axis		Eigen values		Total inertia
	1	2	1	2	
Post-monsoon	4.502	3.487	0.675	0.544	6.603
Pre-monsoon	7.449	4.452	0.619	0.530	8.950

Appendix 8

CCA ordination summary (Eigen value, total variance)

	Post-monsoon			Pre-monsoon		
	CCA1	CCA2	CCA3	CCA1	CCA2	CCA3
Eigen value	0.545	0.376	0.329	0.619	0.530	0.402
Proportion Explained	0.262	0.180	0.158	0.256	0.219	0.166
Cumulative Proportional	0.262	0.442	0.601	0.256	0.476	0.642

Appendix 9

Ordination summary forward tests for axes

Axis	Post-monsoon		Pre-monsoon	
	F	Pr(>F)	F	Pr(>F)
CCA1	2.392	0.008 **	2.291	0.002***
CCA2	1.619	0.53	1.961	0.044*
CCA3	1.513	0.539	1.491	0.555
CCA4	1.347	0.656	1.203	0.902
CCA5	1.127	0.843	0.884	0.993
CCA6	0.627	0.996	0.678	0.998
CCA7	0.401	0.996	0.452	0.998

Appendix 10

Ordination summary on Relative importance of Water Characteristics on Macrophyte composition analyzed based on CCA analysis.

Water parameters	Abbreviations	Post-monsoon		Pre-monsoon	
		F	Sig.(*p*)	F	Sig.(*p*)
Temperature	Temp	1.507	0.023*	1.457	0.017*
pH	pH	0.970	0.522	1.170	0.170
Dissolved oxygen	DO	1.327	0.084	1.707	0.003**
Total Dissolved Solids	TDS	1.148	0.261	1.138	0.222
Conductivity	Cond	1.080	0.325	0.911	0.636
Nitrogen as Nitrate	Nitrate	1.397	0.051	1.044	0.372
Phosphorous as phosphate	Phos	1.598	0.016*	1.442	0.026*

PHOTO TEMPLATES

Pistia stratriotes in the study area

Potamogeton natans

DO measuring in the lake

Herbarium preparation (submerged species)

Hospital sewage drained to the lake

Water sample testing

Species identification at TUCH

Oryzar rufipogon flowering