Bulletin of Pure and Applied Sciences
Zoology (Animal Science), Vol.43B, No.2S,
July-December 2024: P. 419-431

Print version ISSN 0970-0765
Online version ISSN 2320-3188

Original Research Article

Content Available online at: www.bpasjournals.com

PHYSICOCHEMISTRY AND CARBON CONTENT OF THE LOKTAK LAKE AND KEIBUL LAMJAO NATIONAL PARK: A RENOWNED RAMSAR SITE OF MANIPUR, INDIA

Akoijam Caroline, V Yuringwon Zimik, Kshetrimayum Birla Singh*, Thingbaijam Binoy Singh*

Department of Life Sciences (Zoology),
Manipur University, Canchipur-795003, Manipur, India

ABSTRACT

Despite their limited geographic extent, wetlands possess a remarkable capacity to sequester carbon from the atmosphere, storing it in vegetation, sediments, and phytoplankton. The hydrology of the water also exerts a significant influence on the vegetation of the wetland. To our knowledge, research on the relationship between water physicochemical characteristics and the carbon content of macrophytes in Loktak Lake and Keibul Lamjao National Park remains scarce. In this study, seven physicochemical parameters of water, and the carbon content in macrophytes, were analysed across seven sampling sites: four located in Loktak Lake and three in Keibul Lamjao National Park (KLNP). The result of the study reveals that dissolved oxygen (DO), turbidity, and carbon content in macrophytes, exhibited significant differences between Loktak Lake and KLNP ($p< 0.05$). Contrary, no significant differences were observed in pH, total dissolved solids, conductivity, temperature, and salinity between the two study sites ($p > 0.05$). In Loktak Lake, the Water Quality Index (WQI) ranged from 51.76 to 62.79, indicating poor water quality. In contrast, KLNP's WQI ranged from 28.29 to 36.95, suggesting good water quality. The average carbon content was 577.38 ± 58.84 g C m^{-2} in Loktak Lake and 1442.43 ± 276.85 g C m^{-2} in Keibul Lamjao National Park (KLNP), with peak values observed during the monsoon and post-monsoon seasons in both locations. Our studies have revealed that the water quality of Loktak Lake is progressively declining, which poses a significant threat to the carbon sequestration capacity of the macrophytes. If wetlands are not adequately conserved and managed, they may become carbon sources, releasing the carbon they have accumulated over extended periods.

KEYWORDS

Water quality, Carbon Sequestration, Macrophytes, Loktak Lake.

Introduction

Wetlands are recognised as the most vital ecosystems on Earth. They support rich biodiversity and play a critical role in the environment by offering a unique habitat for a diverse array of flora and fauna [1]. Wetlands constitute approximately 5-8% of the Earth's geographical area [1]. Due to their anoxic, waterlogged conditions, wetlands represent optimal natural environments for the sequestration and storage of atmospheric carbon [2]. The hydrology of the water significantly influences the vegetation of the wetland and plants, which in turn can also serve as an indicator of the quality of water [3].

Loktak Lake, a Wetland of International Importance under the Ramsar Convention [4], represents the largest freshwater lake in Northeast India, encompassing an area of approximately 287km^2, which is predominantly regulated by the maintenance of the water level at Ithai, which is maintained at 768.5 meters above mean sea level (LDA), destructing the natural regime of the lake [5,6,7]. The presence of floating mats of vegetation, locally known as *Phumdi*, is a defining characteristic of the study area. *Phumdi* consists of a heterogeneous mixture of soil, vegetation, and organic matter, characterised by varying levels of decomposition. The formation of *Phumdi* initiates with the accumulation of intact organic matter or the proliferation of water hyacinth. Over time, this accumulation traps suspended silt and herbaceous vegetation gradually establishes itself [8]. The southern part of the Lake, which harbours the thick *phumdis*, is the Keibul Lamjao National Park (KLNP), safeguarded for the critically endangered Brow-antlered deer, *Rucervus eldii eldii*, locally known by Sangai [6,7,9].

Wetland macrophytes play a crucial role in carbon sequestration by capturing substantial amounts of atmospheric CO_2 during their lifetimes and continuing to contribute organic carbon to the soil and water after their death and decomposition. These macrophytes are responsible for the production of all organic carbon deposited in the wetland soils [10]. Wetlands sequester atmospheric carbon via sediment deposition and plant biomass production [11]. Macrophytes serve as an important carbon pool in wetlands due to their high productivity, making them among the most productive communities on Earth [12], enhancing the carbon sequestration capacity of wetland ecosystems [10]. Aquatic macrophytes, across various growth forms, are an essential biotic component of the littoral zone in lake ecosystems. Their significant ecological roles are closely associated with their distribution and biomass, which are influenced by a complex interplay of environmental factors [35]. The study aims to evaluate the status of the physicochemical parameters of water and its effect on the carbon sequestration potential of macrophytes in Loktak Lake and Keibul Lamjao National Park.

Materials and Methods

Description of Study Site

Loktak Lake, the largest freshwater lake in Northeast India, is situated in the Bishnupur district of Manipur, spanning longitudes 93° 46' E to 93° 55' E and latitudes 24° 25' N to 24° 42' N. LoktakLake is designated as the Ramsar Wetland of International Importance. The lake is oval in shape, stretching 32 km in length to 13 km in width, with an average depth of 2.7 m (LDA) [27]. Keibul Lamjao National Park (KLNP) is situated in the southern region of Loktak Lake, extending from longitudes 93°48' E to 93°52' E and latitudes 24°26' N to 24°32' N. The Park is renowned for its efforts in the conservation of the critically endangered Brow-antlered deer., *Rucervus eldii eldii*, locally known by Sangai. The Park encompasses an area of 40 km^2, with approximately 26.41 km^2 covered by dense and almost contiguous mats of Phumdi. The Park covers an area of 40 km^2, of which 26.41 km^2 is covered by dense and almost contiguous mats of Phumdi [28].

Physiochemical parameters of water

To assess the physicochemical parameters of water, samples were collected monthly from selected sites of Loktak Lake and Keibul Lamjao National Park (KLNP) (Fig.1), spanning from February 2022 to January 2023 for one year. Samples were collected during morning hours from 6:30 to 11:30 am. Altogether seven parameters were measured. The parameters measured included salinity, temperature, pH, total dissolved solids (TDS), conductivity, and turbidity (NTU), which were recorded on-site using a Systronic Water Analyser 371 Sr. No. 106g. Dissolved Oxygen (DO) levels were estimated by following the Winkler's method, as outlined by the American Public Health Association (APHA, 1998). Vegetation biomass

To determine vegetation biomass, a short-term harvest method was employed using a quadrat with dimensions of 50 × 50 cm^2 [9]. Vegetation within each quadrat was harvested, placed in appropriately labelled polyethylene bags, and brought to the laboratory for further analysis. In the lab, the materials were weighed to determine the wet biomass and subsequently oven-dried at 80ºC until a constant weight was attained to ascertain the dry biomass [10, 13]

For the assessment of below-ground biomass, a monolith of 15 × 15 cm^2 (*Phumdi*) was extracted from within the same quadrat. The collected samples were soaked and washed with water using a 1 mm mesh sieve to isolate the roots. The isolated roots were then oven-dried following the same procedure to determine the dry biomass of the below-ground components [10,14]. The dry biomass of both the aboveground and below-ground components of the plant body was quantified. The dry biomass is assumed to contain 50% carbon [10, 15].

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistic 21 Software. The relationship between the physiochemical parameters of the study sites was assessed using Pearson Correlation Analyses. An independent sample t-test was employed to assess the variations in carbon content and water parameters between the two study sites.

The Water Quality Index (WQI) was computed based on the drinking water quality standards set by the World Health Organization (WHO) and the Bureau of Indian Standards (BIS) [27]. The Water Quality Index (WQI) was calculated by following the weighted arithmetic index method as outlined by Brown et al. (1972) [16].

WQI was calculated from the equation given below:

$$WQI = \sum QnWn / \sum Wn$$

Qn= Quality rating

Wn= Unit weight

n= number of parameters

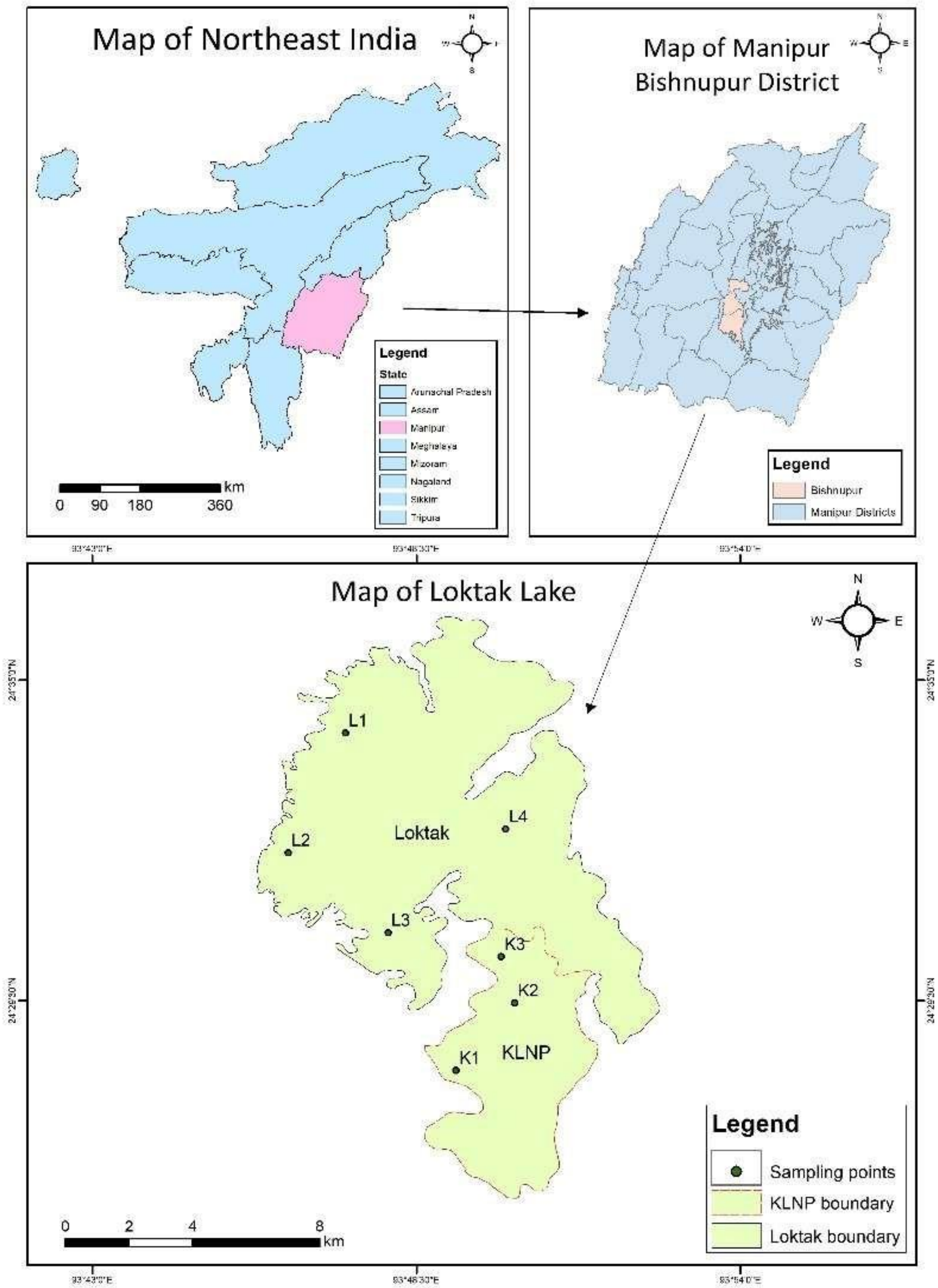

Figure 1: Outline map of Loktak Lake and Keibul Lamjao National Park, showing the sampling points.

*L-1, L-2, L3 and L-4: Sampling points of Loktak Lake and K-1, K-2 and K-3: Sampling points of KLNP

Results

The physicochemical parameters of water in both study areas are shown in Table 1, which displays the maximum value, minimum value, and Mean± Standard Error. The pH ranged from 8.92 ± 0.33 to 9.42 ± 0.03 in Loktak Lake, with the lowest value recorded at site L-4 and the highest at site L-3.

Regarding KLNP, the pH ranged from 8.31±0.55 to 8.75±0.46, with the lowest and the highest values recorded in K-1 and K-2, respectively. A minimum DO of6.46±0.43mg/l was observed in L-1 and a maximum DO of level of 7.46±0.35 mg/l was recorded in L-2 of Loktak Lake. In KLNP, the DO level ranged from 4.96±0.39 mg/l in K-1 to 5.55±0.24 mg/l in K-3.

TDS in Loktak Lake ranged from 70.37±3.51ppm in L-2 to 87.54±5.8ppm in L-3. TDS in KLNP ranged from a minimum of 71.59±1.95 ppm in K-2 to 76.6±2.92 ppm in K-3. The conductivity in Loktak Lake ranged from 115.04±5.47 µS/cm in L-2 to the highest of 145.41±6.64 µS/cm in L-3. In KLNP, the lowest reading of conductivity was observed in K-2 with 128.83±2.27 µS/cm and highest in K-1 with 141.41±6.48 µS/cm. The water temperature in Loktak Lake ranged from 23.83±1.45 ℃ to 25.04±1.62 ℃ in L-1 and L-4, respectively. The water temperature ranged from 19.5±1.23 ℃ in K-3 to 25.43±1.33 ℃ in K1, in KLNP. Turbidity in Loktak Lake ranged from 6.96±1.14 NTU in L-4 to 12.55±1.1 NTU in L-2. The turbidity in KLNP ranged from 3.68±0.33 NTU in K-2 to 4.61±0.44 NTU in K-1. A minimum salinity concentration was recorded in L-2 with 0.06±0.003 ppt to 0.08±0.003 ppt in L-3, in Loktak Lake. In KLNP, the salinity ranged from 0.07±0.001 ppt in K-3 to 0.08±0.003 ppt in K-2.

The water parameters, such as dissolved oxygen (DO), and turbidity, along with carbon content in macrophytes between Loktak Lake and KLNP were significantly different ($p < 0.05$). In contrast, no significant difference ($p > 0.05$) was detected in pH, total dissolved solids, conductivity, temperature, and salinity at the two study sites as shown in Table 2.

The Pearson correlation matrix of the mean of the water parameters for each study site was evaluated to assess the relationship between the sampling points (L-1, L-2, L-3, and L-4 of Loktak Lake and K1, K-2, and K-3 of KLNP) as shown in Table 3 and Table 4 respectively. In Loktak Lake, the temperature was inversely correlated with Total Dissolved Solids (r= -0.824) at p= <0.01 level, whereas Salinity was strongly correlated with Total Dissolved Solids (r= 0.769) at p=<0.01 level. In KLNP, Dissolved Oxygen was negatively correlated with pH (r= -0.599) at a significance level of 0.05. Conductivity had a positive correlation with Dissolved Oxygen (r= 0.664), at p=<0.05 level. Subsequently, water temperature also had a positive correlation with conductivity (r= 0.678), at p= <0.05 level. Turbidity was strongly correlated with temperature (r= 0.744) at a significance level of 0.01. Salinity was correlated with pH (r= 0.697), at p= <0.05 level.

The average carbon content of the aquatic macrophytes in Loktak Lake was 577.38 ± 58.84 g C m^{-2}, whereas in KLNP, it was estimated to be 1442.43 ± 276.85 g C m^{-2}.

Discussion

The independent sample t-test results indicated a statistically significant difference at p=<0.05 level in Dissolved Oxygen, turbidity, and carbon content. However, no significant difference was observed at p=>0.05 level for other parameters including pH, Total dissolved solids, conductivity, temperature, and salinity at the two study sites.

pH indicates the acidic and basic nature of the wetland water. The pH of Loktak Lake ranged from 8.92 ± 0.33 to 9.42 ± 0.03 and in KLNP, the pH ranged from 8.31±0.55 to 8.75±0.46. The pH of water is slightly alkaline, which may be due to the presence of carbonate ions [36, 37, 38]. A study conducted in Loktak Lake during the period 2013-2014 recorded a pH range of 6.15- 7.66 [19]. However, in our study, a high pH of 9.42 was recorded, which may affect aquatic life as the recommended optimum level by BIS is 7-8.5 [28]. The elevated pH value may be attributed to higher temperatures and various geochemical processes [17]. Dissolved Oxygen (DO) is one of the important parameters that regulate the health of the wetland ecosystem. DO in water depends on salinity, temperature, microbial community, pressure, and collection time [19]. During the period 2013-2014, Dissolved Oxygen (DO) levels in Loktak Lake ranged from 3.19- 9.18 mg/L, with the lowest levels recorded in the Thanga region. [19]. In our study, the DO level of Loktak Lake ranged from 6.46±0.43mg/l to 7.46±0.35mg/l, and 4.96±0.39mg/l to 5.55±0.24mg/l in KLNP. DO in KLNP is comparatively lower than Loktak Lake, possibly due to the higher growth of macrophytes [21]. Low DO levels suggest poor water quality, indicating reduced phytoplankton activities in Loktak Lake [19]. The low DO levels may be attributed to elevated temperatures, which accelerate the decomposition of organic matter and consequently increase oxygen consumption [16]. The

Total Dissolved Solids in water are mainly comprised of inorganic and organic matter. TDS values recorded in the year 2013-2014 ranged from 46.52 ppm to 168.9 ppm [19]. TDS was found to range from 70.37±3.51 ppm to 87.54±5.8 ppm in Loktak Lake and 71.59±1.95 to 76.6±2.92 ppm in KLNP. TDS is comparatively higher in Loktak than in KLNP. In a study conducted in Loktak Lake during 2013-2014, TDS values ranged from 46.52 to 168.9 ppm [19]. The TDS in Loktak Lake originate from natural origin, wastewater, and agricultural runoff [17], organic decay, along with increased human activities such as fishing and the harvesting of vegetation for consumption and aquaculture feed [18]. The conductivity value across the two study sites ranged from 115.04±5.47 µS/cm to 145.41±6.64 µS/cm in Loktak Lake and 128.83±2.27 µS/cm to 141.41±6.48 µS/cm in KLNP. The elevated conductivity is attributed to significant anthropogenic activities, including improper waste management, agricultural runoff [19], ecotourism activities, and other anthropic interferences from the surrounding area [20]

Water temperature is the most important controlling factor in wetlands [16, 21], as it alters the functioning of the ecosystem and the growth of aquatic macrophytes and their associated fauna [39].
The water temperature was consistent in both the study areas, ranging from 19.5±1.23 ℃ to 25.04±1.62 ℃. In a study conducted during 2012-2013, the water temperature ranged between 16℃ to 32℃ [21]. Temperature increases associated with global warming may have significant consequences for aquatic plants. These changes could result in earlier warming of spring waters and higher peak temperatures in water bodies during the summer [18]. Turbidity during the period of 2013-2014 ranged from 0.23 NTU to 2.84 NTU [19]. The turbidity recorded in our study ranged from 6.96±1.14 NTU to 12.55±1.1 in Loktak Lake and 3.68±0.33 NTU to 4.61±0.44 NTU in KLNP. High sediment deposition carried by rivers like Nambul and Nambol River, contributes to increased turbidity in the lake and results in a deterioration of water quality [19]. Salinity is a key physical parameter that influences biological diversity by acting as a controlling factor and affecting the habitat distribution of aquatic life [36, 39]. Salinity in Loktak ranged from .06±0.003 ppt to 0.08±0.003 ppt and 0.07±0.001 ppt to 0.08±0.003 ppt in KLNP. In a study conducted in a wetland ecosystem in Tamil Nadu, salinity was recorded to range from 0.82±0.02% to 1.13±0.15%. [36]. The salinity in water bodies can be due to the dissolved solids, primarily from wastewater and surrounding households [23].

The Water Quality Index (WQI) was employed to evaluate the quality of the wetland water. The range of WQI values and their corresponding status, as recommended by BIS [28], are presented in Table 5. In Loktak Lake, the WQI ranged from 51.76 at site L-3 to 62.79 at site L-2 (Table 6), indicating poor water quality. Conversely, in KLNP, the WQI ranged from 28.29 at site K-2 to 36.95 at site K-3 (Table 7), suggesting good water quality. The good water quality in KLNP may be attributed to its status as a protected area, which results in reduced human activities and consequently lower levels of pollutants and runoff entering the Park.

The carbon content of macrophytes in Loktak Lake and KLNP is depicted in Fig. 2. The carbon content in KLNP is notably higher than in Loktak Lake, likely due to KLNP's status as a protected area and the extensive coverage of thick *phumdi*, which spans 26.41km^2 [28]. The average carbon content in Loktak Lake was estimated at 577.38 ± 58.84 g C m^{-2}, whereas in KLNP it was 1442.43 ± 276.85 g C m^{-2}. Carbon content in both study areas peaks during the monsoon and post-monsoon seasons. The alterations in hydrological regimes and favourable temperatures during the post-monsoon season may contribute to the abundant growth of macrophytes, which is favourable for macrophyte growth, as elevated temperatures in the summer can inhibit photosynthetic rates [30, 32]. The post-monsoon season offers optimal conditions for macrophytes due to its favourable temperatures and adequate precipitation [33]. A statistically significant difference ($p < 0.05$) was recorded in dissolved oxygen, turbidity, and carbon content in macrophytes between Loktak Lake and KLNP. Macrophytes contribute to maintaining lake water quality by acting as a sink for various nutrients in the ecosystem, accumulating these nutrients in different plant parts [24]. Aquatic macrophytes can enhance water quality by absorbing excessive nutrient loads, thereby contributing to the maintenance of the wetland ecosystem [25]. A study in the East Kolkata Wetland Ecosystem estimated the carbon sequestration rates of nine marginal and three floating macrophyte species to be 1.17 kg C m^{-2} yr^{-1} and 0.74 kg C m^{-2} yr^{-1}, respectively [31]. In the Hokersar wetland, twelve aquatic macrophytes sequestered carbon at average rates of 2,448.6 kg C ha^{1} during the summer, 4,234 kg C ha^{-1} during the post-monsoon period, and 1,887.9 kg C ha^{-1} during the winter [10].

Conclusion

The water quality directly or indirectly affects the aquatic macrophytes of the wetland ecosystem. Aquatic macrophytes are essential for sustaining biodiversity in freshwater ecosystems. They not only sequester significant amounts of atmospheric CO_2 during their lifecycle but also contribute organic carbon to the soil and water through their decomposition after death. While wetlands are indeed a source of methane, their role in long-term carbon storage, especially in comparison to carbon dioxide, undervalues the importance of their conservation. Wetlands serve as a significant carbon sink over extended timeframes, which highlights their value in mitigating climate change [34]. If not properly conserved and managed, wetlands may become carbon sources, releasing the carbon they have stored over extended periods. The Water Quality Index (WQI) also exhibited significant variation between Loktak Lake and KLNP, indicating the impact of various human activities. Promoting the lake as an ecotourism destination could further intensify these activities, potentially leading to a decline in water quality and biodiversity. Furthermore, a well-defined framework for the sustainable management and preservation of the ecological system should be emphasized.

Acknowledgment: The authors would like to acknowledge the Head, Department of Zoology, Manipur University, Canchipur, India. The laboratory facilities provided by the DBT: BUILDER-Manipur University Instrumentation Facilities funded by the Department of Biotechnology, New Delhi, Govt. of India for carrying out the part of the work is duly acknowledged.

Competing Interests: The authors declare that they have no competing interests.

Reference

1. Mitsch, W. J., Gosselink, J. G., (2017). Wetlands. Fourth Edition.
2. Mitsch, W. J., Bernal, B., Nahlik, A. M., Mander, U., Zhang, L., Anderson, C. J., Jorgensen, C. J., Brix, H., (2013). Wetlands, carbon, and climate change. Landscape Ecology.28. 583–597 DOI: 10.1007/s10980-012-9758
3. National Water Summary on Wetland Resources United States Geological Survey Water Supply Paper 2425 Technical Aspects of Wetlands Wetland Hydrology, Water Quality, and Associated Functions by Virginia Carter, U.S. Geological Survey
4. Laishram, J., and Dey, M., (2020) Seasonal variations and significant difference in selected Physico-chemical characteristics of LoktakLake, Manipur, North-East India. International Journal of Fisheries and Aquatic Studies. 8(6). 01-07
5. Tuboi, C., Irengbam, M., and Hussain, S. A. (2018). Seasonal variations in the water quality of a tropical wetland dominated by floating meadows and its implication for conservation of Ramsar wetlands. Physics and Chemistry of the Earth.103. 107-114. DOI: 10.1016/j.pce.2017.09.001
6. Gray, T. N. E., Brook, S. M., McShea, W. J., Mahood, S., Ranjitsingh, M. K., Miyunt, A., Hussain, S. A., and Timmins, R., (2015). *Rucervus eldii*. The IUCN Red List of Threatened Species.
7. Tuboi, C., Hussain, S. A., (2016). Factors affecting forage selection by the endangered Eld's deer and hog deer in the floating meadows of Barak-Chindwin Basin of North-east India. Mammal. Biol.81. 53-60
8. Singh, A. L., and Khundrakpam, M. L., (2011). Phumdi proliferation: a case study of Loktak lake, Manipur. Water and Environment Journal. 25 (1). 99-105
9. Tuboi, C., and Hussain, S. A., (2018). Plant community structure of the floating meadows of a hypereutrophic wetland in the Indo-Burma Biodiversity Hotspot. Aquatic BotanyVolume. 150. 71-81.
10. Lolu, A., J., Ahluwalia, A. S., Sidhu, M. C., and Reshi, J. A., (2018) Carbon Sequestration Potential of Macrophytes and Seasonal Carbon Input Assessment into the Hokersar Wetland, Kashmir. Wetland .39(4). DOI:10.1007/s13157-018-1092-8
11. Bridgham, S. D., Megonigal, J. P., Keller, J. K., Bliss, N. B., and Trettin, C., (2006) The carbon balance of North American wetlands. Wetlands 26. 889-916.
12. Ondiviela, B., Losada, I. J., Lara, J. L., Maza, M., Galvan, C., Bouma, T. J., Belzen, J. V., (2014) The role of sea grasses in coastal protection in a changing climate. Coastal Engineering. 87. 158-168.
13. Milner, C., and Hughes, R. E., (1968). Methods for the Measurement of Primary Production of Grassland. International Biological Programme, Oxford, England.
14. Singh, J. S., and Yadava, P. S., (1974). Seasonal variation in composition, plant biomass and net primary productivity of tropical grassland at Kurukshetra, India.Ecological Monigraohs. 44 (3). 351-376.
15. Thokchom, A., and Yadava, P. S., (2016). Changes in the seasonal cycle of carbon stocks and fluxes due to fires in the grassland ecosystem of Manipur, Northeast India. Current Science. 110 (6). 1088-1094.
16. Rameshkumar. S., Radhakrishnan, K., Aanand, S., Rajaram. R., (2019). Influence of physicochemical water quality on aquatic macrophyte diversity in seasonal wetlands. Applied water. 9 (1). 1-8. DOI:10.1007/s13201-018-0888-2

17. Annual report (2011–2012) Central Pollution Control Board. http:// cpcb.nic.in/upload/AnnualReports/AnnualReport_43_AR_2011-12_English.pdf\
18. Singh, T. M., Borah, R., Goyari, S., Devi, A., (2023). Assessment of spatial and temporal variations in the water quality of the Loktak Lake – Largest Ramsar Site in North-east India. Research Square Platform LLC. DOI:10.21203/rs.3.rs-3705284/v1
19. Kangabam, R. D., Bhoominathan, S. D., Kanagaraj, S., and Govindaraju, M.,(2017). Development of a water quality index (WQI) for the Loktak Lake in India. Appl Water Sci. 7. 2907-2918
20. Joshi, B. K. S., and Devkota, A., (2024). Seasonal Variation of macrophytes related to hydrochemical parameters in Ghodaghodi lake, Nepal. Pakistan Journal of Botany. 56 (3). DOI:10.30848/PJB2024-3(40)
21. Laishram, J., and Dey, M., (2014). Water Quality Status of Loktak Lake, Manipur, Northeast India and Need for Conservation Measures: A Study on Five Selected Villages. International Journal of Scientific and Research Publications. 4 (6).
22. Bornette, G., and Puijalon, S., (2011). Response of aquatic plants to abiotic factors: a review. Aquat. Sci. 1. 1-14. DOI:10.1007/s00027-010-0162.
23. Laishram, R. J., Singh, T. B., and Alam, W., (2023). A comprehensive health risk assessment associated with bioaccumulation of heavy metals and nutrients in selected macrophytes of Loktak Lake, Manipur, India. Environmental Science and Pollution Research. 30. 105329-105352. https://doi.org/10.1007/s11356-023-29606-2
24. Bhusal, A., and Devkota, A., (2020). Environmental variables and macrophytes of lakes of the Chitwan National Park, Central Nepal. Limnological Review. 20 (3). 135-144. https://doi.org/10.2478/limre-2020-0014
25. Bilton, D. T., Mcabendroth, L., Bedford, A., and Ramsay, P. M., (2006) How wide to cast the net? Cross-taxon congruence of species richness, community similarity and indicator taxa in ponds. Freshwater Biology. 51. 578–590
26. BIS (2003) Indian Standard drinking water-specification. Manak Bhavan, New Delhi
27. www.loktaklake.org
28. Tuboi, C., (2013). Assessment of water quality and biomass productivity of the tropical floating 453 meadows of KeibulLamjao National Park, Manipur. Ph.D. Thesis submitted to Saurashtra University, Rajkot, Gujarat
29. Pal, S., Chattopadhyay, B., Datta, S., and Mukhopadhyay, S. K., (2017) Potential of wetland Macrophytes to sequester carbon and assessment of seasonal carbon input into the East Kolkata wetland ecosystem. Wetlands. 37 (1&2) DOI:10.1007/s13157-017-0885-5
30. Hikosaka, K., Ishikawa, K., Borjigidai, A., Muller, O., and Onoda, Y., (2006). Temperature acclimation of photosynthesis: mechanisms involved in the changes in temperature dependence of photosynthetic rate. Journal of Experimental Botany. 57 (2). 291-302. https://doi.org/10.1093/jxb/erj049
31. Bucak, T., Saraoglu, E., Levi, E. E., Tavsanoglu, N., U, Cakiroglu, A. I., Jeppensen, E., Beklioglu, M., (2012) The influence of water level on macrophyte growth and trophic interactions in eutrophic Mediterranean shallow lakes: a mesocosm experiment with and without fish. Freshwater Biology. 57 (8). 1631-1642. https://doi.org/10.1111/j.1365-2427.2012.02825.x
32. Mitsch, W. J., Zhang, L., Stefanik, K. C., Nahlik, A. M., Anderson, C. J, Bernal, B., and Song, K., (2012) Creating wetlands: a 15-year study of primary succession, water quality changes, and self-design. Bioscience 62 (3) 237-250. DOI:10.1525/bio.2012.62.3.5
33. Nurminen, L., (2003). Macrophyte species composition reflecting water quality changes in adjacent water bodies of lake Hidenvesi, SW finland. Ann. Bot. Fennici. 40. 199-208
34. Badge, U.S. and Verma, A. K., (1995). Limnological studies on JNU Lake, New Delhi, India, Bulletin of Botanical Society. 32. 16-23.
35. American Public Health Association, Andrew D. Eaton, American Water Works Association, Water Environment Federation (2005). Standard Methods for the Examination of Water and Wastewater. 21st ed. APHA-AWWA-WEF, Washington, DC.
36. Verma, P., Chandawat, D., Gupta, U., and Solanki, H., (2012) Water quality analysis of an organically polluted lake by investigating different physical and chemical parameters. Int J Res Chem Environ 2 (1). 105-111
37. Tank, S. K., Chippa, R. C., (2013) Analysis of water quality of Halena block in Bharatpur area. Int J Sci Res Publ. 3 (3). 1-6

38. Sridhar, R., Thangaradjou, T., Kumar, S. S., and Kannan, L., (2006) Water quality and phytoplankton characteristics in the Palk Bay, southeast coast of India. J Environ Biol 27 (3). 561-566
39. Balasubramanian, R., and Kannan, L., (2005) Physico-chemical characteristics of the coral reef environs of the Gulf of Mannar biosphere reserve, India. Int J Ecol Environ Sci 31 (3). 265–271

Table 1: Physicochemical parameters of Loktak and Keibul Lamjao National Park (KLNP) of the selected sampling points

Site		pH	DO (mg/l)	TDS (ppm)	Conductivity (µS/cm)	Temperature (°C)	Turbidity (NTU)	Salinity (ppt)
L-1	Min	6.19	3.5	64.6	81.8	15.7	7.7	0.07
	Max	11.23	8.9	103	166	29	25	0.09
	Mean	9.11±0.41	6.48±0.43	81.96±2.79	130.3±7.2	23.83±1.45	11.94±1.38	0.08±0.002
L-2	Min	7.99	4.5	48.7	86.7	17.5	5	0.05
	Max	11.37	9.5	90.78	140	31.9	19.5	0.08
	Mean	9.38±0.33	7.46±0.35	70.37±3.51	115.04±5.47	24.89±1.64	12.55±1.1	0.06±0.003
L-3	Min	7.29	5.2	65.95	106	17.8	3.1	0.06
	Max	11.32	10.5	120	173	33	16	0.11
	Mean	9.42±0.34	7.34±0.53	87.54±5.8	145.41±6.46	24.34±1.67	10.73±1.17	0.08±0.003
L-4	Min	6.52	5.7	68	80.7	18.2	2.3	0.07
	Max	10.54	9	89	151	34.1	18	0.08
	Mean	8.92±0.33	7.26±0.25	77.48±1.82	133.5±5.47	25.04±1.62	6.96±1.14	0.07±0.001
K-1	Min	6.21	3.3	62	118	19.7	3	0.07
	Max	11.22	7.2	97.1	171	33.3	8.5	0.09
	Mean	8.31±0.55	4.96±0.39	76.6±2.93	141.41±6.48	25.43±1.33	4.61±0.44	0.08±0.002
K-2	Min	6.21	2.8	59	118	19.4	1.81	0.07
	Max	12.08	6.7	78.9	142	32	6	0.1
	Mean	8.75±0.46	5.01±0.39	71.59±1.95	128.83±2.27	25.35±1.13	3.68±0.33	0.08±0.003
K-3	Min	6.05	4.2	65	113	19.5	3.2	0.07
	Max	10.62	6.6	84.5	150	33.3	6.9	0.08
	Mean	8.54±0.37	5.55±0.24	73.3±1.58	130.6±3.69	19.5±1.23	4.55±0.32	0.07±0.001

Table 2: Independent sample t-test analyses of the physicochemical parameters of water and carbon content in macrophytes between the two study sites.

Parameters	LOKTAK	KLNP	F value	P value
pH	9.21±0.17	8.53±0.26	0.12	0.000
DO (mg/l)	7.13±0.20	5.18±0.20	3.785	0.218
TDS (ppm)	79.34±2.04	73.83±1.3	0.22	0.070
Cond. (µS/cm)	131.08±3.39	133.63±2.69	0.293	0.662
Temp. (℃)	24.52±0.77	23.43±0.69	1.995	0.664
Turbidity (NTU)	10.54±0.66	4.28±0.22	1.517	0.000
Salinity (ppt)	0.07±0.002	0.07±0.001	0.207	0.143
Carbon (g C m^2)	577.38±166.7	1442.43±416.39	22.476	0.001

Table 3: Pearson correlation coefficients matrix between the physicochemical parameters of Loktak Lake

Parameter	pH	DO (mg/l)	TDS (ppm)	Conductivity (µS/cm)	Temperature (℃)	Turbidity (NTU)	Salinity (ppt)
pH	1						
DO (mg/l)	-.064	1					
TDS (ppm)	-.434	.438	1				
Cond. (µS/cm)	.083	.215	-.179	1			
Temperature (℃)	.336	-.157	-.824**	.295	1		
Turbidity (NTU)	-.152	.342	.178	-.054	-.249	1	
Salinity (ppt)	-.280	.295	.769**	-.125	-.513	.117	1

** Correlation is significant at the 0.01 level (2-tailed).

Table 4: Pearson correlation coefficients matrix between the physicochemical parameters of KLNP

Parameter	pH	DO (mg/l)	TDS (ppm)	Conductivity (µS/cm)	Temperature (℃)	Turbidity (NTU)	Salinity (ppt)
pH	1						
DO (mg/l)	-.599*	1					
TDS (ppm)	-.071	.250	1				
Cond. (µS/cm)	-.274	.664*	.321	1			
Temperature (℃)	-.023	.091	.057	.678*	1		
Turbidity (NTU)	.506	-.379	.220	.288	.744**	1	
Salinity (ppt)	.697*	-.363	-.079	-.046	.095	.095	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 5: Water Quality Index (WQI) and status of the water quality (BIS 2003)

WQI	Status
0-25	Excellent
26-50	Good
52-75	Poor
76-100	Very poor
>100	Unsuitable for drinking

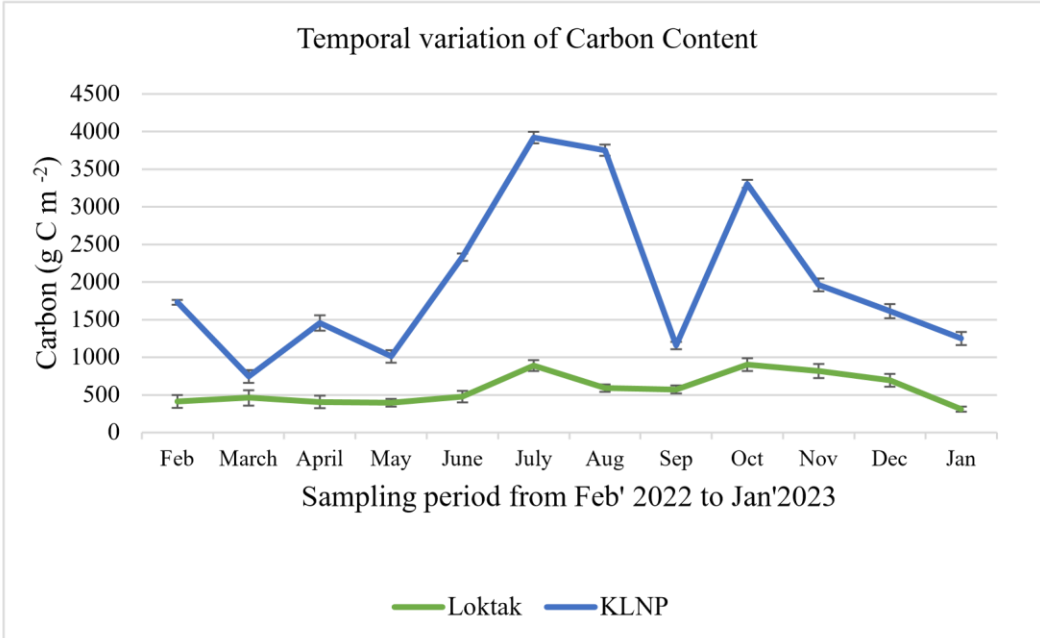

Figure 2: Graphical representation of the temporal variation of carbon content in the aquatic macrophytes of Loktak Lake and KLNP

Table 6: Water Quality Index of Loktak Lake

Sl.No	Parameters	Sn	W n	L-1			L-2			L-3			L-4		
				Vn	Qn	WnQn	Vn	Qn	WnQn	Vn	Qn	WnQn	Vn	Qn	W nQ n
1	pH	8.5	0.08	9.11	140	12.37	9.38	158	13.97	9.42	93	8.22	8.92	43	3.8
2	DO (mg/l)	5	0.15	6.48	80	12.02	7.46	73	10.97	7.34	74	11.12	7.26	226	33.98
3	TDS (ppm)	500	0.001	81.96	16.39	0.02	70.37	14.07	0.02	87.54	17.5	0.02	77.5	15.49	0.02

4	Cond. (µS/cm)	300	0.002	130.31	43.43	0.1	115.04	38.34	0.09	145.41	48.47	0.12	134	44.51	0.11
5	Turbidity (NTU)	5	0.15	11.947	238.83	35.88	12.55	251	37.74	10.73	214.66	32.28	6.96	139. 33	20.95
6	Salinity (ppt)	100	0.007	0.08	11.94	0.08	0.06	0.06	0.0004	0.08	0.08	0.0006	0.07	0.07	0.000526
	Total		**0.4**			**60.5**			**62.79**			**51.76**			**58.86**

* Sn- Standard weight, Wn- Unit Weight, Vn- Mean Concentration Value, Qn- Quality Rating.
L-1, L-2, L-3 and L-4: Sampling points of Loktak Lake

Table 7: Water Quality Index of KLNP

Sl.No	Parameters	Sn	Wn	K-1			K-2			K-3		
				Vn	Qn	WnQn	Vn	Qn	WnQn	Vn	Qn	WnQn
1	pH	8.5	0.08	8.31	87	7.69	8.75	25	2.21	8.54	102	9.02
2	DO (mg/l)	5	0.15	4.96	100	15.03	5.01	99	14.88	5.55	94	14.13
3	TDS (ppm)	500	0.001	76.6	15.32	0.02	71.59	14.31	0.02	73.3	14.66	0.02
4	Cond. (µS/c m)	300	0.002	141.41	47.13	0.11	128.83	42.94	0.1	130.66	43.55	0.1
5	Turbidity (NTU)	5	0.15	4.61	92.33	13.88	3.68	73.68	11.08	4.55	91	13.68

6	Salinity (ppt)	100	0.007	0.08	0.08	0.0006	0.08	0.08	0.0006	0.07	0.07	0.00054
	Total		**0.4**			**36.73**			**28.29**			**36.95**

* Sn- Standard weight, Wn- Unit Weight, Vn- Mean Concentration Value, Qn- Quality Rating.
K-1, K-2 and K-3: Sampling Points of KLNP.