

CHAPTER 3

SEASONAL VARIATIONS IN PHYSICOCHEMICAL PROPERTIES OF LOKTAK LAKE WATER

3.1 INTRODUCTION

Water is a vital resource for all life on Earth, serving as the cornerstone of ecosystems and sustaining various human activities. Across different regions and climates, water bodies undergo dynamic transformations in their physicochemical properties, influenced by seasonal changes and anthropogenic activities. These fluctuations play a crucial role in shaping the ecological balance and functioning of aquatic environments. India possesses numerous perennial and non-perennial water sources, although not all of them are deemed suitable for consumption and other utilitarian applications^[1]. The rise in demand for potable water has resulted in increased strain on freshwater wetlands to meet the requirements for both water quality and quantity^[2]. Pollution in aquatic ecosystems is a significant global issue that arises from various sources, including municipal trash, agricultural runoff, industrial effluents, urbanization, and the dissolution of minerals from rocks^{[3][4][5][6][7]}. The presence of hazardous chemicals and biologically accessible nutrients has been identified as a significant factor contributing to the deterioration of water quality, which has raised concerns regarding public health and the loss of biodiversity^{[8][9]}. According to a study, the mortality rate resulting from severe disease caused by contaminated water was responsible for the deaths of more than two million individuals, predominantly children^[10]. The global utilization of freshwater has experienced a significant increase from 1900 to 1995, surpassing the rate of population

growth by more than double. It is estimated that two out of every three people on Earth are projected to experience stressed conditions by 2025^[11].

Wetlands, which consist of several categories including marshes, swamps, bogs, and fens, possess significant importance in upholding the general well-being and operational efficiency of ecosystems on a global scale^[12]. These unique habitats are characterized by their highwater content, varied assemblages of flora and fauna, and notable ecological roles. The water quality of wetland habitats is a crucial factor that significantly impacts their ecological integrity and the various functions they offer. Globally, numerous factors have led to the loss of over 50% of wetland areas. Furthermore, in densely populated regions such as Europe, East Asia, and North America, over 80% of wetlands have either been destroyed or seen considerable degradation^[13].

The water bodies inside wetland ecosystems experience a significant degree of contamination due to the influx of water from various sources. The quality of water in these wetlands exhibits significant spatial and temporal variability, posing challenges in accurately assessing its quality over the course of a year^{[4][14][15]}. The total quality of water is influenced by various elements, including but not limited to the climate, geology, hydrology, vegetation of soil, anthropogenic activities, and microbial activity^[1]. The pollutants encompass a range of substances like nutrients, sediments, heavy metals, pesticides, and organic contaminants. These substances have the potential to cause detrimental effects on both aquatic organisms and the surrounding environment.

The spatiotemporal variation in climatic and anthropogenic factors influences the change in physicochemical attributes of water. The evaluation of water quality in wetlands involves assessing various physical, chemical, and biological parameters. Physical parameters include temperature, turbidity, and flow rate, which provide information on the physical characteristics of the water. Chemical characteristics include pH, dissolved oxygen, nutrient levels, and pollutant concentrations, which offer valuable information regarding the chemical composition and potential contamination of water. Examining biological factors such as biodiversity, community structure, and ecological indicators is essential for evaluating the overall health and ecological integrity of the wetland. These assessments are crucial for developing effective management strategies aimed at preserving wetland ecosystems. By integrating data from all these parameters, scientists

can better understand the interrelationships within the ecosystem and identify potential threats posed by human activities or climate change.

Effective management strategies for wetlands depend on maintaining or improving water quality. Protection and restoration of degraded wetland areas from pollution sources and the use of best management methods are crucial steps toward preserving and enhancing water quality in these valuable ecosystems. Furthermore, integrating water quality considerations into the processes of land use planning, policy formation, and conservation programs can make a significant contribution to the sustainable management of wetland resources.

Comprehending the variables that influence the quality of water and establishing efficient ways for monitoring and managing these variables are imperative for the conservation and sustainable utilization of wetland ecosystems. To ensure the long-term sustainability of these invaluable habitats, it is crucial to implement measures that protect and maintain the quality of water, thus ensuring the sustained provision of ecosystem services and security. Therefore, it is crucial to consistently monitor the quality of water to obtain accurate and rational outcomes. The study focuses on Loktak Lake in Manipur, where a range of physico-chemical parameters were analyzed on a seasonal basis to monitor the water quality. The implementation of these monitoring measures will greatly enhance the effectiveness of conservation and administration efforts, with far-reaching implications for sectors such as water resource management, agriculture, fisheries, and recreation.

3.2 MATERIALS AND METHODS

3.2.1 Study site

Loktak Lake is the largest freshwater lake in the northeastern region of India. The lake is located at the heart of Imphal valley at an elevation of around 768m above mean sea level, which is surrounded by mountainous ranges with steep slopes^[16]. It is situated between longitudes 93°46' to 93°55' E and latitudes 24°25' to 24°41' N, covering an area of 266 km² with a buffer area of 12 km² comprising agricultural land, along with some forest area^[17]. The lake was in the Ramsar List of wetlands of international importance in 1990 and was subsequently added to the Montreux Record in 1993, considering the degradation of the lake and its ecological problems^[12]. The characteristic feature of this lake is the

rings of floating aquatic vegetation along with thick associated debris called “phumdi.” At the southern part of the lake lies a substantial aggregation of aquatic vegetation, sometimes referred to as a floating mass of weeds. This particular area holds the distinction of being the sole floating national park in the world, serving as a sanctuary for the preservation of an endemic and endangered species of deer in the IUCN (International Union for Conservation of Nature and Natural Resources) red list, which is known as “Sangai” (*Rucervus eldii eldii*). The local community heavily relies on the lake as a primary water source for agricultural irrigation and domestic purposes. Additionally, the lake provides food and a place to rest for migratory water birds throughout the winter season, serving as a crucial habitat for these species.

3.2.1.1 Climate of the study sites

Loktak Lake is surrounded by hillocks, and its climate is largely influenced by the topography of the surrounding hillocks. The study area generally experiences monsoonic weather, with warm, humid summers and cool, dry winters. The mean maximum temperature varied from 20.3⁰C (December and January) to 30.1⁰C (April), and the mean minimum temperature varied from 6⁰C (December and January) to 25⁰C (July). The summer and spring months (March, April, and May) experienced high temperatures due to less rainfall. The cold season begins at the end of October and last until February, experiencing low temperature of the year.

The weather data was retrieved from the meteorological center (METAR &TAF) at Imphal airport, Manipur. The maximum temperature recorded was 27.1⁰C in the month of August during 2020, 30.1⁰C in April during 2021, and 29.8⁰C in August and September during 2022. The average maximum temperatures for the years 2020, 2021, and 2022 were 24.6⁰C, 26.5⁰C and 26.9⁰C, respectively. During this period maximum temperature was recorded April (30.1⁰C) during 2021. Table 3.1 and Figure 3.1 provide detailed data for the maximum temperatures recorded during 2020-2022.

Table 3.1: Monthly maximum temperature (⁰C) observed during 2020-2022.

Month	Maximum temperature (⁰ C)			
	2020	2021	2022	Mean±SD
January	20.8	20.3	18.6	19.9±1.15
February	21.3	23	21	21.8±1.08

March	24.3	27.1	28.5	26.6±2.14
April	24.6	30.1	27.8	27.5±2.76
May	25	29	26.8	26.9±2.00
June	26.3	28.6	29.6	28.2±1.69
July	27.6	28.8	29.3	28.6±0.87
August	29	28	29.8	28.9±0.90
September	27.1	28.1	29.8	28.3±1.37
October	25.8	28.6	28.5	27.6±1.59
November	22.8	25	26.6	24.8±1.91
December	20.3	21.5	26.1	22.6±3.06
Average±SD	24.6±2.80	26.5±3.25	26.9±3.57	26.0±3.00

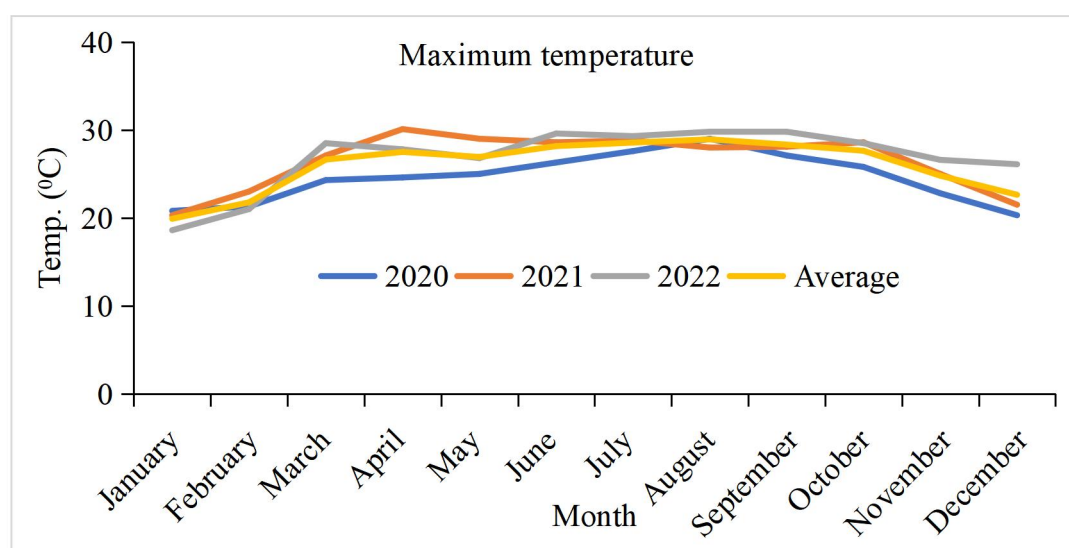


Figure 3.1: Maximum temperature (°C) recorded during 2020-2022.

The average minimum temperature was recorded in the month of December 2020 with 6°C, January 2021 with 6°C and 9°C in February during 2022. The average minimum temperatures for the years 2020, 2021, and 2022 were 16.4°C, 17.2°C and 18.7°C, respectively. Detailed data for the minimum temperature recorded during 2020-2022 is given in Table 3.2 and Figure 3.2.

Table 3.2: Monthly minimum temperature (°C) observed during 2020-2022.

Month	Minimum temperature (°C)			Mean±SD
	2020	2021	2022	
January	8	6	10	8.0±2.00
February	8	9	9	8.7±0.58

March	13	15	15	14.3±1.15
April	19	19	19	19.0±0.00
May	22	21	22	21.7±0.58
June	21	23	25	23.0±2.00
July	23	23	25	23.7±1.15
August	24	23	25	24.0±1.00
September	21	23	24	22.7±1.53
October	20	21	22	21.0±1.00
November	14	16	14	14.7±1.15
December	6	11	13	10.0±3.61
Average±SD	16.4±6.47	17.2±6.05	18.7±6.08	17.4±6.12

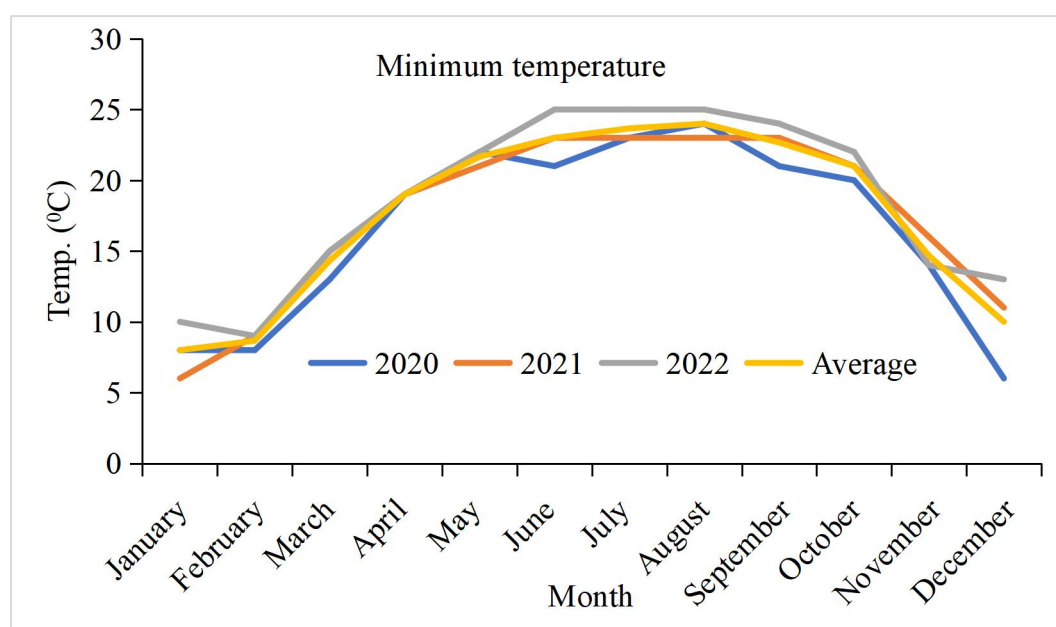


Figure 3.2: Minimum temperature (°C) recorded during 2020-2022.

Figure 3.3 and Table 3.3 present the observed rainfall, drizzle, snow, or hail recorded during 2020-2022. The maximum precipitation recorded during 2020 was 265.31 mm in the month of June, 229.32 mm in August during 2021, and 371.26 mm in June during 2022. The average precipitation for the years 2020, 2021, and 2022 was 121.18 mm, 86.97 mm and 108.40 mm, respectively. During this period, the maximum precipitation recorded was 371.26 mm in June 2022. December 2020 did not record any precipitation. Weather data were retrieved from “CHIRPS Daily: Climate Hazards Center InfraRed Precipitation with Station Data (Version 2.0 Final).”

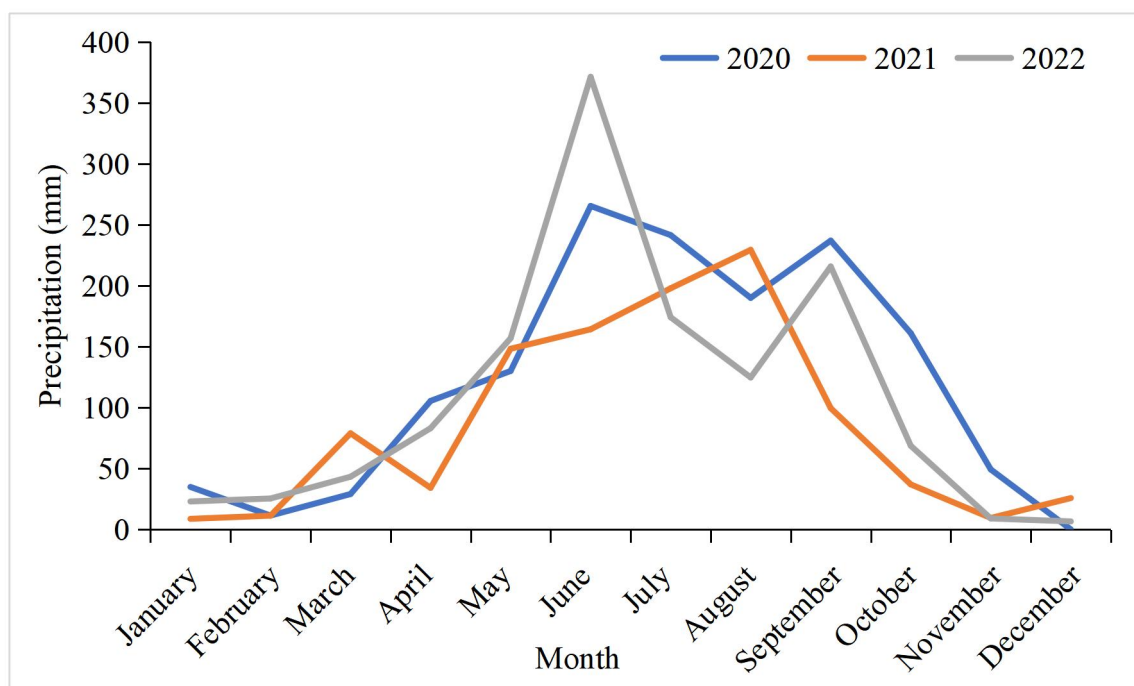


Figure 3.3: Precipitation (mm) trend during 2020-2022.

Table 3.3: Monthly recorded precipitation (in mm) observed during 2020-2022.

Precipitation (mm)				
Month	2020	2021	2022	Mean±SD
January	34.82	8.65	22.91	22.1±10.70
February	11.33	11.25	25.34	16.0±6.62
March	29.00	78.82	43.19	50.3±20.96
April	105.37	34.07	83.00	74.1±29.77
May	129.93	148.17	156.76	145.0±11.18
June	265.31	164.15	371.26	266.9±84.56
July	241.41	197.78	174.03	204.4±27.90
August	189.94	229.32	124.61	181.3±43.18
September	236.91	99.46	215.68	184.0±60.42
October	160.98	36.89	68.59	88.8±52.64
November	49.15	9.35	8.95	22.5±18.85
December	0.00	25.68	6.53	10.7±10.90
Average±SD	121.18±96.84	86.97±79.44	108.40±108.07	105.52±87.62

3.2.2 Sampling and methodology

A total of 38 sampling sites namely Mayang Imphal (I), Mayang Imphal (II), Mayang Imphal (near Karang), Phoubakchao, Komlakhong (north side), Komlakhong (KLNP side), Laphupat Tera, Khordak, Khordak Ichin, Nongmaikhong, Ithai, Yangoi, Keinou (I), Keinou(II), Khoijuman, Nachou, Kha-Potshangbam, Upokpi Khunou, Toubokpi, Ningthoukhong ITI, Ningthoukhong Kha-Khunou, Thinungei, Phubala, Naranshena, Ithing, Thanga Chingka, Thanga Salam, Karang, Thanga Moirangthem, Keibul Ching, Nashik Houbi, Ngakra Kom, Sagram (IV), Sagram (III), Keibul Mayai Leikai, 2nd IB Post (KLNP), Keibul Chingmei and Thangbirel (Table 3.4) were randomly selected throughout the lake. Figure 3.4 shows the location of Manipur, Loktak Lake, and the 38 samplings sites from where the water samples were collected for the present study. The site selection was based on the accessibility of the areas, associated human activities, and the influx of streams and rivers into the lake. Previous studies on water quality of Loktak Lake used a much lesser number of water samples and sampling sites: Mayanglambam and Neelam, 2020^[2] (16 sites); Tuboi et al., 2018^[38] (5 sites); Roy and Majumder, 2019^[39] (10 sites); Kangabam et al., 2017^[42] (5 sites); Singh and Rai, 2014^[45] (4 sites), Laishram and Dey, 2014^[50] (5 sites); Devi et al., 2015^[51] (6 sites) as compared to the present study.

Sampling sites were more on the western side compared to the eastern side of Loktak Lake. This is due to the fact that most of the inflows to the lake originate from the western catchment areas. The sampling period spanned from the monsoon season of 2020 to the pre-monsoon season of 2022 for two years, covering all four seasons (pre-monsoon, monsoon, post-monsoon and winter) based on the classification by the Indian Meteorological Department (IMD)^[18].

Water samples were collected using clean 500 mL polypropylene bottles, adhering to the guidelines provided by the Central Pollution Control Board (CPCB, 2018) in their manual for testing water and wastewater^[19]. To ensure precise outcomes, three replicates (n=3) were collected seasonally from each sampling sites at water depth of 20 cm to 30 cm^[22]. The physicochemical parameters, including electrical conductivity (EC), pH, salinity, total dissolved solids (TDS), dissolved oxygen (DO), temperature, turbidity, total alkalinity (TA), calcium (Ca), chloride (Cl), total hardness (TH), sulphate (SO₄²⁻), potassium (K), and magnesium (Mg) were analysed.

Table 3.4: The details of the sampling sites (n=38) in the Loktak lake of Manipur.

Sl. No.	Sampling site	Geo coordinates	Remarks
1	Mayang Imphal (I)	24.58627 ⁰ N, 93.853312 ⁰ E	Close to fish farm
2	Mayang Imphal (II)	24.572273 ⁰ N, 93.848952 ⁰ E	Natural
3	Mayang Imphal (near Karang)	24.568183 ⁰ N, 93.844875 ⁰ E	Natural
4	Phoubakchao	24.55079 ⁰ N, 93.856145 ⁰ E	Natural
5	Komlakhong (north side)	24.528358 ⁰ N, 93.856016 ⁰ E	Close to fish farm
6	Komlakhong (KLNP side)	24.527591 ⁰ N, 93.854367 ⁰ E	Natural
7	Laphupat Tera	24.496799 ⁰ N, 93.872082 ⁰ E	Close to fish farm
8	Khordak	24.497724 ⁰ N, 93.856726 ⁰ E	Close to fish farm
9	Khordak Ichin	24.455907 ⁰ N, 93.850405 ⁰ E	Close to human habitat
10	Nongmaikhong	24.434895 ⁰ N, 93.843751 ⁰ E	Close to fish farm
11	Ithai	24.441102 ⁰ N, 93.826749 ⁰ E	Natural
12	Yangoi	24.611674 ⁰ N, 93.812553 ⁰ E	Natural
13	Keinou (I)	24.657531 ⁰ N, 93.791326 ⁰ E	Natural
14	Keinou (II)	24.655708 ⁰ N, 93.784075 ⁰ E	Natural
15	Khoijuman	24.593699 ⁰ N, 93.795951 ⁰ E	Close to fish farm
16	Nachou	24.587699 ⁰ N, 93.788151 ⁰ E	Close to fish farm
17	Kha-Potshangbam	24.585467 ⁰ N, 93.781936 ⁰ E	Natural
18	Upokpi Khunou	24.579807 ⁰ N, 93.785792 ⁰ E	Natural
19	Toubokpi	24.579112 ⁰ N, 93.777 ⁰ E	Close to fish farm
20	Ningthoukhong ITI	24.569958 ⁰ N, 93.782466 ⁰ E	Natural
21	Ningthoukhong Kha-Khunou	24.557077 ⁰ N, 93.771369 ⁰ E	Close to fish farm
22	Thinungei	24.545318 ⁰ N, 93.771228 ⁰ E	Natural
23	Phubala	24.533063 ⁰ N, 93.76405 ⁰ E	Close to fish farm
24	Naranshena	24.523481 ⁰ N, 93.76287 ⁰ E	Close to fish farm

25	Ithing	24.526456 ⁰ N, 93.803351 ⁰ E	Close to fish farm
26	Thanga Chingkha	24.535749 ⁰ N, 93.825316 ⁰ E	Close to fish farm and human habitat
27	Thanga Salam	24.52762 ⁰ N, 93.843526 ⁰ E	Natural
28	Karang	24.545671 ⁰ N, 93.834991 ⁰ E	Natural
29	Thanga Moirangthem	24.516561 ⁰ N, 93.820019 ⁰ E	Close to human habitat
30	Keibul Ching	24.510439 ⁰ N, 93.826903 ⁰ E	Close to fish farm and human habitat
31	Nashik Houbi	24.507153 ⁰ N, 93.835931 ⁰ E	Natural
32	Ngakra Kom	24.507486 ⁰ N, 93.840836 ⁰ E	Natural
33	Sagram (IV)	24.50115 ⁰ N, 93.826414 ⁰ E	Close to fish farm and human habitat
34	Sagram (III)	24.492875 ⁰ N, 93.825767 ⁰ E	Natural
35	Keibul Mayai Leikai	24.483594 ⁰ N, 93.817603 ⁰ E	Close to fish farm
36	2 nd IB Post (KLNP)	24.471967 ⁰ N, 93.818314 ⁰ E	Natural
37	Keibul Chingmei	24.468094 ⁰ N, 93.816608 ⁰ E	Close to fish farm
38	Thangbirel	24.487033 ⁰ N, 93.823308 ⁰ E	Close to fish farm

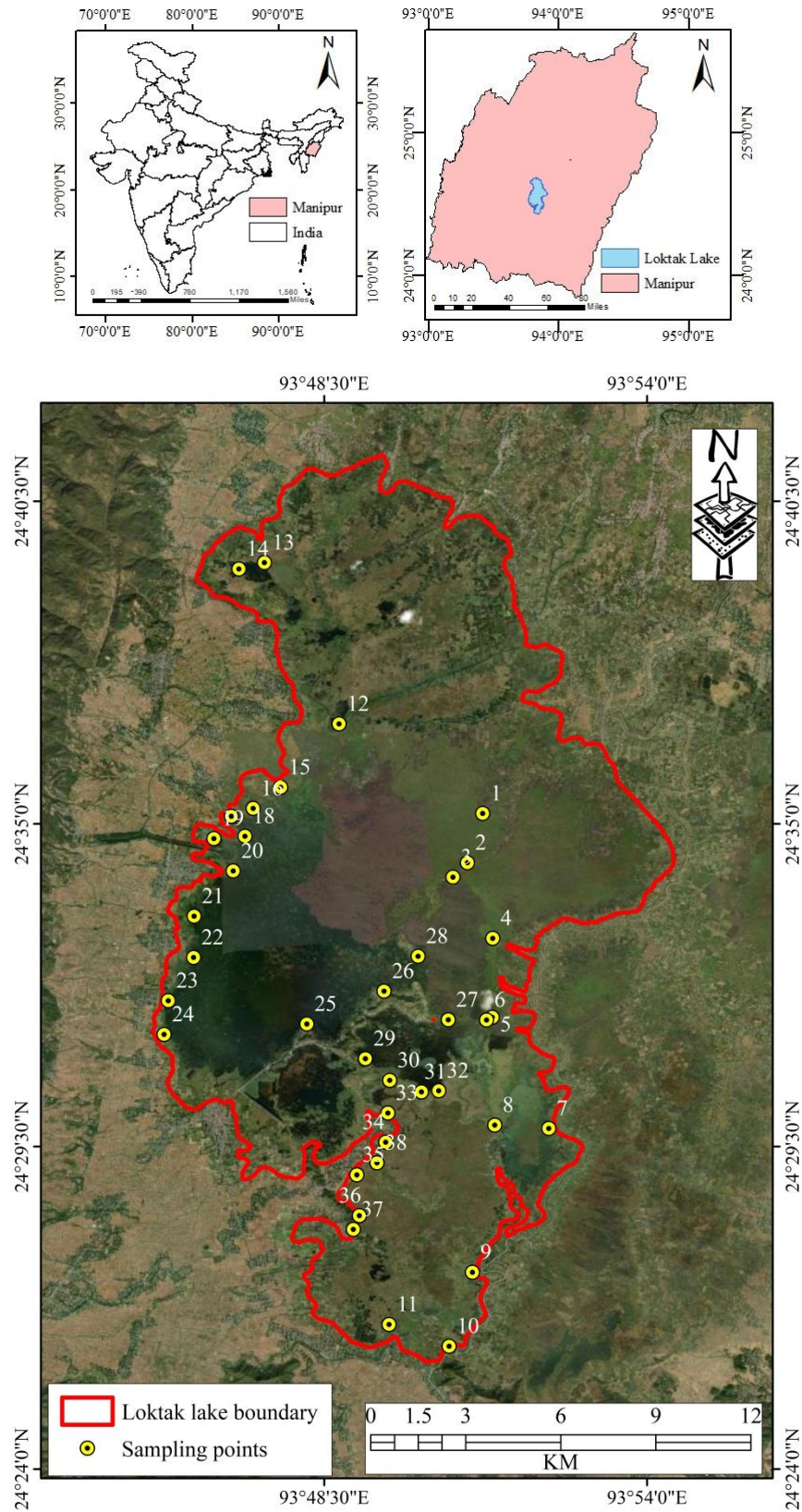


Figure 3.4: Map of study site Loktak lake in Manipur, India, indicating 38 sampling sites across the lake.

The EC, pH, salinity, and TDS were measured at the sampling sites using the Eutech Multi-Parameter PCSTestr 35 instruments, and the dissolved oxygen (DO) levels were determined using the Lutron PDO-519 DO meter. Other parameters were analysed following the established protocols outlined in the APHA (2017)^[20] and CPCB (2018) guide manual for water and wastewater analysis^[19]. Table 3.5 displays the parameters along with their respective units and analytical techniques. The lake's water quality was assessed by comparing the parameters with the permissible limits established by the Bureau of Indian Standards (BIS, 2012)^[21] and the World Health Organization (WHO, 2003)^[22].

Table 3.5: Water quality parameters with their units and methods used

Parameters	Unit	Method/instrument	Source
<u>Physical</u>			APHA (2017) ^[20]
Turbidity (Turb.)	NTU	Nephelometer	
Temperature (Temp.)	°C	Lutron PDO-519	
Total dissolved solids (TDS)	mg/L	PCSTestr 35	
Electrical conductivity (EC)	µS/cm	PCSTestr 35	
Salinity (Sal.)	mg/L	PCSTestr 35	
<u>Chemical</u>			
pH	-	PCSTestr 35	
Total Hardness (TH)	mg/L	EDTA titrimetric	
Dissolved oxygen (DO)	mg/L	Lutron PDO-519	
Total Alkalinity (TA)	mg/L	Titrimetric	
Calcium (Ca)	mg/L	EDTA titrimetric	
Chloride (Cl)	mg/L	Argentometric titration	
Sulphate (SO ₄ ²⁻)	mg/L	Spectrophotometric	
Potassium (K)	mg/L	ICP-MS	
Magnesium (Mg)	mg/L	ICP-MS	

3.2.3 Water sample processing

The water sample bottles were filled and preserved by adding 2 ml of nitric acid. This step ensures that the samples remain stable and free from microbial contamination during

transport and analysis. After sealing the bottles securely, to prevent any leakage, we labeled each one with the name of sampling site, date and time of collection. The bottles were subsequently brought to the laboratory and placed properly in the refrigerator at a temperature of 4°C until the analysis of different physicochemical parameters. All the procedures for sampling and analysis followed the established protocols, including QA/QC procedures outlined in the CPCB (2018)^[19] and APHA (2017)^[20].

3.2.4 Analysis of data and map preparation

Quantitative data for different water quality parameters was represented using descriptive statistics (minimum, maximum, mean, and standard deviation, and desirable limits). Pearson's correlation was carried out to examine the relationship between the water quality parameters. A one-way analysis of variance (ANOVA) was conducted to identify the significant differences (with a significance level of $p=0.05$) among the seasons under study. MANOVA was performed to ascertain if the parameters under investigation showed statistically significant differences between the different sampling sites. Shapiro-Wilk and Levene's test were performed to confirm the normality and homogeneity of the dataset, respectively. To understand how its large size, inflow of water from various water sources, and significant weather changes from season to season affect it, we formulated hypotheses that assumed the water quality parameters were consistent across all seasons and sampling sites (null hypothesis). These analyses aimed to reveal the spatial and temporal fluctuations observed in the parameters being examined. Principal Component Analysis - Absolute Principal Component Score - Multiple Linear Regression (PCA-APCS-MLR) was performed to identify and quantify the contributions of different pollution sources to water quality. Statistical analyses, including descriptive, correlation, ANOVA (Analysis of Variance), multivariate analysis of variance (MANOVA), and PCA-APCS-MLR model, were performed using IBM-SPSS 21 software. Graphs were plotted using R-programming software (Version 4.4.3) and Microsoft Excel (Microsoft for Windows 2021). The boundary map of the study site, Loktak Lake, was acquired from the office of the Loktak Development Authority (LDA) in Manipur, India. Then the study site map (Figure 3.4) was created using ArcGIS 10.4.1 software.

3.2.5 Water Quality Index (WQI):

The Water Quality Index (WQI) is a numerical representation that simplifies the overall water quality of a particular area within a water body^[23]. It employs aggregation methods to transform large sets of water quality data into a single index or value. Worldwide, the WQI model has been utilized to evaluate both surface water and groundwater quality^[24]. Parameters such as TA, Ca, Cl, DO, EC, TH, pH, SO_4^{2-} , TDS, Turbidity, K and Mg were considered for its calculation. It is calculated based on the suitability of human consumption according to water quality standards given by BIS, WHO, and USEPA. Water Quality Index is computed in three steps^[25]. The first step involves assigning a weight (w_i) to each parameter on a scale from 1 to 5 depending on its relative influence on the overall quality of water for drinking purposes (Table 3.6). DO is assigned with the value of 5, and other parameters like pH, TDS, and turbidity were also assigned with a value of 4 due to their major importance in water quality assessment.

Table 3.6: Assigned weights and relative weights of different water quality parameters with their standard values

Parameter	Std. Value	References	Assigned weight (W_a)	Relative weight (W_i)
Total Alkalinity (TA)	200	BIS (2012)	3	0.079
Calcium (Ca)	75	BIS (2012)	2	0.053
Chloride (Cl)	250	BIS (2012)	3	0.079
Dissolved Oxygen (DO)	5	BIS (2012)	5	0.132
Electrical Conductivity (EC)	500	WHO (2011)	3	0.079
Total Hardness (TH)	200	BIS (2012)	3	0.079
pH	6.5-8.5	BIS (2012)	4	0.105
Sulphate (SO_4^{2-})	200	BIS (2012)	3	0.079
Total Dissolved Solids (TDS)	500	BIS (2012)	4	0.105

Turbidity (Turb.)	1	BIS (2012)	4	0.105
Potassium (K)	12	BIS (2012)	2	0.053
Magnesium (Mg)	30	BIS (2012)	2	0.053
Sum			38	1.000

Second step involves calculation of relative weights (W_i) using the assigned weights with the formula:

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i} \quad (1)$$

Where W_i is the relative weight, w_i is the assigned weight of each parameter and n is the number of parameters.

Third step involves assigning each parameter a quality rating (q_i) scale which is calculated as:

$$q_i = \frac{c_i}{s_i} \times 100 \quad (2)$$

Where c_i and s_i are the measured concentration of each chemical parameter and drinking water standard for each parameter in mg/l (except for pH and EC), respectively. The WQI is computed using subindex (SI_i) for each parameter which are given as:

$$SI_i = W_i \cdot q_i \quad (3)$$

$$WQI = \sum_{i=1}^n SI_i \quad (4)$$

The calculated WQI values are categorized into five groups based on their suitability for drinking: excellent (<50), good (≤ 100), poor (≤ 200), very poor (≤ 300) and unsuitable (>300)^[25].

3.2.6 Principal Component Analysis - Absolute Principal Component Score - Multiple Linear Regression (PCA-APCS-MLR) Model

Principal Component Analysis (PCA) is a statistical method used to reduce the dimensionality of a dataset by replacing a large set of intercorrelated variables with a smaller set of independent variables. The original monitoring data was standardized through z-scale transformation in order to avoid misclassification due to wide differences in data dimensionality into a dimensionless form before generating a correlation

coefficient matrix^[26]. This standardization involves subtracting the observed concentration from the mean concentration and dividing by the standard deviation for each element across all observations^[27]. The Kaiser–Meyer–Olkin (KMO) and Bartlett’s test were performed to check the suitability of the data for PCA^{[28][29]}. The KMO statistic values above 0.5 and the significance level of Bartlett’s test of sphericity smaller than 0.05 are deemed acceptable^{[28][30]}. KMO values closer to 1 represent stronger correlations between indicators and therefore higher accuracy for factor analysis outcomes^[31]. Bartlett’s test of sphericity indicates whether the correlation matrix is an identity matrix, which would indicate that variables are unrelated^[29]. The principal components (PC) can be obtained as:

$$(A_z)_{ij} = a_{i1}C_{1j} + a_{i2}C_{2j} + a_{i3}C_{3j} + \dots + a_{im}C_{mj} \quad (5)$$

where A_z is the component score, a is the component loading, C is the measured value of the variable, i is the component number, j is the sample number, and m is the total number of variables^[32]. According to the Kaiser Principle, principal components (PCs) with eigenvalues greater than 1.0 were regarded as significant^{[32][33]}. To reduce the overlap of original variables over each PC, the varimax rotation method was conducted to achieve a simple structure where each variable strongly loads on one principal component and weakly on others^{[32][34]}. Loadings above 0.6 were considered significant for identifying potential sources^[35].

The component scores from the PCA are normalized to perform APCS-MLR for groundwater contaminant source apportionment. A detailed description of this method could be found in Thurston and Spengler (1985)^[27] and Rahman et al. (2021)^[34]. In brief, the APCS-MLR model assumes that the contaminant sources attribute linearly to the pollutant concentration at each sampling site. Hence, the concentration of each contaminant at each sampling site (C_{kj}) can be calculated by a multiple linear regression of the contribution of contaminant sources through Equation (6):

$$C_{kj} = r_{k0} + \sum_{i=1}^P r_{ki} \times APCS_{ij} \quad (6)$$

Where r_{k0} represents the constant term of multiple linear regression for pollutant k ; r_{ki} stands for the coefficient of multiple linear regression of the contaminant source i for the pollutant k ; $APCS_{ij}$ is the absolute principal component scores, and it can be obtained through Equations (7)-(9).

$$(Z_0)_k = -\bar{C}_k / \sigma_k \quad (7)$$

$$(A_0)_i = \sum_{k=1}^m S_{ki} \times (Z_0)_k \quad (8)$$

$$APCS_{ij} = (A_z)_{ij} - (A_0)_i \quad (9)$$

where $(Z_0)_k$ stands for the normalized concentration of contaminant k in a non-pollution site; $\bar{C}_k$ represents the mean concentration, and σ_k indicates the standard deviation of contaminant k ; $(A_0)_i$ is the principal component score in the non-pollution site; S_{ki} represents the score coefficient of component i for pollutant k ; $(A_z)_{ij}$ stands for the principal component score of sample j in principal component i . Here, $r_{ki} \times APCS_{ij}$ implies the contribution of contaminant source i to pollutant k in sample j . The average of all samples, $r_{ki} \times \overline{APCS}_i$ is established as the contribution of contaminant source i to pollutant k . Notably, the calculation process may yield negative values, potentially resulting in a total contribution of all pollutants surpassing 100%. Hence, Gholizadeh et al. (2016)^[32] proposed an absolute value method to calculate the contribution of contaminant sources to water quality parameters, as it is shown in Equations (10) and (11).

$$PC_{ki} = \frac{|r_{ki} \times \overline{APCS}_i|}{|r_{k0}| + \sum_{i=1}^p |r_{ki} \times \overline{APCS}_i|} \times 100\% \quad (10)$$

$$PC_k = \frac{|r_{k0}|}{|r_{k0}| + \sum_{i=1}^p |r_{ki} \times \overline{APCS}_i|} \times 100\% \quad (11)$$

where PC_{ki} stands for the relative contribution rate of contaminant source i to the pollutant k ; PC_k indicates the relative contribution rate of the unrecognized source to the pollutant k ; $\overline{APCS}_i$ is the average value of the absolute principal component scores of all samples.

3.3 RESULTS

3.3.1 Physicochemical analysis

To understand water's quality, its suitability for various uses, and its effects on the environment and human health, it is essential to study its physicochemical properties. Water samples collected seasonally from 38 sampling sites of Loktak Lake were tested in a wet laboratory for their various physicochemical properties. Water samples from the

Khordak site were unable to be collected during the pre-monsoon season of 2021 due to the absence of water caused by drying. The mean values of various water quality parameters during different seasons over the period of two years are given in Table 3.6a, b to Table 3.9a, b. Table 3.10 presents the descriptive data on concentrations of water quality parameters throughout several seasons, along with their desirable limits given by WHO and BIS.

3.3.1.1 Turbidity

In the first year of the monsoon season, the recorded mean turbidity (NTU) value was 9.72 ± 2.18 , ranging from 8.00 at Ningthoukhong ITI to 14.10 at Nashik Houbi. In post-monsoon, it was 10.12 ± 2.05 , ranging from 8.10 at Ngakra Kom to 13.50 at Upokpi Khunou, while in winter it was 4.97 ± 6.73 , ranging from 1.00 at Mayang Imphal (near Karang), Ningthoukhong ITI, Ithing, Thanga Salam, and Nashik Houbi to 38.00 at Khorda. The mean turbidity value (4.92 ± 4.68) varied between 2.00 at eleven (11) sites and 25.00 at Keibul Mayai Leikai in the pre-monsoon. The mean values of monsoon and post-monsoon were found above the desirable limit of 5 NTU as per WHO guidelines.

The mean turbidity (NTU) during the second year varied across seasons and locations. In the monsoon season, the mean turbidity ranged from 1.00 at eight locations to 48.00 at Thinungei, with a mean value of 8.37 ± 9.28 . In the post-monsoon season, the mean turbidity ranged from 1.00 at six locations to 33.00 at Laphupat Tera monsoon, with a mean value of 8.66 ± 7.3 . In the winter season, it was 3.16 ± 4.92 , ranging from 1.00 at sixteen sites to 29.00 at Mayang Imphal (II), and in the pre-monsoon it ranged from 1.00 at three sites to 58.00 at Khordak, with a mean value of 14.24 ± 16.26 . The mean values of monsoon, post-monsoon and pre-monsoon, were found above the desirable limit of 5 NTU. During the study period, the mean turbidity value was found to be lowest in the winter season at the range of 4.97 to 3.16 NTU (Figure 3.5).

3.3.1.2 Temperature

Throughout the initial year, the water temperature exhibited substantial variations across various seasons. The temperature during the monsoon season ranges from 28.2°C in Mayang Imphal (II) to 33.7°C in Naranshena and Sagram (IV), with a mean value of 31.36 ± 1.54 °C. In the post-monsoon season, the temperature ranges from 24°C in Ngakra Kom to 31.90°C in Karang, with a mean value of 26.97 ± 1.69 °C. The mean winter

temperature is $19.82 \pm 1.49^{\circ}\text{C}$, with a range of 16.70°C in Keinou (I) to 22.8°C in Karang. Lastly, during the pre-monsoon season, the temperature ranges from 24.6°C in Naranshena to 33.2°C in Laphupat Tera, with a mean value of $27.71 \pm 2.13^{\circ}\text{C}$.

The mean water temperature in the second year varied from 27.3°C (Mayang Imphal (II)) to 34.2°C (Mayang Imphal (near Karang)), with a mean value of $31.03 \pm 1.56^{\circ}\text{C}$. During the post-monsoon period, the temperature ranged from 24.30°C (Keinou (II)) to 30.00°C (Karang), with the mean of $26.53 \pm 1.43^{\circ}\text{C}$. The mean winter temperature are $19.18 \pm 2.00^{\circ}\text{C}$, with a range of 12.70°C (Keinou (I)) to 23.2°C (Karang). Lastly, during the pre-monsoon season, the temperature ranged from 24.00°C (Khoijuman) to 33.4°C (Laphupat Tera), with the mean value of $27.31 \pm 2.40^{\circ}\text{C}$. Seasonal response of temperature exhibits lowest temperature in the winter season during the study period at the range of 19.82 to 19.18°C (Figure 3.5).

3.3.1.3 Total dissolved solids (TDS)

In the first year of study, the mean TDS concentration (mg/L) during the monsoon was 127.01 ± 23.92 , with values ranging from 70.80 (Naranshena) to 195.00 (Mayang Imphal near Karang)). In the post-monsoon, it varied from 73.10 in Phubala to 342.00 in Keibul Mayai Leikai, with a mean value of 166.86 ± 52.08 . In the winter season, the lowest TDS was observed in Naranshena (98.60) and the highest in Khordak (279.00), resulting in a mean value of 160.12 ± 33.97 . Similarly, in the pre-monsoon, the lowest TDS was also observed in Naranshena (96.70), while Upokpi Khunou observed the highest with 231.00, resulting in a mean value of 150.02 ± 30.22 .

During the second year, the mean TDS concentration (mg/L) in monsoon was 169.89 ± 82.63 ranging from 97.5 (Ithing) to 478.00 (Khordak); in post-monsoon it was 154.75 ± 44.07 , varying from 65.60 (Sagram (III)) to 299.00 (Khordak). Like the previous year, the lowest TDS in winter was observed in Naranshena (98.60) and the highest in Khordak (238.00), with a mean value of 157.88 ± 30.13 . During pre-monsoon season, the site Naranshena also recorded the lowest TDS with 64.90 and the highest in Mayang Imphal (I) with 341.00, and a mean value of 175.18 ± 46.07 . All the values throughout the seasons were found to be within the desirable limit of 500 mg/L. The maximum TDS value was found during the post-monsoon and decreased in subsequent seasons. Seasonal

variation shows maximum TDS in post monsoon with 166.86 mg/L in the initial year while in second year pre-monsoon shows the highest having 175.18 mg/L (Figure 3.5).

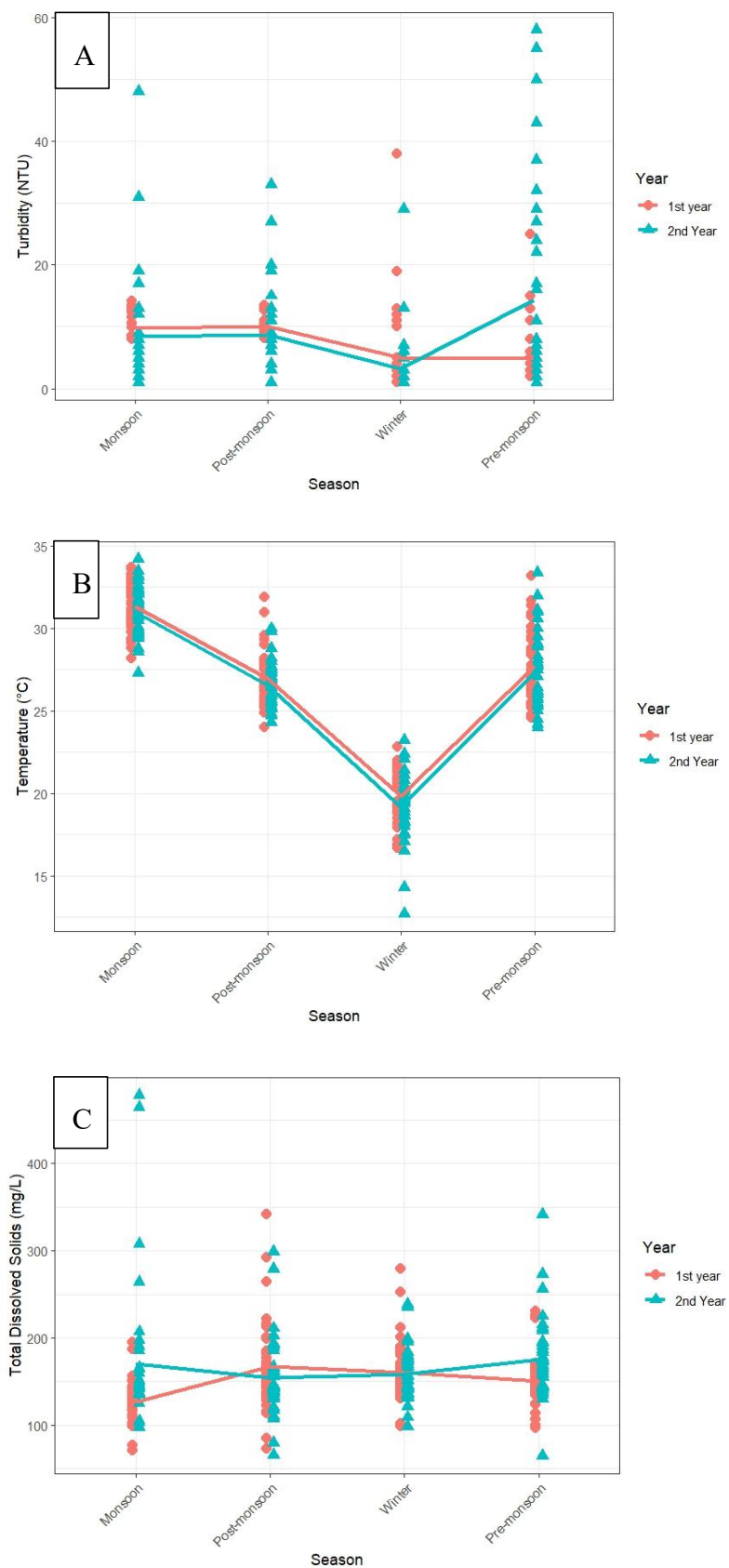


Figure 3.5: Seasonal variation of turbidity (A), temperature (B) and TDS (C) of the studied water samples during the study period (— 1st year and — 2nd year).

3.3.1.4 Electrical Conductivity (EC)

The electrical conductivity ($\mu\text{S}/\text{cm}$) of the samples during the first year, in the monsoon season, was found to be the lowest in Naranshena (98.70) and highest in Mayang Imphal (near Karang) (276.00), with a mean of 179.66 ± 34.52 . The lowest recorded value during the post-monsoon season was 101.60 (Phubala), while the highest recorded value was 483.00 (Keibul Mayai Leikai). The mean value this season was 233.18 ± 73.79 . In contrast, during the winter season, the lowest was 137.80 (Naranshena), and the highest was 390.00 (Khordak), with a mean of 223.57 ± 47.71 . In pre-monsoon, the value ranged from 135.80 (Naranshena) to 325.00 (Upokpi Khunou) with a mean value of 211.51 ± 43.04 .

Electrical conductivity (EC) in the second year recorded at the site Naranshena (136.60) was the lowest in the monsoon and the highest in Khordak (660), with a mean value of 237.02 ± 115.22 . In post-monsoon, EC ranged from 93.8 (Sagram (III)) to 418.00 (Khordak), with a mean of 217.14 ± 61.49 . The mean EC value during the winter months was 221.77 ± 41.56 , with a range of 138.70 (Naranshena) to 331.00 (Ningthoukhong Kha-Khunou). Lastly, in pre-monsoon, it ranged from 91.20 (Naranshena) to 476.00 (Mayang Imphal (I)) with a mean of 247.28 ± 67.89 .

Naranshena had the lowest value across three seasons except during the post-monsoon period in both years. The mean values of all the seasons were found to be within the desirable limit of 500 $\mu\text{S}/\text{cm}$. However, some sites, such as Khordak (660 $\mu\text{S}/\text{cm}$) and Khoijuman (647 $\mu\text{S}/\text{cm}$), exceeded this desirable limit during the monsoon season.

In winter, Mayang Imphal (I), Laphupat Tera, Khordak, Ithai, Yangoi, Upokpi Khunou, and Ningthoukhong Kha-Khunou recorded 356, 264, 390, 259, 254, 280, and 297 $\mu\text{S}/\text{cm}$, respectively, for the first year; and Mayang Imphal (I), Khordak, Nongmaikhiong, Ithai, Upokpi Khunou, Toubokpi, and Ningthoukhong Kha-Khunou recorded 271, 330, 278, 253, 258, 282, and 331, respectively, for the second year. In pre-monsoon Mayang Imphal (I), Khordak Ichin, Upokpi Khunou, and Ningthoukhong Kha-Khunou recorded 314, 254, 325, and 318 $\mu\text{S}/\text{cm}$, respectively, during the first year; and Mayang Imphal (I), Mayang Imphal (II), Mayang Imphal (near Karang), Phoubakchao, Laphupat Tera,

Khordak, Khordak Ichin, Nongmaikhong, Ithai Wapokpi, Kha-potshangbam, Thinungei, 2nd IB Post (KLNP), and Keibul Chingmei with 476, 270, 269, 256, 268, 357, 318, 383, 380, 296, 269, 296, and 287, respectively, from the second season with high values. Examining the seasonal variation, electrical conductivity (EC) was found to be highest in post-monsoon (233.18 $\mu\text{S}/\text{cm}$) and lowest in pre-monsoon (211.50 $\mu\text{S}/\text{cm}$) in the initial year. In contrast, in the second year, pre-monsoon recorded the highest EC with 247.28 $\mu\text{S}/\text{cm}$, and post-monsoon exhibited the lowest, having 217.13 $\mu\text{S}/\text{cm}$ (Figure 3.6).

3.3.1.5 Salinity

In the first year, the salinity levels (mg/L) during the monsoon period varied from 38.20 (Naranshena) to 92.50 (Mayang Imphal (near Karang)), with an average value of 62.31 ± 10.66 . In the post-monsoon period, the salinity levels ranged from 39.00 (Phubala) to 159.00 (Keibul Mayai Leikai), with a mean value of 78.84 ± 23.24 . During the winter season, the salinity levels exhibited a minimum value of 50.20 (Naranshena) and a maximum value of 129.00 (Khordak), resulting in a mean salinity of 76.84 ± 14.85 . In the pre-monsoon period, the salinity levels ranged from a minimum of 49.70 (Naranshena) to a maximum of 108.00 (Upokpi Khunou), with a mean salinity of 72.70 ± 13.43 . The salinity readings exhibited the highest mean values during the post-monsoon period, with minimal variations observed throughout the other seasons.

In the second year, the salinity levels during the monsoon period varied from 47.80 (Naranshena) to 218 (Khordak), with a mean value of 79.57 ± 37.23 . During post-monsoon, the salinity levels varied from 34.70 (Sagram (III)) to 137.00 (Khordak), with a mean value of 72.85 ± 19.47 . During the winter season, a minimum value of 47.30 was observed in Naranshena, and a maximum value was observed in Ningthoukhong Kha-Khunou with 108.00, resulting in a mean salinity of 72.99 ± 13.23 . In the pre-monsoon period, the salinity levels ranged from a minimum of 36.1 (Naranshena) to a maximum of 161.00 (Mayang Imphal (I)), with a mean salinity of 83.71 ± 20.64 . Examining the seasonal variation during the study period, post-monsoon shows the highest (78.84 mg/L) in the initial year but exhibited the lowest in the second year with 72.85 mg/L (Figure 3.6, and Table 3.10).

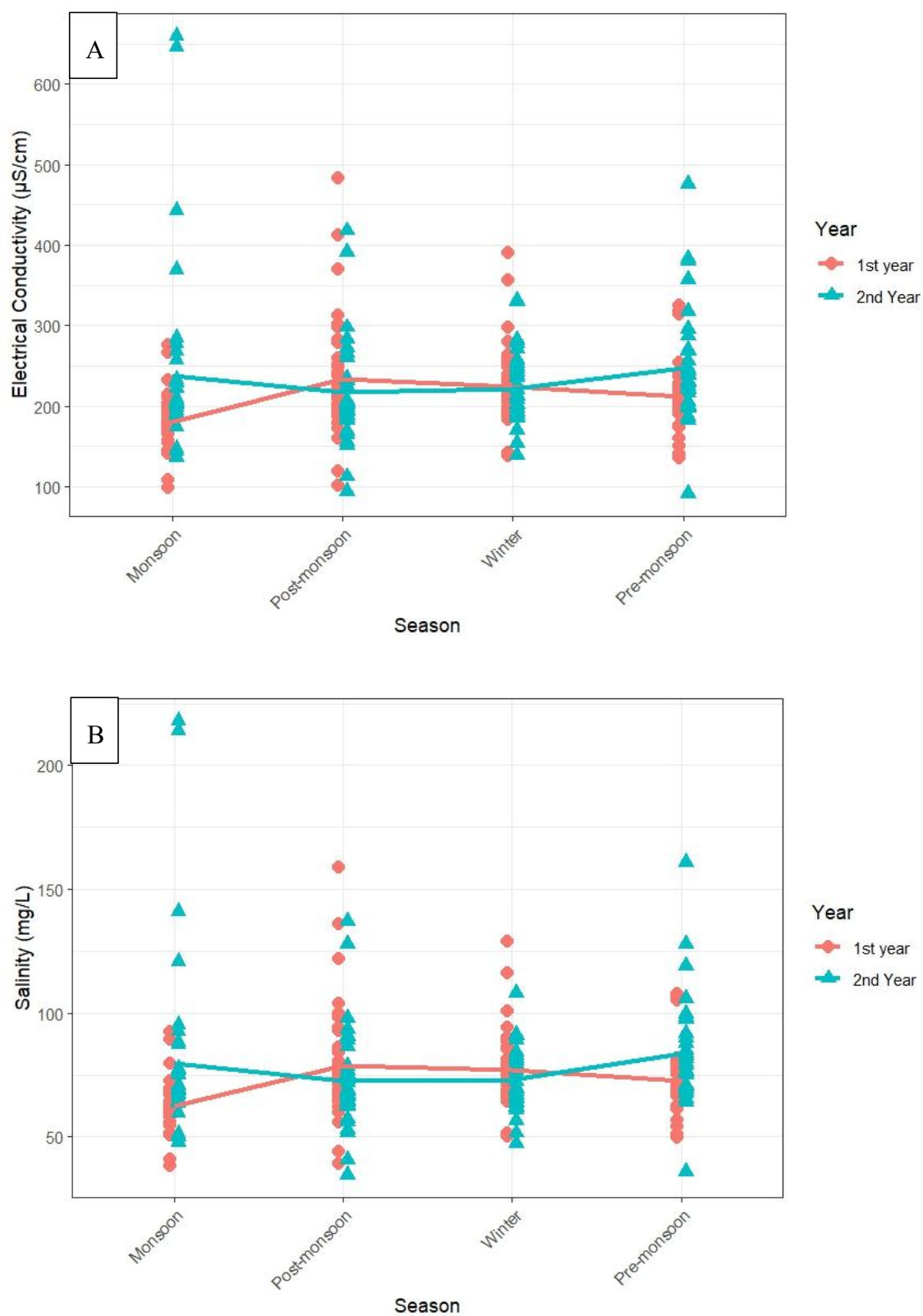


Figure 3.6: Seasonal variation of electrical conductivity (A) and salinity (B) of the studied water samples during the study period (— 1st year and — 2nd year).

Table 3.7a: Mean values of physicochemical parameters of water estimated from 38 samplings sites in Loktak lake of Manipur during monsoon season

Para- meters	Alkalinity (mg/L)		Calcium (mg/L)		Chloride (mg/L)		DO (mg/L)		Sulphate (mg/L)		Hardness (mg/L)		pH	
Sites	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
1	123.33	175.00	16.03	18.04	7.09	24.82	5.2	5.8	1.14	1.46	29.17	120.00	6.86	7.17
2	89.17	75.00	8.68	10.02	4.73	12.53	5	4.7	1.42	1.46	26.67	55.67	7.38	7.06
3	100.00	119.17	12.02	13.76	26.00	15.60	4.8	2.6	1.03	1.20	24.17	70.00	7.23	7.09
4	116.67	106.67	12.69	11.42	4.58	10.75	6.3	3.3	1.36	1.16	30.00	50.00	7.1	7.14
5	100.00	121.67	14.03	10.35	2.36	6.62	5.1	5.1	1.34	1.17	35.00	55.00	7.29	7.63
6	107.50	86.67	16.03	12.56	0.59	25.29	5.1	4.6	1.27	1.33	34.17	62.50	7.14	6.94
7	100.00	116.67	12.69	14.03	6.75	4.61	5.3	4.4	1.37	1.02	30.00	70.17	7.22	7.52
8	107.50	293.33	10.02	37.68	3.55	10.64	5.1	4.1	2.09	2.86	30.00	220.00	7.39	7.23
9	101.67	100.00	10.69	11.89	4.14	2.84	5.9	3.3	0.95	1.02	25.00	73.50	7.09	6.91
10	93.33	124.17	11.36	14.63	5.32	6.03	5.2	2.5	1.13	1.12	24.17	60.17	7.13	6.88
11	106.67	101.67	10.69	11.02	6.50	9.57	5.3	3.6	1.24	1.18	23.33	52.50	7.22	7.08
12	130.00	80.00	6.01	8.02	5.32	6.38	4.8	4	1.11	1.31	15.83	43.67	6.91	7.05

13	95.83	93.33	8.68	11.02	5.91	3.55	4.7	4.2	1.14	1.51	20.00	69.50	6.86	6.94
14	80.00	99.17	13.36	12.02	2.95	3.78	7	3.8	1.02	1.61	21.67	59.33	7.2	7.19
15	93.33	205.83	16.03	59.85	5.91	3.07	6.5	4.3	1.12	2.46	30.00	255.00	7.04	7.43
16	87.50	156.67	12.02	27.45	9.45	7.09	4.8	4.7	1.23	1.23	25.00	100.50	6.96	7.33
17	82.50	132.50	9.35	12.02	4.73	9.57	7.5	5.2	1.25	1.77	24.17	79.50	7.28	6.79
18	92.50	95.00	10.69	12.42	7.09	2.84	5.8	3.6	1.16	1.06	15.00	55.00	7.36	7.26
19	98.33	113.33	10.02	15.63	7.09	2.25	4.8	4.4	1.40	1.00	25.00	70.00	7.54	7.34
20	110.83	90.00	14.03	8.62	9.45	4.96	4.6	4.7	1.02	0.99	20.00	47.83	7.43	7.22
21	75.00	110.83	20.71	8.48	4.73	1.77	5	5.4	1.07	2.32	20.00	53.50	7.62	6.53
22	95.83	87.50	6.68	5.61	6.49	4.25	5.1	4.3	1.03	1.26	15.00	37.83	8.05	6.99
23	67.50	59.17	10.02	5.41	10.04	7.09	4.6	6.2	1.01	1.31	15.00	33.50	7.61	7.25
24	62.50	50.00	6.01	5.14	10.64	3.31	5.8	4.9	2.54	1.32	15.83	34.00	7.3	6.95
25	105.83	71.67	8.02	6.01	4.14	2.48	7.4	5.7	2.10	1.39	20.00	40.00	7.17	6.79
26	101.67	105.00	10.02	11.42	2.36	4.25	4.8	4.8	1.05	1.00	25.00	55.00	7.24	7.27
27	101.67	100.00	14.70	10.62	1.77	5.32	5	3.7	1.27	0.95	25.00	65.00	7.31	6.91
28	107.50	89.17	16.03	11.42	4.14	1.77	4.9	3.3	1.02	1.08	30.00	56.67	7.43	7.07

29	100.83	106.67	14.03	10.29	7.68	7.09	4.1	5.3	1.16	0.86	24.17	61.00	7.44	7.49
30	113.33	89.17	13.36	11.89	7.09	4.02	4.2	6.9	1.33	0.95	25.00	61.50	6.93	6.91
31	100.00	100.00	12.69	14.16	4.73	3.19	4.5	4.9	1.09	1.04	21.67	64.83	6.86	7.25
32	98.33	104.17	12.02	11.02	7.09	7.09	4.5	4.4	0.95	0.92	25.00	56.00	6.39	6.98
33	87.50	105.00	20.04	11.42	5.32	5.32	4.4	4.4	1.07	0.88	20.00	64.33	7.27	6.87
34	93.33	95.00	10.02	11.16	8.86	5.32	5	4.7	1.39	0.97	25.00	61.00	7.44	7.00
35	90.00	85.83	8.02	14.03	11.23	4.25	4.6	5.2	1.28	0.87	21.67	62.50	7.02	7.34
36	122.50	110.00	16.70	12.42	10.64	6.38	4.6	5.8	1.42	0.90	35.00	62.17	7.04	7.01
37	120.00	132.50	10.02	11.62	21.27	7.33	4.8	3.6	1.20	0.83	25.00	62.50	6.86	6.81
38	87.50	105.83	12.02	10.89	13.00	6.74	4.7	3.3	1.18	0.89	15.00	61.50	6.86	6.78

Table 3.7b: Mean values of physicochemical parameters of water estimated from 38 samplings sites in Loktak lake of Manipur during

monsoon season

Para- meters	K (mg/L)		Mg (mg/L)		Salinity (mg/L)		EC (µS/cm)		TDS (mg/L)		Turbidity (NTU)		Temp (°C)	
Sites	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
1	1.32	10.07	4.22	17.99	69.2	141.0	204.0	443.0	144.0	308.0	8.3	9.0	32.4	29.5
2	1.03	1.04	2.83	6.86	67.5	64.9	196.2	191.8	140.0	135.0	8.2	1.0	28.2	27.3
3	2.47	4.58	6.13	8.42	92.5	87.3	276.0	258.0	195.0	186.0	8.1	5.0	33.6	34.2
4	2.90	0.67	8.76	6.93	72.7	64.2	210.0	190.6	150.0	136.0	10.6	3.0	30.5	31.5
5	3.29	0.74	9.16	7.35	66.7	64.1	192.1	188.7	138.0	137.0	8.1	12.0	30.1	29.6
6	1.03	1.44	6.13	9.71	66.9	95.4	194.7	285.0	138.0	207.0	8.6	17.0	29.4	32.3
7	1.13	1.10	1.02	11.31	68.1	76.9	198.8	229.0	141.0	165.0	9.9	8.0	32.1	31.1
8	2.12	3.97	3.13	41.13	72.8	218	214.0	660.0	151.0	478.0	8.4	1.0	30.7	30.1
9	2.05	4.45	7.92	13.14	66.8	88.2	190.8	268.0	137.0	191.0	8.5	19.0	29.2	29.8
10	2.14	2.44	5.66	9.34	59.8	75.6	186.7	222.0	132.0	160.0	8.6	19.0	30.1	29.4
11	1.48	1.40	9.97	7.64	69.5	68.3	201.0	204.0	143.0	145.0	8.5	1.0	32.8	33.5
12	1.94	2.17	4.72	6.87	50.9	51.5	141.4	147.6	123.0	105.0	8.5	6.0	33.2	32.6

13	1.75	2.03	4.92	12.05	54.5	69.6	154.6	204.0	101.0	147.0	8.1	4.0	31.9	32.1
14	2.26	2.05	5.86	12.80	51.6	69.7	144.8	205.0	109.0	145.0	8.2	7.0	33.0	32.2
15	2.29	1.00	8.42	26.59	62.6	214	179.8	647.0	103.0	464.0	11.5	4.0	31.2	30.5
16	3.42	4.41	6.40	9.69	62.7	121	179.6	370.0	128.0	264.0	8.1	17.0	28.8	29.7
17	1.71	2.43	4.94	12.05	54.8	92.8	155.0	278.0	110.0	198.0	8.1	13.0	32.3	31.8
18	1.69	1.88	4.57	7.64	59.8	71	172.3	210.0	121.0	150.0	8.2	12.0	33.3	32.6
19	1.94	1.45	6.48	8.88	60.2	77.6	172.9	233.0	123.0	152.0	8.1	4.0	32.4	31.3
20	1.86	1.73	4.60	7.88	59.2	64.6	169.2	190.8	120.0	166.0	8.0	6.0	30.6	29.8
21	2.16	1.78	5.94	10.24	51.2	59.8	142.1	174.9	102.0	136.0	8.1	1.0	31.6	30.9
22	1.93	3.59	4.72	8.90	50.7	50.3	140.1	143.8	99.3	125.0	8.2	48.0	32.5	31.4
23	2.03	4.31	4.93	13.25	41.0	48.1	108.2	136.8	77.2	103.0	8.1	31.0	32.8	32.2
24	1.89	12.98	5.10	16.33	38.2	47.8	98.7	136.6	70.8	98.2	8.2	8.0	33.7	33.1
25	4.28	20.85	6.40	26.32	60.4	50.1	179.4	144.3	123.0	97.5	8.2	6.0	30.4	29.9
26	2.45	17.66	6.06	45.36	62.2	64.4	182.7	188.1	127.0	103.0	8.2	4.0	31.0	30.7
27	2.25	34.94	5.82	64.53	63.3	69.0	194.4	207.0	130.0	147.0	8.3	1.0	31.9	32.4
28	3.16	41.52	4.95	68.27	66.7	63.7	177.9	188.3	138.0	135.0	8.5	8.0	31.6	30.5

29	5.18	86.65	7.51	88.17	61.9	77.2	172.2	230.0	127.0	165.0	12.7	2.0	30.2	29.6
30	2.75	65.23	6.54	90.07	59.9	68.8	167.8	203.0	122.0	145.0	13.4	1.0	31.5	31.7
31	3.26	75.34	4.69	93.78	58.9	65.7	165.9	194.1	120.0	138.0	14.1	7.0	30.9	30.8
32	1.02	92.29	4.64	92.20	58.0	67.7	166.1	201.0	117.0	144.0	12.9	4.0	33.2	32.4
33	1.68	111.22	5.12	96.69	58.4	67.1	169.0	198.8	118.0	142.0	12.8	5.0	33.7	33.2
34	5.42	103.64	7.32	94.34	59.2	68.5	187.2	203.0	120.0	144.0	13.5	6.0	32.6	32.9
35	3.67	80.82	6.82	107.94	64.2	64.7	186.2	192.4	133.0	137.0	12.4	4.0	30.4	29.7
36	2.69	153.46	9.50	123.39	79.6	70.6	23.02	210.0	156.0	150.0	13.4	1.0	28.8	28.6
37	2.71	162.32	7.82	130.33	89.5	75.1	266.0	223.0	187.0	160.0	13.1	12.0	29.1	28.8
38	1.99	175.74	5.84	130.88	55.8	69.4	157.3	206.0	112.0	147.0	12.8	1.0	29.8	29.4

Table 3.8a: Mean values of physicochemical parameters of water estimated from 38 samplings sites in Loktak lake of Manipur during post-monsoon season

Para- meters	Alkalinity (mg/L)		Calcium (mg/L)		Chloride (mg/L)		DO (mg/L)		Sulphate (mg/L)		Sulphate (mg/L)		Sulphate (mg/L)	
Sites	2020	2021	2020	2021	2020	2020	2020	2020	2020	2020	2020	2021	2020	2021
1	140.00	212.50	20.04	32.67	2.36	0.95	0.95	0.95	0.95	0.95	30.00	107.17	7.29	6.83
2	155.00	139.17	18.70	13.03	3.55	1.10	1.10	1.10	1.10	1.10	56.67	62.50	7.84	6.91
3	145.00	107.50	10.02	11.89	7.09	0.97	0.97	0.97	0.97	0.97	30.00	53.50	7.18	6.80
4	137.33	105.83	10.02	15.76	1.18	1.14	1.14	1.14	1.14	1.14	30.00	66.50	7.30	6.77
5	120.00	100.00	12.02	21.44	10.64	1.16	1.16	1.16	1.16	1.16	31.67	63.17	7.26	7.05
6	56.67	105.00	16.03	25.05	-	1.29	1.29	1.29	1.29	1.29	30.00	62.67	7.44	7.42
7	96.67	100.00	12.69	16.03	4.73	1.08	1.08	1.08	1.08	1.08	35.00	74.00	7.23	7.21
8	110.00	170.00	15.36	21.31	2.36	1.35	1.35	1.35	1.35	1.35	35.83	127.33	7.36	7.32
9	141.67	96.67	10.02	16.03	1.18	1.06	1.06	1.06	1.06	1.06	29.17	61.50	7.55	7.19
10	125.00	105.00	14.03	12.63	7.09	1.25	1.25	1.25	1.25	1.25	31.67	67.50	7.31	6.85
11	75.00	100.83	12.02	12.76	3.55	1.59	1.59	1.59	1.59	1.59	25.00	62.50	7.52	7.24
12	71.67	76.67	14.70	10.82	1.18	1.14	1.14	1.14	1.14	1.14	20.00	40.00	7.10	7.05
13	128.33	117.50	12.69	8.62	8.27	1.35	1.35	1.35	1.35	1.35	31.67	60.00	7.26	7.21

14	176.67	75.00	15.36	19.77	7.09	2.31	2.31	2.31	2.31	2.31	30.00	40.17	7.53	7.33
15	150.00	129.17	12.02	30.06	13.00	1.21	1.21	1.21	1.21	1.21	33.33	86.50	7.30	6.89
16	141.67	100.00	12.69	18.44	4.73	1.32	1.32	1.32	1.32	1.32	28.33	51.50	7.25	7.07
17	105.00	87.50	13.36	9.95	14.18	1.18	1.18	1.18	1.18	1.18	30.00	59.67	7.03	6.74
18	56.67	107.50	14.03	17.03	7.09	1.16	1.16	1.16	1.16	1.16	34.17	61.50	7.52	7.30
19	100.00	106.67	10.02	12.63	3.55	1.34	1.34	1.34	1.34	1.34	25.00	71.50	7.43	7.36
20	100.00	100.00	10.69	11.02	-	1.05	1.05	1.05	1.05	1.05	22.50	60.00	7.40	7.46
21	85.00	100.00	10.69	12.42	-	1.32	1.32	1.32	1.32	1.32	30.00	71.50	7.42	7.42
22	136.67	78.33	11.36	8.02	2.36	1.29	1.29	1.29	1.29	1.29	25.00	42.50	7.30	7.45
23	75.00	71.67	5.34	6.15	-	1.15	1.15	1.15	1.15	1.15	21.67	41.83	7.23	7.13
24	91.67	56.67	8.02	5.61	-	1.00	1.00	1.00	1.00	1.00	10.00	27.50	7.37	6.78
25	85.00	90.00	8.68	8.42	4.73	0.98	0.98	0.98	0.98	0.98	23.33	54.67	7.35	7.09
26	98.33	82.50	10.02	9.89	1.18	1.06	1.06	1.06	1.06	1.06	20.00	59.00	7.30	7.02
27	115.00	111.67	9.35	10.62	-	1.04	1.04	1.04	1.04	1.04	23.33	57.50	7.61	6.99
28	95.00	100.00	10.69	11.62	-	1.27	1.27	1.27	1.27	1.27	30.00	67.83	7.44	7.06
29	113.33	90.00	8.68	10.89	-	1.07	1.07	1.07	1.07	1.07	20.00	57.00	7.44	7.12

30	136.67	110.00	12.02	13.23	-	1.15	1.15	1.15	1.15	1.15	18.33	63.17	7.23	7.22
31	85.00	87.50	10.02	15.03	-	1.14	1.14	1.14	1.14	1.14	25.00	62.50	7.32	7.24
32	111.67	89.17	6.68	12.02	-	1.39	1.39	1.39	1.39	1.39	24.17	62.50	7.18	6.63
33	100.00	95.00	9.35	13.03	21.27	1.18	1.18	1.18	1.18	1.18	30.00	61.50	7.18	6.84
34	78.33	62.50	10.69	7.48	4.73	1.13	1.13	1.13	1.13	1.13	25.00	51.00	7.13	7.08
35	60.00	76.67	6.68	8.62	-	0.98	0.98	0.98	0.98	0.98	15.00	49.33	7.54	6.98
36	125.00	125.00	10.02	15.63	2.36	1.26	1.26	1.26	1.26	1.26	18.33	78.00	7.10	6.54
37	75.00	155.00	17.37	22.31	7.09	1.07	1.07	1.07	1.07	1.07	25.00	95.00	6.89	6.86
38	100.00	105.00	4.68	10.02	3.55	1.12	1.12	1.12	1.12	1.12	20.00	64.67	7.03	6.84

Note: (-) denotes no values detected.

Table 3.8b: Mean values of physicochemical parameters of water estimated from 38 samplings sites in Loktak lake of Manipur during post-monsoon season

Para- meters	K (mg/L)		Mg (mg/L)		Salinity (mg/L)		EC (μ S/cm)		TDS (mg/L)		Turbidity (NTU)		Temp (°C)	
Sites	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
1	1.92	560.37	1.92	560.37	76.70	128.00	229.00	391.00	168.00	279.00	8.70	20.00	25.20	24.30
2	1.88	197.97	1.88	197.97	122.00	72.20	370.00	221.00	264.00	156.00	8.60	3.00	25.40	25.10
3	3.99	193.06	3.99	193.06	72.10	63.00	214.00	187.70	154.00	133.00	9.50	6.00	26.20	25.60
4	3.05	170.10	3.05	170.10	71.20	75.20	209.00	224.00	151.00	160.00	13.30	12.00	27.50	26.60
5	2.04	173.12	2.04	173.12	67.70	75.40	202.00	223.00	145.00	162.00	8.40	1.00	26.50	26.70
6	2.10	182.55	2.10	182.55	74.90	76.90	222.00	225.00	159.00	163.00	8.40	6.00	24.90	26.90
7	3.12	205.70	3.12	205.70	98.00	91.00	297.00	272.00	213.00	193.00	8.20	33.00	28.10	27.70
8	1.64	329.51	1.64	329.51	80.70	137.00	238.00	418.00	170.00	299.00	9.70	19.00	28.00	27.60
9	2.44	184.59	2.44	184.59	74.90	73.20	223.00	223.00	160.00	158.00	10.60	15.00	29.30	28.20
10	2.33	190.73	2.33	190.73	80.50	77.00	241.00	232.00	172.00	166.00	8.60	13.00	28.20	27.30
11	1.29	131.52	1.29	131.52	78.90	69.10	237.00	207.00	168.00	146.00	10.00	1.00	25.70	26.00
12	3.55	177.80	3.55	177.80	56.10	52.90	159.60	154.80	116.00	110.00	9.20	1.00	25.90	25.70

13	17.53	190.33	17.53	190.33	68.90	66.30	202.00	196.00	147.00	138.00	8.60	3.00	25.40	24.70
14	28.35	203.45	28.35	203.45	86.30	57.30	260.00	165.30	185.00	117.00	8.50	3.00	25.80	24.30
15	135.19	213.32	135.19	213.32	93.00	90.40	279.00	273.00	201.00	194.00	8.80	15.00	26.70	26.40
16	180.45	207.53	180.45	207.53	84.10	73.90	251.00	223.00	182.00	158.00	8.40	27.00	25.60	25.30
17	369.71	208.19	369.71	208.19	84.80	69.30	248.00	206.00	177.00	146.00	8.50	7.00	27.10	26.80
18	179.53	128.48	179.53	128.48	104.00	78.60	313.00	234.00	222.00	167.00	13.50	6.00	27.70	27.00
19	207.98	259.32	207.98	259.32	68.60	86.70	201.00	260.00	146.00	186.00	12.60	3.00	28.00	28.20
20	187.68	116.52	187.68	116.52	62.00	67.60	178.50	201.00	129.00	143.00	12.70	4.00	27.80	27.60
21	249.20	258.71	249.20	258.71	94.20	93.60	279.00	283.00	201.00	203.00	13.10	15.00	28.10	27.40
22	774.61	152.41	774.61	152.41	136.00	56.30	412.00	169.20	292.00	120.00	12.80	8.00	27.60	27.10
23	188.66	124.44	188.66	124.44	39.00	51.60	101.60	150.40	73.10	107.00	13.00	8.00	25.20	25.70
24	168.28	143.09	168.28	143.09	44.20	40.80	118.90	112.40	85.40	80.00	12.80	7.00	25.40	24.70
25	178.30	95.87	178.30	95.87	76.20	66.70	226.00	195.30	160.00	140.00	12.70	1.00	29.60	28.80
26	201.42	109.21	201.42	109.21	66.00	64.20	190.80	188.70	136.00	136.00	13.40	15.00	29.00	28.00
27	165.58	137.53	165.58	137.53	65.60	68.60	189.70	203.00	136.00	145.00	12.80	3.00	31.00	29.80
28	158.12	127.24	158.12	127.24	65.30	67.30	189.30	198.80	133.00	142.00	12.60	4.00	31.90	30.00

29	165.39	101.59	165.39	101.59	59.90	68.90	172.20	204.00	123.00	146.00	8.20	1.00	27.80	26.50
30	119.00	110.91	119.00	110.91	64.40	62.50	187.70	184.50	134.00	132.00	8.20	9.00	25.60	26.80
31	116.19	99.71	116.19	99.71	67.80	65.20	198.50	193.70	142.00	138.00	8.30	6.00	25.70	25.90
32	190.78	105.38	190.78	105.38	56.00	64.60	159.70	194.40	114.00	138.00	8.10	9.00	24.00	24.80
33	759.40	104.57	759.40	104.57	100.00	64.70	302.00	194.90	216.00	139.00	8.30	8.00	26.60	26.00
34	154.04	231.92	154.04	231.92	66.20	34.70	192.90	93.80	138.00	65.60	8.40	1.00	25.40	25.20
35	110.96	124.47	110.96	124.47	159.00	63.10	483.00	182.40	342.00	130.00	8.30	13.00	26.80	27.50
36	155.42	145.34	155.42	145.34	72.50	89.00	213.00	266.00	154.00	190.00	8.80	8.00	27.00	25.50
37	195.08	163.12	195.08	163.12	93.70	97.90	283.00	298.00	199.00	211.00	8.90	11.00	26.30	24.70
38	188.09	104.63	188.09	104.63	64.40	67.50	187.60	202.00	133.00	144.00	11.00	4.00	26.80	25.70

Table 3.9a: Mean values of physicochemical parameters of water estimated from 38 samplings sites in Loktak lake of Manipur during winter season

Para- meters	Alkalinity (mg/L)		Calcium (mg/L)		Chloride (mg/L)		DO (mg/L)		Sulphate (mg/L)		Hardness (mg/L)		pH	
Sites	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
1	128.91	126.67	14.03	13.63	-	9.93	4.4	3.7	1.16	1.27	100.00	76.00	6.73	6.95
2	99.63	110.00	11.16	13.63	7.09	4.25	3.9	4	1.20	1.10	75.00	72.00	6.38	6.81
3	72.39	82.50	11.02	8.82	-	0.12	4	11.2	1.50	1.35	70.00	56.00	6.78	7.03
4	85.40	117.50	10.02	14.43	3.55	3.55	4.7	9.4	1.64	1.24	67.50	78.00	6.87	6.84
5	75.23	109.17	10.29	12.45	4.73	6.62	5.2	5.2	1.74	1.95	65.33	74.27	8.39	6.91
6	61.81	100.83	10.22	12.93	-	2.48	7.8	8.1	1.83	1.81	60.00	68.00	9.05	8.03
7	111.83	138.33	12.02	13.63	5.91	1.77	7.7	7	1.81	1.11	76.67	80.00	6.59	7.57
8	117.93	158.33	18.04	13.31	-	8.86	3.5	5.7	1.27	1.11	110.83	100.00	6.51	6.99
9	92.31	121.67	10.35	14.75	4.73	2.01	4.7	8	0.98	1.24	61.67	68.00	7.54	7.04
10	79.30	125.00	12.29	16.83	2.36	6.97	4.4	4.8	1.59	1.40	72.50	76.00	6.81	6.83
11	75.64	135.00	10.89	13.63	5.91	6.26	4.8	4.2	2.05	1.45	76.17	77.73	7.13	6.89
12	99.63	117.50	9.29	8.82	7.09	7.09	4.2	7.6	1.21	1.27	77.50	54.00	6.3	6.95
13	65.47	76.67	9.08	8.07	-	6.03	6.5	8.1	1.32	1.67	55.00	52.00	7.15	7.30

14	61.41	72.50	7.41	5.61	2.36	7.92	7.9	6.6	1.19	1.11	45.83	35.87	7.65	7.07
15	73.20	120.00	10.02	11.33	3.55	6.38	4.3	9.2	1.13	1.09	62.50	68.00	6.78	7.28
16	77.27	104.17	11.16	9.62	1.18	9.57	5.4	6	1.08	1.14	69.50	52.00	7.12	6.95
17	72.39	119.17	8.02	10.42	2.36	6.38	4.6	8.3	0.97	1.16	63.33	64.00	7.23	6.96
18	86.21	137.50	16.37	16.94	8.27	3.55	4.7	6.1	1.20	1.46	83.17	75.87	6.88	7.16
19	87.03	145.00	10.69	15.23	2.36	10.16	4.3	6.2	1.10	1.78	67.50	72.00	7.12	7.04
20	86.62	142.50	13.43	12.02	-	3.43	4.2	6.6	0.97	0.95	65.00	67.73	6.99	7.15
21	85.81	145.83	11.69	14.16	7.09	13.12	7.1	6.7	1.30	1.84	85.33	82.00	6.93	7.13
22	73.20	95.83	7.75	9.94	5.91	7.09	3.7	7.7	1.05	0.97	55.33	60.00	6.73	7.27
23	55.71	85.00	6.81	6.52	-	6.03	3.4	7.7	1.05	0.99	44.50	44.13	6.82	7.48
24	50.83	69.17	5.01	4.81	-	6.38	3.8	8.2	1.05	1.03	43.33	41.73	7	6.99
25	68.32	110.00	8.88	11.01	-	4.02	4.1	4.7	1.05	0.89	60.00	64.00	6.79	7.16
26	73.20	125.83	9.02	11.54	1.18	5.32	7	5.6	0.98	1.09	62.17	66.00	6.66	7.06
27	67.10	120.00	11.36	10.42	2.36	3.78	3.9	3.8	1.40	1.00	74.17	58.00	7.34	7.41
28	85.40	116.67	12.02	14.38	-	3.55	4.1	5.9	1.38	2.38	80.00	70.27	7.03	7.46
29	73.20	110.00	11.89	8.82	2.36	3.55	4.2	5.8	1.00	0.95	60.00	62.00	6.92	7.36

30	80.93	95.00	10.29	11.22	-	2.36	6.3	3.6	1.18	1.03	65.83	52.00	6.54	7.08
31	79.30	95.00	11.02	9.57	-	2.13	3.9	6.2	1.13	1.05	70.00	60.13	7.1	7.37
32	72.39	125.00	14.03	9.14	1.18	8.74	4.5	3.5	1.04	1.07	59.17	56.00	6.78	7.23
33	74.01	105.00	10.02	9.62	2.36	4.61	4.1	7.9	1.05	0.97	60.00	52.00	6.62	7.06
34	80.11	109.17	9.62	11.22	4.73	4.14	4.6	3	1.30	1.03	65.00	50.00	6.67	6.86
35	74.83	105.00	8.62	7.21	-	5.32	3.8	4.4	1.11	0.98	50.67	54.00	6.8	6.67
36	74.01	121.67	8.28	11.12	3.55	5.32	4.3	3.4	1.03	1.07	65.33	56.27	6.78	6.59
37	78.08	108.52	8.02	10.63	7.09	6.56	3.6	3.7	1.14	1.03	74.17	52.39	6.56	6.87
38	79.30	112.50	8.88	9.62	2.36	5.55	3.7	3.2	1.19	1.01	85.00	50.00	6.65	6.91

Note: (-) denotes no values detected.

Table 3.9b: Mean values of physicochemical parameters of water estimated from 38 samplings sites in Loktak lake of Manipur during winter season

Para- meters	K (mg/L)		Mg (mg/L)		Salinity (mg/L)		EC (μ S/cm)		TDS (mg/L)		Turbidity (NTU)		Temp (°C)	
Sites	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
1	1.41	1.68	8.59	3.58	116	89.3	356	271	252	196	3	13	21.7	21.4
2	1.69	0.77	4.49	2.97	81.3	81.9	239	249	171	178	2	29	20.3	18.3
3	0.51	0.33	4.30	2.54	75.7	61.8	218	185.4	157	133	1	2	20.5	19.8
4	0.51	0.42	5.05	3.45	77.7	77	226	238	161	167	2	3	19.3	18
5	0.31	0.31	4.34	3.21	74.2	77.9	215	235	154	168	2	3	17.9	17.5
6	0.51	0.31	4.24	3.18	72.4	75.1	211	226	148	163	2	2	20.8	19.6
7	0.49	0.26	3.49	4.03	90.1	79.7	264	243	190	175	2	3	19.4	19.6
8	0.28	0.77	5.10	5.70	129	108	390	330	279	238	38	7	21	20.4
9	0.45	0.32	3.84	2.86	79.2	79.6	229	242	165	173	5	1	19.1	18.2
10	0.35	0.62	1.82	3.49	85.4	91.5	249	278	180	199	12	1	18.9	18
11	0.38	0.44	4.72	3.19	88.5	83	259	253	186	180	2	1	18.2	17.1
12	0.33	0.53	2.49	2.33	86.3	67.3	254	203	182	145	19	1	19.3	18.6

13	0.73	0.81	3.75	2.37	72	67	208	202	149	144	5	1	16.7	12.7
14	0.42	0.74	4.82	1.66	64.2	51.6	182.9	153.7	131	109	3	1	16.9	14.3
15	0.61	0.86	4.01	2.79	72	77.8	209	239	149	170	5	2	17.2	16.5
16	0.95	0.94	2.38	2.70	75.5	72.3	220	221	157	156	4	2	19.5	19.1
17	0.33	0.85	3.65	2.78	73.5	80.6	213	246	153	176	4	3	21.4	20.8
18	0.29	0.45	4.83	2.60	94.4	84.3	280	258	201	184	13	1	19.2	19.5
19	0.36	1.03	3.15	3.66	81.1	91	236	282	169	199	3	2	21.7	22.1
20	0.50	0.48	3.91	3.06	79.8	72.3	233	221	168	157	1	1	19.2	18.3
21	0.64	1.37	3.37	4.19	101	108	297	331	212	235	11	7	19	18.3
22	0.35	0.54	1.89	2.81	67.2	68.7	193	208	138	146	10	2	20.6	19.7
23	1.20	0.44	2.45	2.27	51.6	56.8	141.8	170.5	102	121	2	1	18.5	18.9
24	0.46	0.39	2.70	1.92	50.2	47.3	137.8	138.7	98.6	98.6	4	2	18.9	18.7
25	0.43	0.41	4.59	3.18	65.4	69.7	187.3	214	135	151	1	1	20.7	20.3
26	0.30	0.39	3.61	2.87	67.7	69.5	194.5	213	139	152	2	1	19.5	19.7
27	0.42	0.37	3.11	2.61	76.2	65.7	222	201	160	142	1	1	19.4	19.7
28	0.27	0.39	3.27	3.22	78	79.7	229	242	163	175	3	1	22.8	23.2

29	0.56	0.32	2.41	2.85	72.2	66.7	208	202	150	143	4	1	21.6	20.5
30	0.46	0.48	2.63	3.19	73.1	64	211	191.8	152	136	3	2	20.9	20.5
31	0.38	0.46	3.50	2.90	68.7	61	197.7	185.2	142	131	1	1	21.9	22.4
32	0.31	0.40	3.11	2.58	68.4	61.9	197.2	185.9	141	132	2	2	19.4	18.3
33	0.51	0.22	4.93	0.97	68.5	63.7	197	194	143	135	3	1	22	21.1
34	0.47	0.54	3.86	3.20	68.7	63.6	197.7	191.7	141	137	3	2	20.5	20.1
35	0.40	0.50	2.79	3.03	67.5	62.4	194.8	189.3	139	133	2	5	18.2	17.6
36	0.41	0.47	3.31	3.05	68.7	66.8	197.3	203	141	144	4	3	21.3	20.5
37	0.48	0.45	3.69	2.92	70.7	65.5	205	197.8	147	141	3	2	20.9	20.3
38	0.51	0.49	3.19	2.80	67.8	63.7	195.7	192.4	139	137	2	6	18.8	19.4

Table 3.10a: Mean values of physicochemical parameters of water estimated from 38 samplings sites in Loktak lake of Manipur during pre-monsoon season

Para- meters	Alkalinity (mg/L)		Calcium (mg/L)		Chloride (mg/L)		DO (mg/L)		Sulphate (mg/L)		Hardness (mg/L)		pH	
Sites	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
1	100.45	277.33	22.18	20.73	10.04	9.57	4.2	4.4	1.32	3.95	90.00	132.00	7.15	7.02
2	80.93	140.00	17.03	13.15	14.77	6.85	2.1	2.4	1.32	1.22	66.17	68.27	6.87	6.52
3	82.96	139.33	13.03	13.73	7.68	7.44	4	3	1.66	1.08	68.33	71.73	7.27	6.5
4	79.30	120.00	14.03	13.95	7.09	2.13	4.2	3.1	1.62	1.05	65.00	69.87	7.24	6.72
5	66.29	98.67	12.02	10.74	6.50	2.48	12.2	10.5	1.67	1.38	59.17	57.33	9.22	9.95
6	82.55	101.33	12.16	10.47	3.55	2.14	8.2	4.5	1.72	1.14	60.33	54.00	9.05	6.89
7	99.63	130.00	5.14	13.63	5.32	1.30	8.4	6.6	1.23	0.97	40.00	80.80	6.7	8.64
8	-	161.33	-	14.27	-	4.96	-	11.5	-	1.08	-	105.20	-	6.83
9	65.07	140.00	7.15	14.11	3.78	1.42	3.8	2	1.21	1.00	54.67	92.00	7.12	6.91
10	73.61	160.00	8.02	20.84	5.32	10.40	8.3	2.1	1.27	2.35	60.00	110.27	6.84	6.64
11	54.90	121.33	6.01	13.63	7.68	6.38	8.5	7.2	1.32	1.08	41.67	75.20	6.46	7.06
12	67.10	100.00	8.62	11.70	7.09	9.57	4.2	3.4	1.21	1.59	59.17	63.87	6.2	6.96

13	68.32	70.00	7.88	9.94	8.86	4.96	8.7	6.8	1.49	4.19	52.50	50.00	8.35	6.96
14	57.75	80.00	5.01	9.73	10.04	5.32	8.1	7.1	1.38	4.35	33.17	50.00	6.82	6.88
15	69.54	74.00	9.29	10.74	6.50	5.44	4.8	4.2	1.32	4.11	57.50	57.20	6.78	6.94
16	76.45	99.33	11.02	10.74	12.41	10.64	7.5	7.3	1.46	28.16	60.00	52.67	7.22	6.85
17	91.91	130.00	9.02	12.02	10.64	7.09	3.7	1.9	1.17	2.08	51.17	82.00	6.88	6.51
18	122.00	100.00	19.77	12.88	11.82	2.72	6.5	4.5	1.83	2.73	92.00	50.80	6.6	7.36
19	87.03	80.00	8.95	8.34	7.68	15.72	7.3	5.8	1.32	6.03	62.50	47.20	9.04	6.6
20	79.30	98.67	8.62	10.53	5.32	6.38	8.5	4.2	1.21	1.08	50.83	56.53	8.93	7.31
21	98.82	84.00	13.03	10.74	20.68	10.64	4.1	5.8	1.46	7.59	75.00	56.00	6.94	7.16
22	76.05	106.00	6.01	11.22	7.09	13.47	5.7	5.5	1.21	2.11	46.67	63.73	7.13	7.11
23	62.63	90.00	4.88	8.02	4.73	10.40	7.2	3.4	1.16	1.62	46.50	48.80	7.31	6.68
24	67.10	60.67	5.61	2.73	7.68	1.77	6.7	4.1	1.20	2.54	35.00	19.20	7.03	6.12
25	77.27	120.00	8.02	9.62	7.68	6.38	5.4	5.1	1.23	0.89	56.17	58.00	7	7.11
26	83.77	130.00	12.02	12.34	8.86	7.09	6.4	7.1	1.41	1.32	67.50	64.00	7.02	7.19
27	78.89	90.00	10.15	7.80	3.55	6.38	7.6	5.7	1.79	1.35	70.00	48.00	8.34	6.95
28	84.59	120.00	15.16	12.34	4.14	5.32	8.7	3.9	1.92	1.27	72.83	66.80	7.45	7.16

29	128.10	104.00	7.15	10.31	5.32	3.55	7	5.3	1.17	0.93	57.50	62.00	7.44	7.37
30	71.57	127.33	9.75	10.42	6.50	8.98	6.1	5.4	1.19	1.02	57.83	56.80	6.72	6.76
31	75.64	110.00	8.15	9.30	7.09	2.84	5.2	5.8	1.23	1.05	61.67	60.13	6.82	6.89
32	77.27	98.67	9.62	9.14	5.32	2.48	4.9	5	1.19	0.96	62.50	56.00	6.72	6.8
33	79.71	100.00	11.16	8.82	5.91	5.67	4.9	6.6	1.25	1.03	67.83	50.80	6.42	6.94
34	75.64	86.00	10.22	8.12	6.50	5.08	3.9	7.4	1.19	1.24	62.83	51.87	6.35	7.06
35	65.07	104.00	6.81	10.58	15.36	8.15	4.7	3.1	1.24	0.95	90.00	62.00	6.28	6.78
36	68.32	130.00	8.02	11.70	5.91	7.56	3.8	4.3	1.15	0.95	52.50	86.00	6.91	7.08
37	80.93	147.33	9.69	12.02	7.68	6.03	2.4	4.4	1.41	1.00	60.33	83.20	6.3	7.09
38	70.35	116.00	8.62	10.74	8.27	8.15	3.4	2.1	1.30	0.89	60.83	66.53	6.03	6.63

Note: (-) indicates no sample.

Table 3.10b: Mean values of physicochemical parameters of water estimated from 38 samplings sites in Loktak lake of Manipur during pre-monsoon season

Para- meters	K (mg/L)		Mg (mg/L)		Salinity (mg/L)		EC (μ S/cm)		TDS (mg/L)		Turbidity (NTU)		Temp ($^{\circ}$ C)	
Sites	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
1	5.12	15.15	12.43	15.77	105	161	314	476	223	341	3	5	28.7	27.1
2	3.79	4.05	8.35	6.28	80.3	91.8	236	270	168	191	5	11	29.3	29.1
3	3.81	4.40	7.25	6.61	76	90	221	269	157	195	2	6	29.5	28.9
4	2.99	1.90	11.73	8.52	78.3	87.9	228	256	163	184	2	4	28.5	28.3
5	0.83	0.61	5.28	7.07	71.9	75.2	209	222	148	156	2	4	31.7	32
6	1.04	0.36	14.93	5.93	75.5	65.5	219	186.8	157	135	2	1	31.4	30.6
7	0.72	0.56	9.27	10.78	51	92	140.6	268	99.1	196	11	5	33.2	33.4
8	-	2.03	-	14.81	-	119	-	357	-	256	-	58	-	29.1
9	1.38	1.26	6.01	12.49	82	106	254	318	152	225	5	1	27.8	27.7
10	2.46	5.75	6.39	13.57	61	128	201	383	147	273	3	1	27.5	25.3
11	2.74	2.17	4.27	9.35	57	88	159.7	380	114	187	3	7	28.4	28.1
12	4.87	2.78	5.82	7.70	71.4	85	207	247	148	178	2	4	28.8	29

13	4.19	2.13	8.35	5.74	68.8	75.8	198.9	221	142	159	4	8	26.4	24.2
14	1.55	2.10	9.03	6.08	54.1	75.1	150.3	216	107	155	4	32	25.5	24.5
15	5.23	2.02	1.10	5.59	66.5	76.6	190.4	225	135	162	3	27	26.2	24
16	3.15	4.04	5.02	5.36	81.9	83.7	240	246	171	176	6	22	28.6	28.9
17	3.01	4.95	7.39	11.51	75.1	99.6	217	296	155	215	11	16	27.4	27.9
18	4.33	1.57	9.26	5.86	108	70.6	325	201	231	146	15	29	26.1	25.7
19	1.10	4.51	4.70	5.61	80.2	83.9	223	244	167	175	2	24	30.9	31.1
20	0.72	1.07	4.63	7.28	62.3	71	176.2	202	125	145	3	7	30.1	30
21	1.04	3.11	5.81	5.94	106	83	318	240	226	174	4	50	30.7	31
22	0.93	4.28	4.43	7.89	61	91.8	174	269	124	191	3	17	29.8	29.5
23	2.85	4.17	4.10	6.32	50.8	70.2	140.4	199.7	99.9	144	3	37	25.2	24.5
24	1.06	2.48	3.57	1.88	49.7	36.1	135.8	91.2	96.7	64.9	8	24	24.6	24.2
25	0.81	0.52	5.39	4.25	68.6	70.7	197.2	205	140	144	2	2	25.3	25.7
26	1.27	1.09	9.92	5.84	77.9	79	227	229	162	165	5	3	27.1	26.4
27	1.49	0.71	1.73	4.77	76.6	64	225	181.9	160	130	2	2	26.4	25.4
28	4.90	0.85	5.00	4.89	82	77	239	220	167	159	3	2	26.9	26.1

29	1.28	1.45	5.24	5.59	69.8	80	202	231	143	167	2	2	26.7	27.5
30	0.92	0.77	4.94	4.30	69.3	68.5	200	199.1	142	143	2	4	24.8	25
31	0.83	0.86	3.70	4.57	67.5	69.2	193.6	198	138	141	2	3	25.9	25.5
32	2.10	0.79	4.28	4.29	68.2	68.7	196.7	198.2	140	141	3	3	25.2	24.5
33	1.10	1.15	3.59	4.02	72.2	67.7	209	197.9	149	138	5	5	26.8	26.2
34	0.72	1.29	5.12	4.37	71.1	69.6	207	201	147	144	5	5	27	26.4
35	1.75	1.89	5.29	5.48	76.4	81.9	223	239	159	173	25	7	28.4	27.8
36	1.50	1.16	4.86	8.06	70.8	97.6	205	296	146	211	4	43	26.5	26
37	1.09	1.09	5.28	7.82	75.4	98.4	221	287	157	208	3	55	25.4	25.5
38	1.67	1.11	4.92	5.00	70.2	81.8	202	230	145	169	13	5	26.6	25.8

Note: (-) indicates no sample.

Table 3.11: Descriptive statistics on seasonal variation of different water quality parameters in Loktak lake of Manipur (sampling sites, n = 38)

Seasons			TA	Ca	Cl	DO	EC	TH	pH	Salinity	Sulphate	TDS	Turbidity	Temp.	K	Mg
			(mg/L)	(mg/L)	(mg/L)	(mg/L)	(µS/cm)	(mg/L)		(mg/L)	(mg/L)	(mg/L)	(NTU)	(°C)	(mg/L)	(mg/L)
Monsoon	(2020)	Min.	62.50	6.01	0.59	4.10	98.70	15.00	6.39	38.20	0.95	70.80	8.00	28.20	1.02	1.02
		Max.	130.00	20.71	26.00	7.50	276.00	35.00	8.05	92.50	2.54	195.00	14.10	33.70	5.42	9.97
		Mean	98.62	12.01	7.12	5.18	179.66	23.99	7.20	62.31	1.26	127.01	9.72	31.36	2.38	5.94
		SD	14.54	3.46	4.85	0.81	34.52	5.51	0.29	10.66	0.33	23.92	2.18	1.54	1.02	1.85
Monsoon	(2021)	Min.	50.00	5.14	1.77	2.50	136.60	33.50	6.53	47.80	0.83	97.50	1.00	27.30	0.67	6.86
		Max.	293.33	59.85	25.29	6.90	660.00	255.00	7.63	218.00	2.86	478.00	48.00	34.20	175.74	130.88
		Mean	110.35	13.57	6.84	4.47	237.02	70.07	7.09	79.57	1.25	169.89	8.37	31.03	34.09	40.66
		SD	41.82	9.58	5.32	0.96	115.22	43.21	0.24	37.23	0.45	82.63	9.28	1.56	51.03	42.26
Post-monsoon	(2020)	Min.	56.67	4.68	1.18	4.20	101.60	10.00	6.89	39.00	0.95	73.10	8.10	24.00	1.29	5.39
		Max.	176.67	20.04	21.27	7.30	483.00	56.67	7.84	159.00	2.31	342.00	13.50	31.90	774.61	187.70
		Mean	107.87	11.50	5.77	5.34	233.18	26.95	7.32	78.84	1.20	166.86	10.12	26.97	146.69	61.14
		SD	29.70	3.40	4.72	0.66	73.79	7.63	0.18	23.24	0.23	52.08	2.05	1.69	175.09	41.78
Post-monsoon	(2021)	Min.	56.67	5.61	1.77	1.60	93.80	27.50	6.54	34.70	1.05	65.60	1.00	24.30	95.87	22.89
		Max.	212.50	32.67	17.84	7.70	418.00	127.33	7.46	137.00	2.13	299.00	33.00	30.00	560.37	323.63
		Mean	103.40	14.16	4.96	4.94	217.14	63.32	7.06	72.85	1.37	154.75	8.66	26.53	175.38	110.43
		SD	29.04	6.14	3.05	1.71	61.49	18.11	0.24	19.47	0.22	44.07	7.34	1.43	83.18	47.86
Winter	(2021)	Min.	50.83	5.01	1.18	3.40	137.80	43.33	6.30	50.20	0.97	98.60	1.00	16.70	0.27	1.82
		Max.	128.91	18.04	8.27	7.90	390.00	110.83	9.05	129.00	2.05	279.00	38.00	22.80	1.69	8.59

	Mean	79.88	10.50	4.06	4.77	223.57	68.03	6.97	76.84	1.25	160.12	4.97	19.82	0.53	3.72
	SD	15.71	2.51	2.19	1.26	47.71	13.74	0.51	14.85	0.27	33.97	6.73	1.49	0.31	1.20
Winter (2022)	Min.	69.17	4.81	0.12	3.00	138.70	35.87	6.59	47.30	0.89	98.60	1.00	12.70	0.22	0.97
	Max.	158.33	16.94	13.12	11.20	331.00	100.00	8.03	108.00	2.38	238.00	29.00	23.20	1.68	5.70
	Mean	113.56	11.24	5.55	6.08	221.77	63.12	7.10	72.99	1.24	157.88	3.16	19.18	0.57	2.97
	SD	20.86	2.93	2.74	2.01	41.56	13.04	0.27	13.23	0.34	30.13	4.98	2.02	0.31	0.76
Pre-monsoon (2021)	Min.	54.90	4.88	3.55	2.10	135.80	33.17	6.03	49.70	1.15	96.70	2.00	24.60	0.72	1.10
	Max.	128.10	22.18	20.68	12.20	325.00	92.00	9.22	108.00	1.92	231.00	25.00	33.20	5.23	14.93
	Mean	79.10	9.97	7.85	5.98	211.51	60.21	7.16	72.70	1.36	150.02	4.92	27.71	2.17	6.17
	SD	15.38	3.91	3.54	2.20	43.04	13.30	0.83	13.43	0.21	30.22	4.68	2.13	1.45	2.87
Pre-monsoon (2022)	Min.	60.67	2.73	1.30	1.90	91.20	19.20	6.12	36.10	0.89	64.90	1.00	24.00	0.36	1.88
	Max.	277.33	20.84	15.72	11.50	476.00	132.00	9.95	161.00	28.16	341.00	58.00	33.40	15.15	15.77
	Mean	114.35	11.36	6.39	5.07	247.28	65.44	7.02	83.71	2.61	175.18	14.24	27.31	2.43	7.03
	SD	36.38	3.17	3.39	2.16	67.89	20.24	0.62	20.64	4.53	46.07	16.26	2.40	2.57	3.12
Desirable limits:	BIS (2012)	200	75	250	5	-	200	6.5- 8.5	-	200	500	1	-	-	30
	WHO (1999)	200	75	250	6	500	-	-	-	-	-	5	-	12	-

3.3.1.6 pH

The pH readings taken at the study site indicate an alkaline nature. During the first year of the study, the pH levels observed during the monsoon season varied between 6.39 (Ngakra Kom) and 8.05 (Thinungei), with a mean value of 7.20 ± 0.29 . During the post-monsoon period, the pH levels in the studied sites ranged from 6.89 (Keibul Chingmei) to 7.84 (Mayang Imphal (II)), with a calculated mean of 7.32 ± 0.18 . During the winter season, the pH value varied from 6.30 (Yangoi) to 9.05 (Komlakhong) on the KLNP side, with a mean value of 6.97 ± 0.51 . Similarly, the pH levels ranged from 6.03 (Thangbirel) to a maximum of 9.22 (Komlakhong North side), with a mean value of 7.16 ± 0.83 during the pre-monsoon period. All of the recorded pH values were within the desirable range of 6.5–8.5, with the exception of one sample during the monsoon at Ngakra Kom (6.39), three samples during the winter season at Mayang Imphal (II) (6.38), Komlakhong (KLNP side) (9.05), and Yangoi (6.3). And ten samples during the pre-monsoon season at Komlakhong North side (9.22), Komlakhong KLNP side (9.05), Yangoi (6.2), Toubokpi (9.04), Ningthoukhong ITI (8.93), Sagram (IV) (6.42), Sagram (III) (6.35), Keibul Mayai leikai (6.28), Keibul Chingmei (6.3), and Thangbirel (6.03), which were found beyond the desirable limit. The mean pH levels were observed to be highest during the post-monsoon season (7.32) and lowest during the winter season (6.97).

During the second year of the study, the pH levels recorded during the monsoon season ranged from 6.53 (Ningthoukhong Kha-Khunou) to 7.63 (Komlakhong North side), with a mean value of 7.09 ± 0.24 . In post-monsoon, the pH levels varied between 6.54 (2nd IB Post) and 7.46 (Ningthoukhong ITI), with a calculated mean of 7.06 ± 0.24 . During the winter season, the pH levels ranged from a minimum value of 6.59 (2nd IB Post) to a maximum value of 8.03 (Komlakhong (KLNP side)), with a mean value of 7.10 ± 0.27 . In contrast, during the pre-monsoon period, the pH levels ranged from a minimum of 6.12 (Naranshena) to a maximum of 9.95 (Komlakhong North side), with a mean value of 7.02 ± 0.62 . All of the recorded pH values were within the desirable range of 6.5–8.5, with the exception of three samples during the pre-monsoon season at Komlakhong (KLNP side) (9.95), Laphupat Tera (8.64), and Naranshena (6.12), which were beyond the ideal range. There is not much seasonal and temporal variation in pH during the study period. The mean pH levels were found to be highest during the winter season (7.10) and lowest

during the pre-monsoon season (7.02) in the second year, while it ranged between 6.9 and 7.3 in the initial year (Figure 3.7).

3.3.1.7 Total Hardness (TH)

For the first year, total hardness (mg/L) in the monsoon season ranged from 15.00 (Upokpi khunou, Thinungei, Phubala, and Thangbirel) to 35.00 (Komlakhong North side and 2nd IB Post) with a mean value of 23.99 ± 5.51 . In post-monsoon, the minimum value of 10.00 was recorded in Naranshena, and the maximum value of 56.67 was observed in Mayang Imphal (II), with the mean of 26.95 ± 7.63 . During the winter season, a minimum of 43.33 was recorded in Naranshena, while the maximum was 110.83 in Khordak, with a mean of 68.03 ± 13.74 . A minimum total hardness of 33.17 (Keinou (II)) and a maximum of 92.00 (Upokpi Khunou) with a mean of 60.21 ± 13.30 were recorded in pre-monsoon.

For the second year, total hardness (in mg/L) in the monsoon season ranged from 33.50 (Phubala) to 255.00 (Khoijuman) with a mean value of 70.07 ± 43.21 . In post-monsoon, the minimum value was recorded as 27.50 (Naranshena), and the maximum value of 127.33 was observed in Khordak with the mean of 63.32 ± 18.11 . During the winter season, a minimum of 35.87 was recorded in Keinou (II), while the maximum was 100.00 in Khordak, with a mean of 63.12 ± 12.99 . A minimum hardness of 19.20 (Naranshena) and a maximum of 132.00 (Mayang Imphal (I)) with a mean of 65.44 ± 20.24 were recorded in pre-monsoon. All the values were below the desirable limit of 200 mg/L, except for Khordak with 220 mg/L and Khoijuman with 255 mg/L during the monsoon season of 2021.

A sharp increase in total hardness can be seen in the first year from post-monsoon (26.95 mg/L) to winter (68.02 mg/L). However, there is not much variation in the second year, which ranges between 63.11 mg/L in winter and 70.07 mg/L in monsoon, as displayed in Figure 3.7.

3.3.1.8 Dissolved oxygen (DO)

For the first year, the levels of DO (mg/L) in the monsoon varied between 4.10 (Thanga Moirangthem) and 7.50 (Kha-Potshangbam) with a mean value of 5.18 ± 0.81 . In post-monsoon, the minimum concentration of DO in the lake water was 4.20 (Thangbirel) and

the maximum was 7.30 (Nongmaikhong), having a mean of 5.34 ± 0.66 . In the winter season, a minimum value of 3.40 (Phubala) and a maximum value of 7.90 (Keinou (II)) were recorded, with a mean value of 4.77 ± 1.26 . The pre-monsoon season recorded a minimum DO value of 2.10 in Mayang Imphal (II) and a maximum of 12.20 in Komlakhong North side, and a mean value of 5.98 ± 2.20 .

During the second year of monsoon season, the lowest DO value was recorded in Nongmaikhong (2.50) and the highest in Keibul Ching (6.90) and the mean was 4.47 ± 0.96 . During post-monsoon, DO was lowest in Mayang Imphal (I) (1.6) and highest in Nongmaikhong and Kha-Potshangbam (7.70) with a mean of 4.94 ± 1.71 . In the winter season, a minimum value of 3.00 (Sagram (III)) and a maximum value of 11.20 (Mayang Imphal (near Karang)) were recorded, with a mean value of 6.08 ± 2.02 . The pre-monsoon season recorded a minimum DO value of 1.9 (Kha-Potshangbam) and a maximum of 11.50 (Khordak), with a mean value of 5.07 ± 2.16 . The overall mean values of DO in winter 2021, monsoon 2021, and post-monsoon 2021 were slightly below the desirable limit of 5 mg/L, as per BIS. However, the value during the other seasons for both the studied years exceeded the limit of 5 mg/L (Figure 3.7).

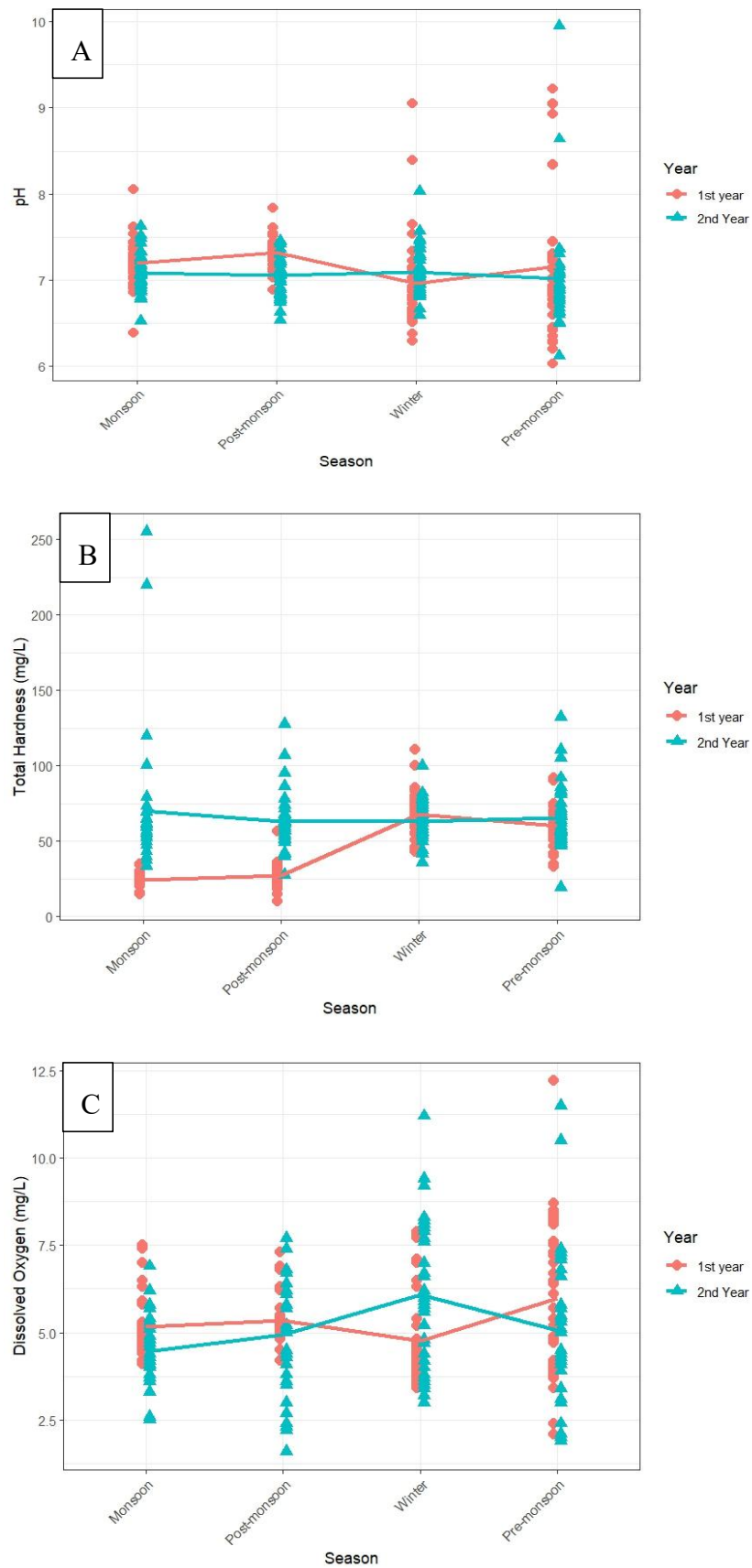


Figure 3.7: Seasonal variation of pH (A), total hardness (B) and dissolved oxygen (C) of the studied water samples during the study period (— 1st year and — 2nd year).

3.3.1.9 Total alkalinity (TA)

Total alkalinity measurement is a fundamental parameter for assessing water quality. It helps in understanding the overall buffering capacity of water, which is essential for maintaining stable pH levels. Fluctuations in pH can affect the health of aquatic ecosystems and the effectiveness of water treatment processes. In the first year (2020-2021) of the study, it was observed that during the monsoon season, total alkalinity (measured in mg/L) was found lowest (62.50) in Naranshena and highest (130.00) in Yangoi with a mean value and standard deviation of 98.62 ± 14.54 . During the post-monsoon period, the recorded lowest value was 56.67 at Komlakhong (KLNP side) and Upokpi Khunou. Conversely, the highest recorded value was 176.67 at Keinou (II). The mean value for this period was calculated to be 107.87 ± 29.70 . In the winter season, the lowest recorded alkalinity was found in Naranshena with 50.83 and the highest at 128.91 in Mayang Imphal (I), exhibiting a mean and standard deviation of 79.88 ± 15.71 . During the pre-monsoon period, the recorded minimum value was 54.90 (Ithai), and the maximum value was 128.10 (Thanga Moirangthem), with a mean and standard deviation of 79.10 ± 15.38 . During the second year of the study, i.e., the 2021-2022 period, TA in the monsoon recorded the lowest in Naranshena (50.00) and the highest in Khordak (293.33) with a mean of 110.35 ± 41.82 . During the post-monsoon, the lowest value was recorded in Naranshena (56.67) and the highest in Mayang Imphal (I) (212.50) with a mean value of 103.40 ± 29.04 . In winter, the lowest TA was recorded in Naranshena (69.17) and the highest in Khordak (158.33), having a mean of 113.56 ± 20.59 . Similarly, the lowest TA during pre-monsoon was recorded in Naranshena (60.67) and the highest in Mayang Imphal (I) (277.33) with a mean of 114.35 ± 36.38 . Based on the results, it was noted that the sampling site Naranshena exhibited consistently low total alkalinity (TA) throughout all seasons during the study period. Seasonal variation shows a low level of total alkalinity in the initial year of the study, with the lowest in the winter season having 79.87 mg/L, while in the second year it was found to be lowest in the post-monsoon with 103.39 mg/L (Figure 3.8).

3.3.1.10 Calcium (Ca)

During the first year, the concentration of calcium (mg/L) varied within a range during the monsoon season, ranging from 6.01 in Yangoi and Naranshena to 20.71 in Ningthoukhong Kha-Khunou with a mean of 12.01 ± 3.46 . In post-monsoon, the lowest

concentration was found in Thangbirel (4.68) and the highest in Mayang Imphal (I) (20.04) with a mean of 11.50 ± 3.40 . During the winter season, Naranshena had the lowest value of 5.01, while Khordak had the highest value of 18.04 with a mean and SD of 10.50 ± 2.51 . In pre-monsoon, the lowest recorded value was 4.88 at Phubala, while the highest value was 22.18 at Mayang Imphal (I). The calculated mean and standard deviation for this data set were 9.97 ± 3.91 .

During the second year, the lowest calcium concentration (mg/L) in the monsoon season was 5.14 in Naranshena, while Khoijuman had the highest with 59.85 and a mean of 13.57 ± 9.58 . In post-monsoon, the concentration ranged from 5.61 (Naranshena) to 32.67 (Mayang Imphal (I)). The mean value was 14.16 ± 6.14 . In the winter season, Naranshena had the lowest value (4.81), and Upokpi Khunou exhibited the highest value (16.94) with a mean of 11.24 ± 2.90 . In pre-monsoon, the recorded lowest value was 42.73 at Naranshena, while the highest value was 20.84 at Nongmaikhong with a mean and standard deviation of 11.36 ± 3.17 . All the analyzed samples were found within the desirable limit of 75 mg/L. The highest calcium concentration was found in the post-monsoon and lowest in the winter season during the study period (Figure 3.8).

3.3.1.11 Chloride (Cl)

For the first year, during monsoon, the chloride concentration (mg/L) was ranged from 0.59 (Komlakhong) to 26.00 (Mayang Imphal (near Karang)). The overall mean value was determined to be 7.23 ± 5.04 . During the post-monsoon period, lowest value was 1.18 at Phoubakchao, Khordak Ichin, Yangoi and Thanga Chingkha while the highest value of 21.27 was found in Sagram (IV) with mean of 5.77 ± 4.72 . In winter season, the values ranged from 1.18 (Nachou, Thanga Chingkha and Ngakra Kom) to 8.27 (Upokpi Khunou) with a mean value of 4.06 ± 2.19 . In pre-monsoon, the values ranged from 3.55 (Komlakhong KLNP side and Thanga Salam) to 20.68 (Ningthoukhong Kha-Khunou) with a mean of 7.85 ± 3.54 . In the second year, the chloride concentration (mg/L) monsoon was found lowest in Ningthoukhong Kha-Khunou and Karang (1.77) and highest in Komlakhong KLNP (25.29) with overall mean value of 6.84 ± 5.32 . During the post-monsoon period, three sites Upokpi Khunou, Thanga Salam and Thanga Moirangthem recorded lowest value of 1.77, while the highest value of 17.84 was recorded in Mayang Imphal (I) with mean of 4.96 ± 3.05 . In winter season, Mayang

Imphal (near Karang) recorded the lowest value of 0.12 and Ningthoukhong Kha-Khunou recorded highest of 13.12 with a mean value of 5.55 ± 2.71 (Figure 3.8).

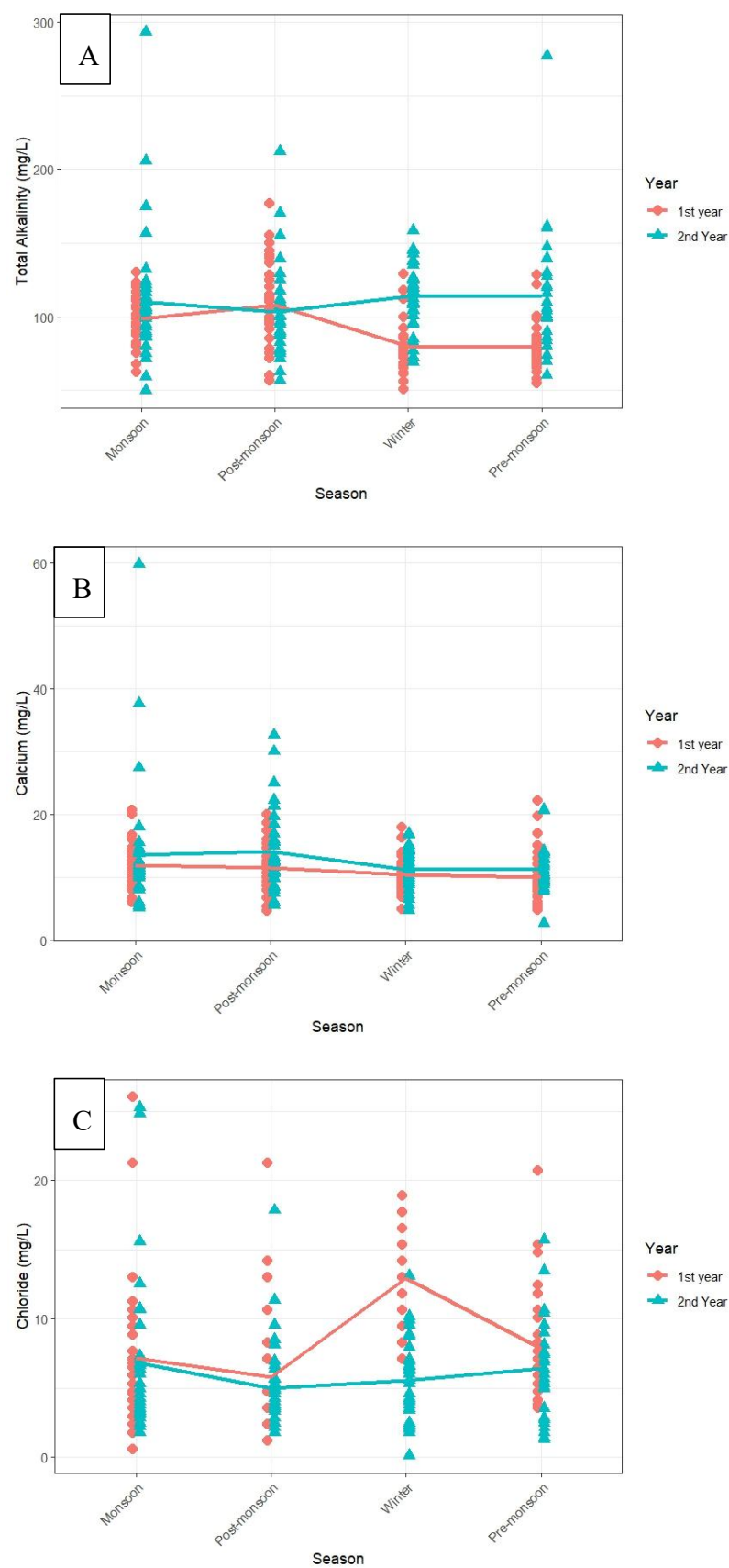


Figure 3.8: Seasonal variation of total alkalinity (A), Calcium (B) and chloride (C) of the studied water samples during the study period (— 1st year and — 2nd year).

In pre-monsoon, the values ranged from 1.30 (Laphupat Tera) to 15.72 (Toupokpi) with a mean of 6.39 ± 3.39 . The chloride levels were determined to be within the acceptable range of 250 mg/L. The highest and lowest value of chloride was observed in pre-monsoon having 7.85 mg/L and 4.06 mg/L in winter respectively, both in the first year of the study period.

3.3.1.12 Sulphate

The sulphate concentration (mg/L) in lake water showed fluctuations across various locations during the monsoon and post-monsoon periods. During the initial year of the study, specifically in the monsoon season, the lowest sulphate concentration was observed at Khordak Ichin and Ngakra Kom (0.95), while the highest concentration was recorded at Naranshena (2.54), resulting in a mean value of 1.26 ± 0.33 mg/L. Conversely, during the post-monsoon season, the minimum sulphate concentration was found at Mayang Imphal (I) (0.95), whereas the maximum concentration was observed at Keinou (II) (2.31), with a mean concentration of 1.20 ± 0.23 mg/L. The lowest concentration during the winter season was 0.97 (Kha-Potshangbam and Ningthoukhong ITI Manak), while the highest concentration was 2.05 (Ithai Wapokpi). The mean concentration over this period was determined to be 1.25 ± 0.27 .

During the pre-monsoon period, the minimum concentration of sulphate was recorded in 2nd IB posts (1.15), while the maximum concentration was seen in Karang (1.92). The average concentration of sulphate throughout this period was found to be 1.36 ± 0.21 mg/L. The sulphate concentration during the second year of the study, the lowest sulphate concentration in the monsoon season, was observed at Keibul Chingmei (0.83), while the highest concentration was recorded at Khordak (2.86), resulting in a mean concentration of 1.25 ± 0.45 mg/L. Conversely, during the post-monsoon season, the minimum sulphate concentration was found at Ningthoukhong ITI (1.05), and the maximum concentration was observed at Mayang Imphal (I) (2.13), resulting in a mean concentration of 1.37 ± 0.22 mg/L.

During the winter season, the estimated value of sulphate ranged from 0.89 (Ithing) to 2.38 (Karang) with a mean concentration of 1.24 ± 0.34 . During the pre-monsoon period, the minimum concentration of sulphate was recorded in Ithing and Thangbirel (0.89), while the maximum concentration was seen in Nachou (28.16). The average

concentration of sulphate throughout this period was found to be 2.61 ± 4.53 mg/L. The results recorded during the entire study period, across all seasons, were significantly lower than the desired threshold of 200 mg/L. There was marginal variation in sulphate concentration across the seasons during the study period except for the pre-monsoon (2.6 mg/L) in the second year. The overall value range is between 1.2 and 1.3 mg/L, as depicted in Figure 3.9.

3.3.1.13 Potassium (K)

In the first year, mean potassium concentration (mg/L) during the monsoon was recorded as 2.38 ± 1.02 , ranging from 1.02 at Ngakra Kom to 5.42 at Sagram (III); in the post-monsoon it was 146.69 ± 175.09 , ranging from 1.29 at Ithai Wapokpi to 774.61 at Thinungei. The winter season exhibited the lowest value with 0.53 ± 0.31 , ranging from 0.27 at Karang to 1.69 at Mayang Imphal (II), while in the pre-monsoon it was 2.17 ± 1.45 , ranging from 0.72 at Laphupat Tera, Ningthoukhong ITI, and Sagram (III) to 5.23 at Khoijuman. The mean value of post-monsoon was found to be above the desirable limit of 12 mg/L as per WHO guidelines, whereas other seasons showed mean concentrations well below the limit.

In the second year, also, potassium concentration (mg/L) displayed considerable variations across various seasons. Mean potassium concentration (in mg/L) during the monsoon was recorded as 34.09 ± 51.03 , ranging from 0.67 at Houbakchao to 175.74 at Thangbirel. In post-monsoon, the value ranged from 95.87 at Ithing to 60.37 at Mayang Imphal (II) with a mean value of 75.38 ± 83.18 ; in winter it was 0.57 ± 0.30 , ranging from 0.22 at Sagram (IV) to 1.68 at Mayang Imphal (I); and in pre-monsoon it was 2.43 ± 2.57 , ranging from 0.36 at Komlakhong (KLNP side) to 15.15 at Mayang Imphal (I). The mean concentrations of potassium during the monsoon and post-monsoon were found above the desirable limit of 12 mg/L. Seasonal analysis of the potassium concentration reveals that there is a peak high in the post-monsoon and a peak low in the winter season during the study period (Figure 3.9).

3.3.1.14 Magnesium

The mean magnesium concentration (mg/L) for the first year was 5.94 ± 1.85 during the monsoon, ranging from 1.02 at Laphupat Tera to 9.97 at Ithai; 61.14 ± 41.78 in the post-monsoon, ranging from 5.39 at Yangoi to 187.70 at Thinungei. In the winter, it was 3.72

± 1.20 , ranging from 1.82 at Nongmaikhong to 8.59 at Mayang Imphal (I); and 6.17 ± 2.87 in the pre-monsoon, ranging from 1.10 at Khoijuman to 14.93 at Komlakhong (KLNP side).

For the second year, the average magnesium concentration was 40.66 ± 42.26 mg/L, with levels ranging from 6.86 at Mayang Imphal (II) to 130.88 at Thangbirel; 110.43 ± 47.86 in post-monsoon, from 22.89 at Sagram (III) to 323.63 at Khordak; 2.97 ± 0.75 in winter, from 0.97 at Sagram (IV) to 5.70 at Khordak; and 7.03 ± 3.12 in pre-monsoon, from 1.88 at Naranshena to 15.77 at Mayang Imphal (I). Throughout the study, the average levels in post-monsoon were above the safe limit of 30 mg/L set by the BIS. Throughout the study, the mean levels in post-monsoon were higher than the safe limit of 30 mg/L set by the BIS. During the entire study period, the mean values of post-monsoon were above the acceptable limit of 30 mg/L set by the BIS. The mean concentrations were significantly below the permissible limit during the other seasons of the year. Figure 3.6 displays the seasonal variation of magnesium estimated in the studied water samples during the study period. Similar to potassium concentration, magnesium concentration also exhibits a peak high in the post-monsoon and a peak low in the winter season (Figure 3.9).

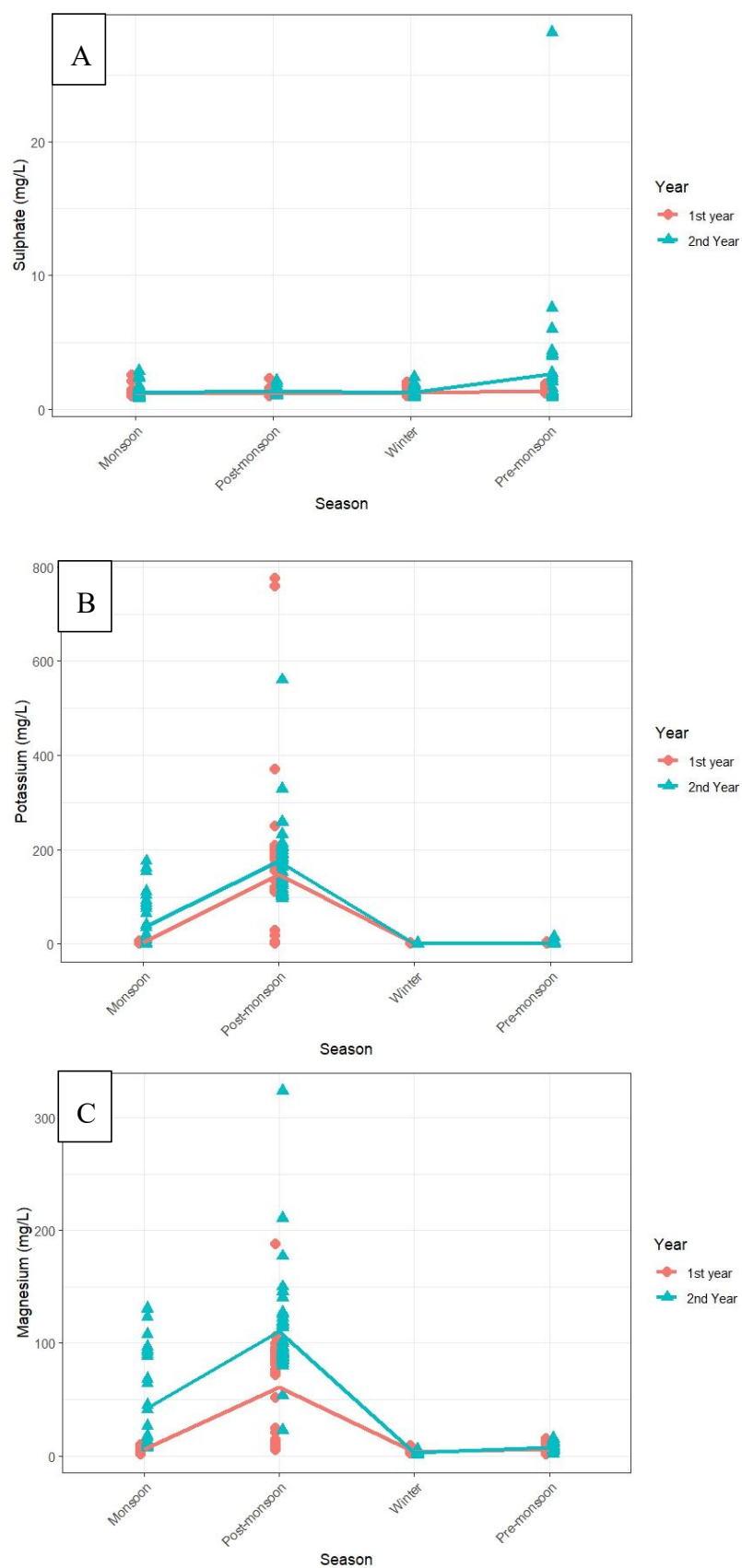


Figure 3.9: Seasonal variation of sulphate (A), potassium (B) and magnesium (C) of the studied water samples during the study period (— 1st year and — 2nd year).

3.3.2 Correlation analysis

Table 3.12 displays the statistical data from the correlation analysis of the estimated physicochemical parameters. Alkalinity shows a strong positive correlation between calcium ($\rho = 0.623$, $P < 0.001$), EC ($\rho = 0.522$, $P = 0.001$), hardness ($\rho = 0.582$, $P < 0.001$), salinity ($\rho = 0.517$, $P = 0.001$), and TDS ($\rho = 0.526$, $P = 0.001$). The chloride levels don't show significant correlation with any of the parameters studied. Additionally, the electrical conductivity (EC) exhibits highly significant positive correlations with hardness ($\rho = 0.803$, $P < 0.001$), phosphate ($\rho = 0.472$, $P = 0.003$), salinity ($\rho = 0.998$, $P < 0.001$), TDS ($\rho = 0.997$, $P < 0.001$), and turbidity ($\rho = 0.415$, $P = 0.010$). DO has a significant positive correlation with pH ($\rho = 0.547$, $P < 0.001$) and sulphate ($\rho = 0.499$, $P = 0.001$). Hardness has a significant positive correlation with phosphate ($\rho = 0.530$, $P = 0.001$), salinity ($\rho = 0.797$, $P < 0.001$), and TDS ($\rho = 0.808$, $P < 0.001$). pH has a significant positive correlation with sulphate ($\rho = 0.034$, $P = 0.034$). Phosphate exhibits a significant positive correlation with salinity ($\rho = 0.482$, $P = 0.002$), sulphate ($\rho = 0.409$, $P = 0.011$), and TDS ($\rho = 0.472$, $P = 0.003$). Salinity has a significant positive correlation with TDS ($\rho = 0.995$, $P < 0.001$) and turbidity ($\rho = 0.422$, $P = 0.008$). TDS and turbidity also exhibit significant positive correlation ($\rho = 0.421$, $P = 0.008$). Magnesium has a highly significant positive correlation with TA ($\rho = 0.489$, $P = 0.002$), EC ($\rho = 0.435$, $P = 0.006$), TH ($\rho = 0.503$, $P = 0.001$), salinity ($\rho = 0.458$, $P = 0.004$), TDS ($\rho = 0.447$, $P = 0.005$), turbidity ($\rho = 0.490$, $P = 0.002$) and potassium ($\rho = 0.520$, $P = 0.001$).

Table 3.12: Correlation (Pearson) among different water quality parameters

Correlations														
	TA	Ca	Cl	DO	EC	TH	pH	Salinity	Sulphate	TDS	Turbidity	Temp	K	Mg
TA	1													
Ca	0.814 ^{**} (0.000)	1												
Cl	0.153	0.142	1											
DO	-0.227	-0.031	-0.246	1										
EC	0.895 ^{**} (0.000)	0.853 ^{**} (0.000)	0.286	-0.139	1									
TH	0.911 ^{**} (0.000)	0.887 ^{**} (0.000)	0.126	-0.162	0.940 ^{**} (0.000)	1								
pH	-0.085	0.099	-0.248	0.648 ^{**}	-0.035	0.041	1							
Salinity	0.897 ^{**} (0.000)	0.855 ^{**} (0.000)	0.290	-0.140	0.998 ^{**} (0.000)	0.944 ^{**} (0.000)	-0.029	1						
Sulphate	0.115	0.286	0.246	0.272	0.235	0.127	0.098	0.237	1					
TDS	0.899 ^{**} (0.000)	0.852 ^{**} (0.000)	0.296	-0.140	0.997 ^{**} (0.000)	0.939 ^{**} (0.000)	-0.025	0.999 ^{**} (0.000)	0.238	1				
Turbidity	0.355 [*] (0.029)	0.291	0.263	-0.085	0.508 ^{**} (0.001)	0.418 ^{**} (0.019)	-0.163	0.529 ^{**} (0.001)	0.297	0.527 ^{**} (0.001)	1			
Temp	0.143	0.067	-0.036	0.150	0.165	0.130	0.379 [*] (0.019)	0.169	-0.061	0.179	-0.051	1		
K	0.093	-0.026	0.290	-0.241	0.105	0.036	-0.245	0.117	0.018	0.117	0.306	0.195	1	
Mg	0.489 ^{**} (0.002)	0.287	0.007	-0.311	0.435 ^{**} (0.306)	0.503 ^{**} (0.001)	-0.207	0.458 ^{**} (0.004)	-0.113	0.447 ^{**} (0.005)	0.490 ^{**} (0.002)	0.065	0.520 ^{**} (0.001)	1

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

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

3.3.3 Spatial and temporal variations on the parameters

One-way ANOVA was performed to analyse the seasonal variations of water quality parameters across all the samples. The null hypothesis (Ho), which posited that the concentrations of various parameters in different seasons were identical, was rejected for most of the parameters, except for sulphate ($P = 0.059$) (Table 3.13).

Table 3.13: Analysis of variance (ANOVA) for different water quality parameters during different seasons

Parameter	Hypothetical expression	df	F	Sig.	Remarks
TA	Ho: M = PoM = W = PrM	3, 147	19.337	$P < 0.001$	X
Ca	Ho: M = PoM = W = PrM	3, 147	2.855	$P = 0.039$	X
Cl	Ho: M = PoM = W = PrM	3, 147	4.968	$P = 0.003$	X
DO	Ho: M = PoM = W = PrM	3, 147	5.084	$P = 0.002$	X
EC	Ho: M = PoM = W = PrM	3, 147	7.649	$P < 0.001$	X
TH	Ho: M = PoM = W = PrM	3, 147	170.435	$P < 0.001$	X
pH	Ho: M = PoM = W = PrM	3, 147	3.097	$P = 0.029$	X
Salinity	Ho: M = PoM = W = PrM	3, 147	7.797	$P < 0.001$	X
Sulphate	Ho: M = PoM = W = PrM	3, 147	2.531	$P = 0.059$	✓
TDS	Ho: M = PoM = W = PrM	3, 147	8.607	$P < 0.001$	X
Turbidity	Ho: M = PoM = W = PrM	3, 147	16.432	$P < 0.001$	X
Temp.	Ho: M = PoM = W = PrM	3, 147	295.773	$P < 0.001$	X
K	Ho: M = PoM = W = PrM	3, 147	25.831	$P < 0.001$	X
Mg	Ho: M = PoM = W = PrM	3, 147	66.969	$P < 0.001$	X

Note: M- Monsoon; PoM- Post-monsoon; W- Winter; PrM- Pre-monsoon; Ho- Null hypothesis; ✓= significant at 95% ($P < 0.05$); X= Not significant at 95% ($P > 0.05$)

The results of the analysis of variance revealed statistically significant variations in the mean concentration of total alkalinity across the seasons ($F_{3, 147} = 19.337$; $P < 0.001$). However, there were little variations observed between the winter and pre-monsoon seasons ($P = 0.866$). The overall mean concentration of calcium in the samples showed significant variation ($F_{3, 147} = 2.855$; $P = 0.039$) but some similarities were observed between monsoon and post-monsoon seasons ($P = 0.508$), monsoon and winter ($P = 0.052$), post-monsoon and winter ($P = 0.197$), post-monsoon and pre-monsoon ($P =$

0.051), and winter and pre-monsoon ($P = 0.497$). A statistically significant difference was seen for chloride levels ($F_{3,147} = 4.968$; $P = 0.003$) across various samples and seasons but there were little variations between the seasons, monsoon and post-monsoon ($P = 0.556$), monsoon and winter ($P = 0.020$), monsoon and pre-monsoon ($P = 0.886$), and post-monsoon and winter ($P = 0.568$).

The overall mean values of dissolved oxygen (DO) were significantly different ($F_{3,147} = 5.084$; $P = 0.002$) between samples and seasons, but no significant differences were seen between monsoon and post-monsoon ($P = 0.619$), monsoon and winter ($P = 0.200$), and post-monsoon and winter ($P = 0.076$). The overall electrical conductivity (EC) was significantly different among the samples ($F_{3,147} = 7.649$; $P < 0.001$), but there were no major differences between post-monsoon and winter ($P = 0.421$), post-monsoon and pre-monsoon ($P = 0.073$), and winter and pre-monsoon ($P = 0.316$). The total hardness values exhibited a significant difference overall among the samples and seasons ($F_{3,147} = 170.435$; $P < 0.001$). Between the monsoon and post-monsoon seasons, there was no statistically significant variation in the hardness values ($P = 0.227$). The pH was found to be significantly different among the seasons ($F_{3, 147} = 3.097$; $P = 0.029$). However, no significant differences were seen between monsoon and post-monsoon ($P = 0.296$), monsoon and winter ($P = 0.053$), monsoon and pre-monsoon ($P = 0.764$), post-monsoon and pre-monsoon ($P = 0.182$), and winter and pre-monsoon ($P = 0.103$). The salinity values in water exhibited statistically significant differences overall ($F_{3, 147} = 7.797$; $P < 0.001$). However, no significant variations were observed between the post-monsoon and winter periods ($P = 0.593$), post-monsoon and pre-monsoon periods ($P = 0.104$), and winter and pre-monsoon periods ($P = 0.272$). There were no significant differences seen in the amounts of sulphate in the samples ($F_{3,147} = 2.531$; $P = 0.059$). A statistically significant variation in sulphate content was observed solely between the post-monsoon and pre-monsoon periods ($P = 0.008$). The contents of total dissolved solids (TDS) varied considerably among different samples and seasons ($F_{3,147} = 8.607$; $P < 0.001$). However, there were no significant differences observed between the post-monsoon and winter seasons ($P = 0.424$), as well as between the winter and pre-monsoon seasons ($P = 0.234$). The study revealed a significant variation in the overall turbidity values among various samples and seasons ($F_{3,147} = 16.432$; $P < 0.001$). Though, no significant differences were seen between the monsoon and post-monsoon seasons ($P = 0.694$) or between the winter and pre-monsoon seasons ($P = 0.957$). Temperature among the seasons varied

significantly ($F_{3, 147} = 295.773$; $P < 0.001$). It was observed that there was a statistically significant variation in potassium ($F_{3, 147} = 25.831$; $P < 0.001$) and magnesium ($F_{3,147} = 66.969$; $P < 0.001$) content among different seasons and samples.

The multivariate analysis of variance (MANOVA) was conducted to determine whether there are statistically significant differences between the sampling sites for different water quality parameters.

Table 3.14: Multivariate tests for sampling sites

Test	Value	F	Hypothesis df	Error df	Sig.
Pillai's Trace	3.994	1.230	518.000	1596.000	0.002
Wilks' Lambda	0.004	1.402	518.000	1381.360	0.000

The significance values (p-values) for both the test statistics are <0.002 , indicating that the sampling sites have a statistically significant effect for water quality parameters (Table 3.14). This means that at least one of the dependent variables differs significantly across different sites.

3.3.4 Water Quality Index (WQI)

Table 3.15(a) and Table 3.15(b) present the water quality index (WQI) and its respective category for different sampling sites in Loktak Lake across four seasons of a year: monsoon, post-monsoon, winter, and pre-monsoon. The calculated WQI values across all the seasons range from 10.13 (pre-monsoon, 2021) to 633.71 (pre-monsoon, 2022). Average WQI values were lowest during winter (38.58-55.77), followed by pre-monsoon (58.92-157.18), monsoon (104.93-113.32), and post-monsoon with the highest recorded values (184.66-190.11). During the period 2020-2021, three sampling sites, namely Thinungei (516.72), Sagram IV (437.28), both during the postmonsoon, and Khordak Check Post (411.62), during the winter, were found unsuitable for drinking purposes. For the period 2021-2022, a total of fifteen sites were found unsuitable, especially during pre-monsoon and post-monsoon, with the highest values (301.85 - 633.71). Thinungei and Phubala during monsoon; Mayang Inphal (I), Laphupat Tera, Khordak (Check Post), Nachou, and Ningthoukhong Kha-Khunou in post-monsoon; Mayang Imphal (II) in winter; and Khordak Check Post, Keinou (II), Upokpi Khunou, Ningthoukhong Kha-

Khunou, Phubala, 2nd IB Post, and Keibul Chingmei during pre-monsoon were found unsuitable for drinking purposes. Khordak (Check Post), Ningthoukhong Kha-Khunou, and Phubala were the most polluted sites with at least two seasons of unsuitable conditions. Table 3.16 provides a detailed statistical description of the percentage contribution of each WQI category in different seasons across the study site.

Table 3.15(a): Water Quality Index (WQI) and its relevant category of sampling sites of Loktak Lake (2020-2021)

Sampling points	Monsoon		Post-monsoon		Winter		Pre-monsoon	
	WQI	Category	WQI	Category	WQI	Category	WQI	Category
1	90.45	Good	98.69	Good	42.61	Excellent	41.90	Excellent
			109.1					
2	88.20	Good	5	Poor	27.59	Excellent	54.32	Good
			106.8					
3	90.67	Good	9	Poor	11.72	Excellent	25.35	Excellent
	117.0		146.0					
4	7	Poor	4	Poor	23.38	Excellent	25.85	Excellent
5	89.70	Good	93.35	Good	31.95	Excellent	47.11	Excellent
6	92.78	Good	92.24	Good	39.13	Excellent	43.18	Excellent
	106.0						121.7	
7	8	Poor	95.87	Good	32.01	Excellent	3	Poor
			107.8		411.6	Unsuitabl		
8	92.50	Good	6	Poor	2	e	NA	NA
			119.4					
9	92.28	Good	2	Poor	57.80	Good	52.94	Good
			100.0		128.8			
10	91.86	Good	6	Poor	5	Poor	38.59	Excellent
			112.5					
11	92.99	Good	2	Poor	24.56	Excellent	38.41	Excellent
					206.9			
12	89.56	Good	96.99	Good	9	Very poor	27.82	Excellent
			105.2					
13	84.29	Good	4	Poor	55.43	Good	58.58	Good
14	88.99	Good	119.5	Poor	38.51	Excellent	45.66	Excellent

			0					
	123.9		172.0					
15	4	Poor	0	Poor	53.68	Good	33.95	Excellent
			187.6					
16	85.90	Good	6	Poor	44.61	Excellent	71.23	Good
			268.4				117.6	
17	88.94	Good	6	Very poor	43.42	Excellent	6	Poor
			244.7		141.8		173.4	
18	88.86	Good	9	Very poor	8	Poor	0	Poor
			241.2					
19	88.78	Good	3	Very poor	33.27	Excellent	40.53	Excellent
			231.7					
20	86.83	Good	6	Very poor	11.43	Excellent	49.26	Excellent
			268.8		123.8			
21	88.23	Good	6	Very poor	8	Poor	47.87	Excellent
			516.7	Unsuitabl	104.5			
22	91.73	Good	2	e	0	Poor	32.37	Excellent
			229.4					
23	85.24	Good	2	Very poor	16.79	Excellent	34.75	Excellent
			220.5					
24	85.08	Good	5	Very poor	36.34	Excellent	83.58	Good
			228.4					
25	91.80	Good	9	Very poor	10.13	Excellent	21.93	Excellent
			245.7					
26	88.08	Good	3	Very poor	25.84	Excellent	57.98	Good
			226.1					
27	90.34	Good	3	Very poor	12.35	Excellent	35.51	Excellent
			218.1					
28	93.89	Good	6	Very poor	32.56	Excellent	44.45	Excellent
	137.5		175.9					
29	7	Poor	9	Poor	41.73	Excellent	29.45	Excellent
	141.5		155.0					
30	4	Poor	4	Poor	37.19	Excellent	24.83	Excellent
	148.8		152.0					
31	4	Poor	4	Poor	10.17	Excellent	22.67	Excellent
32	138.5	Poor	183.5	Poor	21.77	Excellent	34.38	Excellent

	8		0					
	135.3		437.2	Unsuitabl				
33	0	Poor	8	e	33.17	Excellent	57.80	Good
	146.8		168.8					
34	9	Poor	8	Poor	33.76	Excellent	56.54	Good
	130.8		154.6				270.3	
35	8	Poor	8	Poor	19.92	Excellent	4	Very poor
	145.2		178.2					
36	0	Poor	0	Poor	42.61	Excellent	41.32	Excellent
	143.2		197.4					
37	9	Poor	2	Poor	33.62	Excellent	34.52	Excellent
	134.2		210.2				142.2	
38	3	Poor	5	Very poor	22.60	Excellent	3	Poor

Table 3.15(b): Water Quality Index (WQI) and its relevant category of sampling sites of Loktak Lake (2021-2022)

Sampling points	Monsoon		Post-monsoon		Winter		Pre-monsoon	
	WQI	Category	WQI	Category	WQI	Category	WQI	Category
1	118.67	Poor	504.26	Unsuitable	141.34	Poor	80.97	Good
2	11.22	Excellent	141.33	Poor	308.93	Unsuitable	123.01	Poor
3	57.26	Good	166.95	Poor	29.07	Excellent	71.78	Good
4	31.82	Excellent	225.40	Very poor	42.53	Excellent	47.14	Excellent
5	133.15	Poor	114.37	Poor	35.67	Excellent	72.53	Good
6	184.48	Poor	172.60	Poor	34.79	Excellent	11.43	Excellent
7	91.98	Good	472.76	Unsuitable	43.18	Excellent	73.03	Good
8	50.55	Good	413.57	Unsuitable	84.57	Good	633.71	Unsuitable
9	205.46	Very poor	260.79	Very poor	18.50	Excellent	16.62	Excellent
10	202.38	Very poor	248.05	Very poor	17.14	Excellent	25.17	Excellent
11	11.45	Excellent	88.50	Good	15.19	Excellent	85.45	Good
12	61.38	Good	102.80	Poor	15.85	Excellent	44.91	Excellent
13	44.97	Excellent	137.45	Poor	16.62	Excellent	88.34	Good
14	76.93	Good	139.10	Poor	10.35	Excellent	342.22	Unsuitable
15	78.68	Good	282.51	Very poor	32.30	Excellent	285.47	Very poor
16	195.08	Poor	390.95	Unsuitable	24.46	Excellent	241.13	Very poor
17	146.76	Poor	190.46	Poor	39.88	Excellent	177.36	Poor

18	128.63	Poor	137.93	Poor	18.38	Excellent	308.96	Unsuitable
19	48.03	Excellent	173.96	Poor	29.58	Excellent	260.22	Very poor
20	66.02	Good	113.41	Poor	17.44	Excellent	76.70	Good
21	16.64	Excellent	301.85	Unsuitable	85.75	Good	532.15	Unsuitable
22	504.78	Unsuitable	168.88	Poor	27.69	Excellent	186.77	Poor
23	329.41	Unsuitable	151.49	Poor	16.05	Excellent	391.93	Unsuitable
24	87.88	Good	139.69	Poor	22.08	Excellent	252.14	Very poor
25	75.49	Good	70.94	Good	13.18	Excellent	23.98	Excellent
26	58.70	Good	222.59	Very poor	14.44	Excellent	40.02	Excellent
27	36.69	Excellent	106.67	Poor	13.30	Excellent	22.21	Excellent
28	111.87	Poor	116.24	Poor	18.66	Excellent	24.02	Excellent
29	79.92	Good	72.09	Good	15.39	Excellent	27.11	Excellent
30	58.22	Good	164.55	Poor	19.90	Excellent	46.75	Excellent
31	125.25	Poor	124.95	Poor	14.91	Excellent	35.06	Excellent
32	98.48	Good	158.49	Poor	21.90	Excellent	33.88	Excellent
33	119.12	Poor	141.54	Poor	14.99	Excellent	56.12	Good
34	124.98	Poor	113.98	Poor	20.09	Excellent	56.94	Good
35	98.92	Good	207.11	Very poor	54.50	Good	76.26	Good
36	101.87	Poor	171.44	Poor	34.10	Excellent	459.74	Unsuitable
37	222.30	Very poor	213.75	Very poor	21.17	Excellent	586.54	Unsuitable
38	110.59	Poor	100.60	Poor	62.10	Good	54.90	Good

Figure 3.10(A) and Figure 3.10(B) represent the graphical representation of the Water Quality Index (WQI) across different seasons in Loktak Lake for the years 2020-2021 and 2021-2022, respectively. The trends show a sharp deterioration in water quality during the monsoon and post-monsoon, reaching the worst with most of the values near the threshold of 300, followed by improvement in winter and pre-monsoon during the first year, but slight change during the second year with the pre-monsoon season showing higher WQI values.

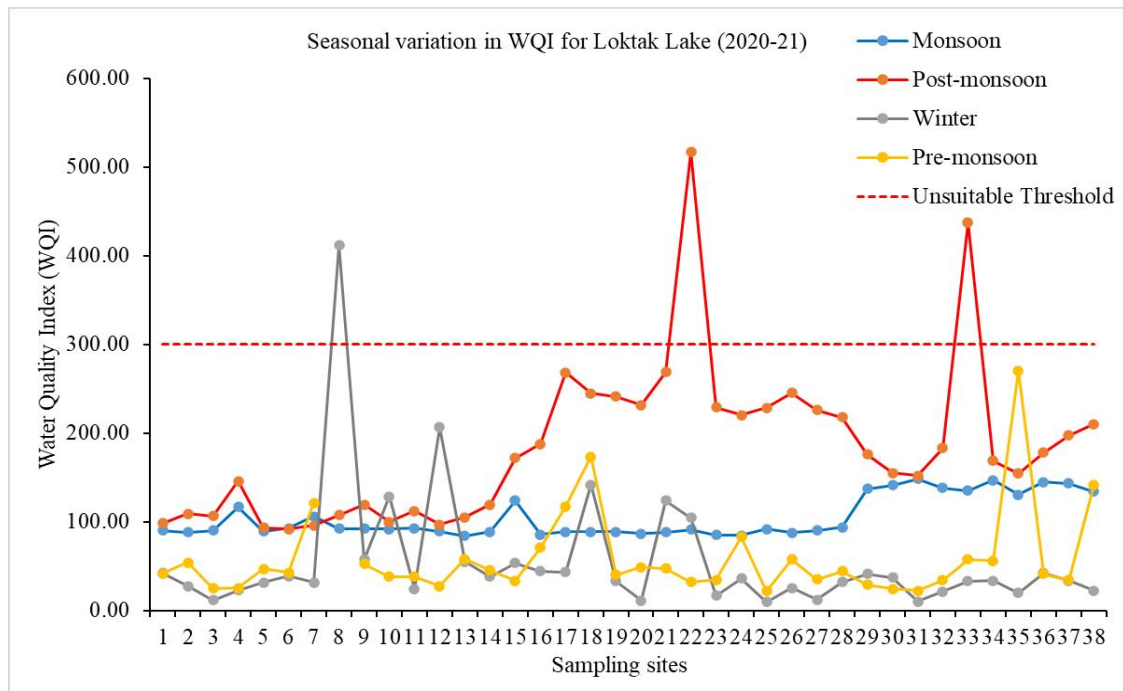


Figure 3.10(a): Seasonal variation in the Water Quality Index (WQI) of Loktak Lake for the years 2020-2021.

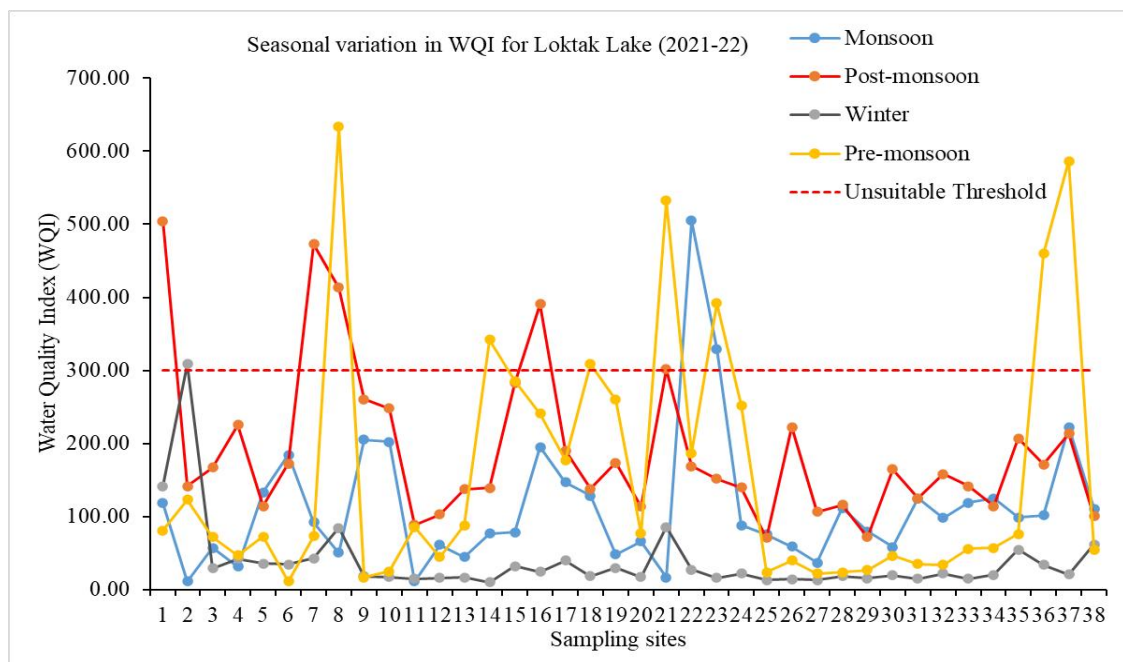


Figure 3.10(b): Seasonal variation in the Water Quality Index (WQI) of Loktak Lake for the years 2021-2022.

Table 3.16: Percentages of each WQI category recorded in different seasons across the study period in Loktak lake.

Year	Category	Monsoon		Post-monsoon		Winter		Pre-monsoon	
		No. of sites	%	No. of sites	%	No. of sites	%	No. of sites	%
2020-2021	Unsuitable	0	0.00	2	5.26	1	2.63	0	0.00
	Very poor	0	0.00	12	31.58	1	2.63	1	2.70
	Poor	13	34.21	19	50.00	4	10.53	4	10.81
	Good	25	65.79	5	13.16	3	7.89	8	21.62
	Excellent	0	0.00	0	0.00	29	76.32	24	64.86
2021-2022	Unsuitable	2	5.26	5	13.16	1	2.63	7	18.42
	Very poor	3	7.89	7	18.42	0	0.00	4	10.53
	Poor	12	31.58	23	60.53	1	2.63	3	7.89
	Good	14	36.84	3	7.89	4	10.53	11	28.95
	Excellent	7	18.42	0	0.00	32	84.21	13	34.21

Based on the values and their classification, for the first year of the study, it was observed that during monsoon season, 34.21 % of the samples were found under poor and 65.79 % under good categories (Table 3.14). In post-monsoon, 5.26 %, 31.58 %, 50%, and 13.16 % were under unsuitable, very poor, poor, and good categories, respectively. In winter, as the contaminants start settling, only 2.63 % of the samples were found unsuitable for drinking purposes, while 2.63 %, 10.53 %, 7.89%, and 76.32 % of the samples were of very poor, poor, good, and excellent categories, respectively. Only 2.70 % of the samples were found very poor, while 10.81 %, 21.62%, and 64.86 % of the samples were of poor, good, and excellent categories, respectively.

For the subsequent year, during monsoon season, 5.26 % of the samples were found unsuitable while 7.89 %, 31.58 %, 36.84 %, and 18.42 % were under very poor, poor, good, and excellent categories, respectively. During post-monsoon, 13.15 %, 18.42 %, 60.53 %, and 7.89 % were under unsuitable, very poor, poor and good categories, respectively. In winter, 2.63 % of the samples were found unsuitable for drinking purpose while 2.63 %, 10.53 %, and 84.21 % of the samples were of poor, good, and excellent categories, respectively. 18.42 % of the samples were found unsuitable for drinking, while

10.53 %, 7.89 %, 28.95 % and 34.21 % of the samples were of very poor, poor, good, and excellent categories, respectively during pre-monsoon period.

3.3.5 PCA-APCS-MLR Model for source apportionment

Principal component analysis (PCA) was performed with varimax rotation to analyze 12 water quality parameters (TA, Ca, Cl, DO, EC, TH, SO_4^{2-} , Sal., TDS, Turb., K, and Mg) at thirty-eight sampling sites to explore the specific sources of pollution by reducing the dimensionality of the data matrix. The original monitoring data was standardized before generating a correlation coefficient matrix^[27]. The Kaiser–Meyer–Olkin (KMO) and Bartlett’s sphericity test values were 0.832 and 0.000, respectively (Table 3.17), indicating the significant relationship among the variables^[27] and the suitability of data for performing PCA^[28,30,36].

Table 3.17: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.832
Bartlett's Test of Sphericity	Approx. Chi-Square	661.812
	Df	66
	Sig.	0.000

Table 3.18 represents the determined initial principal components (PCs), their eigenvalues, and cumulative % of variance contributed in each PC. Based on the Kaiser Rule^[28], the first four principal components are considered with eigenvalues >1, cumulating 72.34 % of the total variance in the water quality dataset. The influence of each indicator on the PCs was obtained by rotating factor loading, enabling pollution sources to be inferred. Factor loadings above 0.75, 0.50 to 0.75, and 0.30 to 0.50 were considered to be strong, moderate, and weak loadings, respectively^[26,37]. Rotated component matrix of those greater than 0.3 and component score coefficient matrix of the selected principal components are given in Table 3.19 and Table 3.20, respectively.

Table 3.18: Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.255	52.127	52.127	6.255	52.127	52.127	5.753	47.943	47.943
2	1.753	14.610	66.737	1.753	14.610	66.737	1.920	16.002	63.945
3	1.381	11.509	78.245	1.381	11.509	78.245	1.419	11.826	75.772
4	1.003	8.358	86.603	1.003	8.358	86.603	1.300	10.831	86.603
5	0.570	4.752	91.355						
6	0.492	4.101	95.456						
7	0.249	2.072	97.528						
8	0.157	1.309	98.837						
9	0.099	0.829	99.666						
10	0.037	0.308	99.974						
11	0.002	0.020	99.993						
12	0.001	0.007	100.000						

Extraction Method: Principal Component Analysis.

Table 3.19: Rotated Component Matrix

	Component			
	1	2	3	4
TH	0.972			
EC	0.959			
Sal.	0.958			
TDS	0.956			
TA	0.930			
Ca	0.917			
K		0.821		
Mg	0.383	0.787		
Turb.	0.370	0.654	0.308	
SO42-			0.798	0.329
DO			0.754	-0.399
Cl				0.922

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

Table 3.20: Component Score Coefficient Matrix

	Component			
	1	2	3	4
TA	0.182	-0.050	-0.112	-0.045
Ca	0.191	-0.137	0.041	-0.025
Cl	-0.040	-0.078	-0.028	0.756
DO	-0.014	0.038	0.563	-0.354
EC	0.169	-0.032	0.011	0.039
TH	0.191	-0.042	-0.060	-0.097
Sal.	0.166	-0.015	0.017	0.032
SO42-	-0.026	0.047	0.558	0.209
TDS	0.166	-0.020	0.017	0.040
Turb.	-0.032	0.392	0.273	-0.021
K	-0.135	0.499	0.006	0.087
Mg	-0.002	0.467	-0.098	-0.296

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

Using the results from the PCA analysis, the APCS-MLR model was used to measure how much each possible source of contamination affects 12 water quality parameters. Table 3.21 presents the percentage contribution of Principal Components (PCs) to the variance of various water quality parameters in Loktak Lake. Multiple sources or processes influence each parameter. Figure 3.11a illustrates the contribution of various sources to different water quality parameters. Figure 3.11(b) shows the outcome of source apportionment via the APCS-MLR model. PC1 (46%) contributes the highest, and PC4 (3%) contributes the lowest amount of pollutants in Loktak Lake.

Table 3.21: Relative source contributions (%) of PCs on different water quality parameters of Loktak Lake

Parameters	PC1	PC2	PC3	PC4	Unidentified	Total
TA	61.413	4.670	8.391	0.224	25.302	100
Ca	73.248	1.434	11.184	0.382	13.751	100
Cl	13.222	6.178	4.123	13.489	62.988	100
DO	6.019	4.878	41.544	2.876	44.683	100
EC	83.610	7.536	6.314	1.850	0.690	100
TH	85.449	6.014	4.285	0.392	3.859	100
Sal.	77.822	8.015	6.227	1.692	6.243	100
SO ₄ ²⁻	10.067	1.363	54.568	2.955	31.048	100
TDS	82.739	8.297	6.770	1.904	0.290	100
Turb.	23.122	20.782	21.785	1.353	32.958	100
K	8.777	46.500	13.115	3.991	27.616	100
Mg	28.368	29.642	21.139	2.165	18.685	100

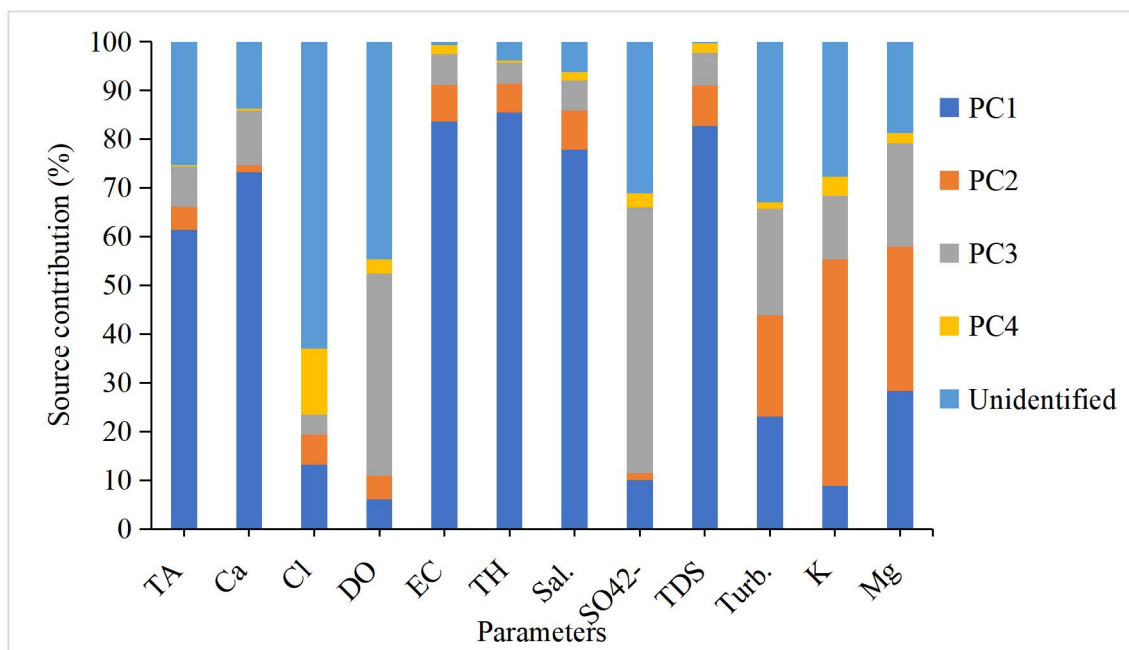


Figure 3.11(a): Contributions of different pollutant sources on water quality of Loktak lake.

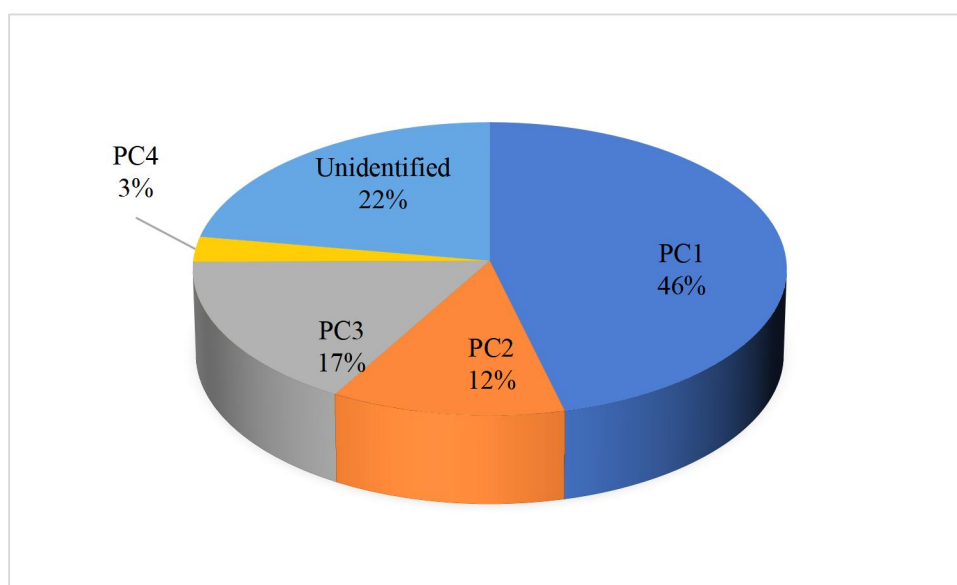


Figure 3.11(b): Average contributions of pollutant sources in the Loktak Lake according to PCA-APCS-MLR model.

3.4 DISCUSSION

The quality of water is essential for the well-being of the ecosystem, human consumption, and numerous ecological processes. Physico-chemical factors serve as crucial markers for assessing and monitoring the quality of water. These factors provide extensive data on the physical and chemical properties of water, which determine its suitability for various purposes.

The acceptable range of turbidity for drinking (1 NTU as per WHO, 2003)^[22] was found only during the winter season in Mayang Imphal (near Karang), Ningthoukhong ITI Manak, Ithing, Thanga Salam, and Nashik Houbi, which means that the lake water is turbid throughout the year in most places. Low turbidity in winter season might be due to less phytoplankton growth and a low sediment load in the lake. Similar trends were reported by Tuboi et al. (2018)^[38] where the monsoon got the highest value (144.44 NTU), followed by summer (27.06 NTU) and winter (16.82 NTU); and Roy and Majumder (2019)^[39] from 4.3 to 13.6 NTU with a maximum during summer. The highest mean turbidity of the Turag River of Bangladesh was 27.41 NTU, and 24.48 to 41.10 NTU as reported by Bhuiyan et al, (2011)^[40] and Rahman et al, (2021)^[41].

Kangabam et al. (2017)^[42] observed a turbidity of 0.23 to 2.84 NTU in Loktak Lake with the highest during monsoon and lowest in winter. A report from Lake Prashar in Himachal Pradesh, India, also showed a similar finding, where turbidity was highest during monsoon (3.18 NTU) and lowest during winter season (1.23 NTU)^[5]. The present finding of turbidity was found to be higher as compared to the previous report of Kangabam et al, (2017)^[42]. High turbidity in monsoon and post-monsoon was due to siltation from the hills, wastewater from the rivers and streams, and runoff resulting from heavy rainfall in the surrounding inhabited region. Pre-monsoon recorded slightly higher values of turbidity than monsoon season in the second year, which may be due to a lesser amount of rain during pre-monsoon which causes surrounding land areas to muddy, and disturbances created by fishermen make lake water more turbid.

In the present study, the highest electrical conductivity (EC) was observed in pre-monsoon, with 247.28 $\mu\text{S}/\text{cm}$, and the estimated EC value was found within the desirable limit of 500 $\mu\text{S}/\text{cm}$ given by WHO. Rai et al. (2011)^[43] reported a similar trend of EC in summer and rainy seasons with 428 and 530 $\mu\text{S}/\text{cm}$, respectively. Pokharel et al. (2018)^[44]

reported a mean of 166 $\mu\text{S}/\text{cm}$ conductivity in the Seti-Khola River in Central Nepal. A study conducted in Prashar Lake in Himachal Pradesh by Kumari and Sharma (2019)^[5] reported slightly different results with the highest value observed during monsoon (87.67 $\mu\text{S}/\text{cm}$) and lowest in winter (49.25 $\mu\text{S}/\text{cm}$), which are found to be comparatively lower than the present study record. Singh et al. (2010)^[16] in Kharungpat lake in Manipur observed similar results where summer observed the highest and lowest value in winter. A comparable outcome was also observed in the study conducted by Tuboi et al. (2018)^[38], where the highest value, 267.28 $\mu\text{S}/\text{cm}$ was found in the monsoon, while the summer got lowest mean values (204.06 $\mu\text{S}/\text{cm}$). High electrical conductivity is due to organic matter decomposition, sewage ion influx, sedimentary rock dissolution, and agricultural runoff discharge. The overall EC values were recorded highest during the post-monsoon (233.18 $\mu\text{S}/\text{cm}$), followed by a gradual decrease, reaching their minimum during the post monsoon season (217.13 $\mu\text{S}/\text{cm}$) in the first year of observation. The decrease in electrical conductivity (EC) in Loktak Lake during the monsoon and post-monsoon seasons can be attributed to the dilution of water caused by rainfall.

The salinity readings exhibited the highest mean values during the post-monsoon period, with minimal variations observed throughout the other seasons. No recommended value of salinity was found. Salts and other ions, primarily from sewage and home runoff, contribute to the observed salinity in water bodies. Examining the seasonal variation during the study period, post-monsoon showed the highest (78.83 mg/L) in the initial year but exhibited lowest in the second year with 72.84 mg/L.

The estimated total hardness values were highest in the winter and lowest in monsoon during the first year of study. The high value of hardness in the water could potentially be attributed to a reduction in water level, which lead to concentration of dissolved salts. The finding is similar to the report of Roy and Majumder (2019)^[39], which also stated the values reached their peak during the winter season and their lowest during the monsoon season, due to a reduction of water level. Similar values of hardness were observed in Loktak Lake, being the lowest of 18.6 mg/L during the rainy season and 68 mg/L during winter (Singh and Rai 2014)^[45]. However, the total hardness value ranges from 23.99 to 70.07 mg/L in the present study. A study conducted in the Nambul river in Manipur reported a wide range of hardness values between 18 and 292 mg/L (Singh and Dey 2014)^[46]. Another study in Loktak lake by Tuboi et al. (2018)^[38] observed that the highest

(139.44 mg/L) and lowest (104.59 mg/L) values were in the monsoon and summer, respectively. Kangabam et al. (2017)^[42] found that the hardness of Loktak Lake was 38 mg/L in pre-monsoon and 130 mg/L in monsoon, which was higher than the present study. As per the criteria of Sawyer and McCarty (1967)^[47], the Loktak Lake water is soft, having <75 mg/L of total hardness.

The maximum TDS value was found during the post-monsoon and decreased subsequently in respective seasons. Similar trends and values were also reported by Tuboi et al. (2018)^[38] with 131.8 mg/L in winter, 125.14 mg/L in summer, and 161.79 mg/L in monsoon. Rai and Raleng (2011)^[43] also reported higher values with a maximum (480 mg/L) during the rainy season and minimum (52.7 mg/L) during the winter in Loktak Lake. Kangabam et al. (2017)^[42] observed a TDS value at Loktak Lake ranging from 46.52 to 168.9 mg/L, which was lower than the result observed in the present study. Another study in the lake showed contrasting and much lower TDS values of 116.8 mg/L in pre-monsoon and 101.9 mg/L in post-monsoon^[2]. In the present, a high TDS value during the pre-monsoon in the 2nd year might be due to the reduced rainfall that resulted in muddy surrounding land areas and disturbances by fishermen leading to increased turbidity compared to the monsoon, where substantial water diluted the sediment particles. High values of TDS in post-monsoon and winter may be attributed to the substantial influx of concentrated residential runoff, decrease in water level, leaching of soil contamination, and excess minerals into water from streams and rivers during monsoon, decomposition of organic matter, and the increased anthropogenic activities like fishing and collection of vegetables and algae for consumption and fish feed during these seasons.

Rai and Raleng (2011)^[43] observed that the pH of Loktak Lake ranged from 6.7 to 8.5, with the lowest value recorded in winter. Singh and Rai (2014)^[45] and Kangabam et al. (2017)^[42] reported values at Loktak Lake ranging from 6.3 to 7.2 and 6.15 to 7.66, respectively. These values were seen to be at their lowest during the winter season. In an investigation conducted in Kharungpat Lake in Manipur, Singh et al. (2010)^[16] found that the pH ranged from 6.10 to 7.90. Afrin et al. (2015)^[48] and Rahman et al. (2021)^[41] also reported pH values of the Turag River water of Bangladesh ranged from 6.98 to 7.93 and from 6.11 to 8.37, respectively. Compared to previous findings, the present observed pH values show a slight shift from acidic to alkaline in nature. The higher pH readings may

be attributed to the presence of carbonate, bicarbonate, and other ions that contribute to the alkaline quality of the water.

In the winter season, there was a noticeable increase in alkalinity, possibly caused by the accumulation of carbonate, bicarbonate, and hydroxide ions that are carried by rivers. The alkalinity reached its minimum level during the post-monsoon period. Ravindra et al. (2003)^[49] reported a consistent pattern of values in the Yamuna River, with alkalinity levels ranging from 80 to 250 mg/L in summer and 150 to 600 mg/L in winter. According to Laishram and Dey (2014)^[50], the average alkalinity values were 75 mg/L during the pre-monsoon period and 42 mg/L during the monsoon period. The alkalinity values observed in Keibul Lamjao National Park ranged from 40 to 70 mg/L, as reported by Devi et al. in 2015^[51]. Increased alkalinity during the winter season promotes the growth of algae and other forms of aquatic life. The observed values of total alkalinity are found to be higher than the values reported in previous studies (Laishram and Dey 2014^[50]; Devi et al. 2015^[51]). While moderate alkalinity supports healthy ecosystems, extremely high levels can disrupt physiological processes in certain aquatic species, as highlighted by Wright and Nebel (2002)^[52]. However, all the measured values of the present study fell within the permissible limits of 200 mg/L, as defined by the Bureau of Indian Standards (BIS).

During the study period, the post-monsoon had the highest calcium concentration, while the winter season had the lowest. The site Naranshena consistently showed the lowest calcium concentration, while Mayang Imphal (I) exhibited the highest concentration in two seasons. The overall mean values decreased gradually from the monsoon to the pre-monsoon season. This phenomenon occurred due to the influx of calcium-containing compounds from the catchment areas delivered by the rivers and streams during the monsoon season. The decrease in concentration observed during the pre-monsoon period may be attributed to organisms' consumption of calcium, which undergoes transformation into other compounds or settles below the water column. Other investigations have produced similar results. For example, Kumari and Sharma (2019)^[5] found that the concentration of calcium in Lake Prashar, Himachal Pradesh, India, was 5.32 mg/L in winter and 9.01 mg/L during summer. Gaury et al. (2018)^[6] observed concentrations of 40.59 mg/L in pre-monsoon, 45.18 mg/L in monsoon, and 55.51 mg/L in post-monsoon in Rewalsar Lake, Himachal Pradesh, India. Tuboi et al. (2018)^[38] measured mean values

of 59.12 mg/L in monsoon, 80.08 mg/L in monsoon, and 64.14 mg/L in winter in Loktak Lake, Manipur. However, Mayanglambam and Neelam (2020)^[2] reported different results of 13.05 mg/L in pre-monsoon and 9.06 mg/L in post-monsoon.

The mean concentration of chloride exhibited its highest value (7.85 mg/L) during the pre-monsoon in the first year of observation, followed by monsoon, post-monsoon, and winter in the subsequent seasons. In the second year, monsoon recorded the highest value (6.84 mg/L), followed by pre-monsoon, winter, and post-monsoon. The presence of chlorine observed in the lake water can be attributed to the utilization of chlorine and chlorine-based substances in nearby urban areas, which are near rivers and streams, as well as the presence of organic matter. Mishra et al. (1990)^[53] and Oberoi (1987)^[54] found that lower water flow and higher amount of concentrated solutes can explain the high levels of chloride in the lake water during the monsoon and post-monsoon seasons. Rai and Raleng (2011)^[43] reported a similar trend of concentration where 11 mg/L, 17 mg/L, and 25 mg/L of chloride were found in winter, summer and rainy seasons, respectively. Kangabam et al. (2017)^[42] also reported similar result, with the monsoon having the highest concentration. A similar trend but higher values were reported in a previous study by Mayanglambam and Neelam (2020)^[2] with 29.36 mg/L and 16.62 mg/L in post-monsoon and post-monsoon, respectively, in Loktak Lake. The second- year estimated chloride values show lower values than the previous year, and the lowest value of chloride was also observed in post-monsoon, having 4.95 mg/L. The lowest value was observed during winter in the first year of the study. Lower values in post-monsoon and winter might be related with a decrease in the inflow of water and runoff due to very little rainfall. The mean chloride concentration of the water samples from the Turag River, a typical river ecosystem in Bangladesh's tropical flood-prone zone, as reported by Rahman et al. (2021)^[41], was within the range of 61–107 mg/L, which was found to be comparatively higher than in the present study. In all seasons, the overall chloride values remained within the desirable limit of 250 mg/L.

The mean value of dissolved oxygen (DO) in the studied water samples, encompassing four seasons, varied from 4.47 to 6.08 mg/L. The DO range is in line with reports from Nepal and other Asian nations^{[55][56][57][44]}. Pokharel et al. (2018)^[44] reported an average of 8.0 mg/L DO in the Seti-Khola River, which falls within the present estimated DO level. The overall mean value of DO (4.47 mg/L) in the monsoon season was slightly lower

than the desirable limit of 5 mg/L, as per BIS. But in order to sustain aquatic life, DO rates above 4.0 mg/L are deemed reasonable; above 6.5 is good, and above 8.0 is exceptional^[58]. The low mean value of dissolved oxygen (DO) may be attributed to the decrease in flow and the increase in decomposition of organic matter caused by the rise in temperature^[59]. Decomposition of organic matter by microbes, which requires oxygen and prolonged coverage of the water surface by phumdis, might be the reason for the lowest mean DO value during the winter season of the first year.

The high mean value of DO in pre-monsoon might be due to the stagnant nature of water and relatively lower temperature, thereby increasing the solubility of gases in water. A study in Loktak Lake by Rai and Raleng (2011)^[43] reported a DO concentration of 6.80 to 9.32 mg/L, which was slightly higher than the current finding. Another study in Loktak Lake water by Tuboi et al. (2018)^[38] also reported higher values than the present recorded value, wherein all the seasons got more than 6 mg/L. Kumari and Sharma (2019)^[5] also found higher DO values (6.84 - 12.1 mg/L) in Prashar Lake in Himachal Pradesh, India. Singh and Rai (2014)^[45] also reported higher values (7.5-9.6 mg/L) in Loktak Lake water than the mean values of all the seasons of the current study. However, lower values were observed by Singh et al. (2010)^[16] in Kharungpat Lake in Manipur (1.4 to 7.8 mg/L), with the highest in summer. As compared with the previous findings, the present study revealed that the dissolved oxygen concentration in Loktak Lake has decreased. It reveals the poor quality of the lake's water, which is not suitable for drinking purposes. However, variation in water quality is a continuous process; therefore, updated water quality data are necessary for water quality assessment.

The concentration of sulphate observed across all seasons consistently was much below the desirable limit of 200 mg/L. The study determined that the mean concentration was highest during the pre-monsoon period and lowest during the post-monsoon period. The concentration of sulphate in the lake was slightly higher but had a similar trend as compared to the findings given by Kangabam et al. (2017)^[42] with 0.016 mg/L in the monsoon and 1.17 mg/L during the pre-monsoon. In contrast, a significantly greater concentration was seen in a comparable environment (Rewalsar Lake) in Himachal Pradesh, India, with 2.478 mg/L in pre-monsoon, 2.035 mg/L in monsoon, and 2.316 mg/L in post-monsoon^[6]. However, this finding contradicts the results provided by Mayanglambam and Neelam (2020)^[2] having 0.01 mg/L and 0.21 mg/L in pre- and post-

monsoon, respectively, in Loktak Lake. The presence of sulphate in lake water can potentially be attributed to various sources, including the process of rock weathering, the discharge of sewage and agricultural runoff, and the deposition of atmospheric sulphur dioxide resulting from the combustion of fossil fuels, which manifests as acid rain.

The mean value of potassium concentration (mg/L) in monsoon and post-monsoon was found to be above the desirable limit of 12 mg/L as per WHO guidelines, whereas other seasons showed mean concentrations well below the limit. High mean potassium concentration in water can result from several factors during monsoon (34.09 mg/L) and post-monsoon (146.69 mg/L) seasons. Runoff of fertilizers from agricultural fields and decomposed organic waste and plant material may be responsible for increased concentrations of potassium levels in the lake water^{[60][61]}. The higher potassium values in post-monsoon compared to the monsoon and other seasons may be due to the increased accumulation of elements in water bodies during rainfall^{[62][60]}.

The mean magnesium content in lake water is highest during the post-monsoon period with 61.14 mg/L, which was higher than the acceptable limit of 30 mg/L set by the BIS for the entire period of the study. Runoff of fertilizers from agricultural fields and decomposed organic waste and plant material may be responsible for the increased concentration of magnesium in the lake water^[60]. The order of seasons with mean magnesium content is as follows: post-monsoon > pre-monsoon > monsoon > winter. Conversely, the mean concentrations were significantly below the permissible limit during other seasons of the year. Winter exhibited the least mean value of magnesium with 3.72 mg/L.

Correlation analysis found strong positive relationships between the variables, indicating that calcium salts and other dissolved solids might be affecting changes in other water properties. The presence of calcium in water leads to a rise in several parameters when it is dissolved in its ionic state or when it combines with other ions to form compounds such as CaCO_3 , Ca(OH)_2 , CaCl_2 , etc. The data shows that as chloride levels go up, the pH goes down, meaning that more chloride interacts with hydroxide ions and lowers the pH. High significant positive correlations of electrical conductivity with hardness, phosphate, salinity, TDS, and turbidity suggest that the presence of calcium salts, phosphate, and other dissolved solids significantly increases the electrical conductivity. Hardness also has a moderate positive correlation with phosphate. The presence of a higher

concentration of phosphate might also increase the hardness of water to some extent. The presence of salts and ions in the water results in high magnesium and potassium and exhibits a highly significant positive correlation with total alkalinity, EC, hardness, salinity, TDS, and turbidity.

The multivariate tests with Pillai's Trace ($p=0.002$) and Wilks' Lambda ($p<0.001$) showed that there are important differences in water quality measurements at the different sampling sites, which means we do not accept that they are all the same (rejected the null hypothesis). The Wilks' Lambda value of 0.004 indicates that 99.6% of the differences in water quality parameters come from variations within the sampling sites. This significant statistical evidence indicates that environmental variables or human activities may be influencing water quality in these areas. Further investigation is necessary to identify the specific causes of these variations and to implement appropriate measures for water quality management.

The WQI values across four seasons for the study periods 2020-2021 and 2021-2022 demonstrate considerable variation, indicating dynamic changes in water quality. Most sites classified their WQI values as 'good' during the monsoon in 2020. However, by 2021, there was a slight deterioration, with several sites showing 'poor' conditions (e.g., Phoubakchao and Komlakhong). Increased runoff and nutrient inflow during the monsoon likely contributed to elevated nutrient levels, leading to increased biological activity and poorer water quality at certain sites. Post-monsoon WQI showed a wide range from 93 to 504, higher than the previous record in Loktak Lake^[63]. Kangabam et al. (2017)^[42] also reported much lower WQI values (64-77) from the lake. Some sites maintained 'good' quality (Mayang Imphal (I)), while others deteriorated to 'poor' or even 'unsuitable' categories in 2021. The high values of 504.26 at Mayang Imphal (I) in 2021 suggest the possibility of organic pollution, an increase in suspended matter, and frequent disturbance by fishermen during the post-monsoon period. During winter, WQI values were relatively lower, with several sites categorized as 'excellent' at Mayang Imphal (I) and Phoubakchao, and a few sites showing 'poor' or 'unsuitable' conditions. Lower biological activity and reduced surface runoff during winter might be the reason for improved water quality. Pre-monsoon showed relatively better conditions, with most sites being 'good' or 'excellent.' Stable water quality before the onset of

monsoon suggests reduced external influences. However, in 2022, a few sites like Mayang Imphal (II) showed deterioration to 'poor' condition.

The worst water quality occurs in the monsoon and post-monsoon, indicating extreme pollution likely due to runoff, flooding, and contamination. In winter, many sites improve to "good" or "excellent" quality, indicating seasonal recovery. The evidence suggests that seasonal factors such as reduced runoff, lower pollutant inflow, and natural purification contribute to water quality recovery. Unsuitable WQI categories indicate possible domestic and agricultural discharges, which are common in the Loktak Lake catchment. Mixing contaminants from agricultural and urban areas leads to poor overall water quality. Areas with persistent "unsuitable" classification may have high contamination levels, requiring urgent pollution control measures. Extreme variations across seasons highlight the dynamic nature of Loktak Lake's ecosystem, influenced by weather, human activities, and natural processes. The growth of phumdis and macrophytes may affect nutrient dynamics and oxygen levels, altering water quality index (WQI) values. Loktak Lake faces severe water quality deterioration during the monsoon and post-monsoon, making it unsuitable for drinking purposes in many areas. Therefore, it is crucial to implement proper management and pollution control measures, particularly during and after the monsoon season. Regular monitoring, especially post-monsoon and during monsoon, is critical to mitigate pollution impacts. Controlling vegetation growth on the phumdi and ensuring proper flushing of water can enhance lake health.

Source apportionment using the PCA-APCS-MLR model gives four major sources of pollutants. PC1 is the dominant contributor for most parameters: TA (61.41%), Ca (73.25%), EC (83.61%), TH (85.45%), Salinity (77.82%), and TDS (82.74%), indicating the influence of natural geogenic processes such as the weathering of carbonate and silicate rocks. The dissolution of carbonate and silicate minerals is the primary source of parameters like Ca, Mg, and TH. The concentration of dissolved ions (cations and anions), which increase through mineral weathering and ionic leaching, drives EC and TDS in water. Dissolved salts from natural sources or agricultural return flows strongly influence the salinity of water. PC2 shows high contributions on K (46.50%), Mg (29.64%), and turbidity (20.78%). Agricultural runoff and domestic waste discharge are associated with this source. High loading of K suggests agricultural fertilizers as the primary source. Another source of Mg might come from wastewater discharge in densely populated areas

in the catchment of Loktak Lake. Land use changes, runoff, and increased sedimentation from human activities might influence turbidity of the water.

PC3 has a high contribution for DO (41.54%), SO_4^{2-} (54.57%), Mg (21.14%), and turbidity (21.79%), suggesting biological and atmospheric processes. DO is influenced by biological processes like photosynthesis by phytoplanktons and macrophytes and respiration by fishes and other organisms. SO_4^{2-} is likely derived from atmospheric deposition, emissions from brick kilns, burning of biomass, and organic matter oxidation. Turbidity is also associated with organic matter decay and suspended particles in the lake. PC4 moderately contributes to the Cl (13.49%), K (3.99%), Mg (2.17%), and DO (2.87%) in the lake. This component accounts for localized variations and minor anthropogenic inputs such as sewage intrusion, organic matter, or discharge from small farms.

Unidentified Sources contribute significantly to Cl (62.99%), DO (44.68%), SO_4^{2-} (31.05%), K (27.62%), and turbidity (32.96%), highlighting the need for further investigation into unknown or unmeasured influences. These could stem from unmonitored discharges, atmospheric deposition, burning of biomass, microbial activities to organic decomposition, and variability due to seasonal hydrological fluctuations. Equal contributions from PC1, PC2, and PC3 indicate complex and diverse sources of turbidity.

3.5 CONCLUSION

Physico-chemical parameters provide essential insights into water quality, affecting its suitability for various uses and the health of aquatic ecosystems. Regular monitoring and management of these parameters are vital for ensuring safe drinking water, protecting aquatic life, and maintaining sustainable agricultural and industrial practices. Understanding and addressing the factors influencing these parameters can help mitigate water quality issues and promote environmental and public health.

This study aims to evaluate 14 (fourteen) physical and chemical properties of the water in Loktak Lake, Manipur, in relation to its suitability for drinking purposes. Mean concentrations of nine metrics, namely total alkalinity, calcium, chloride, electrical conductivity, pH, sulphate, temperature, total hardness and total dissolved solids, were discovered to be within the acceptable range. The average concentration of dissolved oxygen (DO) during the pre-monsoon period was above the desirable limit, but the

remaining three seasons exhibited levels below the desired limit of 6 mg/L. This observation suggest a significant presence of microbial activity resulting from pollution, thereby reducing DO level in water^[64]. During the winter and pre-monsoon seasons, it was observed that the pH levels of lake water varied from slightly acidic to strongly alkaline in certain areas of the lake. At some locations, pH value exceeds the desirable limit throughout a majority of the year, with the exception of the post-monsoon period. The total dissolved solids (TDS) were also observed to be slightly elevated but still below acceptable limits for potable water use. During the monsoon and post-monsoon periods, we observed elevated turbidity levels, rendering the water unsuitable for consumption. It was observed that some of the physicochemical parameters of the present study, like Ca, EC, sulphate, TDS, K, and Mg, exhibited higher values compared to previous studies of Laishram and Dey 2014^[50]; Devi et al. 2015^[51]; Kangabam et al. 2017^[42]; Singh and Rai 2014^[45]; Singh and Dey 2014^[46]; Rai and Raleng 2011^[43]; Singh et al. 2010^[16]; Mayanglambam and Neelam 2020^[2]. In certain sampling locations, the values of TA, DO, TH, pH, TDS, turbidity, K, and Mg were found beyond the desirable limits, indicating poor water quality status. The overall condition of the Loktak Lake water exhibited a mild level of pollution, necessitating appropriate treatment to render it suitable for domestic use for drinking. The potential consequences of this situation affect the wetland's biodiversity, particularly the globally renowned brow-antlered deer species known as "Sangai," and other services. This study highlights the necessity of monitoring the quality of lake water throughout several seasons for long periods of time and evaluating contaminants and their origins. It also emphasizes the importance of implementing effective conservation and management strategies to ensure the long-term sustainability and well-being of the wetland ecosystem of Loktak Lake. From the WQI values, it was observed that the water quality during the monsoon and post- monsoon was mostly of poor condition, while it was recovered during the winter and pre-monsoon seasons, indicating seasonal recovery. Monitoring of runoff and discharge into the lake especially during rainy seasons, is necessary. Control of the proliferation of phumdi, and proper management of hydrological regime is recommended.

The PCA-APCS-MLR model of water quality parameters in Loktak Lake revealed that the majority of the pollutants are contributed by four different sources, with varying degrees of contribution from natural, anthropogenic, and biological processes. The primary sources influencing the water chemistry of Loktak Lake are the natural geogenic

processes, including weathering of carbonate and silicate minerals, ionic dissolution, and mineral leaching.

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