Environment and Ecology 41 (3B) : 1667—1673, July—September 2023
Article DOI: https://doi.org/10.60151/envec/QFBP2278
ISSN 0970-0420

A Study on Phytoplankton Diversity in Relation to Physico-Chemical Parameters of Freshwater Lake Kharungpat, Manipur, India

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Received 6 January 2023, Accepted 7 June 2023, Published on 21August 2023

ABSTRACT

The phytoplankton present in various water bodies collectively account for around half of the earth's primary producers. The present study attempts to gain a better insight into the phytoplankton diversity and its relationship with physico-chemical parameters of freshwater lake Kharungpat in Manipur, India from September 2019 to August 2021. The lake water was characterized by moderate temperature (16.68-29.21 °C), fluctuating transparency (53.00-119.30 cm), suitable level of pH (6.26-7.74) and dissolved oxygen (5.10–9.35 mg/l), favorable total alkalinity (31.21-66.29 mg/l), total hardness with a value of 28.37-66.49 mg/l which can sustain low growth of fish, fluctuating level of free carbon dioxide (3.78-10.23 mg/l), phosphate phosphorus and nitrate nitrogen content with a value ranged from 0.001 to 0.018 mg/l and 0.01-0.30 mg/l. A total of 22 phytoplankton genus were identified in the lake, out of which 13 belonged to Chlorophyceae, seven to Cyanophyceae, six to Bacillariophyceae and two to Euglenophyceae. Chlorophyceae, Cyanophyceae, Bacillariophyceae and Euglenophyceae are the four major phytoplankton groups identified with a percentage composition of 51.79%, 31.00%, 13.12% and 4.33% respectively. An analysis of seasonal variation of phytoplankton diversity indices indicated that the highest recorded Simpson_1-D was 0.956 and 3.180, 4.023 and 0.976 for Shannon_H, Margalef and Equitability_J respectively.

Keywords Phytoplankton, Seasonal variation, Diversity, Freshwater, Lake Kharungpat.

INTRODUCTION

The freshwater lakes of Manipur are degraded due to excessive influx of sediments through erosion from catchment area, discharge of untreated sewage and solid waste, accumulation of agricultural runoff and over-exploitation through fishing and recreation activities (Sharma *et al.* 2010, Ramesh and Krishnaiah 2013). Due to high level of degradation, most of the lakes in the state have already reached to the stage of wetlands (Sharma 1999). Lake Kharungpat ranks third among freshwater lake of Manipur which lies

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between longitudes 93° 90' to 93° 97' E and latitudes 24°53' to 24°60' N.

Phytoplankton make their energy through photosynthesis, the process of using chlorophyll and sunlight to create energy. Phytoplankton account for about half of the photosynthesis on the plant, making them one of the world's most important producers of oxygen. Attributed by longer sunshine hours, increased pH, salinity and tropho-tropic activities, summer season favored the growth of phytoplanktons in freshwater lakes (Goswami *et al.* 2018).

In an aquatic ecosystem, phytoplankton is most abundant, unicellular and tiny life form. Seasonal changes have been one of the important factors regulating the phytoplankton growth pattern of an ecosystem. The phytoplankton also form one of the most important food sources of zooplankton and fish fauna and thus are the basic food producers in any aquatic ecosystem. In the present study an attempt has been made for gaining a better insight of the change in phytoplankton diversity and its relationship with physico-chemical parameters of freshwater Kharungpat lake in Manipur.

MATERIALS AND METHODS

The present study was conducted during September 2019- August 2021 in lake Kharungpat of Manipur, India. It lies between longitudes 93° 90' to 93° 97' E and latitudes 24°53' to 24°60' N and situated at 781m above mean sea level with an area of 18 km². Phytoplankton and water sample were collected monthly from five sampling stations. Different physico-chemical parameters such as pH, temperature, dissolved oxygen, total alkalinity, total hardness, free carbon dioxide, phosphate phosphorus, nitrate-nitrogen and transparency were analyzed by standard methods (Adoni 1985, APHA 2012). Water samples for quantitative and qualitative analysis of phytoplankton were carried out by filtering 50 L of water through plankton nets having 150 µm mesh size following the standardized method presented in Edmondson and Winberg (1971). Numerical abundance of phytoplankton was estimated by using a Sedgwick Rafter cell (Adoni 1985, APHA 2012). The values observed were presented as numbers per lit. Pearson correlation coefficient was used to find the relationships among the various environmental factors including phytoplankton population. The diversity indices such as Shannon index (H), Evenness index (e^H/S), Simpson index (1-D) and Dominance (D) of phytoplankton were calculated using a computer-based software 'PAST version 2.02'.

RESULTS AND DISCUSSION

Physico-chemical characteristic of water

Monthly variation in water parameters observed in Kharungpat lake during 2019-2021 were presented in Tables 1-2. During the year 2019-2020, the minimum and maximum surface water temperature of Kharungpat lake recorded was 16.68°C and 29.21°C in the month of December, 2019 and August, 2020 respectively. Similarly, during the year 2020-2021 the minimum surface water temperature was observed in the month of December, 2020 (16.87°C) and maximum surface water temperature of 28.82°C was recorded during April, 2021. Water temperature ranging between 13.5 to 32 °C is reported to be suitable for the development of the planktonic organisms (Gaikwad *et al.* 2008). The surface water temperature of the present study ranges from 16.68 to 29.21°C. Thus, the studied lake is found to be suitable for planktonic organism's development.

During the present investigation water transparency value varied between 54.22 and 119.30 cm during the year 2019-20 with lowest being in the month of June 2020 and highest being in the month of December, 2020. Similarly, during the year 2020-2021, the minimum and maximum water transparency 53.00 and 115.42 cm were observed in the month of August 2021 and December 2021. In the present study the irregular seasonal variation in water transparency may be due to inflow of water from the catchment area of the lake that carrying heavy load of organic and inorganic matters and fishing activities. Higher value of water transparency during monsoon may be attributed to higher rainfall and may also be due to inflow of suspended matter and dissolved particles from the surrounding catchment area of the lake.

During the first half of the study period (2019-

Table 1. Monthly variation in water parameters observed in Kharungpat lake during 2019-2020.

Months	Temperature (°C) Ave ±SE (Range)	Transparency (cm) Ave ±SE (Range)	pH Ave ±SE (Range)	Dissolved oxygen (mg/l) Ave ±SE (Range)	Total alkalinity (mg/l) Ave ±SE (Range)	Total hardness (mg/l) Ave ±SE (Range)	Free carbon dioxide (mg/l) Ave ±SE (Range)	Phosphate phosphorus (mg/l) Ave ±SE (Range)	Nitrate-nitrogen (mg/l) Ave ±SE (Range)
September 2019	27.31 ±0.315 (26.99-27.62)	85.60 ±2.000 (83.60-87.60)	45 ±0.105 (6.34-6.55)	7.52 ±0.130 (7.39-7.65)	35.36 ±1.090 (34.27-36.45)	33.43 ±3.215 (30.21-36.64)	7.84 ±0.240 (7.60-8.08)	0.016 ±0.001 (0.015-0.017)	0.18 ±0.015 (0.16-0.19)
October	27.31 ±0.180 (27.13-27.49)	96.32 ±1.150 (95.17-97.47)	6.55 ±0.050 (6.50-6.60)	7.40 ±0.285 (7.11-7.68)	39.94 ±0.770 (39.17-40.71)	36.19 ±1.955 (34.23-38.14)	6.67 ±0.220 (6.45-6.89)	0.005 ±0.001 (0.004-0.006)	0.29 ±0.015 (0.27-0.30)
November	23.05 ±1.445 (21.60-24.49)	106.89 ±6.540 (100.35-113.43)	6.85 ±0.105 (6.74-6.95)	8.33 ±0.235 (8.09-8.56	36.06 ±0.730 (35.33-36.79)	36.59 ±2.740 (33.85-39.33)	6.21 ±0.385 (5.82-6.59)	0.007 ±0.001 (0.006-0.008)	0.16 ±0.010 (0.15-0.17)
December	18.95 ±2.265 (16.68-21.21	114.76 ±4.545 (110.21-119.30	7.25 ±0.130 (7.12-7.38	9.28 ±0.070 (9.21-9.35)	47.33 ±0.905 (46.42-48.23	36.12 ±3.790 (32.33-39.91)	4.26 ±0.480 (3.78-4.74)	0.008 ±0.001 (0.007-0.008)	0.04 ±0.010 (0.03-0.05)
January 2020	19.05 ±2.125 (16.92-21.17)	106.75 ±4.450 (102.30-111.20)	7.40 ±0.165 (7.23-7.56)	8.38 ±0.260 (8.12-8.64)	56.31 ±1.115 (55.19-57.42)	53.71 ±3.515 (50.19-57.22)	5.16 ±0.265 (4.89-5.42)	0.003 ±0.001 (0.002-0.003)	0.02 ±0.010 (0.01-0.03)
February	19.87 ±2.745 (17.12-22.61)	94.49 ±0.630 (93.86-95.12)	7.49 ±0.130 (7.36-7.62)	7.92 ±0.065 (7.85-7.98)	60.72 ±2.975 (57.74-63.69)	50.13 ±1.475 (48.65-51.60)	6.51 ±0.360 (6.15-6.87	0.005 ±0.001 (0.004-0.005	0.03 ±0.010 (0.02-0.04)
March	26.04 ±0.730 (25.31-26.77)	82.15 ±2.025 (80.12-84.17)	7.70 ±0.040 (7.66-7.74)	7.65 ±0.230 (7.42-7.88)	62.35 ±3.965 (58.38-66.31)	57.87 ±2.005 (55.86-59.87)	7.78 ±0.300 (7.48-8.08)	0.005 ±0.001 (0.004-0.006)	0.15 ±0.015 (0.13-0.16)
April	27.11 ±0.320 (26.79-27.43)	89.35 ±3.250 (86.10-92.60)	7.09 ±0.190 (6.90-7.28)	7.51 ±0.340 (7.17-7.85)	56.21 ±0.955 (55.25-57.16)	54.06 ±3.300 (50.76-57.36)	8.42 ±0.110 (8.31-8.53)	0.003 ±0.001 (0.002-0.004	0.13 ±0.010 (0.12-0.14)
May	27.30 ±0.160 (27.14-27.46)	94.39 ±2.210 (92.18-96.60)	7.00 ±0.200 (6.80-7.20)	6.68 ±0.200 (6.48-6.88)	45.81 ±1.400 (44.41-47.21	37.14 ±1.655 (35.48-38.79)	10.01 ±0.220 (9.79-10.23)	0.006 ±0.001 (0.005-0.006)	0.08 ±0.010 (0.07-0.09)
June	28.17 ±0.815 (27.35-28.98	56.54 ±2.315 (54.22-58.85)	6.70 ±0.400 (6.30-7.10)	5.46 ±0.265 (5.19-5.72)	47.23 ±0.915 (46.31-48.14)	37.34 ±2.130 (35.21-39.47)	9.89 ±0.100 (9.79-9.99)	0.009 ±0.001 (0.008-0.009)	0.13 ±0.015 (0.11-0.14)
July	27.70 ±0.090 (27.61-27.79)	75.44 ±2.785 (72.65-78.22)	6.53 ±0.270 (6.26-6.80)	6.30 ±0.150 (6.15-6.45)	47.19 ±2.015 45.17-49.20)	33.69 ±3.560 (30.13-37.25)	10.03 ±0.140 (9.89-10.17)	0.015 ±0.001 (0.014-0.016)	0.05 ±0.010 (0.04-0.06)
August	28.60 ±0.615 (27.98-29.21)	79.68 ±0.555 (79.12-80.23	6.63 ±0.070 (6.56-6.70)	7.29 ±0.140 (7.15-7.43)	33.94 ±0.840 (33.10-34.78)	32.01 ±3.600 (28.41-35.61)	8.29 ±0.145 (8.14-8.43)	0.005 ±0.001 (0.004-0.006)	0.03 ±0.010 (0.02-0.04)
Annual average	**25.04 ±0.984 (24.05-26.02)**	**90.19 ±2.705 (87.49-92.90)**	**6.97 ±0.155 (6.81-7.12)**	**7.48 ±0.198 (7.28-7.67)**	**47.37 ±1.473 (45.90-48.84)**	**41.52 ±2.745 (38.78-44.27)**	**7.59 ±0.247 (7.34-7.84)**	**0.007 ±0.001 (0.01-0.01)**	**0.11 ±0.012 (0.09-0.12)**

20), lowest pH (6.26) of Kharungpat lakewater is recorded in July 2020 and highest (7.74) in March 2020 whereas, during the second year (2020-21), lowest (6.20) and highest pH (7.79) was observed during September 2020 and March 2021 respectively. The optimum pH of inland water for warm water

Table 2. Monthly variation in water parameters observed in Kharungpat lake during 2020-2021.

Months	Temperature (°C) Ave ±SE (Range)	Transparency (cm) Ave ±SE (Range)	pH Ave ±SE (Range)	Dissolved oxygen (mg/l) Ave ±SE (Range)	Total alkalinity (mg/l) Ave ±SE (Range)	Total hardness (mg/l) Ave ±SE (Range)	Free carbon dioxide (mg/l) Ave ±SE (Range)	Phosphate phosphorus (mg/l) Ave ±SE (Range)	Nitrate-nitrogen (mg/l) Ave ±SE (Range)
September 2020	27.93 ±0.815 (27.11-28.74)	64.72 ±7.450 (57.27-72.17)	6.34 ±0.140 (6.20-6.48)	7.30 ±0.12 (7.18-7.42)	34.20 ±3.220 (30.98-37.42	32.01 ±3.640 (28.37-35.65)	9.28 ±0.130 (9.15-9.41)	0.017 ±0.001 (0.016-0.018)	0.19 ±0.015 (0.17-0.20)
October	27.37 ±0.370 (27.00-27.74)	81.54 ±9.175 (72.36-90.71)	6.51 ±0.065 (6.44-6.57)	7.19 ±0.060 (7.13-7.25)	34.92 ±1.670 (33.25-36.59)	36.17 ±1.885 (34.28-38.05)	8.74 ±0.245 (8.49-8.98)	0.004 ±0.001 (0.003-0.004)	0.27 ±0.020 (0.25-0.29)
November	22.84 ±1.715 (21.12-24.55)	98.22 ±1.670 (96.55-99.89)	6.63 ±0.255 (6.37-6.88)	7.87 ±0.180 (7.69-8.05)	33.89 ±2.320 (31.57-36.21)	36.69 ±2.595 (34.09-39.28)	8.36 ±0.260 (8.10-8.62)	0.007 ±0.001 (0.006-0.008)	0.15 ±0.010 (0.14-0.16)
December	19.47 ±2.600 (16.87-22.07)	111.06 ±4.365 (106.69-115.42	7.37 ±0.050 (7.32-7.42)	8.79 ±0.105 (8.68-8.89)	34.57 ±2.055 (32.51-36.62)	33.97 ±1.700 (32.27-35.67)	4.39 ±0.575 (3.81-4.96)	0.006 ±0.000 (0.006-0.006)	0.03 ±0.010 (0.02-0.04)
January 2021	19.32 ±2.325 (16.99-21.64)	99.22 ±1.06 (98.15-100.28)	7.42 ±0.060 (7.36-7.48)	8.59 ±0.105 (8.48-8.69)	46.67 ±2.055 (44.61-48.72)	53.49 ±3.520 (49.97-57.01)	5.25 ±0.170 (5.08-5.42)	0.002 ±0.001 (0.001-0.003)	0.02 ±0.010 (0.01-0.03)
February	19.96 ±2.570 (17.39-22.53)	102.44 ±3.790 (98.65-106.23)	7.48 ±0.095 (7.38-7.57)	7.74 ±0.085 (7.65-7.82)	51.76 ±1.790 (49.97-53.55)	47.76 ±3.765 (43.99-51.52)	7.56 ±0.180 (7.38-7.74)	0.003 ±0.001 (0.002-0.004	0.03 ±0.010 (0.02-0.04)

Table 2. Continued.

Months	Temperature (°C) Ave ±SE (Range)	Transparency (cm) Ave ±SE (Range)	pH Ave ±SE (Range)	Dissolved oxygen (mg/l) Ave ±SE (Range)	Total alkalinity (mg/l) Ave ± SE (Range)	Total hardness (mg/l) Ave ±SE (Range)	Free carbon dioxide (mg/l) Ave ±SE (Range)	Phosphate phosphorus (mg/l) Ave ±SE (Range)	Nitrate-nitrogen (mg/l) Ave ± SE (Range)
March	26.34 ±0.865 (25.47-27.20)	98.27 ±1.540 (96.73-99.81)	7.75 ±0.045 (7.70-7.79)	7.09 ±0.075 (7.01-7.16)	64.79 ±1.500 (63.29-66.29)	63.53 ±2.960 (60.57-66.49)	7.80 ±0.215 (7.58-8.01)	0.003 ±0.001 (0.002-0.004)	0.13 ±0.015 (0.11-0.14)
April	27.91 ±0.910 (27.00-28.82)	78.31 ±1.980 (76.33-80.29)	7.38 ±0.280 (7.10-7.66)	7.08 ±0.045 (7.03-7.12)	53.98 ±1.255 (52.72-55.23)	54.05 ±3.340 (50.71-57.39)	8.12 ±0.095 (8.02-8.21)	0.003 ±0.001 (0.002-0.003)	0.12 ±0.015 (0.10-0.13)
May	27.67 ±0.440 (27.23-28.11)	54.85 ±1.600 (53.25-56.45)	7.15 ±0.150 (7.00-7.30)	6.59 ±0.305 (6.28-6.89)	34.31 ±2.935) (31.37-37.24)	34.30 ±2.180 (32.12-36.48)	9.14 ±0.115 (9.02-9.25)	0.005 ±0.001 (0.004-0.006)	0.06 ±0.010 (0.05-0.07)
June	27.56 ±0.385 (27.17-27.94)	58.27 ±4.855 (53.41-63.12)	6.92 ±0.085 (6.83-7.00)	5.36 ±0.260 (5.10-5.62)	35.46 ±2.565 (32.89-38.02)	34.78 ±4.630 (30.15-39.41)	9.74 ±0.180 (9.56-9.92)	0.007 ±0.001 (0.006-0.008)	0.10 ±0.005 (0.09-0.10)
July	27.77 ±0.065 (27.70-27.83)	56.70 ±3.500 (53.20-60.20)	6.71 ±0.125 (6.58-6.83)	6.30 ±0.220 (6.08-6.52)	32.31 ±1.100 (31.21-33.41)	33.14 ±4.18 (28.95-37.32)	9.97 ±0.085 (9.88-10.05)	0.013 ±0.001 (0.012-0.014)	0.04 ±0.010 (0.03-0.05)
August	27.97 ±0.200 (27.77-28.17	55.66 ±2.655 (53.00-68.31)	6.65 ±0.150 (6.50-6.80)	6.71 ±0.145 (6.56-6.85)	32.49 ±1.070 (31.42-33.56)	33.46 ±3.250 (30.21-36.71)	9.61 ±0.160 (9.45-9.77)	0.004 ±0.001 (0.003-0.005	0.02 ±0.010 (0.01-0.03)
Annual average	**25.17 ±1.105 (24.05-26.28)**	**79.94 ±3.637 (76.30-83.57)**	**7.02 ±0.125 (6.90-7.15)**	**7.21 ±0.142 (7.07-7.36)**	**40.78 ±1.961 (38.82-42.74)**	**41.11 ±3.138 (37.97-44.25)**	**8.16 ±0.201 (7.96-8.36)**	**0.006 ±0.001 (0.01-0.01)**	**0.10 ±0.012 (0.08-0.11)**

fish culture practice ranges between 6.00 to 9.00 (Bhatnagar *et al.* 2004). The pH of Kharungpat lake recorded during the study period was observed to be lower during monsoon and post monsoon season. Lower pH recorded during monsoon may be due to the inflow of considerable organic matter from the catchment area along with surface run-off, coupled with mixing of bottom water rich in organic matter and their subsequent decomposition.

During the first year (2019-20) of the study period, the minimum dissolved oxygen concentration of Kharungpat lake water was observed in June 2020 (5.19 mg/l) and the maximum in December 2019 (9.35 mg/l). Similarly, during second year (2020-21), the minimum and maximum dissolved oxygen concentration of the studied were 5.10 and 8.89 mg/l recorded in the month of June 2021 and December 2020 respectively. The dissolved oxygen levels recorded in the present study were above the critical level.

During 2019-20, the minimum value of total alkalinity in Kharungpat lake water observed was 33.10 mg/l in August 2020 and maximum was 63.31 mg/l during March 2020. Similarly, the minimum total alkalinity of 31.21 mg/l in July 2021 and maximum of 66.29 mg/l in March 2021 was observed during 2020-2021. Water having total alkalinity in the range between 20.00-40.00 mg/l indicates low productivity while a range of 40.00-90.00 mg/l favor high productivity. Hence, the recorded total alkalinity value indicates that Kharungpat lake becomes under low productivity.

The recorded minimum and maximum total hardness of Kharungpat lake water during the year 2019-2020 were 28.41 mg/l (August 2020) and 59.87 mg/l (March 2020) respectively. During 2020-21, the lowest and highest total hardness was observed in the month September 2020 (28.37 mg/l) and March 2021 (66.49 mg/l). The seasonal variation of total hardness of the lake was in similar pattern to that of total alkalinity observed in both the year of the study period. The monthly average total hardness of water in Kharungpat lake showed an almost similar magnitude with the total alkalinity (31.82 to 64.88 mg/l) because calcium and magnesium, bicarbonate and carbonate ions in water are derived in equivalent quantities from the solution of limestone in geological deposits of the catchment areas. The present findings of total hardness of Kharungpat lake (28.37 to 66.49 mg/l) indicated that the lake water might sustain low growth of fish.

During 2019-2020, the minimum free carbon dioxide (3.78 mg/l) in Kharungpat lake was recorded in the month of December 2019 and maximum (10.23

Table 3. Monthly phytoplankton groups distribution of Kharungpat lake during 2019-2020.

Groups	Chlorophyceae		Cyanophyceae		Bacillariophyceae		Euglenophyceae		Average
Months	Average Nos/lit	%	Average Nos/lit	%	Average Nos/lit	%	Average Nos/lit	%	total
September 2019	220	54.73	96	23.88	69	17.16	17	4.23	402
October	165	29.31	234	41.56	140	24.87	24	4.26	563
November	420	45.41	325	35.14	126	13.62	54	5.84	925
December	720	50.96	432	30.57	174	12.31	87	6.16	1413
January 2020	633	60.11	310	29.44	47	4.46	63	5.98	1053
February	294	40.66	289	39.97	100	13.83	40	5.53	723
March	320	45.33	269	38.10	86	12.18	31	4.39	706
April	587	66.55	195	22.11	76	8.62	24	2.72	882
May	138	43.13	110	34.38	53	16.56	19	5.94	320
June	300	51.11	174	29.64	98	16.70	15	2.56	587
July	277	69.08	78	19.45	36	8.98	10	2.49	401
August	143	55.21	69	26.64	42	16.22	5	1.93	259

mg/l) in the month of May 2020. In second year of the study period, the recorded minimum free carbon dioxide was 3.81 mg/l in December 2020 and the maximum (10.05 mg/l) value was observed in the month of July 2021. Surface water normally contained less than 10.00 mg/l of free carbon dioxide, while some ground water may exceed that concentration. In Kharungpat lake, monthly average free carbon dioxide concentration fluctuated from 4.26 to 10.03 mg/l, which is within the tolerable range of warm water fish.

During the first year of study period (2019-2020), the minimum phosphate-phosphorus value Kharungpat lake observed was 0.002 mg/l in January 2020 and April 2020 and the maximum was 0.017 mg/l during September 2019. Similarly, during the second year (2020-2021), the minimum and maximum value of phosphate- phosphorus of the studied lake observed was 0.001 mg/l and 0.018 mg/l in January, 2021 and September, 2020 respectively. Phosphate content at a level of 0.06 mg/l is desirable for fish culture and a water body with phosphorus ranged of 0.01 to 3.00 mg/l is productive (Bhatnagar and Devi, 2013). In the present study, the phosphate phosphorus content ranged from 0.001 to 0.018 mg/l, hence Kharungpat lake ecosystem is found to be less productive.

During the first year (2019-2021), the minimum nitrate-nitrogen content of the studied lake water recorded was 0.01 mg/l during the month of January 2020 and the maximum of 0.30 mg/l was recorded in the month of October 2019. The minimum nitrate-nitrogen content of 0.01 mg/l in the month of January 2021 and August 2021 and maximum value of 0.29 mg/l (October 2020) was recorded during second year of the study period. The nitrate nitrogen below 0.1 mg/l, in the range between 0.1 to 0.2 mg/l and above 0.2 mg/l are considered as poor productive, average productive and productive. The recorded value of nitrate nitrogen in the present study (0.01 to 0.30 mg/l), indicates low productive nature of the lake.

Phytoplankton

A total of 22 genera belonging to 16 orders were identified during 2019-2021 in which *Spirulina* spp. was observed highly abundant followed by *Chlorella* spp., *Closterium* spp., *Oscillatoria* spp. and *Anabaena* spp. Chlorophyceae, Cyanophyceae, Bacillariophyceae and Euglenophyceae are the four major phytoplankton classes identified in Kharungpat lake with a percentage composition of 51.21, 31.55, 12.72 and 4.72 % respectively during 2019-2020. The minimum average total of phytoplankton (259 units per liter) was observed during August 2020 with a percentage composition of 55.21, 26.64, 16.22 and 1.93% by Chlorophyceae, Cyanophyceae, Bacillariophyceae and Euglenophyceae respectively (Table 3).

During the second year (2020-21) of the study periods, the monthly phytoplankton classes distribution of the lake shows that, the average total was maximum (959 units per liter) in the month of December 2020 with a percentage composition of 50.99 % (Chlorophyceae), 32.85% (Cyanophyceae), 12.20%

Table 4. Monthly phytoplankton groups distribution of Kharungpat lake during 2020-2021.

Groups Months	Chlorophyceae Average Nos/lit	%	Cyanophyceae Average Nos/lit	%	Bacillariophyceae Average Nos/lit	%	Euglenophyceae Average Nos/lit	%	Average total
September 2020	420	77.92	60	11.13	50	9.28	9	1.67	539
October	236	55.79	134	31.68	36	8.51	17	4.02	423
November	364	60.67	120	20.00	90	15.00	26	4.33	600
December	489	50.99	315	32.85	117	12.20	38	3.96	959
January 2021	200	36.43	275	50.09	44	8.01	30	5.46	549
February	345	55.56	165	26.57	87	14.01	24	3.86	621
March	121	29.95	205	50.74	62	15.35	16	3.96	404
April	180	52.94	52	15.29	98	28.82	10	2.94	340
May	264	61.54	85	19.81	71	16.55	9	2.10	429
June	57	29.84	89	46.60	40	20.94	5	2.62	191
July	76	37.62	100	49.50	21	10.40	5	2.48	202
August	80	56.74	36	25.53	19	13.48	6	4.26	141

(Bacillariophyceae) and 3.96% (Euglenophyceae). The minimum average total of phytoplankton (141 units per liter) in the studied lake was observed during August 2021 with a percentage composition of 56.74, 25.53, 13.48 and 4.26% by Chlorophyceae, Cyanophyceae, Bacillariophyceae and Euglenophyceae respectively (Table 4). Lower plankton population in the studied lake may be due to utilization of nutrients by profuse growth of macrophytes. Phytoplankton abundance was lower during the monsoon seasons in the Kharungpat lake when the water column was remarkably stratified to a large extent because of heavy rainfall, high turbidity caused by run-off, and decreased temperature and pH.

The phytoplankton population structure observed in Kharungpat lake was in the descending trend of Chlorophyceae > Cyanophyceae > Bacillariophyceae > Euglenophyceae which matched with the trend reported by Laskar and Gupta (2009) in Chatla flood plain lake, Teneva *et al.* (2014) in Skalenski lake and Ajah (2013) in Ohana lake.

The coefficient correlation (r) between phytoplankton and hydrological parameters are given in Table 5. Phytoplankton showed a significant positive correlation between water transparency ($r = 0.897$, p 0.01) and dissolve oxygen ($r = 0.839$, $p < 0.01$).

Biodiversity indices of phytoplankton

The biodiversity indices of phytoplankton in Kha-

Table 5. Simple coefficient correlation (r) between plankton and hydrological parameters of Kharungpat lake.

Parameters	PP	WT	TP	pH	DO	AL	TH	FCD	TPP	NN
PP	1									
WT	-0.845**	1								
TP	0.897**	-0.855**	1							
pH	0.502	-0.565	0.531	1						
DO	0.839**	-0.803**	0.940**	0.400	1					
AL	0.252	-0.303	0.314	0.880**	0.171	1				
TH	0.262	-0.301	0.379	0.826**	0.265	0.952**	1			
FCD	-0.915**	0.885**	-0.926**	-0.503	-0.928**	-0.256	-0.319	1		
TPP	-0.248	0.329	-0.409	-0.633*	-0.277	-0.512	-0.595	0.382	1	
NN	-0.129	0.428	-0.053	-0.426	-0.133	-0.185	-0.093	0.180	0.147	

Note: PP-Phytoplankton; ZP-Zooplankton, WT - Water temperature; TP- Transparency pH- Water pH; DO - Dissolve oxygen, AL-Alkalinity, TH- Total hardness, FCD- Free carbon dioxide TPP- Total phosphate phosphorus; NN - Nitrate nitrogen. * Correlation is significant at 0.05 level (2-tailed), ** Correlation is significant at 0.01 level (2-tailed).

Table 6. Site wise biodiversity indices calculated on phytoplankton population of Kharungpat lake during 2019-2020.

Indices	Site 1	Site 2	Site 3	Site 4	Site 5
Simpson_1-D	0.956	0.954	0.953	0.954	0.954
Shannon_H	3.180	3.162	3.141	3.162	3.166
Margalef	3.263	3.360	3.263	3.446	3.442
Equitability_J	0.976	0.971	0.976	0.971	0.972

Table 7. Site wise biodiversity indices calculated on phytoplankton population of Kharungpat lake during 2020-2021.

Indices	Site 1	Site 2	Site 3	Site 4	Site 5
Simpson_1-D	0.951	0.949	0.945	0.940	0.936
Shannon_H	3.138	3.127	3.082	3.073	3.035
Margalef	3.625	3.800	3.568	3.937	4.023
Equitability_J	0.952	0.939	0.946	0.922	0.911

rungpat lake during the first year (2019-20) is in Table 6. Site wise biodiversity indices shows that, Shannon index value of the studied lake is more or less similar in all the sites. During the first year of the study period, the Shannon index value ranged from 3.141 to 3.180. Simpson index was found highest in Site 1 (0.956) and lowest in Site 3 (0.953).

The Simpson index value of phytoplankton in Kharungpat lake 2020-21 was highest in Site 1 followed by Site 2, Site 3, Site 4 and Site 5 with an index value of 0.951, 0.949, 0.945, 0.940 and 0.936 respectively Tables 6-7. The recorded Shannon index value of phytoplankton in the studied lake ranged between 3.138 to 3.035.

Equitability evenness index gives the evenness of various species distribution in the sample. The maximum value indicated the equal abundance of phytoplankton species in that particular sites and minimum value indicated less distribution of phytoplankton diversity. The Simpson index and Equitability index value of the studied lake is comparable with the findings of Kirumampakkam and Korkalu lake (Mani *et al.* 2017).

ACKNOWLEDGMENT

This investigation is a part of PhD research work of the first author. The author wishes to thank the authorities of Central Agricultural University, Imphal for granting study leave to pursue PhD program.

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