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Account of Limnological Diversity of Lentic Freshwater Ecosystem: Nakki Lake, Mount Abu (Rajasthan, India)

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ABSTRACT. Nakki Lake serves as the lifeline being city's primary source of water and a popular destination for visitors to Mount Abu. It covers the annual requirements of fresh water and other uses of the local population as well as of the millions of visitors who attend the sanctuary every year, and of the endemic species that dwell there. In the present era, however, due to ongoing pollution and eutrophication it is a significant question, whether it is possible or not to preserve the primary source of water. The present study is an attempt to evaluate the annual statistics of the quality of the lake's limnological parameters (2017-2019). This gives us the ability to understand the potability of the water as well as to determine the level of pollution and eutrophication in order to keep the optimal water quality standards for a healthy aquatic ecosystem.

Keywords: Limnology, Nakki Lake, Mount Abu, Aquatic ecosystem

1. Introduction

Water can be considered as the foundation of sustainable development and is essential for the survival of flora and fauna, socio-economic development and a robust ecosystem. Water is a main component of the ecosystem as a link that proportionately connects the climate, environment and the human society. Water poses a significant obstacle to the process of sustainable development. Water is an irreplaceable resource that is fundamental to the well-being of humans and the renewable source that needs to be managed effectively.

Rajasthan (Fig. 1) is the wide-ranging state in the Indian subcontinent. It is predominately an arid state for the majority of its territory, located in the north-western part of the western union (23˚30' and 30˚11' North and 69˚29' and 78˚17' East). The state has an irregular rhomboid shape, and its maximum length is 869 kilometres from west to east and 826 kilometres from the length of the state's western border is 1,070 kilometres long, which is also a portion of the international boundary between India and Pakistan. It encompasses most of the area of the large inhospitable Great Indian Desert (Thar Desert), which has an edge paralleling the Sutlej and Indus Rivers to the southwest, Madhya Pradesh to southeast, Uttar Pradesh and Haryana to the northeast and Punjab to the north.

The land area of Rajasthan, which comprises 342.239 km^2, is approximately comparable to that of some urbanised nations located in the western hemisphere, such as Norway (385.203 km^2), Poland (312.679 km^2), and Italy (301.338 km^2). The physiography of Rajasthan is the result of processes of erosion and deposition that have taken place over a long period of time. The geological formation and structures have had a significant impact on it and played a determining role in the development of both the present-day landforms and drainage systems. It has been determined that the state is home to four significant physiographic conditions. They include the Aravali Mountain ranges, the Eastern plains, the South-Eastern plateau Region, and the Western Thar desert. The dry western section of Rajasthan state is separated from the semiarid eastern region by the hill ranges of the Aravali Mountain, which run in a direction from north-east to south-west. In addition, it serves as a significant watershed for the state. The Aravali mountain range composed of igneous rocks (Granite and Basalt), which is often considered as the world's oldest mountain range.

Mount Abu, also known as "Arbudanchal" (Fig. 1), has the only hill station of the state of Rajasthan located in the Aravali Mountain ranges. It is a popular tourist destination and a wild life sanctuary with millions of tourists visiting the town every year (Gothwal and Gupta 2018). Nakki Lake (Fig. 1) is the study area selected for research purpose. The selected water body is annually filled by rain water, situated at Mount Abu, the highest peak of the Aravali Mountain range with an altitude of 2000 meters above the sea

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level. The lake is 3.5 km sq. in area, about one and half mile in length and half a mile in width. It is a very ancient and sacred lake, and according to Hindu legend it is the first man-made lake dug out by Nails. The lake is an ecstasy for nature lovers, flanked by beauty of the magnificent mountains. The lake is truly a gem, real treasure, located in the centre of the town. The lake has an average depth of around 80-100 ft. (25-30m), which is surrounded on all sides by lush greenery, verdant mountains and strangely shaped rocks and other natural features (Location – 24.596140°N, 72.703066°E, Town – Mount Abu, State – Rajasthan, Country – India)

The quality of water from any water resource is an important aspect for the development of nearby region because water reservoirs (natural or man-made) are needed for water supply to agricultural, aqua-cultural and domestic requirements. They consist of dissolved solid substances (organic and inorganic) such as sulphate, sodium, carbonate, chloride, nitrate etc. (Jain and Seethapati, 1996). Nakki Lake has the utmost significance for the locals. The locals use the water of Nakki Lake for drinking and other domestic activities and is directly linked with daily life. The specific status of limnological characteristics of Nakki Lake has been studied through different weather cycles (2017-2019) across three regions based on the geography and in contact with human population over top and bottom water samples. Hence, maintaining the quality of water is most important and its potability needs to be checked at specific time intervals to avoid contamination of potable water and water-borne diseases.

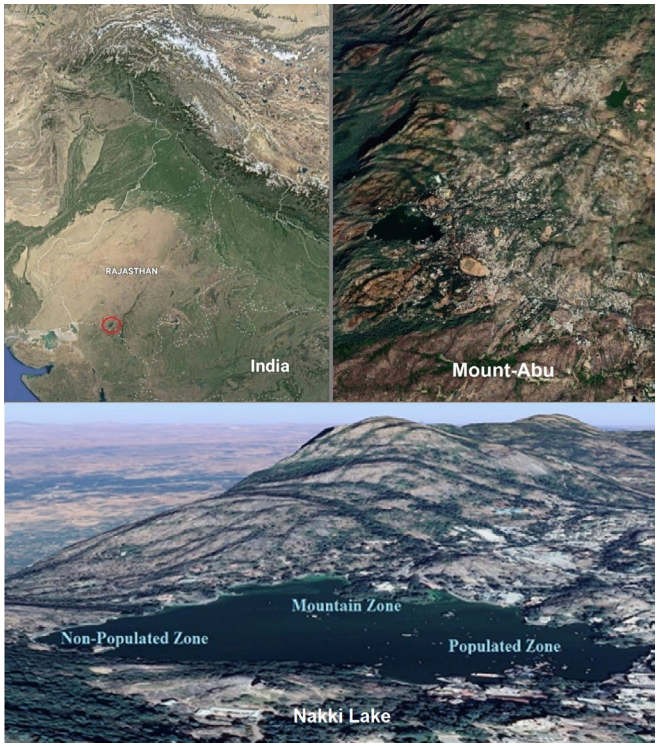

Fig.1. Topography and Site specification: Nakki Lake, Mount Abu, (Rajasthan), India

2. Materials and Methods

2.1. Study area

Nakki Lake was selected for monitoring the standards of water quality and study of their physico-chemical aspect (Fig.2). The water of Nakki Lake is utilized by locals and tourist as well as the endemic species of the habitat for agriculture, drinking and domestic purpose. Observations of the present study were carried out for a period of twenty-four months (March 2017 to February 2019), observation and analysis were done every month. However, the results expressed of a season are the average values of monthly observations; as variation in monthly observation was of fewer enormities. As per the climate of the area (Mount Abu) three clearly defined seasons were identified viz. Summer (March to June), Rainy (July to October) and Winter (November to February).

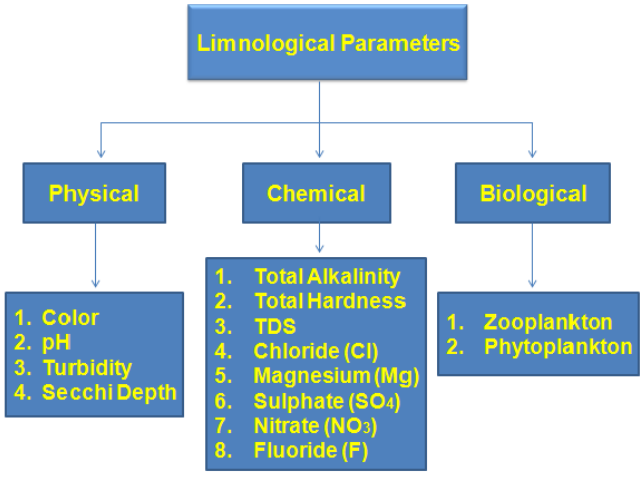

Fig.2. Parameters - Limnological analysis of water

2.2. Selection of sampling sites

Nakki Lake is about a mile in length and about half a mile in width. It is an important tourist attraction of the town. The water body is 3.5 sq. km in area. For research purpose, selected waterbody (Nakki Lake) is classified into three specific sites or regions (Fig.1) depending on different topographic situations and area in contact with human population in relation to waterbody, which are as follows:

1. ***Populated region (Site 1)*** – the north-east area, with high human density rate.
2. ***Non-Populated region (Site 2)*** – the south-east area and some part of west, with low contact with humans or with no contacts with human population.
3. ***Mountain region (Site 3)*** – area of Nakki Lake covered with rocks in the north-west area surrounding at the Aravali Mountains.

2.3. Sampling procedure and laboratory analysis

The sampling was done during morning hours (7:30 to 09:30 am), water samples were collected from pre-selected three sampling sites or regions (populated, non-populated and mountain region) during the seasons. Water samples were collected in clean and rinsed polyethylene sampling bottles from the top surface (top water) and bottom area (deep water, averagely 40-45 ft. (13-14 m) below) of the respective sampling site. The important physico-chemical parameters of water included the following: temperature, transparency, color (Hazen), turbidity (NTU), pH value, Secchi depth, total alkalinity (mg/l), total hardness (mg/l), iron (Fe, mg/l), chloride (Cl, mg/l), fluoride (F, mg/l), total dissolved solids (TDS, mg/l), calcium (Ca, mg/l), magnesium (Mg, mg/l), sulphate (SO_4, mg/l), nitrate (NO_3, mg/l), chemical oxygen demand (COD), biological oxygen demand (BOD).

The temperature was measured by a mercury thermometer and transparency was measured by Secchi disc and then water samples were brought to the research laboratory for other limnological analyses. The methods used for other limnological analysis were obtained by the methods given by Welch (1948), Adoni et al. (1985), IS:1622 (1988), IS:3025 (1988) and APHA (2005).

3. Results and Discussion

3.1. Physico-chemical analysis

The comparative and proportional analysis of limnological parameters and their alterations in Nakki Lake are given in Tables 1 and 2. Table 1 is concerned with the data collected from three different sampling sites of Nakki lake and their mean over top (Surface) water sample in peak of three different seasons (summer, rainy, and winter). Table 2 is concerned with bottom water samples with an average depth of 40-45 ft. (13-14 m) meters and their mean in peak of three different seasons (summer, rainy, and winter).

The results of physico-chemical study of water suggest that the rate of temperature in air and water both varies with the change of the distinct seasons. The air temperature in summer season changes from 33 to 40˚C, however, in rainy season it varies from 18 to 34˚C, whereas in winter season the temperature of Mount Abu is roughly about 3 to 8˚C conversely the temperature may turn till – 4˚C from late December to mid of January. The differences in temperature can be attributed to the significant high-altitude differences, approximately 2000 meters above average sea level.

The current study reveals that the average pH of Nakki Lake in summer season over top surface water was 7.06, whereas it was 7.12 at bottom surface water. Average pH value during rainy season was observed as 7.34 and it was 7.62 over top and bottom surface water; however, it was 7.86 top surface water and it was 7.88 at bottom surface water in winter season. The raise in pH in summer season compared to other seasons might be due to boost in rate of photosynthesis as stated by Sreenivasan (1967). Goldman and Horne (1983) also suggested that compound process of carbon dioxide, carbonate and bicarbonate consequently changes the pH of lentic water in a water body. Maximum pH was found in the mountain region of the lake over top and bottom surface water samples over all seasons, it may occur due to the inflow and accumulation of organic salts results in higher growth of algae and plants in that region. Kaushik and Saxena (1999) suggested that the temperature is striking in summer and monsoon season; therefore, the concentration of salts increases in the waterbody due to evaporation of surface water. The pH is also controlled by the dissolved chemical compounds and the biological process occurs in the waterbody at specified temperature. Optimum pH across the year promotes healthy habitat for fishes and other aquatic species to grow, survive and prosper. The average seasonal pH over top and bottom water samples lies between 7.06 and 7.88 in all the samples which are within the prescribed limits as per the APHA standards (2005).

The colour (Hazen value) in Nakki Lake ranges the acceptable limits. The average value of Hazen scale observed in Nakki Lake over top and bottom water is 0.64 to 0.68 in summer, 0.69 to 0.72 in rainy, 0.62 to 0.61 in winter season. The observed Hazen value promotes clear water during the entire year; it also maintains the temperature of lake water.

The average Secchi depth over three selected sampling regions of Nakki Lake with respective seasons shows mean value of 62.2 cm in summer season, 61.27 cm in rainy season and 63.42 cm in winter season. The variations recognized in the transparency could be endorsed to the phytoplankton blooms (Nissa and Bhat, 2016). The minimum value of Secchi depth reflecting in rainy season represents minimum light penetration. This reduction is also renowned by Chisty (2002), Baghela (2006) and Malara (2008) in nearby wetlands of Udaipur region.

Lower level of turbidity was recorded in the present research study. The average seasonal turbidity recorded over top and bottom water samples are 0.81 to 0.87 NTU (Nephlometeric Turbidity Units), 0.76 to 0.81 NTU and 0.89 to 0.92 NTU in summer, rainy and winter season is a key indicator of apparent water in Nakki Lake. Turbidity in the polluted water bodies ranged from 11 to 25 NTU due to sediment, macrobiotic matter and autochthonous sources such as planktons and algal blooms.

In the present research analysis (Fig. 3, 4), the seasonal mean values of total alkalinity during the study period showed a diminutive deviation over top and bottom water samples and ranges in between 89.67 to 108.67 mg/l. The seasonal mean values over top and bottom water samples are 101.33 and 103 mg/l in summer season, 92.67 and 108.67 mg/l in rainy season, 96 and 89.67 mg/l in winter season.

The experiential research values of total alkalinity are within the prescribed limit of 20 to 200 mg/l. The variation in alkalinity is associated with the diurnal change in photosynthesis and seasonal change in biomass. Change in concentration of pH, carbonates

Table 1. Comparative Limnological study of top water in summer, rainy, and winter seasons (Nakki Lake 2017-2019)

No.	Parameters	Summer				Rainy				Winter			
		Populated top	Non-populated top	Mountain top	Mean summer top	Populated top	Non-populated top	Mountain top	Mean rainy top	Populated top	Non-populated top	Mountain top	Mean winter top
1	Color (Hazen)	0.4	0.56	0.95	**0.64**	0.54	0.63	0.89	**0.69**	0.51	0.58	0.77	**0.62**
2	Turbidity (NTU)	0.7	0.76	0.98	**0.81**	0.7	0.73	0.84	**0.76**	0.83	0.89	0.95	**0.89**
3	pH value	7.11	6.95	7.11	**7.06**	7.38	7.19	7.46	**7.34**	7.86	7.54	8.19	**7.86**
4	Secchi depth, cm	57.91	67.71	60.98	**62.2**	61.45	62.46	59.91	**61.27**	63.27	64.58	62.42	**63.42**
5	Total alkalinity (TA), mg/l	102	90	112	**101.33**	92	84	102	**92.67**	96	88	104	**96**
6	Total hardness ($CaCO_3$), mg/l	89	105	89	**94.33**	95	121	103	**106.33**	84	91	86	**87**
7	Total dissolved solids (TDS), mg/l	142	146	193	**160.33**	156	172	210	**179.33**	132	139	164	**145**
8	Iron (Fe), mg/l	0.022	0.025	0.02	**0.02**	0.024	0.028	0.025	**0.03**	0.022	0.024	0.023	**0.02**
9	Chloride (Cl), mg/l	104.22	102.56	115.43	**107.4**	101.38	99.59	111.33	**104.1**	99.58	96.62	107.43	**101.21**
10	Fluoride (F), mg/l	0.25	0.24	0.34	**0.28**	0.23	0.21	0.31	**0.25**	0.22	0.21	0.29	**0.24**
11	Calcium (Ca), mg/l	60.2	53.29	53.65	**55.71**	59.37	51.47	52.29	**54.38**	57.42	50.24	51.68	**53.11**
12	Magnesium (Mg), mg/l	20.4	18.68	21.3	**20.13**	19.8	17.85	20.67	**19.44**	18.56	18.27	20.34	**19.06**
13	Sulphate (SO_4), mg/l	120.4	122.4	128.4	**123.73**	118.5	120.3	125.6	**121.47**	115.7	117.3	121.4	**118.13**
14	Nitrate (NO_3), mg/l	32.1	30.56	30.67	**31.11**	33.38	31.54	32.46	**32.46**	30.63	29.72	30.67	**30.34**
15	Chemical oxygen demand	8.11	7.45	9.3	**8.29**	8.72	8.32	9.63	**8.89**	8.93	9.46	9.84	**9.41**
16	Biological oxygen demand	28.4	22.68	30.1	**27.06**	25.7	21.4	28.3	**25.13**	23.5	19.6	24.8	**22.63**

Table 2. Comparative Limnological study of bottom water in summer, rainy, and winter seasons (Nakki Lake 2017-2019)

No.	Parameters	Summer				Rainy				Winter			
		Populated deep	Non-populated deep	Mountain deep	Mean summer deep	Populated deep	Non-populated deep	Mountain deep	Mean Rainy Deep	Populated deep	Non-populated deep	Mountain deep	Mean winter deep
1	Color (Hazen)	0.56	0.69	0.78	**0.68**	0.56	0.68	0.91	**0.72**	0.53	0.56	0.75	**0.61**
2	Turbidity (NTU)	0.93	0.85	0.82	**0.87**	0.78	0.77	0.87	**0.81**	0.86	0.92	0.98	**0.92**
3	pH value	7.24	7.03	7.09	**7.12**	7.67	7.29	7.91	**7.62**	7.91	7.59	8.14	**7.88**
4	Total alkalinity, mg/l	97	109	103	**103**	90	89	104	**94.33**	98	92	102	**97.33**
5	Total hardness ($CaCO_3$), mg/l	95	102	94	**97**	94	125	107	**108.7**	87	93	89	**89.67**
6	Total dissolved solids, mg/l	165	142	183	**163.3**	159	177	216	**184**	130	138	166	**144.7**
7	Iron (Fe), mg/l	0.03	0.022	0.027	**0.03**	0.027	0.029	0.028	**0.03**	0.02	0.03	0.022	**0.02**
8	Chloride (Cl), mg/l	107	110.3	118.8	**112.1**	103.8	101.2	113.9	**106.3**	96.7	94.3	104.6	**98.53**
9	Fluoride (F), mg/l	0.27	0.29	0.32	**0.29**	0.28	0.25	0.34	**0.29**	0.31	0.29	0.32	**0.31**
10	Calcium (Ca), mg/l	58.4	50.4	40.65	**49.82**	61.26	54.78	57.56	**57.87**	59.4	52.2	55.46	**55.7**
11	Magnesium (Mg), mg/l	19.3	20.54	22.65	**20.83**	17.6	18.32	21.33	**19.08**	18.8	19.3	22.58	**20.23**
12	Sulphate (SO_4), mg/l	123	126.4	123.7	**124.4**	120.5	121.6	127.3	**123.1**	117	119	120.6	**119.1**
13	Nitrate (NO_3), mg/l	31.4	29.84	32.56	**31.27**	32.57	31.28	34.68	**32.84**	32.3	30.3	30.54	**31.07**
14	Chemical oxygen demand	13.5	11.5	5.1	**10.03**	12.7	11.83	7.37	**10.63**	11.8	10.5	10.36	**10.89**
15	Biological oxygen demand	45.1	45.2	20.44	**36.91**	41.3	42.8	38.3	**40.8**	39.7	39.3	27.9	**35.63**

and bicarbonate fractions also affects the total alkalinity (Hutchinson, 1957).

The prescribed values of total hardness range from 300 to 600 mg/l, however, in the present research study, the seasonal mean value of total hardness observed in Nakki Lake through summer season is 94.33 and 97 mg/l, 106.33 and 108.67 mg/l in rainy season while 89.67 and 96 mg/l was in winter season over top and bottom water samples.

The hardness of water is a resultant of both calcium and magnesium. The lake water is found to be the hardest in rainy season across the month of June. It may occur due to the impact of effluents run-off towards the lake. Bhongade and Patil (2012) also reported the comparable research findings in Mohgavhan Lake (Maharashtra). The mean value of Total dissolved solids (TDS) is 160.33 and 163.33 mg/l in summer, 179.33 and 184 mg/l in rainy season and 145 and 144.67 mg/l in winter season, the observed value of total dissolved solid in Nakki Lake is within the allowable limits. The allowable concentration of calcium and magnesium hardness is within the ranges between 75 to 200 mg/l; TDS is above permitted limit, which signifies polluted water in the lake.

The mean value of Calcium (Ca) hardness observed in three distinct seasons is 55.71 and 49.82 mg/l in summer, 54.38 and 57.87 mg/l in rainy and 53.11 and 55.70 mg/l in winter. The observed mean value of Magnesium (Mg) hardness is 20.13 mg/l, 20.83 mg/l in summer, 19.44 mg/l, 19.08 mg/l in rainy and 19.06 mg/l, 20.23 mg/l in winter season over top and bottom water samples. Philipose (1960), Swarnalatha and Narsing Rao (1991) also obtained the same research findings in their results of limnological study. As per guidelines for drinking-water quality (1997) WHO, the permissible limit for fluoride in drinking water is 1.0 mg/l. The mean observed value of fluoride in water samples across all seasons is within the acceptable limits of 0.28 mg/l, 0.29 mg/l in summer, 0.25 mg/l, 0.29 mg/l in rainy, 0.24 mg/l, 0.31 mg/l in winter season, while the value of iron observed during the research study in Nakki Lake is 0.02 mg/l, 0.03 mg/l in summer, 0.03 mg/l, 0.03 mg/l in rainy, 0.02 mg/l, 0.02 mg/l in winter season in top and bottom water samples, which is less than the allowable value of 0.9 mg/l. The present research study of Nakki Lake shows the mean value of chloride ranges between 98 mg/l to 112 mg/l. The prescribed concentration of chloride is 250 mg/l to 1000 mg/l, however the observed chloride value over top and bottom water sample shows 107.4 mg/l, 112.07 mg/l in summer, 104.1 mg/l, 106.3 mg/l in rainy, 101.21 mg/l, 98.53 mg/l in winter season.

Chloride concentration in Nakki Lake could be attributed to anthropogenic sources in the form of natural or incomplete treated sewage that enters into the lake system (Rather et al., 2016). The mean observed value of sulphate is in the optimum mark of 123.73 mg/l, 124.44 mg/l in summer, 121.47 mg/l, 123.13 mg/l in rainy, 118.13 mg/l, 119.07 mg/l in winter season. The mean experiential quantity of Nitrate (NO_3) in Nakki Lake is 31.11 mg/l, 31.27 mg/l in summer, 32.46 mg/l, 32.84 mg/l in rainy and 30.34 mg/l, 31.11 and 31.27 mg/l in winter season. The observed seasonal values are enormously low compared to the permissible limits. It promotes bacterial and algal growth, together served as food for fishes in the lake. The optimum concentration of phosphate and nitrate-nitrogen results in enhanced productivity in lakes (Yousuf et al., 2006). COD refers to the required amount of oxygen for its oxidation to produce carbon dioxide and water. The criterion value of COD ranges among 0.5 mg/l to 200 mg/l. The observed mean value of COD in the present research limnological study is 8.29 mg/l to 10.03 mg/l in summer, 8.89 mg/l to 10.63 mg/l in rainy and 9.41 mg/l to 10.89 mg/l in winter season. COD is highest in winter due to increase of water level in the lake after monsoon season and minimum in summer due to evaporation and change in temperature. BOD is a natural contamination to both waste and surface water. High BOD is a sign of poor water quality; BOD represents the aggregate oxygen demands from aerobic organisms present in water. Disposal of biodegradable matter in the aquatic system leads to reduction of dissolved oxygen due to consumption. The standard concentration of BOD ranges from 0 to 35 mg/l. The

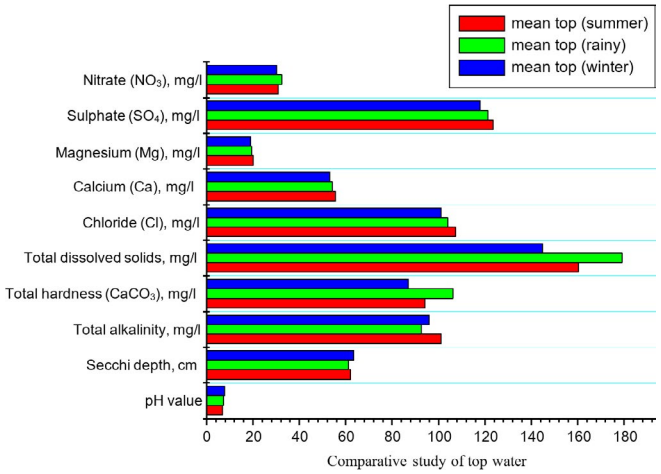

Fig.3. Comparative analysis of limnological parameters in summer, rainy, and winter season (2017-2019) (top surface water), Nakki Lake, Mount Abu

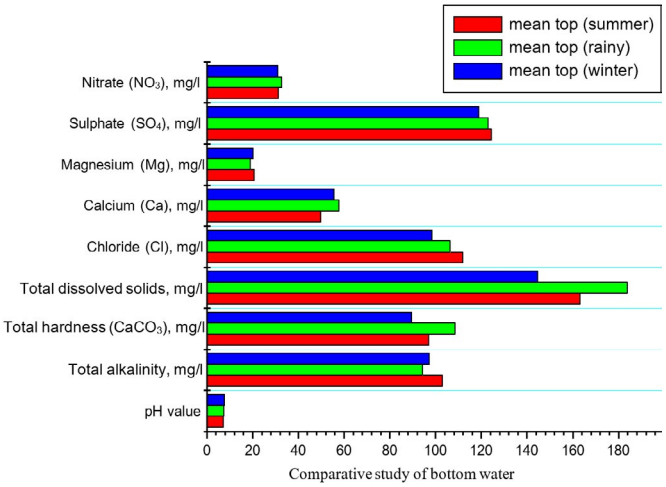

Fig.4. Comparative analysis of limnological parameters in summer, rainy, and winter season (2017-2019) (bottom surface water), Nakki Lake, Mount Abu

average seasonal concentration of BOD in Nakki Lake, during the research analysis occurs 27.06 mg/l, 36.91 mg/l in summer, 25.13 mg/l, 40.8 mg/l in rainy, 22.63 mg/l, and 35.63 mg/l in winter season. The BOD values were higher in summer season compared to rainy and winter season. Basavarajappa et al. (2009) supported these interpretations of BOD and COD in their research findings on water quality parameters of four fresh water lakes of Mysore, Karnataka. Liu et al. (2010) also obtained maximum BOD in summer and minimum in winter season.

Gothwal and Gupta (2018a) conducted limnological study on Nakki Lake, Mount Abu in summer season. The outcome of the research reports moderately alkaline water with pH 7.08, alkalinity of 102.16 mg/l and other limnological parameters showed low mean values including TDS 161.83 mg/l, hardness 95.66 mg/l and chloride (Cl) 109.73 mg/l. The average dissolved oxygen levels were at 5.75 mg/l while average nitrate (NO_3) and sulphate (SO_3) levels were 31.19 mg/l and 123.73 mg/l. Based on the results of quality parameters of water, Nakki Lake is prone to be eutrophic. Gothwal and Gupta (2018b; 2019) studied soil properties of Sant-Sarover pond; Gothwal and Jangir (2020) studied soil properties of Nakki Lake of lentic ecosystem in semi-arid region, according to the findings of their investigation, the soil parameter is responsible for preserving the transportability of water and preserving biological symmetry in lake ecosystems. This is accomplished through its interdependent relationship with phytoplanktons and zooplanktons.

The ichthyofauna and limnological parameters of Sant-Sarover pond and Nakki Lake, Mount Abu were studied by Gothwal (2019) and Gothwal and Jangir (2019), with statistical analysis to determine the exact number of fish in the population using the quadrat sampling method and the significance in homogeneity by means of chi-square test.

3.2. Correlation of coefficients

Table 3 represents the statistical analysis of correlation coefficients, the variables of water samples across all sites of Nakki Lake, which were analyzed to obtain positive or negative relations between them. The color showed strong positive correlation with total hardness ($r = 0.948$), total dissolved solids ($r = 0.959$), iron ($r = 0.926$) and nitrate ($r = 0.881$). Magnesium was found vigorously positive correlated with total alkalinity ($r = 0.836$) and total dissolved solids is robustly positively correlated with iron ($r = 0.844$), nitrate ($r = 0.940$) and total hardness ($r = 0.990$). Strong positive correlations were found between nitrate and iron ($r = 0.784$), sulphate and chloride ($r = 0.920$), whereas total hardness ($r = 0.990$) is significant correlation with iron ($r = 0.854$) and nitrate ($r = 0.977$). Similarly BOD is positive correlated with fluoride ($r = 0.831$) and COD ($r = 0.787$). Correspondingly, there was no linear relationship found between color ($r = 0.000$) and iron ($r = 0.000$) with fluoride.

3.3. Test of analysis of variance

The test of analysis of variance (ANOVA) in Table 4, calculated from the mean values over top and bottom water samples of Nakki Lake in summer, rainy and winter seasons as shown in Table 1 and 2, for Site 1 (populated region), Site 2 (non-populated region) and Site 3 (mountain region), the result of ANOVA states that the calculated F-value of 2.82 is larger than F-critical value of 2.34 with 5% level of significance, hence, it does not accept null hypothesis (H_o). Hence, the test of ANOVA concludes that there is a significant variation between the mean values of physico-chemical parameters over top and bottom water samples of Nakki Lake in the weather cycle of (2017-2019) for summer, rainy and winter seasons. The variation occurs between the physico-chemical parameters over top and bottom water samples of Nakki lake for the weather cycle (2017-2019) for summer, rainy and winter seasons is due to the topography at different sampling sites and their frequent, moderate contacts and the absence of contacts with human population for Site 1 (populated region), Site 2 (non-populated region) and Site 3 (mountain region).

4. Conclusion

Limnological parameters within the optimal borders of an aquatic ecosystem can be used to determine the ecological diversity of any given aquatic ecosystem. The portability of water of a reservoir can be acknowledged from its planktonic abundance. The physical, chemical and biological or bacteriological characteristics of a water resource usually describe the standards of its water quality. The current research finding brings it abundantly clear that the fluctuations in the limnological parameters of water samples of Nakki Lake are within the acceptable ranges for their optimum values. The limnological analysis of Nakki lake, Mount Abu for the weather cycle of 2017-2019 in three distinct seasons of summer, rainy, and winter over top and bottom water samples, across Site 1, Site 2 and Site 3 (populated, non-populated and mountain region) demonstrated that the nature of Nakki Lake seems to be eutrophic, however, in the peak period of winter season it can be recognized as a mesotrophic lake.

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Table 3. Correlation coefficient analysis of limnological variables over top and bottom water samples across all sites of Nakki Lake in summer, rainy, and winter seasons (2017-2019)

Parameters	*Color (Hazen)*	*Turbidity (NTU)*	*pH value*	*Total alkalinity mg/l*	*Total Hardness ($CaCO_3$), mg/l*	*Total Dissolved Solids, mg/l*	*Iron (Fe) mg/l*	*Chloride (Cl) mg/l*	*Fluoride (F) mg/l*	*Calcium (Ca) mg/l*	*Magnesium (Mg) mg/l*	*Sulphate (SO_4) mg/l*	*Nitrate (NO_3) mg/l*	*Chemical oxygen demand*	*Biological oxygen demand*
Color (Hazen)	1														
Turbidity (NTU)	-0.693	1													
pH value	-0.381	0.554	1												
Total alkalinity, mg/l	-0.268	0.370	-0.552	1											
Total hardness ($CaCO_3$), mg/l	0.948	-0.803	-0.335	-0.432	1										
Total dissolved solids, mg/l	0.959	-0.848	-0.419	-0.372	0.990	1									
Iron (Fe), mg/l	0.926	-0.549	-0.365	-0.212	0.854	0.844	1								
Chloride (Cl), mg/l	0.597	-0.372	-0.844	0.574	0.409	0.492	0.585	1							
Fluoride (F), mg/l	0.000	0.360	-0.025	0.416	0.017	-0.050	0.000	0.105	1						
Calcium (Ca), mg/l	0.128	-0.291	0.325	-0.530	0.332	0.293	-0.162	-0.427	0.220	1					
Magnesium (Mg), mg/l	-0.206	0.322	-0.520	0.836	-0.268	-0.272	-0.018	0.438	0.593	-0.534	1				
Sulphate (SO_4), mg/l	0.656	-0.506	-0.862	0.486	0.567	0.626	0.573	0.920	0.325	-0.105	0.440	1			
Nitrate (NO_3), mg/l	0.881	-0.725	-0.184	-0.519	0.977	0.940	0.784	0.244	0.128	0.469	-0.297	0.455	1		
Chemical oxygen demand	0.084	0.561	0.594	-0.118	0.028	-0.077	0.173	-0.236	0.625	0.129	0.062	-0.194	0.161	1	
Biological oxygen demand	0.446	0.188	0.030	0.180	0.370	0.309	0.434	0.296	0.831	0.183	0.305	0.434	0.442	0.787	1

Table 4. Two-way ANOVA in variables over top and bottom water samples of summer, rainy, and winter seasons (2017-2019), from Table 1 and 2

***Null hypothesis (H_0)*:** there is no significant variation between the mean values of physico-chemical parameters of the sampling sites

***Alternative hypothesis (H_A)*:** there is significant variation between the mean values of physico-chemical parameters of the sampling sites.

Parameters	Count	Sum	Average	Variance
Colour (Hazen)	6	3.96	0.66	0.00
Turbidity (NTU)	6	5.06	0.84	0.00
pH value	6	44.88	7.48	0.13
Total alkalinity, mg/l	6	584.66	97.44	16.11
Total hardness ($CaCO_3$), mg/l	6	583.00	97.17	76.79
Total dissolved solids, mg/l	6	976.66	162.78	274.92
Iron (Fe), mg/l	6	0.15	0.03	0.00
Chloride (Cl), mg/l	6	629.61	104.94	22.89
Fluoride (F), mg/l	6	1.66	0.28	0.00
Calcium (Ca), mg/l	6	326.59	54.43	7.62
Magnesium (Mg), mg/l	6	118.77	19.80	0.51
Sulphate (SO_4), mg/l	6	729.97	121.66	6.68
Nitrate (NO_3), mg/l	6	189.09	31.52	0.89
Chemical oxygen demand	6	58.14	9.69	1.02
Biological oxygen demand	6	188.16	31.36	54.33

*Variance value (Color – 0.00188), (Turbidity – 0.003586), (Iron – 0.00003), (Fluoride – 0.000706)

Parameters	Count	Sum	Average	Variance
Mean top (summer)	15	738.23	49.22	2907.99
Mean top (rainy)	15	753.27	50.22	3212.24
Mean top (winter)	15	691.52	46.10	2492.59
Mean deep (summer)	15	757.69	50.51	2991.10
Mean deep (rainy)	15	787.12	52.47	3310.61
Mean deep (winter)	15	712.53	47.50	2457.93

ANOVA

Source of Variation	SS	Df	MS	F	P-value	F criterion
Between rows	241292.99	14	17235.21	627.83	1.126	1.83
Between columns	387.82	5	77.56	2.82	0.022	2.34
Residual error	1921.62	70	27.45			
Total	**243602.44**	**89**				

Conflict of interest

The authors declare no conflict of interest.

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