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Assessment of Lake Water Quality by using Trophic State Index Indicators : A Case Study of Nainital, Kumaun Region, Uttrakhand, India

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Abstract : Lakes, water reservoirs and streams are the most valuable source of drinking water for the country. However, the lakes and reservoirs have special characteristics, which make them vulnerable to pollution and degradation. Additionally, water quality evaluation can be made by assessment eutrophication. The input of organic contaminants from different sources may result in the alteration of water quality. In order to ensure the water quality, it is important to have a complete inventory of the lakes/reservoirs/wetlands and their status. Till date number of inventorization of Lakes, Reservoirs & wetland have been done by the number of agencies, but the information is lacking on Water Quality of Lakes, Reservoirs & Wetlands with reference to eutrophication status of these inland water bodies in India. Due to the unavailability of the scientific database on Lake Water Quality, a proper conservation plan cannot be prepared. This study has been undertaken for the inventizization of Lake Water Quality with reference to Eutrophication Status of Nainital, located at Longitude 29^{0}22'30", N Latitude 79^{0}27'30" E and Altitude: 1,938 m. and preparation of a conservation plan for restoration of Nainital. The four water chemistry parameters to determine the water body's trophic state: total chlorophyll, total phosphorus, total nitrogen, and Transparency (water clarity). These four parameters serve as indicators of a water body's biological productivity - its ability to support life. Biological productivity is not measured directly hence word indicator is applied. However, it can be estimated. Read on to find out how each parameter relates to the biological productivity of your water body and to its trophic state. The study will help in the identification of hot spots and polluted water bodies in India, which will help in the rational planning of Pollution Control Strategies. Results revealed that the concentration of important parameters that mainly govern the catchment area characteristics was found above to the threshold level of eutrophication. By perusing the results of Trophic Index results of trophic state index indicate that Nainital is in a higher stage of Mesotrophic due to high nutrients loading through uncontrolled disposal of domestic waste from the catchment area.

Key Words: Nainital, Trophicstateindex, Eutrophication, Lake Restoration.

Introduction

Lakes, water reservoirs, and streams are the foremost valuable source of beverage for the earth's population. The livelihood of the citizenry and a couple of other living components depends upon natural lakes for beverage and agriculture & industrial activities. However, the lakes and reservoirs have special characteristics, which make them vulnerable to pollution and degradation. The input of organic contaminants from different sources may end within the alteration of water quality.

India has many manmade water bodies located in typical of the tropics. The Reservoirs, Ponds, and Tanks are manmade (artificial) water bodies though it's a commonplace. While it's difficult thus far the natural lakes, most of the manmade water bodies like Ponds and Tanks are historical. The huge reservoirs are all of the recent origins. Most without any exception have impacted environmental degradation. Only the degree of degradation differs. The degradation itself could also be a result of a scarcity of public awareness. Things are changing but slowly. This is often thanks to the shortage of availability of environmental databases on these lakes & reservoirs in India. Environmental activism and legal interventions have put the sustainability of lakes and reservoirs within the vanguard of environmental issues.

The foremost environmental issue related to lakes and reservoir is Eutrophication. As also been described by Ansari, Abid A., Gill, Sarvajeet Singh (2014) in their book"Eutrophication: Causes, Consequences and Control".Through. Introduction of nutrients from agricultural run-off and untreated industrial and concrete discharges cause Eutrophication of lakes and reservoirs which also enhanced degradation process. Accelerated eutrophication of lakes and reservoirs, experienced during this century in most parts of the earth represents a big degradation of water quality.

Impairment of water quality because of eutrophication can cause health-related problems and end in economic losses.

Many problems originate from the event of activities. Agricultural growth, including the event of irrigation and drainage systems and thus the excessive use of fertilizers and pesticides, cleaning of forests, and thus the development of factories. Human settlements in lake and reservoir watersheds often cause eutrophication of the lakes and reservoirs.

Proper planning and management of the associated watershed are required for control of eutrophication or restoration of eutrophic lakes and reservoirs generally, man-made factors increased eutrophication through the elimination or reduction of nutrient supplies from different sources, like municipal and industrial wastewater, agricultural wastes and fertilizers, etc. However, in most cases, it's impossible to eliminate all sources of nutrients. Therefore, it is vital to understand the connection which exists between the nutrient supplies and thus the degree of eutrophication. This data is vital to develop sound management strategies to manage the eutrophication of lakes or reservoirs at minimum costs.

To date, efforts were made during a scattered manner and not during a scientific manner on Water Quality of Lakes, Reservoirs, and Wetlands in India. The available data has not been compiled/available which may help different government agencies to make a conservation plan for these water bodies. Very limited action plans are available and executed which are being delayed. This might be due to the non-availability of the Limnological conditions of these water bodies.

Organic pollution and nutrient enrichment are one among the foremost significant and widespread water quality issues. Thanks to demographic pressure and rapid urbanization around the water bodies, eutrophication has become a standard problem in freshwater ecosystems. A gradual increase in water eutrophication is the biggest problem of the governments and therefore the public in recent years. This because of the reason that the mechanisms of water eutrophication are not fully understood, but excessive nutrient loading into the surface water system is considered to be one among the main factors (Fang *et al*., 2004, Tong *et al*., 2003). Many freshwater lakes undergo eutrophication with the increasing input of nutrients (Zang, 2008). Certain chemicals, like nitrogen, phosphorus play the most roles in distorting aquatic ecosystems by increasing productivity. In most of the lakes, the severe eutrophication, degeneration of ecosystems, and deterioration of water quality have resulted in uncontrolled nutrient inputs to water bodies and their proximity to agriculture and use in aquaculture (Chen *et al.,* 2003). within the recent past, in several parts of the planet including India, there have been several studies conducted on the physic-chemical and biological characterization of lotic and lentic ecosystems by different authors viz. Parikh and Mankodi (2012), PatilShilpa G *et al.* (2012), Seyed Ahmad Reza Hashem *et al.* (2012), Hashemzadeh, and Venkataramana (2012), Safari *et al.* (2012), Kumar Manoj and Padhy Pratap Kumar (2013) and Pathakand Mankodi (2013). Aside from surface water bodies, Physico-chemical and microbiological characterization of subsurface water were reported by several authors Parihar *et al.* (2012), Nirmala (2012). In line with the wise use of resources, Lake Gahar Basin was assessed as a possible site for focused ecotourism by Gholipoor Mehranoosh (2012). Ray *et al.,* (2021) added another indicator - Phytoplankton communities eutrophic freshwater bodies (Kerala, India) in relation to the physicochemical water quality parameters and investigated that fast growing non-toxic algal species such as *Kirchneriellalunaris*, *Ankistrodesmusfalcatus*, *Radiococcusnimbatus*, *Coelastrummicroporum* and *Scenedesmusdimorphus*, which are industrially useful and can contribute to ecotechnological innovations essential for sustainable development.

Surface water quality during a region is essentially determined both by natural processes and by anthropogenic inputs. The anthropogenic discharges constitute a continuing polluting source, whereas surface runoff may be a seasonal phenomenon, largely suffering from climate within the basin Singh *et al.* (2004). Vega (1998). Land erosion within the lake catchment not only affects the physical and chemical properties of soils but also enriched the lake water with nutrients Upadhyay *et al.* (2012). For any urban water body, the expansion of the habitation around the lake vicinity without a correct sewerage system further exaggerates organic and nutrient loading within the lake. Inline thereupon hydrochemical changes also are found in lakes thanks to the immersion of idols and non-secular offerings which are common in India Dhote and Dixit (2011). Thus, point and non-point sources both are liable for the degradation of the water quality of the limnetic environment.

The trophic state index (TSI) is a widely used indicator to assess and define water quality. Proposed TSI parameter by Carlson (1977) in the 1970s, this index method has been applied worldwide to assess the water quality of lakes Walker (1979), Carlson

(1991), Matthews (2002) & Adamovich *et al.* (2019). In China, water quality of many lakes has deteriorated with economic development and growing populations. Due to the varied topographies, cultural environments, and human activities, the assessment methods of lake eutrophication in China are different for different regions, in that comprehensive trophic level index TLI (P) Zanget. *et al.* (2011) & Huo *et al.,* (2013) are often applied to assess the conditions of water quality. The data for calculating these indicators are typically sourced from long-term experiments and satellite remote sensing Calrson (1977) and Duan *et al.,* (2007). To date, lake water quality studies in China have been conducted predominately in regions of the most rapid economic progress, such as the Yangtze River Basin Le.C *et al.* (2010), Duan *et al.* (2016), Huang et.al. (2009), Zhang *et al.* (2016) Wang & Qiao (2019), whereas the lakes in impoverished agricultural regions have rarely been studied for eutrophication risks. In recent years, elevated concentration of TN and TP has been found in the lakes in high-latitude North-eastern China, especially those surrounded by crop irrigation fields. There is an imperative to carry out water quality studies, initially on a case-by-case basis, to assess the eutrophication risk of these lakes and to prevent irreversible environmental damages from taking place.

In this paper, the Nainital of Nainitallake considered as a test suit. The Nainital is found in Nainital within the Kumaon region of Uttrakhand, India, and is that the only source of water for the town. Economic also as recreational activities of the town also are heavily hooked into the supply of water within the lake, which is received organic and nutrients load through various points and non-point sources. Therefore, this study is administered to realize the subsequent targets: i. Assessment of organic pollution and concentration of plant nutrients in Nainital, ii. Assessment of Trophic index to work out the extent of organic pollution in Nainital, iii. to work out the trophic level of Nainital by using the Trophic State Index (TSI).

Material and Methods

The Nainital lake is a kidney-shaped lake which lies between Latitudes 29^{0}22'30" N" and, 79^{0}27'30" E The maximum length of the lake is 1423 meters, the width varies between 423 m and 250 m. (Fig. 1). The maximum depth of the lake is 27.3 m and the mean depth is 18.52 m. The surface area is 0.463 sq. km, while the volume is 8.58 cu. Mm and the shoreline is 3458 m. The lake is divided into two sub-basins, Mallital and Tallital. The monthly maximum and minimum temperatures in the town range between 28^{0}C and 7^{0}C. The rainy season begins earlier than in the plains and continues up to the end of September. The heaviest rainfall is observed on the outer slopes of the hills. As per the 1999 records, the total average rainfall of the district was 1338 mm. Rainfall during winter falls temperature in considerably. Nainital records heavy rainfall in these months mainly due to the local rain. Due to rainfall in winter, temperature fall noticed considerably. Snowfall is that the heaviest in January or in early February. Frost is additionally experienced within the winter season. The summer season remains between April to June is pleasant.

The lake Nainital is a closed water system. It is surrounded by hills and has a catchment area of 40.90 hect. with an average annual rainfall of approximately 1338 mm (Figure 1). The lake has a mango shape basin. with a surface area of is 0.463 sq. km (30.6 ha) at an elevation of 1314m and a volume of 8.58 million cu.m. The Lake has 1423 meters, the width varies between 423 m and 250 m, and a maximum /minimum depth ranges from 11 to 27 m. It receives water from springs and through the canal in different parts of the year.in Table-1.

Figure 1: A View of Nainital

The lake receives flows from the peripheral drainage area that contains the Hill slopes and comes. The hydrologic studies associated with water balance and deposit were done victimization radioisotopes for estimating/measuring the various parts of the influx and outflow into the lake. The influx and outflow were vital – ranging from to 63% and 41% to 44% indicates the submarine influx and outflow severally, of the complete influx and outflow, except in years of exceptionally significant downfall. The parts of outflows were the surface outflow, the submarine outflow through the springs on the downstream facet, and draft through wells for meeting the water system of Nainital city and evaporation loss from the lake surface. The mean water retention time for the lake was computed as one.16 years for the mean annual downfall.

Catchment Area (Watershed):

The Nainital catchment is known for its good drainage network. There are 21 major and 3 minor drains joining the lake. Of these 21 major drains, 14 are from the Sher-kadanda side (North-side of catchment) and only 6 are from the Ayarpatta side (South-side of the catchment). But by far the largest feeder is the one which collects the drainage and spring waters of the western end of the valley – called the 'Naina Devi Temple drain' or 'baranalla'. Only this drain and the one entering the lake near the Mallital rickshaw stand are perennial. The difference between the two sides of drainage is large because of the rock type. The Ayarpatta mainly consists of limestone and dolomite which are highly permeable to rainwater. Consequently, this catchment side has a sparse drain network. There are a number of springs, generally located on cross/fractures and faults. The 'Parda' spring, as an example, is located at Nainital fault close to its junction with the Sleepy Hollow and Snowdon faults. The main feeder stream passing through NainaDevi Temple derives a large part of its discharge from the Parda spring, pouring out water at the rate of 2173 liters per minute in September to 534 liters per minute in June (Sharma, 1980). Besides, there are a large number of gulleys, descending down the steep slopes, carrying discharges from springs. Sukhatal is an ephemeral lake-let or a valley-fill, which holds water in its bed from its catchment. The water eventually finds its way through the shattered rocks of the fault zone to the Parda spring, which finally feeds the lake. In the process, however, water gets filtered. There is a direct correlation between the amounts of rainfall and spring discharges. The morphometric features of Lake Nainital are given inTable-1

Table - 1: Salient Features of the Study Site

SN	Features	Nainital
1.	Longitude	29^{0} 22’30” N”
2.	Latitudes	79^{0} 27’30”E
3.	Catchment area	40.90 hect.
4.	Submergence area at FTL	0.463 km^{2} (30.6 ha)
5.	Storage capacity	8.58 million cu.m
6.	Maximum Depth	27 m
7.	Maximum Water level (R.L)	06 m
8.	Main water uses	Potable water supply
9.	Source of water	Rain water/Springs

Bathymetric mapping of the lake floor (Fig. 2) gives a detailed topographic database at 1 – m contour interval. The lake floor is divided into four segments (i) South eastern or Tallital basin, (ii) North western or Mallital basin, (iii) Central ridge and (iv) Deltaic deposits along the shores. The South Eastern and North Western Parts of 11 to 25 m and 4 to 27 m deep respectively are filled with unconsolidated sediments, 15 m thick on an average. A number of small and rapidly growing deltas along the shoreline indicates accelerated pace of sediment input, resulting from erosion in catchment area (Hasmi et al., 1993).

Bathymetric Survey of Nainital Lake has been carried out using conventional (manual) sounding methods (Holland, 1895; Purohit, 1981; Rawat, 1987). The calculation of was carried out with the

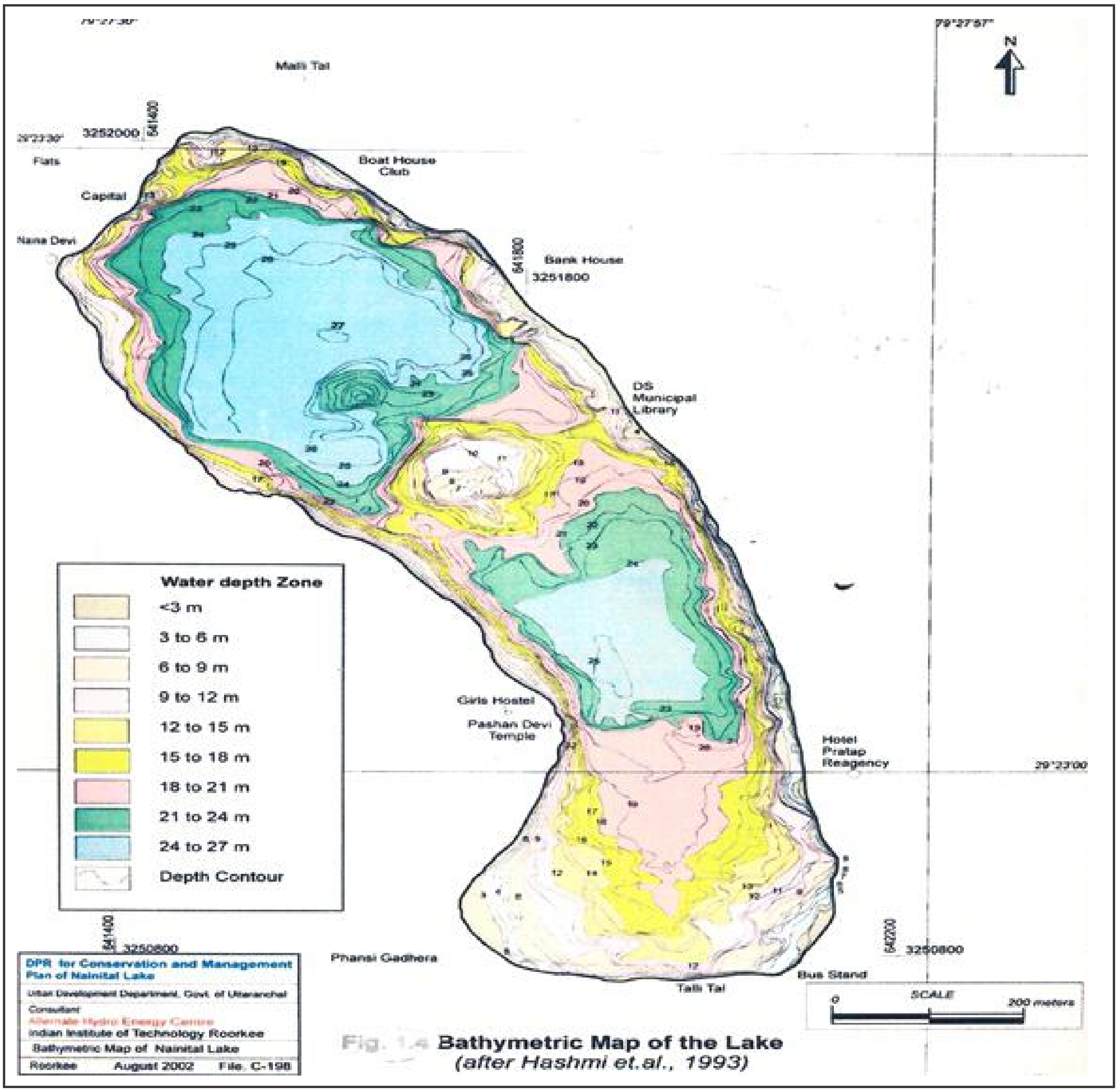
Table - 2 Lake Area at Different Depth Intervals and Layer-wise Volume for Whole Nainital Lake

Depth		Area (m^2)	Volume (m^3)
From	To	Upper Layer	
+0.53	0	463365	244852
0	1	459730	456442
1	2	451721	445786
2	3	441625	440263
3	4	439340	438196
4	5	437052	435908
5	6	434765	433621
6	7	43478	431335
7	8	430192	427015
8	9	423846	418739
9	10	413653	407967
10	11	402307	393010
11	12	383846	374868
12	13	365961	357466
13	14	349038	341704
14	15	334423	327959
15	16	321538	312650
16	17	303846	297541
17	18	291280	280378
18	19	269615	257771
19	20	245000	228752
20	21	211346	200165
21	22	186376	180226
22	23	169230	161404
23	24	147115	130994
24	25	112307	87332
25	26	67307	53487
26	27	40769	157713
Greater then 27		769	133
Total Volume (0=3.28 m)			8581714

help of Hashimi *et al.* (1993) from 4 m to 27 meter depths only. For the calculation of area from surface to 4 meter depth. The data was further interpolated to determine the depth contours in shallow zone. Thus the complete are and then the volume of the lake have been computed and are presented in given in Table 2 & Table 3. The variations in lake are and volumes with respect to depth have been shown in Fig. 2 & 3.

Table - 3: Layer wise Volume and Cumulative Volume of NainitalLake, considering North (Mallital) and South Tallital) Sub-basin Separately

Depth (m)	Tallital Su-basin	Cumulative Volume (m^3)	Mllital Sub -basin	Cumulative Volume (m^3)	Total Lake Cumulative Volume (m^3)
+0.53	-	-	--	-	8581714
0	-	-	--	-	8336862
1	-	-	--	-	7880420
2	-	-	--	-	7434634
3	-	-	--	-	6994371
4	-	-	--	-	6556175
5	-	-	--	-	6120267
6	-	-	--	-	5686646
7	-	-	--	-	5255311
8	-	-	--	-	4828296
9	-	-	--	-	4409556
10	-	-	--	-	4001588
11	-	-	--	-	3608547
12	-	-	--	-	3233679
13	-	-	--	-	2876212
14	-	-	--	-	2534507
15	-	-	--	-	2206547
16	-	-	--	-	1893896
17	-	-	--	-	1596355
18	106831	418484	150940	897493	1315977
19	87438	311653	141314	746553	1059206
20	69578	224215	130586	605239	829454
21	58463	154637	121764	474653	629289
22	48761	96174	112643	352889	449063
23	35042	47413	95952	240246	287659
24	12371	12371	74961	144294	156665
25	-	-	53487	69333	69333
26	Nil	-	846		15846
27	Nil	-	133	133	133



Source: Irrigation Department, Nainital District

Fig.-2. Bathymetric Map of Nainital. (Source: Irrigation Department, Nainital District.)

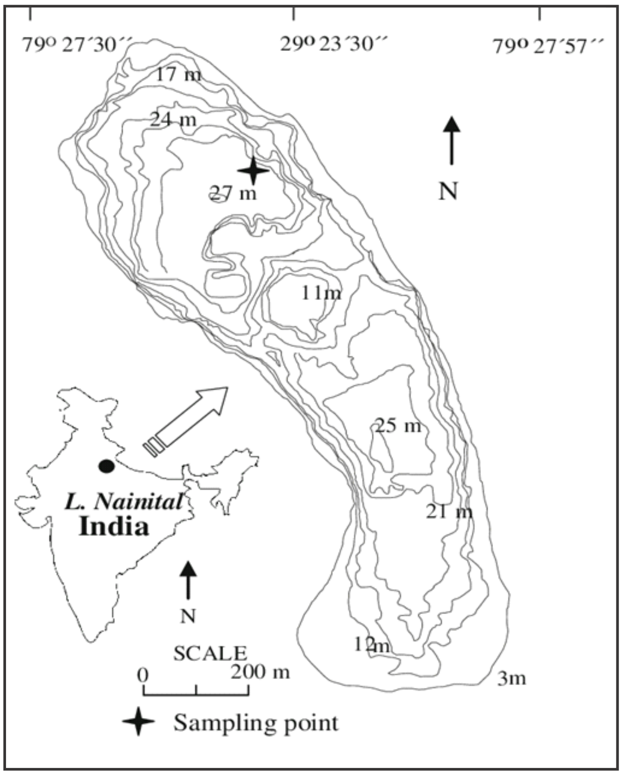


Fig.-3. Lake Area at Different Depth Intervals and Layer-wise Volume for Whole Nainital Lake

The following methodologies were adopted:

1. Used questionnaire for collection of basic information about lake. This questionnaire was sent to authorized concerned agencies in the State and collected during ground level monitoring by the project team.
2. Survey, Monitoring & collection of Lake were done.
3. The Composite samples were collected from three different zone Surface Middle & Bottom of Lake wherever boating facilities was available, otherwise samples were collected all around the lake and make it composite for following three zones as given Figure 3, 4, 5 & 6
   a. North Zone
   b. Central Zone &
   c. Southern zone of Lake
4. Samples were collected to analyzed main following Physical, Chemical & Biological Parameters as per the standard method given in Limnological Method (Welch, 1948) and Water & Wastewater Examination APHA (2000):

Physical: pH, Transparency, Total Dissolved Solids

Chemical: Alkalinity, Ammonia, BOD, COD, Calcium, Copper, Dissolved Oxygen, Free CO_2, Hardness, Manganese, Nitrate, Nitrite, Phosphate, Potassium, Sodium, Zinc.

Biological: Chlorophyll, Plankton, Total & Fecal Coliform

Water Quality & Pollution Status:

The water quality of the lakes deepens largely on catchment characteristics, geology, and inputs of human activities. A catchment of poorly weathered rocks and impact the natural ecosystems will produce water with low fertility. A catchment with reactive rock and soils will produce more fertile waters. The inputs in the form of sewage, sullage, and remains of construction material along with forest runoff add to a multitude of organic and inorganic molecules that undergo a change in the body of receiving waters.

The water quality monitoring is done to ensure that the concentration of particular chemicals are not exceeded, that no deleterious biological effects have occurred, to bring out species richness and/or diversity, to ensure long term sustainable use of aquatic ecosystem by human society and to determine compatibility with other components of the ecological landscape.

Water quality monitoring has many purposes viz. to ensure, that the concentration of particular chemicals is not exceeded, that no deleterious biological effects have occurred, to bring out species richness and/or diversity, to ensure long term sustainable use of aquatic ecosystem by human society and to determine compatibility with other components of the ecological landscape.

This Lake is a large water body in this region of Kumaun hill which is separated into two basins known as Mallital and Tallital. The two basins are separated by ridge 100 m wide, 7-20 m below the water surface. The lake is monomictic and has one period of circulation in winters (January-February) and a prolonged stagnation period of ten months.

The composite water samples were collected from North; Central & South Zone of Lake (Figure 4) analyzed and compares trophic status with the following Figure 5, 6 & **7.**

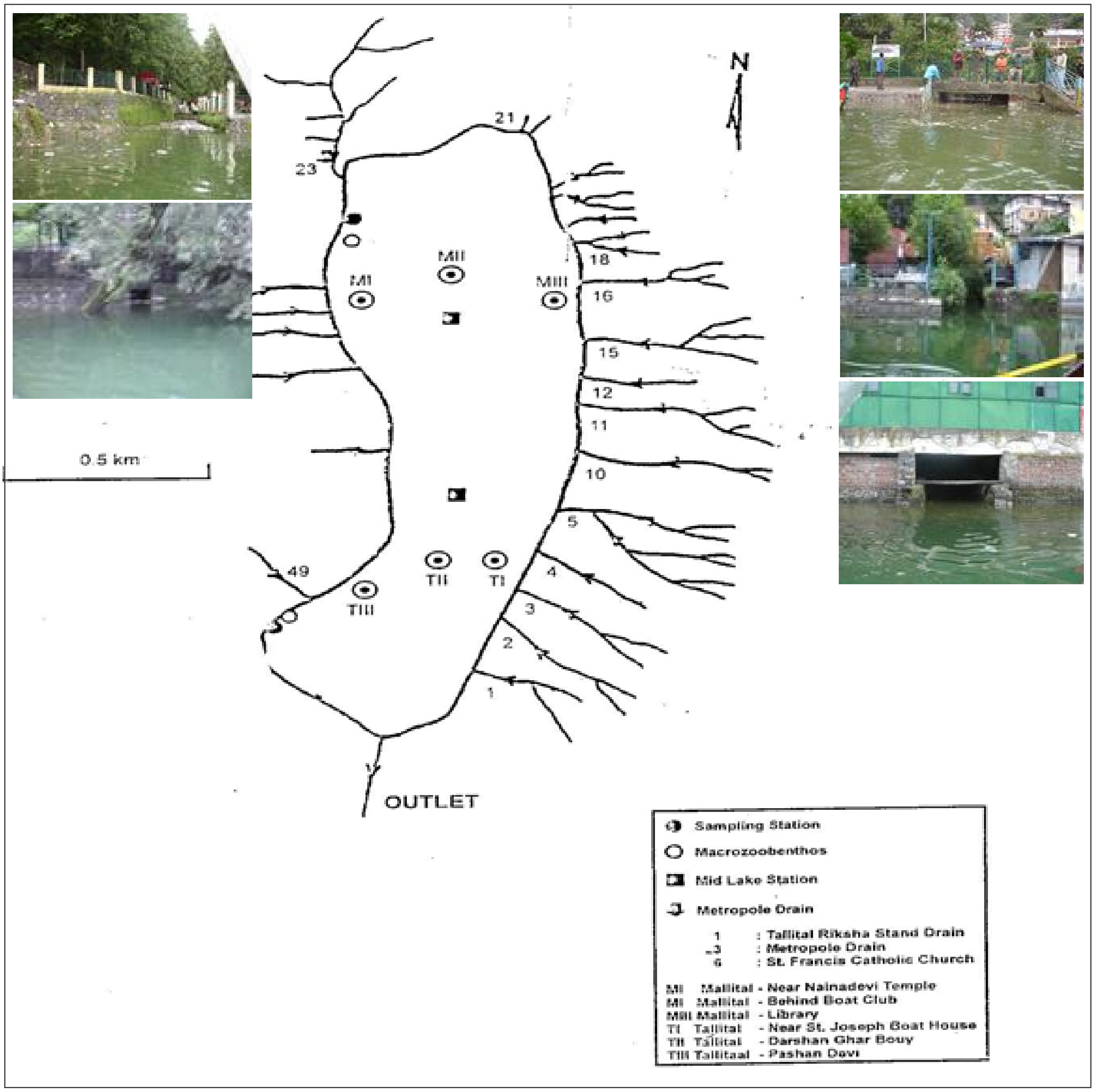


Fig. 4 : Distribution of Various Inlets entered into Nainital Lake

Fig. - 5 Sampling at Northern Side of Nainital

Fig. -6. Sampling of Central Zone of Nainital

Fig. -7. Sampling of Southern Zone of Nainital

Simpson's diversity index (also known as Species diversity index) is a measure of diversity. In ecology, it is often used to quantify the biodiversity of a habitat. It considers the number of species present, as well as the relative abundance of each species. The Simpson index represents the probability that two randomly selected individuals in the habitat belong to the same species.

The term 'Simpson's Diversity Index' can actually refer to any one of 3 closely related indices.

Simpson's Index (**D**) measures the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species). There are two versions of the formula for calculating **D**. either is acceptable but be consistent.

$D = \Sigma(n / N)^2$ $\qquad$ $D = N(N-1)/ni\,(ni-1)$

n = the total number of organisms of a particular species

N = the total number of organisms of all species

The value of **D** ranges between 0 and 1
With this index**, 0 represents infinite diversity and 1, no diversity**. That is, the bigger the value of D, the lower the diversity. This is neither intuitive nor logical, so to get over this problem, D is often subtracted from 1 to give:
Simpson's Index of Diversity 1 - **D**
The value of this index also ranges between 0 and 1, but now, the greater the value, the greater the sample diversity. This makes more sense. In this case, the index represents the probability that two individuals randomly selected from a sample will belong to different species.
Another way of overcoming the problem of the counter-intuitive nature of Simpson's Index is to take the reciprocal of the Index:

Simpson's Reciprocal Index 1 / **D**
The value of this index starts with 1 as the lowest possible figure. This figure would represent a community containing only one species. The higher the value, the greater the diversity. The maximum value is the number of species (or another category being used) in the sample. For example, if there are five species in the sample, then the maximum value is 5. *i.e.* "Values of D range from 0 to 1. A Diversity Index value of 1 represents very low species richness. A value of 0 represents very high species richness -- the value you get if there is only one species present,

Results and Discussion

The water quality of Nainital lake may be deteriorating due to the fact that the sludge accumulation in lake takes place under water basins between pockets of these seven ridges which may help in acceleration of degree of eutrophication in this lakes apart from the induction of nutrient load from it's catchment area as also been indicated by Rawat (1987) according to the measurement of the lake on the premise of mensuration of depth on several traverses across the lake. The information 1895, 1969, and 1979 unconcealed the presence of underwater crosswise ridge, seven – twenty m below the water surface. The comparison of maps conjointly unconcealed a progressive reduction in lake capability because of the buildup of sediments (Hashmi *et al.,* 1993).

As it is also been evident from Bathymetric mapping of the lake floor (Figure 3) provides close geography information at a one – m contour interval. The lake floor is split into four segments (i) Southeastern or Tallital basin, (ii) North-western or Mallital basin, (iii) Central ridge, and (iv) Deltaic deposits on the shores. The South jap and North Western elements of eleven to twenty-five m and four to twenty-seven m deep severally square measure stuffed with loose sediments, fifteen m thick on a mean. Variety of little and apace growing deltas on the boundary indicate the accelerated pace of sediment input, ensuing from erosion within the drainage basin (Hashmi *et al.,* 1993).

The lake receives flows from the encircling drainage basin that includes hill slopes and is derived. The hydrologic studies associated with water balance and deposit were done victimization radioisotopes for estimating/measuring the varied parts of the flow and outflow into the lake. Studies indicated that the belowground flow and outflow were vital – starting from forty-three to sixty-three and forty-one to fifty-four nada, severally, of the overall flow and outflow, except in years of exceptionally serious precipitation. The parts of outflows were the surface outflow, the belowground outflow through the springs on the downstream aspect, and draft through wells for meeting the water system of Nainital city and evaporation loss from the lake surface. The mean water retention time for the lake was computed as one.16 years for the mean annual precipitation (NLRSADA, Jan 2003).

Water Quality & Pollution Status:

The water quality of the lakes deepens largely on catchment characteristics, geology, and inputs of human activities. A catchment of poorly weathered rocks and impact the natural ecosystems will produce water with low fertility. A catchment with reactive rock and soils will produce more fertile waters. The inputs in the form of sewage, sullage, and remains of construction material along with forest runoff add to a multitude of organic and inorganic molecules that undergo a change in the body of receiving waters.

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Water quality monitoring has many purposes viz to ensure, that the concentration of particular chemicals is not exceeded, that no deleterious biological effects have occurred, to bring out species richness and/or diversity, to ensure long term sustainable use of aquatic ecosystem by human society and to determine compatibility with other components of the ecological landscape.

The Nainital is a Medium water body with nine shaped basin. The lake is monomictic and has one period of circulation in winters (January-February) and a prolonged stagnation period of ten months.

The Florida Lake watch Program monitors used the four water chemistry parameters to determine a water body's trophic state: total chlorophyll, total phosphorus, total nitrogen, and Transparency (water clarity). These four parameters serve as indicators of a water body's biological productivity — its ability to support life. The word “indicator” is employed here because biological productivity isn't something that will be measured directly. However, it can be estimated. Read on to find out how each parameter relates to the biological productivity of your water body and to its trophic state.

Chlorophyll - is the dominant green pigment found in most algae (the microscopic plant-like organisms living in a water body). Chlorophyll enables algae to use sunlight to make food. In fact, most algae are so dependent upon chlorophyll pigments for survival that a measurement of the concentration of all the chlorophyll pigments found during a water sample (called total chlorophyll) can be used to estimate the amount of free-floating algae in that water body. When large amounts of total chlorophyll are found within the sample, it generally means there are tons of algae present. Once we have an estimate of the number of algae in a water body, we can take it a step further and use this information to estimate a trophic state. Since algae are a basic food source for many aquatic animals, their abundance is a crucial factor in how much life a water body can sustain. In general, when measurements of total chlorophyll (i.e. Chlorophyll a,b,&c) are high (indicating lots of algae are present), the water body will be more biologically productive.

Phosphorus - is a nutrient necessary for the growth of algae and aquatic plants. It's found in many forms in water body sediments and dissolved in the water. Lakewatch uses a measurement called “total phosphorus” that has all the varied sorts of phosphorus during a sample. When this nutrient is in low supply (and all other factors necessary for plant and algae growth are present in sufficient amounts), low biological productivity is often expected. On the opposite end of the trophic state scale, highly productive water bodies usually have an abundance of phosphorus. In some water bodies, phosphorus may be at a level that limits further growth of aquatic plants and/or algae. When this is true, scientists say phosphorus is the "limiting nutrient."

Nitrogen - is also a nutrient necessary for the growth of algae and aquatic plants. The sum of all sorts of nitrogen called "total nitrogen. are considered by Lake watchmeasurement" When total nitrogen is in low supply (and other factors necessary for plant and algae growth are present in sufficient amounts), low biological productivity can be expected. Like phosphorus, nitrogen can be a limiting nutrient.

Transparency (Water clarity) - refers to the clearness or transparency of water. Water clarity is decided by using an 8-inch diameter disk, called a Secchi (pronounced SEC-ee) disk. The maximum depth at which the Secchi disk is often seen when lowered into the water is measured. Several factors can affect water clarity within the following ways:

free-floating algae in the water can make water bodies less clear;

dissolved organic compounds (called tannins) can cause water bodies to appear reddish or brown; and

Suspended solids (tiny particles stirred up from the water body's bottom or washed in from the watershed) can cause the water to be less clear.

Therefore these simple bases are considered in the present study for the assessment Water Quality & Pollution Status of Nainital Lake (Fig. - 7).

The composite water samples were collected from the North; Central & Eastern Zone of Lake (Figure 3, 4, 5, & 6) analyzed and compares trophic status with Table 4 & Figure 8.

Table - 4. Comparison of Classification Schemes.

Trophic State Index	Trophic State Classification	Water Quality
≤ 60	Oligotrophic through Mid-Eutrophic	Good
61-70	Mid-Eutrophic through Eutrophic	Fair
>70	Hypereutrophic	Poor

Also see LAKEWATCH publication, Trophic State: A Water body's Ability to Support Plants Fish and Wildlife" at http://lakewatch.ifas.ufl.edu/LWcirc.html.

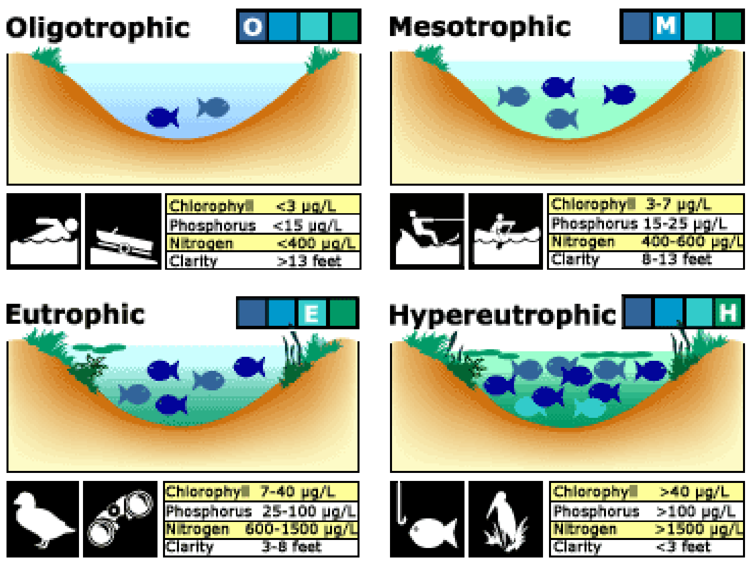

Figure 8: Reference: Trophic State Index Calculation Method

The results are given in Table 5, Table 6 & Table 7 of Physico-chemical and biological profiles indicated that Nainital is discussed below:

Physical Characteristics: It is seen from Table 5 that the Temperature: The Air Temperature was 25.5 ºC whereas the Water Temperature ranged from 25.0 to 25.2 ºC from North to South Zone of Lake. The temperature difference between the North & South Zone is higher than the Central Zone of Lake. This may be due to the effect of wind velocity and shoreline impact. The pH ranged from 7.70 to 7.90 from North to South Zone of Lake. The pH difference between North & South Zone is higher than the Central Zone of Lake. This may be due to the effect of drainage water & photosynthetic activity of Phytoplankton. Transparency: Transparency was ranged from 2.4 to 3 meters from North to South Zone of Lake. The Transparency difference between North & South Zone is lower than the Central Zone of Lake. While comparing with FDEP (1996) report given in Figure 6, the Nainital Lake is showing Eutrophic Conditions on North & South Zone of lake whereas it is Mesotrophic condition in Central Zone. This may be due to the effect of drainage water and other turbulence flow into the lake from the catchment area. Total Dissolved Solids: The Total Dissolved Solids (TDS) was ranges from 388 to 684 mg/l from North to South Zone of Lake. The TDS difference between North & South Zone is higher than the Central Zone of Lake. This may be due to the effect of drainage water and other turbulence flow into the lake from the catchment area, has also been reported by Bhaterial& Jain (2016).

Chemical Characteristics: It is seen from Table 5 that the Alkalinity: The Alkalinity was ranged from 170 to 220 mg/l from North to South Zone of Lake. The Alkalinity difference between to North & South Zone is higher than the Central Zone of Lake. This may be due to the effect of drainage water and photosynthetic activity of Phytoplankton. Ammonia: The Ammonia was ranged from 0.19 to 0.43 mg/l from North to South Zone of Lake. The conc. of Ammonia difference between to North & Central Zone is higher than the Southern zone of Lake. This may be due to the effect of drainage water and decomposition of organic matter in the Lake. Biochemical Oxygen Demand (BOD): The BOD was ranged from 17 to 20 mg/l from North to South Zone of Lake. The BOD difference between to North & Central Zone is lower than the Southern Zone of Lake. This may be due to the effect of drainage water and the mixing of organic matter accumulation in these zones. Calcium: The Calcium was ranged from 40.1 to 70.5 mg/l from North to South Zone of Lake. The Calcium difference between to North & Central Zone is higher than the Southern Zone of Lake. Chemical Oxygen Demand (COD): The COD ranged from 4.0 to 7.0 mg/l from North to South Zone of Lake. The COD difference between North & South Zone is higher than the Central Zone of Lake. This may be due to the effect of drainage water and organic matter accumulation in these zones. Copper: The Copper was ranged from ND to 0.01 mg/l from North to South Zone of Lake. The Copper difference between North & Central to South Zone is higher. But it within the permissible limit as per IS 10500.Dissolved Oxygen (DO): The DO ranged from 5.0 to 6.8 mg/l from North to South Zone of Lake. The DO difference between to North & South zone is lower than the Central Zone. This may be due to the installation of 35 numbers of Aerators into the lake basin. Free Carbon Dioxide (Free CO2): The Free Caron Di Oxide was not detected in any Zone of Lake which shows that all the Carbon dioxide used in the photosynthetic activity of Phytoplankton. Hardness: The Hardness was ranged from 288 to 312 mg/l from North to South Zone of Lake. The Hardness difference between to North & South zone is lower than the Central Zone. This may be due to the drainage of catchment water into the lake. Manganese: The Manganese was ranged uniformly 0.02 mg/l from North to South Zone of Lake. Nitrate: The Nitrate was ranged from 600 to 690 µg/l from North to South Zone of Lake. The Nitrate difference between to North & South Zone is lower than the Central Zone of Lake. While comparing with FDEP (1996) report given in Figure 6, the Nainital Lake is showing Eutrophic Conditions of the lake. Although The nitrate is slightly higher on both the side in comparison to the central zone this may be due to the effect of drainage water and other turbulence flow into the lake from the catchment area. Nitrite: The Nitrite was ranged from 520 to 530 µg/l from North to South Zone of Lake. The Nitrite difference between North & South Zone is lower than the Central Zone of Lake, which shows the degree of eutrophication in different zones of the Nainital Lake. Although nitrite are slightly higher on both the side in comparison to central zone this may be due to the effect of drainage water and other turbulence flow into the lake from the catchment area. Phosphate: The Phosphate was ranged from 65 to 80 µg/l from North to South Zone of Lake. The Phosphate difference between North & South Zone is lower than the Central Zone of Lake. While comparing with FDEP (1996) report given in Figure 6, the Nainital Lake is showing Eutrophic Conditions of the lake. Although The Phosphate is slightly higher on both the side in comparison to the central zone this may be due to the effect of drainage water and other turbulence flow into the lake from the catchment area. Potassium: The Potassium was ranged from 7.29 to 11.24 mg/l from North to South Zone of Lake. The Potassium difference between to South & Central zone is higher than the North Zone. This may be due to the drainage of catchment water into the lake. Sodium: The Sodium was ranged from 19.69 to 25.48 mg/l from North to South Zone of Lake. The Sodium difference between to South & Central zone is higher than the North Zone. This may be due to the drainage of catchment water into the lake. Zinc: The Zinc was ranged uniformly 0.01 mg/l from North to South Zone of Lake. Similar Water Quality parameters has also been reported by Bhaterial& Jain (2016).

Biological Characteristics: It is seen from Table 5 that the Total Coliform: The Total Coliform was ranged from 980 to 1400 MPN/100 ml from North to South Zone of Lake. The Total Coliform difference between to North & South zone is higher than the Central Zone. This may be due to the drainage of catchment water into the lake. Fecal Coliform: The Fecal Coliform was ranged from 380 to 580 MPN/100 ml from North to South Zone of Lake. The Fecal Coliform difference between to North & South zone is higher than the Central Zone. This may be due to the drainage of catchment water into the lake. Chlorophyll: The Total Chlorophyll was ranged from 0.84 to 0.92 μg/l from North to South Zone of Lake. The Chlorophyll difference between to North & Central Zone is higher than the South Zone of Lake. While comparing with FDEP (1996) report given in Figure 6, the Nainital Lake is showing Eutrophic Conditions of the lake. Although The Chlorophyll is slightly higher on North & Central Zone in comparison to the Southern zone this may be due to the effect of higher productivity water in this Zone. The Chlorophyll concentration in Central Zone may be due to the impact of Aeration in Central Zone which increases the phytoplankton density as the Phosphate values are lower in this zone. It is seen from Table 2 that the Trophic Status Index was calculated from North, Central & South Zone of Nainital Lake by assessing Chlorophyll-a concentration. This is calculated as per the FDEP (1996) report. Based on the Trophic Status Index it is clearly indicated that on both the side Water Quality is Fair to Good. Plankton: The biological community of Lake depends not on only thermometry of the Lake, but the trophic status also plays an active role. The presence of Nitrate-Nitrogen & Phosphate together with light penetration on the surface promotes the growth of algae. Over a period a grazing food chain can be established. This Phytoplankton, Zooplankton, Benthos & Nekton can be established. The List of Identified Phytoplankton, Zooplankton & Benthos is given in Table 3. It is seen from Table 5 that The Plankton Density was ranged from 77 to 657x10^3 cells/100 ml from North to South Zone of Lake. The Plankton Density was higher in the central Zone than the North & South Zone. Similar Water Quality parameters has also been reported by Bhaterial& Jain (2016).

The List of Identified Phytoplankton, Zooplankton & Benthos is given in Table 4. It is seen from Table 5 that The Plankton Density was ranged from 980 to 1400 x10^3 cells/100 ml from Central toSouthern Zone of Lake. The Plankton Density was higher in the Southern Zone than the Eastern & North Zone.

Biodiversity:

Nainital Lake aquatic ecosystems showed rich and diverse phytoplankton, Zooplankton & Benthic Organism population Table-3. Phytoplankton in the collections belonged to Chlorophyceae, Cyanophyceae, Bacillariophyceae. Zooplankton collection belongs to the Rotifers, Cladocera& Copepods whereas the Benthic organism collection belongs to the Oligochaeta, Hirudinea, Odonata, Coleoptera, Diptera & Gastropoda.

During the study, 25800 species belonging to 124 genera were recorded for Phytoplankton, 265000 species belonging to 178 genera of Zooplankton, and 49000 species of 49 Genera of Benthic organism. Station-wise list of phytoplankton, Zooplankton, and Benthos of all the three stations are given in Table 7 & Figure 9.

In the present study Simposon's Diversity Index is used for assessment of Species richness in Nainital Lake. The Diversity Index Vales of Each group of Phytoplankton, Zooplankton & Benthic organis are given in Table -8.

The Diversity is “0” in Nainital lake shows that very high species richness which shows the Eutrophic Condition of Lake. Similar diversity index studied by Manickam, Narasimman *et al.* (2020).

On the basis of indicator parameter Chlorophyll, the assessment of trophic status of Lake was done. It is seen from the Table 9 that the Lake water quality at North Zone is Fair whereas the at Central & South Zone is Good while comparing with the *TSI As per FDEP305 (B) Report 1996.*

Table – 5: Physico Chemical & Biological Water Quality of Nainital

S.No.	Parameter	Unit	Obtained Values		
			Northern Zone	Central Zone	Southern Zone
A.	**Physical**				
	pH		25.5	25.5	25.5
	Transparency	Meter	25.2	25.0	25.2
	TDS	mg/L	7.90	7.70	7.90
B.	**Chemical**		2.5 (8Feet)	3.0 (9 feet)	2.4 (7 Feet)
	Alkalinity	mg/L	684	388	414
	Ammonia	mg/L			
	BOD	mg/L	180	170	220
	Calcium	mg/L	0.43	0.21	0.19
	COD	mg/L	18	17	20
	Copper	mg/L	70.5	60.9	40.1
	Dissolved Oxygen	mg/L	7.0	4.0	5.0
	Free CO_2	mg/L	0.01	ND	ND
	Hardness	mg/L	5.0	6.8	6.0
	Manganese	mg/L	ND	ND	ND
	Nitrate	µg/L	312	288	296
	Nitrite	mg/L	0.02	0.02	0.02
	Phosphate	µg/L	680	600	690
	Potassium	mg/L	530	520	528
	Sodium	mg/L	75	65	80
	Zinc	mg/L	7.29	8.9	11.24
C.	**Biological**		19.69	20.79	25.48
	Chlorophyll	µg/L	0.01	0.01	0.01
	Fecal Coliform	MPN/100 mL			
	Plankton	Cells/mLx10^3	1060	980	1400
	Total Coliform	MPN/100 mL	500	380	580

Table - : 6. Distribution and Density of Identified Phytoplankton, Zooplankton & Benthos at Different Zones in Nainital

S N	North Zone		S N	Central Zone		S N	South Zone	
1	PHYTOPLANTON	No.of species Cells/L			No.of Species Cells/L			No.of species Cells/L
A	**Chlorophycese**		A	**Chlorophycese**		A	**Chlorophycese**	
1	*Ankistrodesmusfalcatus*	2000	1	*Ankistrodesmusfalcatus*	2000	1	*Ankistrodesmus convolutes*	1000
2	*Colestrummicrosporum*	1000	2	*Ankistrodesmus convolutes*	2000	2	*Colestrummicrosporum*	1000
3	*Closteriumsimansis*	1000	3	*Colestrummicrosporum*	1000	3	*Closteriumlongissiama*	1000
4	*Closteriumacerosum*	1000	4	*Closteriumsimansis*	1000	4	*Closteriumacerosum*	1000
5	*Chlorella vulgaris*	1000	5	*Closteriumlongissiama*	2000	5	*Chlorella conglarumeta*	1000
6	*Chlorococcumhumicola*	1000	6	*Closteriumacerosum*	2000	6	*Chlorococcumhumicola*	1000
7	*Chlamydomonareinhardtii*	1000	7	*Chlorella vulgaris*	2000	7	*Chlamydomonareinhardtii.*	1000
8	*Eudorinaelegnse*	1000	8	*Chlorella conglarumeta*	2000	8	*Eudorinaelegnse*	1000
9	*Scenedismusquadricauda*	2000	9	*Chlorococcumhumicola*	3000	9	*Scenedismusquadricauda*	2000
10	*Scenedismuscummunis*	2000	10	*Chlamydomonareinhardtii.*	2000	10	*scenedesmusacuminatus*	2000

11	*Pediastrum simplex*	2000	11	*Eudorinaelegnse*	3000	11	*Pediastrum duplex*	2000
12	*Pedistrumboryanum*	2000	12	*Scenedismusquadricauda*	4000	12	*Pedistrumboryanum*	2000
13	*Pleodorinastarrii*	1000	13	*Scenedismuscummunis*	4000	13	*Pleodorinastarrii*	1000
14	*Oocystisirrigularis*	1000	14	*scenedesmusacuminatus*	3000	14	*Oocystisirrigularis*	1000
15	*Pandorinamorum*	1000	15	*Pediastrum simplex*	2000	15	*Pandorinamorum*	1000
16	*Selenestrumdimorphus*	1000	16	*Pediastrum duplex*	3000	16	*Selenestrumdimorphus*	1000
16	*Micractiniumpusilium*	1000	16	*Pedistrumboryanum*	3000	16	*Micractiniumpusilium*	1000
17	*Planktospheriagilatinosa*	1000	17	*Pleodorinastarrii*	2000	17	*Planktospheriagilatinosa*	1000
18	*Oscystisnatanus*	1000	18	*Oocystisirrigularis*	2000	18	*Oscystisnatanus*	1000
19	*Euastrumoblongum*	1000	19	*Pandorinamorum*	2000	19	*Euastrumoblongum*	1000
20	*Actinastrumhentzshii*	1000	20	*Selenestrumbibraianum*	3000	20	*Actinastrumhentzshii*	1000
21	*Desmidiumgrevillii*	1000	21	*Micractiniumpusilium*	3000	21	*Desmidiumgrevillii*	1000
22	*Dictyosphaeriumehrenbergianum*	1000	22	*Planktospheriagilatinosa*	1000	22	*Dictyosphaeriumehrenbergianum*	1000
23	*Disporacrucigenioides*	1000	23	*Oscystisnatanus*	2000	23	*Disporacrucigenioides*	1000
20		**29000**	24	*Euastrumoblongum*	2000	**20**		**28000**
			25	*Actinastrumhentzshii*	2000			
			26	*Desmidiumgrevillii*	2000			
			27	*Dictyosphaeriumehrenbergianum*	2000			
			28	*Disporacrucigenioides*	2000			
			21		**66000**			
B	**Bacillariophyceae**		**B**	**Bacillariophyceae**		**B**	**Bacillariophyceae**	
1	*Gomphonemaintericatum*	1000	1	*Gomphonemaintericatum*	3000	1	*Gomphonemaintericatum*	1000
2	*Naviculasublaniris*	1000	2	*Naviculasublaniris*	3000	2	*Naviculalanceolata*	1000
3	*Nitzschiaacicularis*	1000	3	*Naviculalanceolata*	3000	3	*Nitzschiaacicularis*	1000
4	*Tabellariafenestrata*	1000	4	*Nitzschiaacicularis*	3000	4	*Tabellariafenestrata*	1000
5	*Fragilariacylindrus*	1000	5	*Tabellariafenestrata*	3000	5	*Fragilariacylindrus*	1000
6	*Diatomavulgare*	1000	6	*Fragilariacylindrus*	4000	6	*Diatomavulgare*	1000
7	*Cymbellastuxbergii*	1000	7	*Diatomavulgare*	3000	7	*Cymbellastuxbergii*	1000
8	*Rhopalodiaacuminata*	1000	8	*Cymbellastuxbergii*	3000	8	*Rhopalodiaacuminata*	1000
9	Pinnulariaappendiculata	1000	9	*Rhopalodiaacuminata*	2000	9	Pinnulariaappendiculata	1000
10	*Gyrosigmaspenceri*	1000	10	Pinnulariaappendiculata	4000	10	*Gyrosigmaspenceri*	1000
11	*Amphora Ehrenberg*	1000	11	*Gyrosigmaspenceri*	3000	11	*Amphora Ehrenberg*	1000
12	*Asterionellaformosa*	1000	12	*Amphora Ehrenberg*	3000	12	*Asterionellaformosa*	1000
12		**12000**	13	*Asterionellaformosa*	3000	**12**		**12000**
			12		**40000**			
C	**Cyanophyceae**		**C**	**Cyanophyceae**		**C**	**Cyanophyceae**	
1	Chroococcusgiganteus	1000	1	*Aphanocapsaholsatica*	3000	1	*Aphanocapsaholsatica*	1000
2	*Anabanenaspiroids*	1000	2	Chroococcusgiganteus	5000	2	Chroococcusgiganteus	1000
3	Merismopediaangularis	1000	3	*Anabanenaspiroids*	5000	3	*Anabanenaspiroids*	1000
4	*Gomphosphaerialacustris*	1000	4	Merismopediaangularis	6000	4	Merismopediaangularis	1000
5	*Microcystisauriginosa*	5000	5	*Gomphosphaerialacustris*	4000	5	*Gomphosphaerialacustris*	1000
6	*Spirulina platensis*	5000	6	*Microcystisauriginosa*	6000	6	*Microcystisauriginosa*	5000
7	Oscillatoriaacuminata	2000	7	Oscillatoriaacuminata	5000	7	*Spirulina platensis*	5000
8	Nostoccaeruleum	2000	8	Nostoccaeruleum	5000	8	Oscillatoriaacuminata	2000

9	Phormidiumautumale	2000	9	Phormidiumautumale	6000	9	Nostoccaeruleum	2000
						10	Phormidiumautumale	2000
9		**20000**	**9**		**45000**	**9**		**21000**
2	**Zooplankton**		**2**	**Zooplankton**		**2**	**Zooplankton**	
A	**Rotifera**		**A**	**Rotifera**		**A**	**Rotifera**	
1	*Colurella obtuse*	1000	1	*Philodinaroseola*	2000	1	*Philodinaroseola*	1000
2	Mytilinacompressa	1000	2	*Colurella obtuse*	2000	2	Mytilinacompressa	1000
3	*Rotatoriatridenta*	1000	3	Mytilinacompressa	2000	3	*Rotatoriatridenta*	1000
4	*Euchlanisdilatata*	1000	4	*Rotatoriatridenta*	2000	4	*Euchlanisdilatata*	1000
5	*Philodenivorousparadoxus*	1000	5	*Euchlanisdilatata*	2000	5	*Philodenivorousparadoxus*	1000
6	*Anuropsisfissa*	1000	6	*Philodenivorousparadoxus*	2000	6	*Anuropsisfissa*	1000
7	*Brachionusnilsoni*	1000	7	*Anuropsisfissa*	2000	7	*Brachionusnilsoni*	1000
8	*Brachionuscaudatus*	1000	8	*Brachionusnilsoni*	2000	8	*Brachionusdedutata*	1000
9	Brachionusangularis	1000	9	*Brachionusdedutata*	2000	9	*Brachionuscaudatus*	1000
10	Cephalodellaabstrusa	1000	10	*Brachionuscaudatus*	4000	10	Brachionusangularis	1000
11	*Epiphanes*brachionus	1000	11	Brachionusangularis	4000	11	Cephalodellaabstrusa	1000
12	Monostylaarcuata	1000	12	Cephalodellaabstrusa	2000	12	*Epiphanes*brachionus	1000
13	Keratellacochlearis	1000	13	*Epiphanes*brachionus	1000	13	Monostylaarcuata	1000
14	Keratellacruciformis	1000	14	Monostylaarcuata	1000	14	Keratellacochlearis	1000
15	Keratellatropica	1000	15	Keratellacochlearis	3000	15	Keratellacruciformis	1000
16	*Epistylisrotans*	1000	16	Keratellacruciformis	3000	16	Keratellaamericana	1000
12		**16000**	17	Keratellaamericana	2000	17	Keratellatropica	1000
			18	Keratellatropica	4000	18	*Epistylisrotans*	1000
			12		**42000**	**12**		**18000**
B	**Cladocera**		**B**	**Cladocera**		**B**	**Cladocera**	
1	*Daphnosomaexisum*	1000	1	*Daphnosomaexisum*	4000	1	*Daphnosomaexisum*	1000
2	*Atonaaffinis*	1000	2	*Atonaaffinis*	1000	2	*Atonaaffinis*	1000
3	*Leyedgaacenthocesoid*	1000	3	*Leyedgaacenthocesoid*	1000	3	*Leyedgaacenthocesoid*	1000
4	*Simocephalus*serrulatus	1000	4	*Simocephalus*serrulatus	1000	4	*Simocephalus*serrulatus	1000
5	*Diphnialongspina*	1000	5	Chydorusangustirostris	1000	5	Chydorusangustirostris	1000
5		**5000**	5	*Diphnialongspina*	4000	5	*Diphnialongspina*	1000
			21		**12000**	**21**		**6000**
C	**Copepoda**		**C**	**Copepoda**		**C**	**Copepoda**	
1	*Cyclops vicinus*	1000	1	*Cyclops vicinus*	3000	1	*Cyclops vicinus*	1000
2	*Microcyclopsvaricans*	1000	2	*Microcyclopsvaricans*	3000	2	*Microcyclopsvaricans*	1000
3	*Tropocyclopspracinus*	1000	3	*Tropocyclopspracinus*	4000	3	*Tropocyclopspracinus*	1000
4	*Eucyclopsserrulatus*	1000	4	*Eucyclopsserrulatus*	3000	4	*Eucyclopsserrulatus*	1000
4		**4000**	**4**		**13000**	**4**		**4000**
3	***Benthic Organism***		**3**	***Benthic Organism***		**3**	***Benthic Organism***	
A	**Oligochaeta**		**A**	**Oligochaeta**		**A**	**Oligochaeta**	
1	*Tubifextubifex*	1000	1	*Tubifextubifex*	1000	1	*Tubifextubifex*	1000
2	*Oligochaetaunid*	1000	2	*Limnodrilussp*	1000	2	*Limnodrilussp*	1000
2		2000	3	*Oligochaetaunid*	1000	3	*Oligochaetaunid*	1000
			3		3000	3		3000
B	**Hirudinea**		**B**	**Hirudinea**		**B**	**Hirudinea**	
1	*Hemclepsismarginata*	1000	1	*Hemclepsismarginata*	1000	1	*Hemclepsismarginata*	1000
2	*Glossiphoniaweberi*	1000	2	*Glossiphoniaweberi*	1000	2	*Glossiphoniaweberi*	1000
3	*Barbronicaweberi*	1000	3		2000	3	*Barbronicaweberi*	1000
3		3000				3		3000

3	*Leyedgaacenthocesoid*	1000	3	*Leyedgaacenthocesoid*	1000	3	*Leyedgaacenthocesoid*	1000
4	*Simocephalus*serrulatus	1000	4	*Simocephalus*serrulatus	1000	4	*Simocephalus*serrulatus	1000
5	*Diphnialongspina*	1000	5	Chydorusangustirostris	1000	5	Chydorusangustirostris	1000
5		**5000**	5	*Diphnialongspina*	4000	5	*Diphnialongspina*	1000
			21		**12000**	**21**		**6000**
C	**Copepoda**		**C**	**Copepoda**		**C**	**Copepoda**	
1	*Cyclops vicinus*	1000	1	*Cyclops vicinus*	3000	1	*Cyclops vicinus*	1000
2	*Microcyclopsvaricans*	1000	2	*Microcyclopsvaricans*	3000	2	*Microcyclopsvaricans*	1000
3	*Tropocyclopspracinus*	1000	3	*Tropocyclopspracinus*	4000	3	*Tropocyclopspracinus*	1000
4	*Eucyclopsserrulatus*	1000	4	*Eucyclopsserrulatus*	3000	4	*Eucyclopsserrulatus*	1000
4		**4000**	**4**		**13000**	**4**		**4000**
3	***Benthic Organism***		**3**	***Benthic Organism***		**3**	***Benthic Organism***	
A	**Oligochaeta**		**A**	**Oligochaeta**		**A**	**Oligochaeta**	
1	*Tubifextubifex*	1000	1	*Tubifextubifex*	1000	1	*Tubifextubifex*	1000
2	*Oligochaetaunid*	1000	2	*Limnodrilussp*	1000	2	*Limnodrilussp*	1000
2		2000	3	*Oligochaetaunid*	1000	3	*Oligochaetaunid*	1000
			3		3000	3		3000
B	**Hirudinea**		**B**	**Hirudinea**		**B**	**Hirudinea**	
1	*Hemclepsismarginata*	1000	1	*Hemclepsismarginata*	1000	1	*Hemclepsismarginata*	1000
2	*Glossiphoniaweberi*	1000	2	*Glossiphoniaweberi*	1000	2	*Glossiphoniaweberi*	1000
3	*Barbronicaweberi*	1000	3		2000	3	*Barbronicaweberi*	1000
3		3000				3		3000

Table – 7. Distribution of Genera & Species of Phytoplankton, Zooplankton & Benthic Organism in Nainital Lake

SN	Class of Plankton & Benthos	North Zone		Central Zone		South Zone		Total	
		Genera Nos	Species (cells/L)	Genera Nos	Species (cells/L)	Genera Nos	Species (cells/L)	Genera Nos	Species (cells/L)
A	**Phytoplankton**								
1	Chlorophycease	20	20000	21	60000	20	28000		
2	Bacillariophyceae	12	12000	12	40000	12	12000		
3	Cyanophyceae	9	20000	9	45000	9	21000		
		41	**52000**	**42**	**145000**	**41**	**61000**	**124**	**258000**
B	**Zooplankton**	41	52000	42	145000	41	61000		
1	Rotifera	12	16000	12	42000	12	18000		
2	Cladocera	5	5000	21	12000	21	6000		
3	Copepoda	4	4000	4	13000	4	4000		
		62	**25000**	**79**	**212000**	**37**	**28000**	**178**	**265000**
C	**Benthic Organism**								
1	Oligochaet	2	2000	3	3000	3	3000		
2	Hirudinae	3	3000	2	2000	3	3000		
3	Odonata	2	2000	2	2000	2	2000		
4	Coleptera	3	3000	4	4000	3	3000		
5	Diptera	3	3000	3	3000	3	3000		
6	Gastropoda	3	3000	2	2000	3	3000		
		16	**16000**	**16**	**16000**	**17**	**17000**	**49**	**49000**

Distribution of Species in Nainital Lake

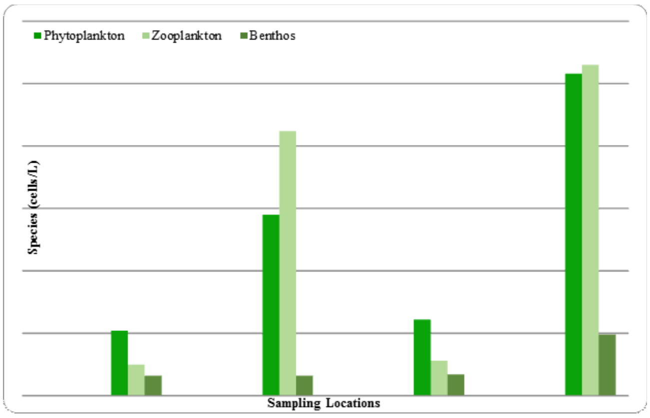

Figure – 9. Distribution of General & Species in Nainital lake

Table – 8. Species Diversity Index of Nainital lake

		Simpson's Diversity Index (D)=N(N-1)/ni(ni-1)#			
		North	**Central**	**South**	Total
A	**Phytoplankton**				
1	Chlorophycease	9.5E-07	1.2E-07	4.8E-07	
2	Bacillariophyceae	9.2E-07	8.3E-08	9.2E-07	
3	Cyanophyceae	1.8E-07	3.6E-08	1.6E-07	
		6.1E-07	**8.2E-08**	**4.4E-07**	**2.3E-07**
B	**Zooplankton**	6.1E-07	8.2E-08	4.4E-07	
1	Rotifera	5.2E-07	7.5E-08	4.1E-07	
2	Cladocera	8.0E-07	2.9E-06	1.2E-05	
3	Copepoda	7.5E-07	7.1E-08	7.5E-07	
		6.1E-06	**1.4E-07**	**1.7E-06**	**4.5E-07**
C	**Benthic**				
1	Oligochaet	5.0E-07	6.7E-07	6.7E-07	
2	Hirudinae	6.7E-07	5.0E-07	6.7E-07	
3	Odonata	5.0E-07	5.0E-07	5.0E-07	
4	Coleptera	6.7E-07	7.5E-07	6.7E-07	
5	Diptera	6.7E-07	6.7E-07	6.7E-07	
6	Gastropoda	6.7E-07	5.0E-07	6.7E-07	
		9.4E-07	**9.4E-07**	**9.4E-07**	**9.8E-07**

Table – 9. Assessment Trophic Status of Nainital Lake

Sampling Location in Nainital Lake	**Chlorophyll (μg/L)**				**TSI of Chl.a 16.8+14.4*Chl a #**	**Trophic Status Index Range (TSI)**	**Assessment of Lake Quality**
	a	**b**	**c**	**Total**			
North Zone	**0.19**	0.20	0.53	0.92	20	60	Fair
Central Zone	**0.17**	0.25	0.50	0.92	19	50-60	Good
South Zone	**0.16**	0.19	0.49	0.84	19	50-60	Good

 # TSI As per FDEP305 (B) Report 1996 *(For lakes: 0-59 is good, 60-69 is fair, 70-100 is poor.)*

Table 9 indicates that the water quality of Nainital Lake based on chlorophyll indicator parameter at Northern Zone is Fair whereas Central and southern zones are having good water quality. Lake Nainital, located in the Kumaun Himalayan region in northern India, is a major drinking water source, Fisheries, Recreation & Religious to the people living in and around the lake basin. The degree of Eutrophication is more at Northern region of lake in compare to Central and southern region. This may be due to mixing of domestic waste at northern region effected the water quality through presence of *Microcystisaeruginosa, Ankistrodesmusfalcatus*, *Coelastrummicroporum* and *Scenedesmusdimorphus*, and several macrophytes whereas due to some of self-purification capacity of lake, Central and southern zone water quality maintain minimum requirement of standard.

Conclusion

The main aim of this study was to understand the level of organic pollution and nutrient concentration in the lake and results revealed that concentration of all the important parameters which mainly govern the lake chemistry is beyond the permissible limits and threshold level of eutrophication. By perusing the results of the Trophic State Index, it can be concluded that Nainital is an organic polluted and nutrient-enriched lentic ecosystem. The concentration of Total Phosphorous and Total Nitrogen is mainly responsible for Nainital eutrophication and having significant impacts on lake water quality. These nutrients can also enhance the rate of cultural eutrophication and increase lake productivity which reflects through the presence of floating blue-green algae such as *Microcystisaeruginosa, Ankistrodesmusfalcatus*, *Coelastrummicroporum* and *Scenedesmusdimorphus*, and several macrophytes in the Nainital at Northern Zone. The increase of the Organic pollution load may be due to Decay and the decomposition of these biological species, reduction in the euphotic zone, and hypolimnetic dissolved oxygen contents.

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