Water Quality and Trophic Status of Sagar Lake for its Restoration

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ABSTRACT

The Sagar lake is situated in the heart of the Sagar city of Madhya Pradesh which falls in the Vindhyan terrain of Bundelkhand region. The quality of lake water has poorly deteriorated and has become unsuitable for various uses. In the present study, physico-chemical analysis has been carried out to assess the present status of water quality and trophic status of the lake. Water samples were collected from twenty one locations of the lake at three different depths and six major nallas. The study indicates that the transparency, pH, and dissolved oxygen (DO) contents of the lake water have significantly reduced while the alkalinity, nitrate, phosphate and iron level of the lake water have greatly increased over the past eighteen years. The lake water also contains the fecal coliform bacteria and high algae activity. Results of the present study are compared with 1990 data as well as Indian Standards. The six major nallas have been identified as the point sources of major pollution to the lake. The trophic state index (TSI) has been computed on the basis of nitrate, phosphate and Secchi depth to assess the eutrophication of the Sagar lake. The increased level of nitrogen and phosphorous contents and reduced Secchi depth indicate that the lake has attained the hyper-eutrophic state. Based on the TSI value, the lake has become unsuitable for drinking, bathing and even for fish culture.

INTRODUCTION

The Sagar lake is a beautiful lake and falls in the heart of city Sagar of Madhya Pradesh. This lake has served drinking water supply to the Sagar town upto 1965. Thereafter the lake started deteriorating at an alarming rate due to multiple reasons. In this context, the present study has been carried out on the water quality aspects of the Sagar lake. The physio-chemical properties of lake water provide first hand information about its quality. These properties include pH, conductance, temperature, dissolved oxygen (DO), BOD, TDS, transparency, alkalinity, hardness, chloride, sulphate, nitrate, etc. The outcome of the study will help in proper management of water quality of Sagar lake, conservation of the valuable lake water, favourable ecosystem and recreation, recharging of surrounding wells with good quality water, and providing valuable information base.

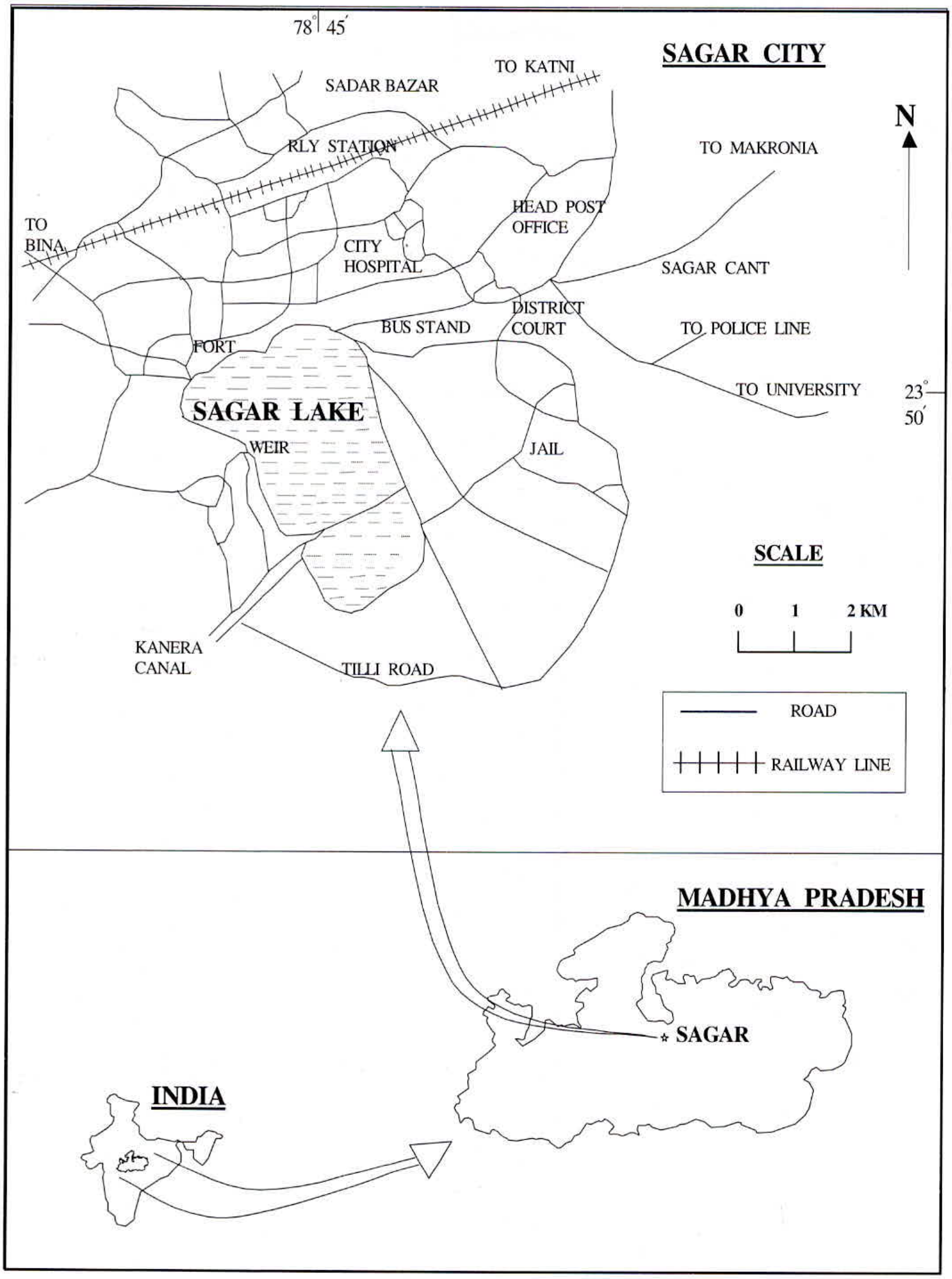
A number of studies are carried out on the microbiological aspects of the Sagar lake (Adoni, 1975, Singhal 1980, Awataramani 1980, Yadav 1986, Yatheesh 1990).

Some ecological studies on the lake and surrounding have been done by Babu and Tamrakar (1987) and Gupta (1987). Agarwal and Bais (1991) have done the hydrobiological study on the Sagar lake. The general observations of these studies show a high trophic status and high organic pollution in the Sagar lake. The average sedimentation rate in the Sagar lake is 0.58 cm/year (Singh et al., 2008). Water eutrophication has also become a worldwide environmental problem in recent years, and understanding the mechanisms of water eutrophication will help in prevention and remediation of water eutrophication. The major influencing factors on water eutrophication include nutrient enrichment, hydrodynamics, environmental factors such as temperature, salinity, carbon dioxide, element balance, etc., and microbial and biodiversity. Therefore, urgent attention is required to critically examine the present status of water quality and eutrophication for the restoration of the Sagar lake.

STUDY AREA

The Sagar lake is situated in the heart of Sagar city, which falls to the North of Tropic of Cancer at an altitude of 517 m above MSL in the Bundelkhand region at the latitude of 23o 50' N and longitude of 78o 45' E. An earthen dam named Sanjay drive divides the lake physically into two part, the main lake and small lake. Both these lakes are interconnected by a bridge on Sanjay drive. The lake has a number of small inflowing channels carrying wastewater from the Sagar city and has single outflow section as Mogha weir. The northern, western and eastern shores of the lake are well guarded against encroachment and erosion due to the presence of buildings and fences. The southern, south-eastern and part of south-eastern shores of lake are open and large quantity of silt from the uphills is being carried into the lake during the rainy season. Large number of temples along the shore indicates the extent of religious sentiments attached to the lake. Apart from religious ablutions, large number of people is daily taking bath and washing clothes in the lake. The southern and south-eastern parts of the lake are being used for washing cattle and the cattle are allowed to wallow at the shallow regions of the lake. Laundry men are using huge quantity of bleaching powder for washing along with other detergents. This is a common phenomenon throughout the year. The activities of trapa and lotus farming increase the deposition of residue in the lake. In the cultivating areas of the lake, people are using pesticides indiscriminately besides the addition of fertilizers (Yatheesh, 1990).

The lake has a periphery of 5230 m with maximum length 1247 m and width 1207 m. Mean depth of the lake is 2.69 m with maximum depth of 5.3 m at full-tank level. The total water-spread area of the lake is 145 ha and the volume is 389 ha-m at full-tank level. The catchment area is 1817 ha and exhibits various landuse patterns as 40.9 % barren land, 20.9 % agriculture, 18.7 % settlement, 11.5 % open forest and 8.1 % water body. The index map of the Sagar lake is shown in Figure 1.



Fig, 1 : Index map of the Sagar lake

MATERIALS AND METHODS

Sampling and Preservation

The water sampling has been done from 21 locations of the lake from March 2006 to May 2008 (Figure 2). The sampling sites are selected in a grid pattern keeping in view the path of water flow in the lake from inflow channels up to the outflow point. Water samples were collected from three different depths viz. 0.25, 1.5 and 3.0 m to study the depth-wise variation in the water quality. Water samples are also collected from six nallas (No. 13, 14, 15, 16, 17 and 20), which discharge wastewater into the lake.

Methods of Analysis

The physical parameters viz. transparency, temperature, pH and dissolved oxygen were determined in the field at the time of sample collection using portable water testing kit. Biochemical oxygen demand (BOD) was determined by incubation and titration method. Total dissolved solids (TDS) were determined by filtration and evaporation method. Chloride concentration was determined by argentometric method in the form of silver chloride. Alkalinity and total hardness were determined by titrimetric method using phenolphthalein and methyl orange indicators. Phosphate, nitrate, iron and fluoride concentrations were determined using UV-VIS Spectrometer. The presence of fecal coliform bacteria was determined using the qualitative analysis. The transparency of lake water was determined using the Seechi disc. The trophic status of the lake has been computed using the Carlson (1977) trophic state index.

RESULTS AND DISCUSSION

The average physico-chemical properties of the lake and inflow channels are presented in Table 1 to 2. The temperature of lake water varies from 17.5 oC and 31.0 oC with an average of 23.9 oC. The transparency of the lake water varies from 0.10 to 0.73 m in terms of Secchi depth with an average of 0.23m. The low transparency is due to high density of algae and plankton in the lake water. The pH value ranges from 5.5 to 8.0 with an average of 6.6 which is towards the lower borderline. The depth wise analysis indicates that pH is decreasing with depth. Rao (1991) has pointed out that low pH value occurs in bottom zone of lake is due to liberation of acids from the decomposing organic matter under low oxygen conditions. The electrical conductance of lake water varies from 452 to 754 μmhos/cm with an average of 582 μmhos/cm. The dissolved oxygen of lake water varies from 1.2 to 9.0 mg/L with an average of 4.4 mg/L. The reduced level of dissolved oxygen is because of high algal and micro bacterial activity that consumes oxygen when they die. Another reason may be the presence of high amount of organic matter in the lake water, which consumes dissolved oxygen while decomposition. With increase in depth of the lake, DO decrease. The alkalinity of lake varies from 70.0 to 250.0 mg/L with an average of 157.2 mg/L. The hardness of lake water varies from

112.0 to 296.0 mg/L with an average of 178.1 mg/L. There is increase in hardness from surface to bottom. Temperature affects the variation of hardness because the solution of CaCO3 as bicarbonate is prompted in cold waters and solubility of CO2 is enhanced (Pettijohn, 1984). The nitrate content of lake varies from 0.20 to 35.0 mg/L with an average of 9.8 mg/L. The level of nitrate in the lake water is increased due to sewage and organic waste inflow as well as the leaching of fertilizers from the agricultural fields surrounding the small lake. Nitrate contents are found to increase with increase in depth of the lake. The chloride content of lake water varies from 26.0 to 132.0 mg/L with an average of 63.3 mg/L. The phosphate content of lake varies from 0.05 to 1.00 mg/L with an average of 0.44 mg/L. The main causes of higher concentration of phosphate in the lake are agricultural runoff, contribution of detergents through washing of clothes and urban wastes entering into the lake. The iron content of lake water varies from 0.01 to 4.0 mg/L with an average of 1.71 mg/L. The high level of iron contents may be due to the iron-bearing wastes and effluents from picking operations surrounding the lake. With increase in depth of the lake, iron content increases.

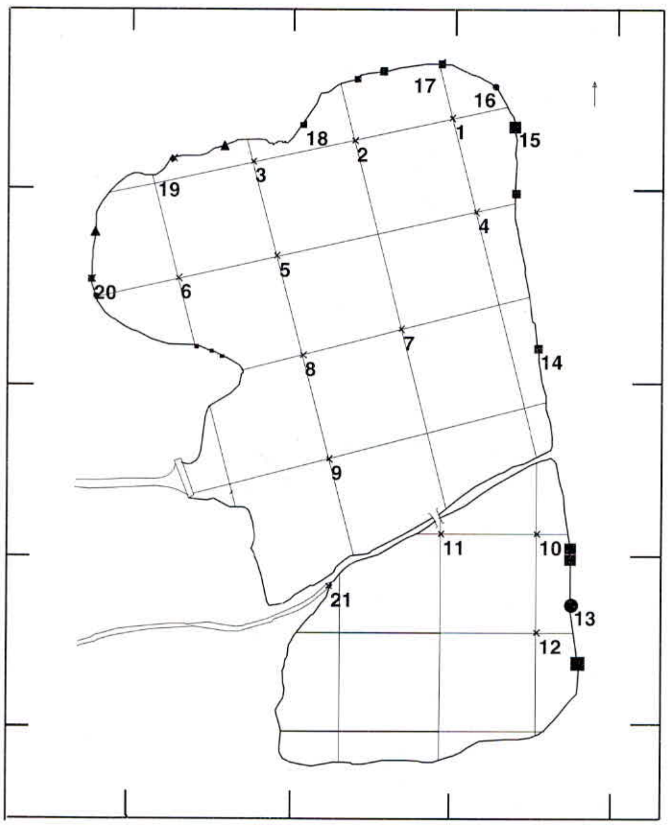


Fig. 2 : Map of Sagar lake showing sampling locations

The BOD of lake water is 7.4 to 13.8 mg/L with an average of 11.4 mg/L. The high level of BOD indicates high organic input in the lake water which consumes more oxygen in oxidizing the organic matter. The TDS of lake water varies from 294 to 490 mg/L with an average of 378 mg/L. The coliform bacteria were found present in the water samples collected from various locations of the lake.

Table 1. Water quality results of the Sagar lake

Sl. No.	Parameter	Average Value of Parameters
1	Temperature (°C)	23.9
2	Transparency (m)	0.23
3	pH	6.6
4	Dissolved Oxygen (mg/L)	4.4
5	TDS (mg/L)	378.0
6	Alkalinity (mg/L)	157.2
7	Hardness (mg/L)	178.1
8	Nitrate (mg/L)	9.8
9	Chloride (mg/L)	63.3
10	Phosphate (mg/L)	0.44
11	Iron (mg/L)	1.71
12	Faecal Coliform	Present
13	BOD (mg/L)	11.4

Point Sources of Pollution

The water samples were collected from six nallas (No. 13, 14, 15, 16, 17 and 20) and tested in the laboratory (Table 2). The average values of these nallas indicate low pH (6.0), very low DO (2.6 mg/L), high BOD (23.7 mg/L), high TDS (651 mg/L), high alkalinity (334.7 mg/L), high nitrate (16.0 mg/L), high phosphate (1.01 mg/L) and iron (2.1 mg/L). These nallas are the main pollution sources which directly discharge waste water into the lake. Furthermore, all the nallas are the pollution sources of fecal coliform bacteria.

Comparison of Lake Water Quality With Yatheesh (1990)

The water quality of Sagar lake is compared with Yatheesh (1990) and presented in Table 3. It is seen that at present the transparency, pH and DO of the lake water are greatly reduced while the alkalinity, hardness, nitrate and phosphate level are tremendously increased which indicates that the lake has become acidic and eutrophic level of the lake is greatly increased. However, no appreciable change is found in the chloride level. The comparison also clears that the pollution level of the lake has fatally increased during the past eighteen years.

Table 2 : Water quality results of the inflow channels of the lake

Sl. No.	Parameter	Average Value of Parameters
1	Temperature (°C)	24.2
2	pH	6.0
3	Dissolved Oxygen (mg/L)	2.6
4	TDS (mg/L)	651.0
5	Alkalinity (mg/L)	334.7
6	Hardness (mg/L)	216.3
7	Nitrate (mg/L)	16.0
8	Chloride (mg/L)	86.7
9	Phosphate (mg/L)	1.0
10	Iron (mg/L)	2.1
11	Fecal Coliform	Present
12	BOD (mg/L)	23.7

Table 3 : Comparison of lake water quality with Yatheesh (1990)

Sl. No.	Parameter	Yatheesh (1990)	Present Study
1	Temperature (°C)	23.9	23.9
2	Transparency (m)	0.55	0.23
3	pH	8.5	6.6
4	Dissolved Oxygen (mg/L)	5.5	4.4
5	Alkalinity (mg/L)	137.9	157.2
6	Hardness (mg/L)	168.6	178.1
7	Nitrate (mg/L)	0.14	9.8
8	Chloride (mg/L)	59.9	63.3
9	Phosphate (mg/L)	0.22	0.44

Evaluation of Lake Water for Drinking purpose as per IS:10500 Standards

The average values of pH, DO, BOD, hardness, chloride, nitrate, fluoride and iron have been compared with the IS: 10500 standards for class A and C type (Table 4). It is found that the lake water is not suitable as per both the classes because most of the parameters are either beyond the limit or on the borderline.

Trophic Status of the Sagar Lake

Carlson (1977) has given the multivariate trophic state index (TSI) for the lakes

Table 4. Comparison of lake water quality with IS:10500 Standards

Parameter	pH	DO (min)	BOD_5	Hardness (max)	Chloride (max)	Nitrate (max)	Iron (max)
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Class-A*	6.5–8.5	6	2	300	250	20	0.3
Class-C#	6.5–8.5	4	3	-	600	50	0.5
2006-08 Data	6.6	4.4	11.4	178.1	63.3	9.8	1.71

**Class-A: Inland Surface Waters for use as Drinking Water Source without Conventional Treatment but after Disinfection.*

Class-C: Inland Surface Waters for use as Drinking Water Source with Conventional Treatment followed by Disinfection.

and reservoirs as given in Table 5 and the TSI values for the Sagar lake have been computed using the following regression equations (Reokhow and Chapra, 1983)

$$TSI(SD) = 60.0 - 14.41 * \ln(SD) \quad (1)$$

$$TSI(TP) = 14.42 * \ln(TP) + 4.15 \quad (2)$$

$$TSI(TN) = 54.45 + 14.43 * \ln(TN) \quad (3)$$

where SD = Secchi depth (m); TP = Total phosphorous (mg/L), and TN = Total nitrogen (mg/L).

The TSI values estimated on the basis of these three parameters indicate that the Sagar lake is in the hyper eutrophic state (Table 6). A comparison of the TSI value

Table 5 : Carlson's Trophic State Index (1977)

TSI	Trophic Status
0-25	Strongly Oligotrophic
26-32	Oligotrophic
33-37	Slightly Oligotrophic
38-42	Slightly Mesotrophic
43-48	Mesotrophic
49-53	Strongly Mesotrophic
54-57	Slightly Eutrophic
58-61	Eutrophic
62-64	Strongly Eutrophic
65+	Hyper- Eutrophic

for1983 (vide Sinha and Thakural, 1998), 1988-89 (Yatheesh, 1990) and 2006-08 data of the Sagar lake is shown in Figure 3. The comparison of present trophic status of the lake with Yatheesh (1990) indicates that the TSI value has greatly increased by 27.9 over the past eighteen years. Based on the trophic status of the Sagar lake, its water has become unsuitable for drinking, bathing, industrial supply as well as fish culture. However, based on TDS and electrical conductance, the lake water can be used for the irrigation purpose. The high eutrophication level can have negative biological, social and economical impacts on man's use of lake water.

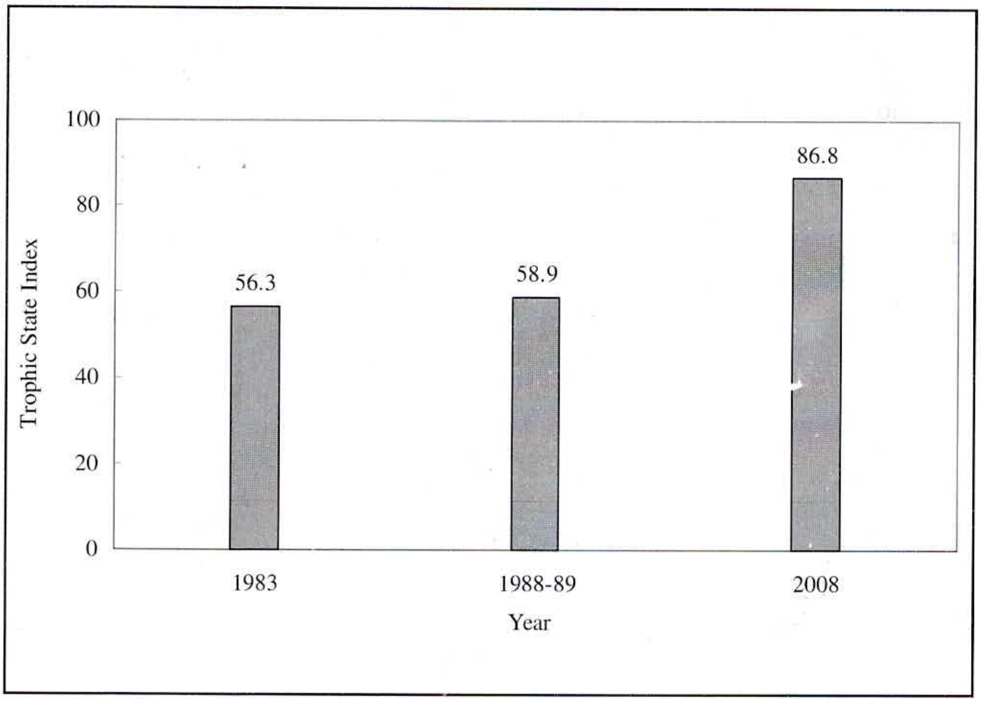


Fig. 3. TSI value of Sagar lake based on Carlson Bi-variate Index

Table 6. Trophic status of Sagar lake based on Carlson Bi-variate Index

Sl. No.	Parameter	Average Value	Carlson, TSI	Trophic Status
1	Phosphorous (micro-gram/L)	440	91.9	Hyper Eutrophic
2	Nitrogen (mg/L)	9.8	87.4	Hyper Eutrophic
3	Secchi Depth (m)	0.23	81.2	Hyper Eutrophic
Average			86.8	Hyper Eutrophic

The criteria of Ryding and Rast (1989) has been used to assess the suitability of the lake water for various purposes on the basis of trophic status of the lake. A summary of intended water uses and the optimal versus minimally acceptable trophic state for such uses is given in Table7.

Table 7 : Criteria for intended lake and reservoir water uses in relation to trophic conditions (Ryding and Rast, 1989)

Desired Utilization	Trophic Status Required	Still Tolerable
Drinking Water Purpose	Oligotrophic	Mesotrophic
Fish Culture	Oligotrophic	Mesotrophic-Eutrophic
Bathing Purpose	Mesotrophic	Slightly Eutrophic
Industrial Supply	Mesotrophic	Slightly Eutrophic
Water Sports (without bathing)	Mesotrophic	Eutrophic
Irrigation	-	Strongly Eutrophic
Energy Production	-	Strongly Eutrophic

The suitability of the Sagar lake for various uses is given in Table 8 and it can be seen that based on the trophic status, the Sagar lake is in the hyper eutophic state and the water of the lake has become unsuitable for most of the important uses.

Table 8 : Suitability of the Sagar lake for various uses

Desired Use of Lake Water	Suitability of Water (without treatment)
Drinking Water Purpose	Unsuitable
Fish Culture	Unsuitable
Bathing Purpose	Unsuitable
Industrial Supply	Unsuitable
Water Sports (without bathing)	Unsuitable
Irrigation	Can be used

CONCLUSIONS

In this paper, a detailed physico-chemical analysis of the Sagar lake has been carried out to determine the present status of the water quality. The analysis indicates that the lake water is yellowish green with high algae activity and the transparency has reduced to the great extent. A comparison of the present status of lake water with earlier data shows that the pollution level of the lake has greatly increased over the past eighteen years. The lake water cannot be used for drinking purpose with regards to the standards of class A and C type water. The lake water also contains the fecal coliform bacteria.

The study shows that most of the water quality parameters of the lake water are beyond the permissible limits. The nallas carrying wastewater inflow into the lake contribute various kinds of pollutants and are the point sources of major pollution to the lake. The increased level of nitrogen and phosphorous contents and reduced Secchi depth has put the lake into the hyper-eutrophic state. The water quality of Sagar lake has reached the alarming stage and urgent attention is required for its restoration.

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