Water Balance Study, Water Quality Analysis and Management Plan for Sagar Lake

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ABSTRACT

The Sagar lake is situated in the heart of Sagar city of Madhya Pradesh and is two hundred years old with an artificial origin. Today, this lake is facing the same problems being faced by other lakes in India such as deterioration in the water quality, diminishing lake life, spreading of water borne diseases, encroachment of lake area and inflow of pollutants. In this paper, the water balance study of Sagar lake is carried out using the mass balance equation to account for various input and output components. The lake has periphery of 5230 m with maximum length 1247 m and width 1207 m. Mean depth of the lake is 2.69 m and maximum depth is 5.0 m at its full tank volume of 389 ha-m. The water quality study is carried out through physico-chemical analysis of the lake water by collecting samples from 21 locations of the lake at three different depths. The analysis of water quality parameters indicates the deteriorating condition of Sagar lake. The management plan for Sagar lake includes suggestions for diversion of wastewater, laying sewer line and treatment plant, lake aeration, minimizing nutrient input, partial dredging, sluice gate operation and construction of silt traps, cattle entry control, fencing of shoreline, catchment treatment plant to reduce sedimentation in lake, aquatic plant control and vegetation restoration, fish removal, restocking and wildlife habitat enhancement, development of institutional capability and public awareness.

INTRODUCTION

Lakes are the valuable natural resources and have always been of great importance to mankind since ancient times for providing water for domestic purposes. A lake is a sort of catalyst in the development of any city but unfortunately, the popularity of lakes often leads to its deterioration. The increased input of industrial waste, domestic waste, other sediments and the human activity hampers the usefulness of the lake. The Sagar lake, situated in the middle of Sagar city in Madhya Pradesh, was the perennial source of water supply to the Sagar city up to 1960s. Due to improper and inadequate attention, the Sagar lake is now facing various problems like sedimentation, deteriorating water quality, diminishing lake life, spreading water borne diseases in the surroundings and encroachment of the lake area. The waste water from several municipal wards of Sagar city consisting of sewage and sludge water mixed with garbage, night soil and solid waste find its way in to the lake thereby causing contamination of the impounded lake water (Thakural, Sinha & Galkate, 2002). The Sagar lake water is unsuitable for potable use and urgent attention is needed to make Sagar lake a prospective water resource for its utilization for bathing, irrigation and industrial purposes (Thakural, Galkate, Nayak & Thomas, 2004). The average annual rainfall in and around the Sagar city is 1200 mm. Though the lake gets completely filled up during monsoon season, major portion of lake dries during summer season. The life of lake is decreasing because of sediment entering into the lake through city wastewater and catchment runoff during monsoon season (Singh & Thakural, 2004). Many scientific studies have been carried out on the Sagar lake in the year 1975 (Adoni, 1975), 1980 (Awatramani, 1980), 1986 (Yadav, 1986) and 1990 (Yatheesh, 1990) which were concentrated on the physico-chemical properties and their possible interrelationship with biological factors like plankton, macrophytes, macrofuna, etc. The general observations of these studies show a high trophic status and a high organic pollution level in the Sagar lake. The present study is aimed to study the water balance components and water quality status of Sagar lake for preparation of management plan which proposes the guideline for restoration of the lake.

STUDY AREA

The Sagar lake is situated in the heart of Sagar city in the Bundelkhand region of Madhya Pradesh and located at the latitude of 23° 50' N and longitude of 78° 45' E with an average altitude of 517m above sea level. The index map of Sagar lake is shown in Fig. 1. An earthen dam named Sanjay drive divides the lake physically into two parts, viz. main lake and small lake. A bridge on the Sanjay drive interconnects both these lakes. The lake receives fresh precipitation water from the catchment through number of inflow channels and drains carrying city wastewater. Geological evidence says that originally the lake had an area of 580 ha against the present 145 ha and the maximum depth was about 18.0 m against the present depth of about 5.0 m (Yatheesh, 1990). The lake has a shore area periphery of 5230 m with maximum length 1247 m and maximum width 1207m. At full tank level the maximum depth of water at the centre of lake is 5 m and the overall mean depth of lake is 2.69 m. The total volume of water contained in the lake at its full tank level is 389 ha-m. The catchment area of the lake is 18.17 km^2 consisting of 41% barren land, 21% agricultural land and remaining land use includes open forest, water bodies and settlement. The soils in the lake catchment area are reddish-brown lateritic soil on hilltops and black soil at the foothills.

WATER BALANCE STUDY

Materials and Methodology

The water balance equation, derived from the mass balance, i.e., continuity equation, states that all waters entering into a storage basin during any particular period of time must either go into storage, be consumed or go out during that period. The general water balance equation is written as

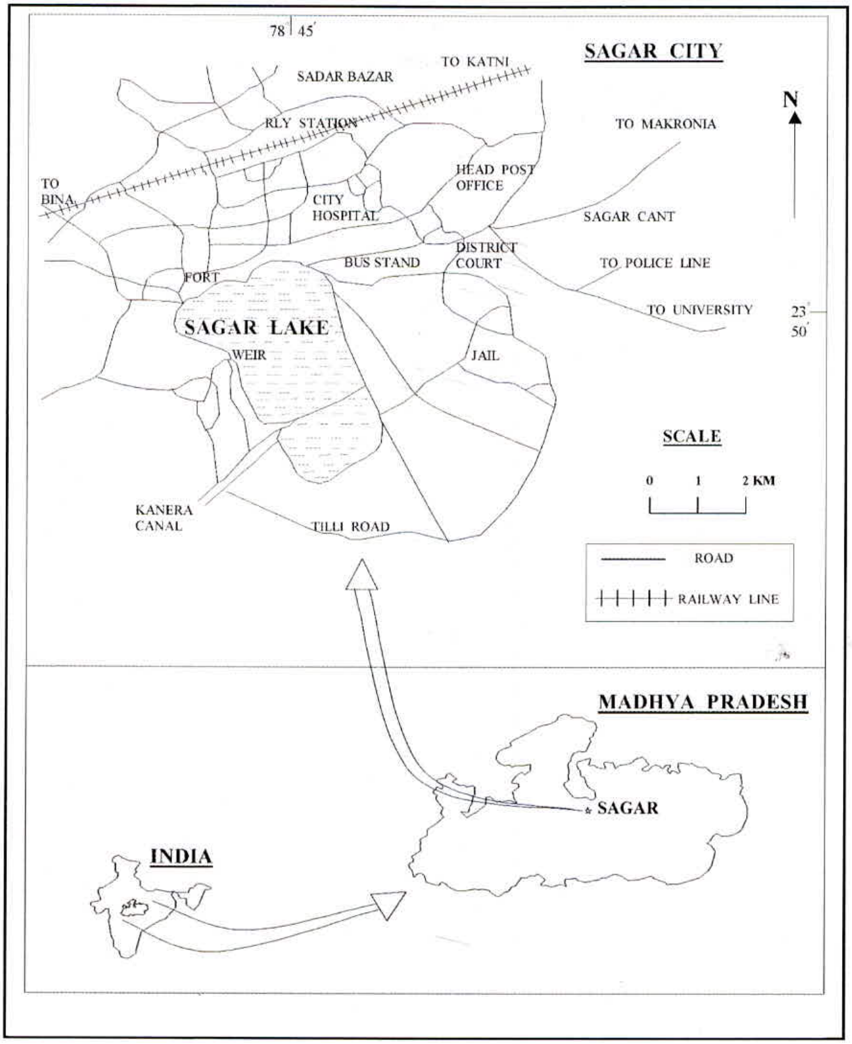

Fig. 1: Index map of Sagar lake

Change in Storage = Inflow – Outflow

i.e.,

$$\Delta S = I - O \tag{1}$$

$$\Delta S = S_i + D_i + P_i + SS_i - E_o - W_o - L_o - S_o - SS_o \tag{2}$$

where, ΔS is change in lake storage; I is inflow to the system and O is outflow from the system. In case of the Sagar Lake, the inflow includes surface inflow (S_i), inflow of city wastewater through drains (D_i), direct precipitation (P_i) over the lake surface and subsurface inflow (SS_i). The outflow includes surface evaporation (E_o), overflow from Mogha weir (W_o), leakage through Mogha weir (L_o), siphon out over Mogha weir (S_o) during summer season and subsurface outflow (SS_o). The study of water balance is carried out over a time scale of one year (1999).

Surface inflow (S_i)

The total surface inflow in response to rainfall has been divided into two parts, the first being measured inflow from Kanera canal catchment and the other unmonitored inflow from rest of the lake catchment estimated using Soil Conservation Service - Curve Number (SCS - CN) method. The monthly flow through the canal is presented in Table 1.

Table 1. The water balance components of Sagar Lake for the year 1999

Month	Lake Level (m)	*Pptn*	ΔS	P_i	D_i	S_i	SS_i	S_o	E_o	W_o	L_o	SS_o
	msl	mm	mcm	mcm	mcm	mcm	mcm	mcm	mcm	mcm	mcm	mcm
Jan	526.300	3	-	0.004	0.052	0.000	0.000	0.000	0.122	0.000	0.002	0.092
Feb	526.153	65	-	0.086	0.047	0.000	0.000	0.000	0.142	0.000	0.001	0.118
Mar	526.003	0	-	0.000	0.052	0.000	0.000	0.000	0.199	0.000	0.000	0.212
Apr	525.727	0	-	0.000	0.050	0.000	0.000	0.014	0.240	0.000	0.000	0.123
May	525.451	48	-	0.058	0.052	0.000	0.000	0.014	0.282	0.000	0.000	0.125
Jun	525.225	34	-	0.040	0.050	0.000	0.000	0.009	0.221	0.000	0.000	0.080
Jul	525.320	443	0.66	0.530	0.052	1.587	0.000	0.000	0.155	0.000	0.000	1.356
Aug	526.381	436	1.00	0.609	0.052	7.931	3.872	0.000	0.157	11.298	0.013	0.000
Sep	526.519	678	0.04	0.962	0.050	7.002	5.302	0.000	0.188	13.079	0.016	0.000
Oct	526.438	100	-	0.140	0.052	0.427	1.104	0.000	0.183	1.631	0.016	0.000
Nov	526.286	0	-	0.000	0.050	0.089	0.000	0.000	0.133	0.000	0.011	0.324
Dec	526.096	0	-	0.000	0.052	0.000	0.000	0.000	0.108	0.000	0.005	0.088
Total		1808	-	2.429	0.611	17.036	10.278	0.037	2.130	26.008	0.064	2.518
% of total Inflow/Outflow				**8.0**	**2.0**	**56.0**	**34.0**	**0.12**	**6.9**	**85.0**	**0.20**	**8.0**

City wastewater inflow through drains (D_i)

The lake receives the city wastewater through a number of drains. The estimation of inflow of this wastewater has been done on the basis of daily per capita consumption of water. For this purpose, per day per capita consumption of water was taken as 75 liters out of which 50% was considered as wastewater as per the prevailing conditions. The monthly computation of city wastewater inflow is presented in Table 1.

Direct precipitation over the lake surface (P_i)

During the rainfall, lake directly receives precipitation and it is computed using

Lagrange interpolation technique and multiplied with the rainfall of that day to yield daily precipitation over the lake surface. The quantity thus estimated on daily basis is converted to monthly values and is presented in Table 1.

Evaporation (E_o)

The lake evaporation is estimated using the pan evaporation data of Sagar district with a pan coefficient of 0.8. Based on daily lake level, the daily water spread area is computed with the aid of interpolation technique. The monthly evaporation from the Sagar lake is given in Table 1.

Discharge through overflow from Mogha weir (W_o)

During monsoon, the lake becomes full and starts overflowing from Mogha weir. The overflow from the weir has been estimated using broad crested weir formula using the lake level data, as the daily measurement of flow velocity over the weir crest could not be possible. The coefficient of discharge (C_d) was worked out to be 0.66.

$$Q = \frac{2}{3}\sqrt{2g}\,.C_d\,.L\,.h^{\frac{3}{2}} \qquad (3)$$

where, Q is discharge flowing per second through the weir gates (m^3); L is length of the gate over the crest (m); h is overflow height (m) and g is acceleration due to gravity (m/sec^2). The monthly discharge through overflow is presented in Table 1.

Leakage through Mogha weir (L_o)

As the lake level reaches close to the weir level, huge amount of water starts leaking through the body of weir. The leakage starts during monsoon and lasts till February or March. Measurement of this component is done using the velocity-area method. The computation of this leakage is presented in Table 1.

Siphoning over the Mogha weir (S_o)

During the summer season, the groundwater level goes deep drastically in the downstream side of lake and creates a serious water scarcity problem. To meet the water requirements in the downstream side of the lake, water is siphoned out over the Mogha weir everyday for 10 hours using pipe of 9 m length and 7.5 cm diameter. The siphoned water is estimated using the pipe flow formula.

$$\text{Siphoned Discharge} = \frac{\pi d^2}{4} V \qquad (4)$$

where, $$V = \frac{\sqrt{2gh}}{1.5 + \frac{fL}{d}}$$

f is friction factor; h is head difference (m); L is pipe length (m) and d is diameter of pipe (m). The siphoned discharge is presented in Table 1.

Subsurface inflow (SS_i) and outflow (SS_o)

The estimation of these parameters is the most difficult task among all the parameters of the water balance Equation 2. The estimation of subsurface inflow and subsurface outflow has been done by the conventional methods, i.e., estimation of all the surface inflow and outflow components and then deducing the subsurface inflow and outflow from the balance. The monthly estimation of subsurface inflow and outflow components is presented in Table 1.

Change in storage (DS)

The water level of lake varies with time as it is a natural phenomenon. However, the change in storage can be seen with the change in water level in 24 hours or in a month or in a year. The decline of water level is almost gradual and uniform as a result of evaporation from the lake surface and siphoning out of water from the Mogha weir. The water level starts rising since July due to monsoon rainfall, attains maximum in August or September and starts declining since October. The monthly changes in total storage of lake for the year 1999 are presented in Table 1.

RESULTS AND DISCUSSION

The analysis of water balance components of the lake indicates that the major inflow component to the lake is surface runoff. Out of the total annual inflow, the lake receives about 56 % surface runoff, 8 % direct precipitation, 2 % city wastewater and remaining 34 % subsurface inflow. The subsurface inflow occurs during monsoon season only and then declines since September. Every year a huge amount of water flows out of the lake by spilling over the Mogha weir. Table 1 shows that the major outflow from the lake is weir overflow which accounts about 85 % of the total annual outflow, evaporation accounts for 6.9 %, siphoning accounts for 0.12 % and remaining 8 % is attributed to the subsurface outflow.

WATER QUALITY ANALYSIS

Materials and Methodology

The physico-chemical properties of Sagar lake are evaluated, which provides the first hand information about its water quality. These properties include pH, conductance, temperature, dissolved oxygen (DO), BOD, TDS, transparency, alkalinity, hardness, chloride, sulphate, nitrate, etc. The water quality of the Sagar lake is monitored by collecting the water samples from 21 locations at three different depths viz. 0.25, 1.5 and 3.0 m from March 2006 to May 2008. The sampling sites are selected in a grid pattern keeping in view the path of water flow in the lake from inflow channels to the outflow point. Various water quality tests were conducted in the field as well as in the laboratory to determine the physico-chemical properties of the lake using the standard methods (APHA, 1985; Jain and Bhatia, 1988). The physical parameters, viz. transparency, temperature and chemical parameters such as pH and dissolved oxygen (DO) were determined in the field at the time of sample collection using portable water testing kit. Chloride concentration was determined by argentometric method in the form of silver chloride. Alkalinity and total hardness were determined by the titrimetric method with the aid of phenolphthalein and methyl orange indicators. Phosphate, nitrate, iron and fluoride concentrations were determined using UV-VIS Spectrophotometer. The presence of fecal coliform bacteria was determined by the qualitative analysis. The transparency of lake water was determined using the Seechi Disc.

WATER QUALITY OF THE SAGAR LAKE

The average physico-chemical properties of the water samples collected from different locations of the lake and inflow channels for period from March 2006 to May 2008 are presented in Table 2. From the analysis of data it is observed that the temperature of lake water varies from 17.5 °C and 31.0 °C with an average of 23.9 °C. The transparency of the lake water varies from 0.10 to 0.73 m in terms of Secchi depth with an average of

Table 2 : Water quality results of the Sagar lake

Sl. No.	Parameter	Unit	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	Fecal Coliform	-	Present
13	BOD	mg/L	11.4

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 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.

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. 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 high due to sewage and organic waste inflow as well as the leaching of fertilizers from the agricultural fields surrounding the small 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. 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.

Point sources of pollution

The water samples of six inflowing nallas were collected and tested in the laboratory. Water quality results of the inflow channels of the lake are shown in Table 3. These nallas are the main pollution sources to the lake which directly discharge waste water into the lake. 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). Furthermore, all the nalahs are the pollution sources of fecal coliform bacteria.

MANAGEMENT PLAN FOR RESTORATION OF SAGAR LAKE

The systematic study on water balance, water quality and factors threatening the lake has been carried out for suggestion of protection measures and preparation of management plan for the restoration of Sagar lake. The measures suggested under management plan and their background are discussed in detail as below.

Table 3 : Water quality results of the inflow channels of the lake

Sl. No.	Parameter	Unit	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

City Wastewater Diversion, Laying Sewer Line and Treatment Plant

Total annual inflow of water into the lake is around 20.146 MCM through six major drains and one canal. Out of total annual inflow, 58% water comes into the lake through various inflow channels including monsoon flow and city wastewater. The city wastewater, which is directly discharging various pollutants into the lake, contributes 2% of the total annual inflow. This is one of the major causes for deterioration of water quality of the lake. Therefore, all the surrounding nallas, which directly discharge wastewater into the lake, either need to be diverted in order to limit the nitrate, phosphate, chloride, iron, etc, or properly treated before entering into the lake. The houses at the southern and western shores of lake are very close to the lake, hence sewer line surrounding the lake is to be laid and territory sewage treatment plants need to be established.

Lake Aeration

The average DO level of lake water is 4.4mg/L which is significantly low. The lake is heavily infested with algae, which hinders sunlight penetration to deep waters. Oxygen is produced and absorbed at the surface and the bottom area of the lake runs out of oxygen. Without bottom oxygen, the self-purification abilities of the lake are reversed. In absence of desired level of DO, the nutrients that are normally bound to the sediments are released into water and deteriorate the water quality and become threat to aquatic life. There is an urgent need to facilitate the lake with aeration facilities like fountain; boating activity, etc which increase the DO level of the water. In the hypolimnetic zone, water is raised to the surface, aerated and returned to the lower layers. The aeration keeps the aerobic bacteria active by assuring them a constant supply of oxygen, which helps in breakdown of organic matter and reduces algal densities. The aeration will help to reduce BOD and COD, sedimentation rate (muck accumulation), improve water clarity, improve fishery and reduce algae growth.

Minimizing Nutrient Input

An intensive washing activity is in practice on all surrounding ghats of Sagar lake. The nutrient level of the lake is very high, it contains an average of 9.8 mg/L nitrate, 0.44 mg/L phosphate, minor nutrients such as sulfur and micronutrients such as iron, manganese, magnesium, zinc, molybdenum, cobalt, etc. The Sagar lake has high algae content and the production of toxic blue green algae (Cyanobacteria) is also increased. The primary need to control algae and weed is to minimize the nitrate and phosphate input in to the lake. Aluminum sulfate (alum) treatment can be effectively used to inactivate phosphorus present in the lake sediment to control algal growth. Alum treatment in shallow lakes for phosphorus inactivation may last for eight or more years whereas in deeper lakes, it may last for longer period. It is an established practice to maintain the water pH between 6 and 7.5 during treatment.

Dredging

Over the period of time the depth of lake is greatly reduced. The average depth of lake is less than 2.40 m whereas its original depth is reported as 18 m. The rate of sedimentation in the lake is 0.58±0.028 cm/year (Singh & Thakural, 2004). During summer, as the water level of the lake recedes, the sediment deposited in the bottom of lake emits very foul smell. To protect the biodiversity of Sagar lake the dredging is required in the lake. The lake needs hydraulic dredging inside the lake and dry dredging around the lake periphery during summer season when the water level completely recedes to its bottom level. This aspect will help in removing nutrient-rich sediments, toxic substances, rooted aquatic plants, lessen sediment re-suspension and improve fish habitat. The dredging plan should include the excavation, removal and proper disposal of contaminated sediment.

Sluice Gate Operation and Construction of Silt Traps

In the monsoon, as the water level of lake reaches to maximum level of 526.479 above msl, the lake starts overflowing at the Mogha weir. Due to the weir arrangement for overflow, water is not getting refreshed, which allows the pollutants to settle into the lake as the velocity of inflow water reduces greatly. This problem can be tackled by construction and operation of sluice gates at the outlet of lake to refresh the water in bottom layer by deepwater discharge. This will result in removal of nutrient rich waters from hypolimnion. Silt traps can be constructed on the inflow channels which bring sufficient silt and sediment in to the lake. These traps could be an enlargement of the drain or water course at a suitable point or location, which allow the water to flow through the channel at low velocity and allow the sediments to settle out in the trap.

Cattle Entry Control

Presently there is no control over the entry of cattle into the lake. Daily around 200 to 300 buffalos and other animals take bath in the lake and pass on their urine and excreta in the lake. This has become the main cause of pollution due to the fecal coliform as it resides in the intestine of these animals. Hence the entry of cattle into the lake can be restricted by fencing on entire boundary of the lake. The lake also contains Cyanobacteria, which is very harmful to human beings. These bacteria leave a poisonous compound named micosystien, which remains floating on the surface water in green colour. Due to these bacteria, many species of fish have disappeared. In the year 1972, there were 30 species of fish in the lake which are now reduced to 5 to 7 species in the year 2008. Coliform bacteria are naturally killed by ultraviolet rays, emitted by the sun. Measures to be adopted to weaken and kill the coliform bacteria are the oxygenating the water body, creating an environment where aerobic bacteria thrive, reducing the nutrient media, raising the pH and exposing pathogenic bacteria to sunlight.

Fencing of Shoreline

The south-western shoreline of the main lake is around 1000 m and not guarded, it needs to be fenced to restrict the lake encroachment by surrounding habitants. The southern and western shores of small lake are adjacent to the agricultural fields having around 1000 m length and are also are not guarded. During monsoon, the small lake receives sediment, pesticides and fertilizers from these lands. The shores of the lake need to be protected form all sides to avoid the encroachment of the lake area and to reduce agricultural pollution and sedimentation. A road needs to be constructed around the lake at its periphery and should be beautified and recreational activities should be taken up. There is need to develop a hotspot for eco-tourism. As per International Conservation Guideline, 10-30 m strip of land along the lake shoreline and next 90 m strip is recommended for buffer zone and controlled development zone respectively with horticultural and agro-forestry activities (IUCN, 1995).

Catchment Treatment

Various activities in the catchment are always threats to the lake, which includes excessive use of pesticides and fertilizers for maximizing the agricultural production, faulty septic systems, improper waste disposal and accelerated soil erosion. The treatment practices in the lake catchment should include the following measures:

- Maintaining septic systems.
- Managing waterfowl.
- Developing good landscape practices adjacent to lake.
- Controlling runoff and soil erosion.
- Reducing or eliminating fertilizer and pesticide use.
- Properly disposing of pet wastes.
- Washing of vehicles away from the lake and drains.

AQUATIC PLANT CONTROL AND VEGETATION RESTORATION

Although many aquatic plants are essential for the restoration efforts but some plants could be nuisances and causes threat to the lake. The nuisance plants may be controlled either by occasionally draining the lake or by mechanical harvesting. Useful plants are capable of removing pollutants through a variety of physical, chemical and biological processes. In addition, aquatic vegetation near the shoreline provides valuable fish and wildlife habitat. The restoration of vegetation back into the lake, primarily near the shore area (known as the littoral zone) is accomplished by physically planting the selected vegetation.

Fish Removal, Restocking and Wildlife Habitat Enhancement

If the lake is subjected to any form of sediment removal or dredging, then a primary goal is to remove the contaminated fish after sediment remediation. The final phase of the restoration is to restock native fish in the lake and restore the vegetation. This is done through a combination of planting appropriate areas with a variety of plant beneficial to fish and construction of deeper water holes and areas containing rocks to create a diversity of habitats. Many of the plant species selected for the restoration; enhances the wildlife in the area. In addition, wildlife is enhanced by landscaping wildlife-attractive trees and shrubs.

Institutional Capabilities

Institutional inefficiency in terms of inadequate cooperation and coordination among stakeholders hinders the efforts of sustainable management of the lake. There is strong need of a specific authority responsible for the conservation and management of the lake.

Public Awareness

Presently, the people around the lake are not aware about the importance of the lake. They are unaware of the necessity to upkeep the lake and use it like a dustbin.

There is strong need to create awareness amongst public about the lake conservation by means of education, cultural activities, recreational activities, social and legal law enforcement.

CONCLUSIONS

The water balance study of Sagar lake evaluates the inflow and outflow components of the lake. The major inflow to the lake is catchment runoff, which accounts for nearly 56% of the total annual inflow. The major outflow component from the lake is weir overflow, which occurs in monsoon season only and accounts for about 85% of the total annual outflow. Out of the total annual outflow, about 92% outflow takes place during the monsoon period only. Since there is heavy inflow to the lake even with normal rainfall, there is no scarcity of water to fill the lake.

The physico-chemical analysis indicates poor water quality of Sagar lake. The lake water is greenish in colour with low transparency due to high density of algae and plankton. The pH value is towards the lower borderline. The low level of dissolved oxygen in the lake is due to high algal and microbacterial activities. The hardness of water is found to increase from surface to bottom. The high level of nitrate and phosphate in the lake is due to sewage inflow, agricultural runoff and detergents. The high level of BOD indicates high organic input in the lake. The TDS of lake water is within the permissible range. The harmful coliform bacteria are present in the lake. The six inflowing nallas discharging city waste water directly in to lake are the main sources of pollution.

The measures suggested in the management plan needs to be implemented for restoration of Sagar lake. All the surrounding nallas adding pollutants to the lake are need to be diverted, sewer line is to be laid around the lake periphery and sewage treatment plants needs to be established. There is an urgent need to facilitate the lake with aeration facilities like fountain, boating activity, etc which will increase the DO level of the water. The algae and weed growth is to be controlled to minimize the nitrate and phosphate input in to the lake. Dredging can be undertaken in the lake to remove the deposited sediment. Construction and operation of sluice gates at the outlet of lake will help to refresh the water in bottom layer of lake by deepwater discharge. The entry of buffalos and other animals should be restricted in the lake as they add fecal coliform in the lake. The coliform bacteria can be weakened and killed by oxygenating the water body. A fencing and road needs to be constructed around the lake to avoid the encroachment of the lake area. A hotspot for eco-tourism is to be developed. The healthy management practices like maintaining septic systems, developing good landscape adjacent to lake, controlling soil erosion and reducing fertilizer and pesticide use are to be adopted in the lake catchment. The growth of nuisance plants needs to be controlled. All fish are to be eradicated and the sources of the contaminants are to be removed before dredging. The final task of the restoration is to restock native fish in the lake by developing variety of plants beneficial to fish, construction of deeper water holes and creating diversity of habitat. Other important aspects are the development of institutional capabilities and building awareness about the lake conservation by means of education, cultural activities, recreational activities, social and legal law enforcement.

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