IMPORTANCE OF FIRST FLUSH IN RESTORATION OF LAKE WATER QUALITY: A CASE STUDY OF MANSAGAR LAKE

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ABSTRACT *Water quality in lakes is significantly affected by stormwater. After first rains, the lake water quality deteriorates due to washing up of municipal waste from the catchment area. In our country, the management of municipal waste is not very efficient and the initial stormwater generated during rains has a high concentration of organics besides other suspended solids thus having a huge potential for the deterioration of water quality of the lake receiving it. The present paper discusses the negative impact of first flush on lake water quality with a case study of Mansagar Lake, Jaipur, where exceptionally high values of BOD were found in the flushes after the first few rainfall events. The deterioration of the lake water quality immediately after the first rains in terms of biological quality has been monitored for 5 years and the effects have been reported, which may be applicable to most of the lake catchments in India.*

Key words: Stormwater, First flush, BOD, COD, Nitrogen, Catchments.

INTRODUCTION

Lakes provide humankind with many services: aesthetic enjoyment, recreation, fish, transportation, water for irrigation, drinking, and dilution of pollutants. These services are impaired by exploitation of lakes and the lands of their catchments. The goal of management is to balance the uses of lakes with conservation measures to sustain ecosystem services over time (Carpenter & Lathrop, 1999). Lakes, both natural and man-made suffer from urban, industrial, agricultural and other impacts. As a result, many aquatic ecosystems have become severely degraded and need to be restored. In many countries, large sum of money is now being spent to restore such lakes (Allan 1997).

Anthropogenic pressures on lakes have increased rapidly in recent decades. Major changes have occurred in the land use in the catchments of lakes where natural vegetation is cleared, and agricultural, urban and industrial activities are intensified. The anthropogenic activities (deforestation, agriculture, urban settlements and industries) have accelerated the aging process as increased amount of sediments, nutrients and toxic substances enter the lakes with the runoff (MoEF, 2010).

Most of the lakes in India, both natural and man-made, are in different states of degradation. The most important and common form of lake degradation is that of deterioration of water quality due to organic pollution from disposal of domestic wastewater and other solid wastes. Eutrophication, i.e., enrichment with nutrients, is another major and most widespread problem in almost all lakes. Enrichment occurs due to nutrients entering with the runoff from catchments. Stormwater runoff from urbanized catchments brings a variety of toxic substances besides nutrients and particulate matter. Siltation due to high sediment load in the runoff caused by erosion is also a serious problem in all reservoirs and lakes (MoEF, 2010).

Stormwater runoff, one of the most common forms of nonpoint source (NPS) pollution, has been identified as a potential threat to human and ecosystem health due to the high levels of chemical and biological contaminants it contains that have been directly linked to disease outbreaks , toxic effects in aquatic life, and dramatic negative impacts on water quality. As precipitation washes over land, it picks up and transports a variety of chemicals, pesticides, metals, petroleum products, sediment, and human and animal faecal wastes (Parker et al., 2010). The pollutant impact and 'shock load' associated with stormwater runoff can be significantly higher than secondary treated domestic sewage effluent (House et al., 1993; Novotny et al., 1985). The quality of the stormwater and the characteristics (physical, chemical or microbial) of the pollutants present are dependent on the types of surfaces the stormwater encounters (roads, parking lots, roofing material, recreational areas etc.).

The completion of wastewater treatment plants mandated by the Clean Water Act has reduced pollution from point sources to the waters of the United States. As a result, non-point source pollution such as stormwater runoff is now the major contributor to pollution of receiving waters. The problem of stormwater pollution is growing worse because of continuing development, which results in increased impervious surface area (Lee et al., 2007). Proper measures for stormwater treatment are required particularly in developing countries like India because of lack of proper MSW management that results in bringing lot of organic matter with it.

In recent years, many government and community organizations have placed increasing emphasis on developing and implementing strategies to reduce urban stormwater pollution. Design and implementation of stormwater treatment strategies often involve a substantial investment in the construction of stormwater treatment measures. Several stormwater treatment measures are used (e.g., ponds, wetlands, swales, infiltration systems), depending on the nature of the stormwater pollutants being targeted, and on scale and available space. In many cases, a sequence (often called a "treatment train") of measures may be used. For example, linear infiltration or bio-filtration systems may be placed within the urban streetscape, and may convey water to a sedimentation basin and constructed wetland, before discharging to an ornamental pond (Wong et al., 2006). The management of quantity impacts of stormwater runoff is relatively straight forward. The common approach is the provision of various physical measures such as detention/retention basins, wetlands

or features such as porous pavements to retain part of the runoff volume and/or attenuate the runoff hydrograph.

The 'first flush' concept is another issue which is questionable in relation to urban water quality management strategies currently adopted. The 'first flush' relates to the initial portion of the runoff being more polluted than the remainder due to the washout of deposited pollutants by rainfall. As reported by numerous researchers, the first flush has been noted as an important and distinctive phenomenon within pollutant wash-off. It produces higher pollutant concentrations early in the runoff event and a concentration peak preceding the peak flow (Deletic, 1998). Goonetilleke et al. (2005) undertook an in-depth investigation of pollutant wash-off by analysing the hydrological and water quality data from three primary catchments and three sub-catchments based in Gold Coast, in the Southeast region of Queensland State, Australia. The results showed high levels of TOC ranging from 11.0-189.8 mg/L in stormwater obtained from six different catchments.

The aim of the present study is to assess the effect of first flush on water quality of Mansagar Lake, Jaipur that observed a mass killing of fish in 2010 due to excessive ingress of organics with initial storms resulting in significant reduction in DO of the lake. The data pertaining to chemical characteristics of the lake from 2007 onwards have been compiled for both pre- and post- monsoon periods to exemplify the importance of management of first flush in water quality management of the lake.

MATERIALS AND METHODS

Study Area

Mansagar Lake, located North of Jaipur was constructed by damming Darbhawati River around 1610 A.D. by Raja Man Singh I, the then ruler of Amer, for irrigation and recreation. In 1962, the sewage from the walled city of Jaipur was diverted into the lake. It resulted in rapid siltation, the water storage capacity decreased considerably and the palace got submerged to a depth of 3 m or more during the rainy season. The most notorious aquatic weed water-hyacinth (*Eichhornia crassipes)* entered the lake in 1975. It suppressed algal growth and disturbed the trophic structure of lake. In August 1981, unprecedented rain caused heavy floods that brought enormous amounts of silt and sand from the south eastern side filling up large area of the lake. It was depressing to see mass carnage of fish at Jal Mahal on 22 July 2010.

Mansagar Lake (popularly known as Jalmahal) is located between 26° 56' 45'' N latitude and 75° 51' 45'' E longitude. It is approximately 130 hectares in its full spread and has a catchment area of 23.5 square kilometres of maximum depth 5.5 meters having water holding capacity of 54.12 × 104 cubic meters. Approx. 40 % of the catchment falls inside dense urban area and the remaining area is covered by denuded hills. (Sharma et al., 2007; Raina, 2008).

The lake receives runoff from the flanked hills and walled city of Jaipur. In addition it used to receive treated/bye-passed wastewater from the sewage treatment plant (STP) as well as untreated wastewater from Brahmpuri and Nagtalai Nallas. Runoff from agricultural fields and discharges from Air Force colony, Parashuramdwara area, Kanak Vrindavan area, housing colonies around the lake and textile industrial wastes from small scale Dyeing & Printing industries located in the Brahmpuri area were all received into the lake. The major inflows contributing to the lake water were Brahmpuri Nalla and Nagtalai Nalla. Brahmpuri Nalla used to give the maximum discharge. The lake conservation plan for the Mansagar Lake under the NLCP, stressed upon the diversion and treatment of wastewater, desiltation, bioremedition and catchment treatment. Since 2006 only 7 MLD out of the total of 27 MLD received from the STP has been allowed to enter the lake after tertiary treatment and the rest is bypassed over the weir.

Secondary Data

Various works have been done on Mansagar lake water quality. A research study was published by Dr. K. P. Sharma from Botany department Rajasthan University, and students of MNIT Jaipur have also worked on lake water quality during their project works. Data from Jal Mahal Resort Pvt. Limited, who have undertaken the task for restoration of lake water quality, have also been obtained. Published data from these papers and reports have been compiled and analyzed.

Primary Data

Data were collected by monitoring the water quality parameters of Mansagar Lake between the months of June to October 2011.The quality of water of Mansagar Lake was analyzed pre monsoon and post monsoon to find out the effect of first flush on the lake water quality. Samples were collected through grab sampling from five different points shown in figure1 from 1 m depth; four samples were collected from shore side and fifth sample was taken from middle of the lake with the help of boat. Samples were collected in autoclaved 1 L sample bottles.

The samples were subjected to physicochemical analysis following the procedures prescribed by APHA (1989). Parameters like pH, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), phosphate and Nitrogen were analyzed.

RESULT AND DISCUSSION

Table, 1 shows the values of various parameters of water quality in Brahmpuri and Nagtalai Nallas that carry water into the lake. Brahmpuri Nalla has less variation in BOD and COD values due to the fact that it carries treated wastewater

from STP, Jaipur (North) mixed with some stormwater. Nagtalai Nalla, on the other hand, carries only stormwater from outer areas of the city which brings lots of organic solids and leachate from open solid waste dumping sites in nearby area. Discharge of untreated wastewater from drains which open in Nagtalai Nalla contributes significantly to organic pollution as these are used for open defecation. After 2006, improvement in the water quality of Nallas can be observed due to upstream measures taken to prevent some raw sewage entering the drain by strengthening the sewerage system. After observing high organic content of the first flush, it was decided to divert this flush from 2007 onwards through a bypass over the weir without allowing it to enter the lake. This resulted in preventing lot of organics from entering the lake.

Slight variation in TSS of Brahmpuri Nalla was observed but the variations in Nagtalai Nalla were large because it carries suspended material deposited in Nalla or nearby area which is brought by storm water or from solid waste dumping sites. Both the Nallas bring high amount of TSS to the lake. The DO level of storm water carried by both Brahmpuri and Nagtalai Nallas was close to zero, whenever measured. The reason was the presence of lot of organic matter in the storm water exerting high oxygen demand. This type of storm water decreases the overall DO level of the lake making it unfit for aquatic life. Since in the years 2007-2009 the first flush was bypassed, the effect of it on lake water quality and hence the aquatic life was tolerable, however, fish in large numbers were killed in the Mansagar Lake in 2010 monsoons, when the first flush was again permitted to enter the lake due to protests from the villagers living downstream as it was resulting in spread of bad odours. DO levels of the lake measured at different points 1 to 5 shown in figure 1

Fig. 1 Sampling Points in the lake (Source: Google Earth (5/8/11, 12:46:17 PM)

were 0.8, 0.3, 0.6, 0.5 and 2.5 mg/l respectively, as high oxygen demand was exerted due to storm water inflow (Shiv kumar, 2010). In 2011, it was again decided to bypass the first flush through discharge weir without entry to the lake.

Under NLCP, Jalmahal Resort Pvt. Ltd. has constructed a stormwater management system within the lake bed in May 2007. A settling tank was constructed for the management of stormwater pollution having an area of $3x10^4$ m^2 and depth of 7m. Thus, having a total capacity of 0.21 million cubic metres (MCM) which is a small fraction of the total capacity of lake, which is about 3.13 MCM (Raina, 2008). Settling tank is followed by submerged wetlands. Stormwater has to first fill the settling tank before entering the lake but due to high stormwater inflows, the retention time available is very low making it partially effective. It was decided that the settled solids will be quickly dredged out after the first few rains, however, due to some operational problems this could not be achieved and hence the benefit of prevention of silt could be obtained but that of organic solids was not effective. After 2006, due to diversion of treated sewage from STP and also the first flush, values of BOD, COD, and TKN decreased in the lake after initial rain events. Table, 2 summarizes the main water quality parameters of Mansagar Lake before and after first flush to see the effect of stormwater on water quality parameters. BOD is increasing after first flush in the lake due to washing of municipal waste from the catchment area into the lake. The first flush imposed significant effect on lake water quality. D.O of lake water is also decreasing after first flush. TSS is decreasing after first flush due to settling of particles in the settling tank. It can also be seen that BOD values have considerably reduced after 2005. In 2006 lake water quality was monitored comprehensively for the first time. After 2006, sewage was diverted downstream and other measures were taken like upgrading of STP and construction of settling tanks and diversion of first flush which brought about positive changes in lake water quality over this period. D.O levels in the lake increased in 2009 as compared to 2008 substantially both before rains and after the first few rain events. On comparing B.O.D values of the lake before first flush from 2006 to 2009, it can be clearly seen that B.O.D values have reduced with time indicating consistent improvement in water quality of lake. This has also led to fish proliferating in the lake. The fish need a minimum of 4 ppm dissolved oxygen (DO) in water to survive.

A very high flow during July 2010 broke down the wall of settling tank and some settled material in settling tank also entered the lake along with polluted stormwater. The organic material exerted high oxygen demand and resulted in depletion of oxygen in the lake which caused mass scale fish kill in the lake and produced foul smell due to polluted water and degradation of the fish. The BOD in lake water increased substantially and D.O in lake decreased to near zero levels at all locations. Learning lessons for this episode, the height of the settling tank has been increased by 3 feet; the first flush was again diverted from the lake and STP upgrading measures were further intensified. The wetlands developed for tertiary treatment of 7 MLD sewage, which has been allowed to enter the lake, have now been fully operational and the year 2011 has shown a vast improvement in both pre monsoon and post rain scenarios as exemplified in Table 2. This shows that the lake has good recuperation capacity. The results also indicate that importance of the quality of first flush cannot be ignored in any lake restoration project and any such

projects should be duly integrated with the municipal solid waste management system as well as provisions for reducing open defecation in the catchment to bring down the contribution of first flush to the ingress of organics to the lake.

Table 1: Summary statistics of main water quality parameter in Brahmpuri and Nagtalai Nalla Source: - Jal Mahal resorts pvt. Ltd data*, Primary data**

	2006 * Brahmpuri nalla(19/6)	2006 * Nagtalai nalla(19/6)	2007 * Brahmpuri nalla (5/7)	2007 * Nagtalai nalla(5/7)	2010 * Brahmpuri nalla(22/7)	2010 * Nagtalai nalla(22/7)	2011 ** Brahmpuri nalla(23/6)	2011** Nagtalai nalla(23/6)
pH	6.6	6.8	6.9	7	7.5	8.7	7.9	8.3
BOD (mg/l)	937	830	340	523	280	190	120	240
COD (mg/l)	2224	1984	596	832	590	490	418	798
TSS (mg/l)	3080	2352	220	280	1570	2606	68	80
Phosphorous (as PO_4) (mg/l)	26	14	19	35	NA	NA	3.08	4.71
TKN (mg/l)	59	70	41	41	NA	NA	20	28
Nitrate (as NO_3) (mg/l)	120	62	31	44	NA	NA	NA	NA

Table 2: Summary statistics of main water quality parameter in Mansagar Lake before and after flush (Source :- Jal Mahal resorts pvt. Ltd data *; Manju Raina, 2008**, Primary data***)

	2005* (15/8/05)	2006** Before 1st flush	2006** After 1st flush	2008** Before 1st flush	2008** After 1st flush	2009** Before 1st flush	2009** After 1st flush	2011 *** Before 1st flush	2011*** After 1st flush
pH	5.2	7.6	7.5	8	7.1	9.64	9.11	8.58 ± 0.08	8.47 ± 0.05
BOD (mg/l)	210	43	67.33	28	55	24.3	60	8.6 ± 1.07	11.6 ± 1.24
COD (mg/l)	228	196	131.67	128	146	395.5	214	85.24±4.85	78.38±5.66
DO (mg/l)	2.8	NA	NA	1.7	0.7	12.65	7.57	6.2 ± 0.32	5.2 ± 0.53
TSS (mg/l)	NA	43	40.67	52	46	615	122	35 ± 1.6	46.54±5.06
Phosphorous (PO_4) (mg/l)	NA	16	20	10	2.1	0.3	1.29	0.53 ± 0.04	0.81 ± 0.05
TKN (mg/l)	NA	27	NA	NA	NA	1.92	3.92	26.1 ± 4.2	43.18±1.20
Nitrate (NO_3) (mg/l)	NA	12	33.67	12	13	46.09	28.56	NA	NA

CONCLUSION

The Mansagar lake water quality shows high pollution levels after first few rains, signifying the importance of stormwater as one of the major sources of organic ingress to the lake. Stormwater of high BOD, COD, TSS and low DO enters the lake through Brahmpuri and Nagtalai Nallas disturbing its ecosystem and creating problems for the aquatic life. Lake restoration measures like diversion of first flush, diversion of sewage from STP and provision of settling tank for stormwater have resulted in significant improvement of lake water quality and the role of first flush in deterioration of water quality has been exemplified quantitatively. Municipal solid waste management should be integral to any lake restoration program for controlling the quality of the first flush.

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