Impact of sewage treatment plant effluent on water quality of Dal Lake, Kashmir, India

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Abstract

Present paper attempts to study and discuss the impacts of sewage treatment plant effluent on water quality of a typical urban Dal Lake situated in Jammu & Kashmir. Using Correlation analysis and Principal component analysis changes in water quality were analysed. The result showed that Fluidised Aerobic Bed reactor (FAB) based STP was malfunctioning and resulted in increasing the concentration of electrical conductivity, ortho-phosphate, nitrate-nitrogen and nitrate-nitrogen at influx of sewage into the lake. This has resulted in bifurcating the lake into two distinct zones, one being polluted and other being unpolluted. The main reason being the release of partially treated effluents directly into the lake.

Keywords: FAB STP, Sewage, Dal Lake, PCA, Water quality

Introduction

Dal Lake is known as “liquid heart” of Srinagar, the summer capital of Jammu and Kashmir. It is located between geographical co-ordinates of 34°07’N and 74°52’E at an altitude of about 1584m above mean sea level. It is a multi-basin freshwater post glacial lake comprising of five basins viz.; Hazratbal, Nishat, Nehrupark, Nigeen and Brarinambal. Each basin maintains its individual character and vary in their morphometry, water quality and biodiversity (Abubakr and Kundangar, 2005) [1]. The morphometric data of each basin of Dal Lake is presented in Table 1.

Dal lake has a huge catchment area, according to estimates of AHEC (2000) [10], lake catchment area is spread over to 337.17 sq. kms of which the largest segment is Telbal-Dachigam with 234.17 sq. kms (69%), followed by Hill side 14 sq. kms, Srinagar city (North & Central) 14.5 sq. kms and the lake 18.5 sq. kms. The catchment area under different land use is given in Table 2.

Telbal Nallah is the main inflow channel to the Dal Lake which drains mostly through Harwan, Burzukot and Mahadev range. Moreover, 10-12 small channels discharge their water into Dal Lake. Approximately 292x10^6 m^3 of total inflow to the lake, 80% is supplied by the Telbal Nallah. Two perennial outflow channels, one known as Dalgate exit and other Nallah Amir Khan drain the water out of the lake (Kundangar and Abubakr, 2001) [18]. Dal lake ecosystem is under tremendous anthropogenic pressure since more than four decades now, with people still living within the lake in hamlets, houseboats and doonga boats. As per recent estimate of 2020, about 4792 families are living in 60 hamlets in Dal interiors. The myriad ways in which people use the lake, along with numerous pollutant generating activities have stressed the lake ecosystem in diverse ways. These stresses have caused significant impairment to lake quality.

Based on the importance of Dal Lake, a number of restoration plans by National and International agencies were implemented from time to time to date. Lately and finally, Ministry of Environment and Forests (MoEF) (now Ministry of Environment, Forest and Climate Change i.e., MoEFCC), Government of India, decided to invite Alternate Hydro Energy Centre (AHEC), University of Roorkee (now IIT, Roorkee), to prepare a Detailed Project Report (DPR) on Dal lake, Srinagar. The final project report, submitted to the Govt. in December 2000, was finally accepted in 2005 and Govt. started implementation of various recommendations. Among the number of recommendation, one recommendation was treatment of sewage entering into Dal Lake using Fluidised Aerobic Bed reactor (FAB) technology.
Kundangar (2003) [17], while monitoring the FAB based STP at one of the hotels in the immediate vicinity of Dal Lake, had cautioned about the adoption of this technology for Dal Lake sewage treatment. However, ignoring scientific acumen, Govt. installed three FAB based STP at Hazratbal, Habak and Laam area around Dal Lake for treatment of sewage entering into the lake. Adnan and Kundangar (2008) [5] and Adnan and Kundangar (2009) [6], while studying Dal lake ecology and its environment have reported through their research on the functioning of FAB based STP’s, that these treatment plants are malfunctioning and according to authors, this situation will not only exacerbate the problem of pollution of Dal Lake but shall have catastrophic consequence, as the non- point sources of pollution are being made the point sources of pollution. A report on Dal Lake published by the Comptroller and Auditor General of India (2012) [2], also contained observation that the working of STP installed at Hazratbal, Habak and Laam are highly inefficient.

Table 1: Morphometric characteristics of Dal Lake of each basin

| Parameters               | Units | Hazratbal | Nishat | Nehru park | Nigeen |
|--------------------------|-------|-----------|--------|------------|--------|
| Max. water depth         | m     | 3.0       | 2.8    | 2.5        | 5.7    |
| Mean water depth         | m     | 0.76      | 0.86   | 0.70       | 1.37   |
| Open water area          | Sq. m | 4.50      | 5.70   | 1.3        | 0.89   |
| Volume of water x 10^6   | m^3   | 2.76      | 4.92   | 0.93       | 1.22   |

Source: Abubakr & Kundangar, 2009) [6]

Table 2: Different land use in Dal Lake

| S. No. | Land use class       | Area (sq. km) | Percentage (%) |
|--------|----------------------|---------------|----------------|
| 1.     | Bare grounds         | 160.97        | 47.74          |
| 2.     | Dense forests        | 52.02         | 15.42          |
| 3.     | Built-up/ unclassified | 45.44       | 13.47          |
| 4.     | Open forest          | 34.15         | 10.12          |
| 5.     | Lakes/ shadows       | 33.35         | 9.93           |
| 6.     | Snow                 | 9.25          | 2.74           |
| 7.     | Degraded forest      | 1.85          | 0.54           |
| 8.     | Total                | 337.17        |                |

Source: Zutshi and Yousuf, 2014 [27]

Material and Methods

Study Area
Dal Lake, a typical example of an urban multi-utility lake, receives large quantities of untreated sewage from the point and non point sources. In order to arrest the point source of pollution, three STP’s were installed at Hazratbal, Habak, and Laam areas with sewage treatment capacity of 7.5 MLD, 3.5 MLD and 4.5 MLD respectively. These 3 STP’s are treating the wastewater on FAB technology and after treatment the waste water is being discharged directly into Dal Lake (Fig1.)

In order to investigate the impact of treated sewage on water quality of Dal Lake, three sampling points were selected within the lake where STP’s discharge treated sewage, viz., site 1(a) at Hazratbal, site 2 (a) at Laam and site 3 (a) at Habak. For each sampling point, a complementary site [site 1 (b); site 2(b) and site 3(b)], 500m away was selected which hardly affected by the influx of sewage discharged by STP’s. Sites S1(a), S2(a) and S3(a) were hypothesized as polluted sites, while sites S1(b), S2(b) and S3(b) were hypothesized as unpolluted sites for the present work.

The water quality was monitored at all the six designated sites monthly from October 2018 to March 2019 covering autumn and winter seasons. The water samples were collected at a depth of 0.1m -0.3m below the water surface by hand in the polyethylene bottles. Air temperature (AT), Water temperature (WT), dissolved oxygen (D.O), depth, water transparency (SDT) were measured on site, whereas, electrical conductivity (EC), pH, orthophosphate (PO4-P), total phosphorus (T.P), chloride (Cl), ammonia (NH4-N), nitrate-nitrogen (NO3-N), nitrite-nitrogen (NO2-N) and silicate (Si) were determined in laboratory, using standard methods as described in A.P.H.A (2012) [12] and Adoni et al. (1985) [9].

A series of statistical method, including Correlation analysis (CA) and Principal Component Analysis (PCA) was employed to study and discuss the impact of STP effluents on water quality of Dal Lake. Statistical Analysis was performed for data generated using software programmes of SPSS (version 20.0) and PAST software. PCA was applied to determine the difference between sites as polluted and unpolluted.
unpolluted and to explain the water quality variations with transformed data. For PCA, the transformed data for polluted sites were clubbed as a zone called polluted zone and the same was done for the unpolluted sites called unpolluted zone. Eigenvalue >1 was used as the criterion to determine the appropriate number of Principal Components (Ouyang et al., 2006) [22].

Results & Discussion

Analysis of water quality

The values of the assessed water quality parameters of Dal Lake are shown in Table 3. PCA analysis was used to determine and identify the important water quality parameters responsible for influencing water quality of Dal Lake. In the present study all the samples of polluted sites were clustered together irrespective of seasons and same was done for unpolluted sites. A scree plot for the eigenvalues obtained in this study showed a marked change of slope after the fifth eigenvalue, for both polluted and unpolluted sites (fig. 2 and 3).

Eigenvalues for polluted zone are displayed in Table (4). The five PCs together accounted for about 80.19% of the total variances and the rest of the 9 components only accounted for about 19.80%. The largest source of variation 29.45% in PC1 showed a strong positive loading of PO4-P and EC, moderate positive loading of NO2-N, NO3-N, T.P, Si and positive weak loading by WT, Cl- and NH4-N and negative moderate loading of D.O. and pH. Positive loading of PO4-P, EC, NO3-N, NO2-N, T.P and Si clearly indicate that all these three sites, where STP discharge treated effluents directly show higher concentration of nutrients. The concentration of nutrients, especially nitrogen increased significantly at sites with influx of STP effluents, indicating that STP effluent was the main source of NO3-N and NO2-N in Dal lake, and is responsible for changing its water chemistry rendering these sites as polluted / highly eutrophic. Similar results were reported by Vega et al. (1998) [25] and Al-Barzingly et al. (2010) [13] and they reported high levels of phosphate and organic matter may originate from municipal wastewaters discharges since it is an important component of detergents.

The second component of polluted zone PC2 with 22.11% variance explained a moderate positive loading of D.O, depth, SDT and Cl- and positive weak loading of PO4-P and Si and moderate negative loading is explained by WT and weak negative loading by NH4-N. Jin et al. (2017) [16] also observed significant difference in D.O. after the influx of STP effluent indicating strong impact of STP effluent on receiving ecosystem. Abubakr et al. (2018) [18] have related low D.O state with high organic matter and sewage which consumes oxygen for decomposition in different lakes in Kashmir. The positive D.O. and negative water temperature loading is attributed to the capacity of water to hold more D.O at lower temperatures (Hutchinson, 1975) [15].

Table 3: Water quality parameters of Dal Lake

| Parameters | unit | Hazratbal basin | LAAM basin | Habak basin |
|------------|------|-----------------|------------|------------|
| A.T °C     |      | STP 1(a) min.– max. mean± S.E | O.W 1(b) min.– max. mean± S.E | STP 2(a) min.– max. mean± S.E | O.W 2(b) min.– max. mean± S.E | STP 3(a) min.– max. mean± S.E | O.W 3(b) min.– max. mean± S.E |
| W.T °C     |      |                 |            |            |            |            |            |
| pH         |      |                 |            |            |            |            |            |
| EC Scm⁻¹   |      |                 |            |            |            |            |            |
| Depth m    |      |                 |            |            |            |            |            |
| SDT m      | 0.43 ±0.03 | 0.30–0.76 | 0.28–0.70 | 0.33 ±0.02 | 0.30–0.73 | 0.28–0.69 | 0.33 ±0.02 | 0.30–0.73 | 0.28–0.69 | 0.33 ±0.02 | 0.30–0.73 | 0.28–0.69 |
| D.O mg/l   | 3.2 ±0.7 | 3.8–4.5 | 3.8–4.9 | 3.6 ±0.7 | 3.7–4.6 | 3.7–4.8 | 3.6 ±0.7 | 3.7–4.6 | 3.7–4.8 | 3.6 ±0.7 | 3.7–4.6 | 3.7–4.8 |
| Cl mg/l    | 28 ±3.4 | 25–32 | 25–32 | 28 ±3.4 | 25–32 | 25–32 | 28 ±3.4 | 25–32 | 25–32 | 28 ±3.4 | 25–32 | 25–32 |
| NO2-N µg/l | 0.7 ±0.6 | 0.5–0.9 | 0.4–0.8 | 0.7 ±0.6 | 0.5–0.9 | 0.4–0.8 | 0.7 ±0.6 | 0.5–0.9 | 0.4–0.8 | 0.7 ±0.6 | 0.5–0.9 | 0.4–0.8 |
| NO3-N µg/l | 45 ±4.5 | 40–51 | 40–51 | 45 ±4.5 | 40–51 | 40–51 | 45 ±4.5 | 40–51 | 40–51 | 45 ±4.5 | 40–51 | 40–51 |
| NH4-N µg/l | 79 ±8.9 | 70–91 | 70–91 | 79 ±8.9 | 70–91 | 70–91 | 79 ±8.9 | 70–91 | 70–91 | 79 ±8.9 | 70–91 | 70–91 |
| PO4-P µg/l | 43 ±3.8 | 38–48 | 38–48 | 43 ±3.8 | 38–48 | 38–48 | 43 ±3.8 | 38–48 | 38–48 | 43 ±3.8 | 38–48 | 38–48 |
| T.P µg/l   | 102 ±9.4 | 90–115 | 90–115 | 102 ±9.4 | 90–115 | 90–115 | 102 ±9.4 | 90–115 | 90–115 | 102 ±9.4 | 90–115 | 90–115 |
| Si mg/l    | 3.6 ±0.5 | 3.3–3.9 | 3.3–3.9 | 3.6 ±0.5 | 3.3–3.9 | 3.3–3.9 | 3.6 ±0.5 | 3.3–3.9 | 3.3–3.9 | 3.6 ±0.5 | 3.3–3.9 | 3.3–3.9 |
The third component, PC3 of polluted zone accounted for 12.36% of total variance explained strong negative loading of NH$_4$-N and moderate negative loading of Si. PC3 showed an additional input of organic related parameter (NH$_4$) which may be due direct discharge of partially treated effluent from STPs. Vega et al. (1998) explained the origin of high levels of ammonia-nitrogen from decomposition of nitrogen-containing organic compounds such as proteins and urea occurring in the municipal wastewater discharges. Further, the increase in NH$_4$ can also be related to the process of denitrification with the reduction of D.O content (Kiely, 1997).

The fourth component, PC4 with 8.73% of total variance explained moderate positive loading of Cl$^-$ and pH with weak positive loading of Si and weak negative loading of NO$_2$-N and depth. This can be ascribed to direct discharge of effluent from the STPs which contain high concentration of chloride in it. Dwivedi & Odi, 2003 while working on Dickrong river and Sanap et al. (2006) also suggested that the increased chloride values were due to sewage and domestic waste contamination in Godavari river. Mathew & Vasudavan (2000) related the elevated chloride to the flow of sewage in river Pamba while Abubakr & Kundangar (2008) worked on number of Kashmir Lakes and reported higher values of chloride and attribute it to the presence of organic matter originated from sewage. Therefore, at polluted zone, water quality parameters were dominated by the presence of higher concentration of EC, PO$_4$-P, NO$_3$-N, NO$_2$-N while D.O recorded low values. The first changes resulting from discharge of effluents/pollution are decrease in the concentration of D.O or increase in the oxygen consumption, with rise in the concentration of electrolytes including chlorides. In addition to it, decrease in transparency with increase in pH, phosphorus and nitrogen were observed during the study. All these changes are because of influence of partially treated effluents from STP. These results are graphically represented in Figure 4.
Table 4: Eigen value and percentage of variance explained by each of the five principal components (PC’s) for polluted zone for studied variables

| Principal Component | PC1  | PC2  | PC3  | PC4  | PC5  |
|---------------------|------|------|------|------|------|
| Eigenvalue          | 4.123| 3.097| 1.731| 1.223| 1.054|
| % total variance explained | 29.451 | 22.119 | 12.361 | 8.733 | 7.531 |
| % cumulative variance | 29.451 | 51.57 | 63.931 | 72.664 | 80.194 |

Fig. 4: Principal component analysis (PCA) scatter plot for polluted zone water samples on the basis of studied water variable characteristics

Eigenvalues for unpolluted zone are displayed in Table (5), the first component, PC1, with 27.42% variation showed positive strong loading of depth, PO$_4$-P, water transparency, T.P, and moderate positive loading for D.O and E.C. These characteristics of water quality are attributed to cleaner water a condition which is characterized by increased depth, high transparency and high D.O. content. Although phosphorus concentration was found to be high at all the three unpolluted sites but the concentration was much lower than polluted zone. The higher values of phosphorous shows sign of nutrient enrichment of waters on account of eutrophication as suggested by various authors (Sawyer, 1947 [24], Welch and Lindell, 1980 [26]).

The second component, PC2, accounted for 23.57% of total variance and explained strong positive loading for NO$_3$-N and WT. This may be attributed to the organic matter decomposition along with the reduction in D.O. The higher nitrate loading showed the signs of enrichment of waters of Dal. Goreski et al. (2019) [14] reported that nitrate values are higher in autumn and winter due to limited biological activities. Moderate positive loading is explained for pH and E.C and weak positive loading for Si.

Release of treated STP effluent directly into Dal Lake resulted in bringing a marked change in the water chemistry of Dal Lake near the outfall. No such change was observed in the water quality at other locations/stations. These results are statistically confirmed and shown through graphical representation in Fig. 5.

Dal Lake has been bifurcated into two distinct zones, based on the water quality parameters, one polluted and other unpolluted. The main reason behind this is the release of partially treated effluent from STP’s. At polluted zone, water quality parameters were dominated by the presence of higher concentration of EC, PO$_4$-P, NO$_3$-N, NO$_2$-N while low concentration of D.O. Thus, confirming the reduced water quality at this zone. At unpolluted zone, dominant parameters were depth, transparency and D.O. These results were statistically substantiated by the use of bi-variate plot of PC1 and PC2 extracted from PCA, which clearly showed 2 distinct plots as depicted in Figure 6.

Table 5: Eigen value and percentage of variance explained by each of the five principal components (PC’s) for unpolluted zone for studied variables

| Principal Component | PC1  | PC2  | PC3  | PC4  | PC5  |
|---------------------|------|------|------|------|------|
| Eigenvalue          | 3.84 | 3.3  | 1.999| 1.334| 1.053|
| % total variance explained | 27.429 | 23.573 | 14.281| 9.529 | 7.518 |
| % cumulative variance | 27.429 | 51.002 | 65.283| 74.812 | 82.331 |
Conclusion
From the present study, it is clear that functioning of FAB based Sewage treatment plants installed to treat and improve wastewaters around Dal Lake is improper. STPs are not only malfunctioning but are exacerbating the problem of Dal lake pollution by bringing a catastrophic consequence as non-point sources of pollution are being made the point source of pollution. This has also manifested by an increase in the oxygen consumption in the hypolimnion, rise in the BOD, COD and the concentration of chlorides, sulphides, phosphorus and nitrogen. The same has also reported by Abubakr & Kundangar (2009)\(^7\).

Thus, there is an urgent need to upgrade these FAB based STPs so that they are able to reduce N & P concentrations more efficiently. The long term solution in our opinion to this problem under Kashmir conditions (where there is already energy crisis and severe winter) is the adoption of proven Root Zone technology/ artificial wetland technology for waste water treatment. The same has been emphasized by Abubakr and Kundangar (2004)\(^4\) and Abubakr and Kundangar (2009)\(^7\).
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