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Assessment of water quality of Bellandur Lake in Bengaluru, Karnataka

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Abstract
Bellandur Lake is considered to be the largest water body in Bengaluru city with catchment area of 287sqm and water storing capacity of 17.66 million cubic feet. Water quality of this lake has been a major issue since for a long time with foam appearance and accidental burning of lake has become national importance in recent times. Eleven parameters, from three different locations, of the lake were monitored during March, 2014 and December, 2017. Majority of the Physico-chemical and biological parameters were beyond the optimal range for surface waters and were not in desirable limits. Heavy metals concentrations were also high, with major source from untreated sewage, industrial effluents, solid waste, etc. The dissolved oxygen was nil in many locations and seasons during the study period. The high BOD concentrations indicated that this lake contains copious amount of organic load that utilizes dissolved oxygen for decomposition, by microbes, and makes the water body anaerobic on several occasions. There is urgent need to initiate proper management measure to rejuvenate this water body by stopping all the illegal entry of pollutants.

Keywords: Bellandur Lake, water quality, heavy metal, pollution

Introduction
Water is the most important natural resource available to mankind and the present global water scenario is very much alarming including India. In India, approximately 36% of urban and 65% of rural people have no access to safe drinking water (WHO, 2014). Further, nearly 70% of surface water in our country is contaminated one way or the other. Freshwater is essential to the very existence of life. Water of acceptable quality is essential not only for drinking and domestic purposes but also for agriculture, industrial and commercial uses. But, unfortunately the anthropogenic activities are the main cause for pollution in the fresh water systems in our country (Haniffa *et al.*, 1993).

Lakes are not only the source of precious water, but provide valuable habitats to plants and animals, moderate hydrological cycles, influence microclimate, enhance the aesthetic beauty of the landscape and extend many recreational opportunities to human kind. Bangalore city had 389 lakes according to Lakshman Rau committee report, 1986 (Thippaiah, 2009) and popularly known as "Garden City" surrounding these innumerable lakes. On the contrary, now around 35% of the water bodies in the city have been lost during the past 20 years (Deepa *et al.*, 1998) [3] and now majority of lakes are on the verge of extinction, as they are getting filled with solid wastes and untreated sewage. Further, the lakes have been largely encroached for urban infrastructure in the heart of the city and today only 17 good lakes exist as against 51 healthy lakes in 1985 (Deepa *et al.*, 1998) [3].

The Bellandur Lake is one of the largest lakes in Bengaluru city in recent years, its catchment area has been subjected to extreme anthropogenic stress. Part of the catchment area falls under Bangalore city municipal limits and most of the domestic sewage flows into the lake apart from the natural storm water. With increasing pressures on land in the municipal limits, the lake bed has also been subjected to ad-hoc development approaches. The functional ability of the ecosystem is impaired due to structural changes in the ecosystem. This is evident from poor water quality, breeding of disease vectors, contamination of ground water in the catchment, frequent flooding in the catchment due to topography alteration, decline in ground water table, erosion in lake bed, etc. It is in this context, a study was taken up to understand the health condition of this lake by way of monitoring the water quality.

Materials and Methods

Bellandur Lake, one of the largest man-made lakes in Southeast Asia, located at latitude of 12º58' N and longitude of 77º35' E at an altitude of 921 m above mean sea level, is the largest lake in Bangalore city spreads across an area of 892 acres. The lake has a catchment area of 148 square kilometres and its water storing capacity is of 17.66 million cubic feet. Its length is 3 km while width is 2.75 km.

The status of various physical, chemical and biological water quality parameters of Bellandur lake was monitored from March, 2014 to December 2017. The samples collected were analysed as per the standard procedures. Two out flows of the lake namely Station 1 and station 3 along with station 2 between the two outflows were selected for the study. The water samples were collected at all the three locations of the lake to understand the status of water quality parameters to assess the health condition of the lake. Different parameters monitored include Water temperature, pH, Dissolved Oxygen, Biochemical Oxygen Demand (BOD), Nitrate nitrogen, Phosphate phosphorous, heavy metals like lead and mercury, bacterial loads like Total Coliforms (Total plate count) and *E. coli* counts.

Results and Discussion

Samples collected from three locations, of the lake, were used for analysis of physico-chemical and biological components and were categorized based on season and spatial variation during the study period. The data is presented in Table 1 and 2. The water temperature is one of the most important water quality parameter influencing the physiology of aquatic life. The surface water temperature at all the three locations exhibited uniform trend without much spatial variation indicating uniform temperature distribution in the lake surface. The seasonal variation with highest water temperature was registered during the end of post monsoon season. Reported maximum temperature, 31.9ºC, during September month was due to shortage of rainfall during the year 2017. During the study period, the mean values of surface water temperature varied between 25.10°C (March 2014) and 29.11°C (September 2017) which conducive to aquatic life.

The pH indicates the degree to which water is acidic or alkaline and is considered as productive index of a water body. The surface water pH gradually decrease over a period of time was evident by 7.2 and 7.3 at initial period of monitoring (March, 2014) came down to 6.7, 6.9 and 6.8 at stations 1, 2 and 3 respectively during December 2017. The trend indicates that the pH is slowly moving towards acidic condition from more or less neutral condition, if the situation continues like this, the water may have decreased pH leading to collapse of primary productivity in the lake. The seasonal variation in pH reveal that the rainy months had an impact on the pH variation, with reducing the concentration while during summer and winter seasons the pH increased to a neutral condition. The statistical analysis of the data shows that there is significant difference between stations and seasons. Neutral pH condition in the same location, of the lake, has been reported by Pattu (2013) [11] and Helen (2008) [7] during their studies. A pH concentration range of 6.0 to 8.5 is essential for the productive nature of any water body (Garg *et al.*, 2010) [5].

Tropic levels influence the dissolved oxygen levels in the lakes but depletion of dissolved oxygen in Bellandur lake water was mostly result from water pollution in the form of heavy organic load. The depletion of dissolved oxygen was recorded at all the sampling stations and seasons except in the month of July, 2014. The presence of high organic load derived, from untreated sewage, and industrial effluents cause depletion of dissolved oxygen content to the extent of zero, in the surface waters, during majority of the sampling periods, and below the optimal levels throughout the study period. This kind of depletion of dissolved oxygen will have direct impact on aquatic biota ultimately rendering the water body unsuitable for biotic components to prevail. Further, depleted dissolved oxygen condition was supported by increased BOD concentration in the lake which was beyond the permissible limits and posed major concern for aquatic biota. The dissolved oxygen concentration of 7.23 mg/l during July 2014 was a result of peak rainfall in the locality.

Biochemical Oxygen Demand is the amount of oxygen required by the bacteria to decompose organic matter in aerobic condition in a specified period of time. Extent of pollution caused by domestic and industrial waste in a water body can be assessed by monitoring the BOD levels. The BOD concentration registered increasing trend from minimum of 9.12, 8.77 and 9.72 mg/l, at station 1, 2 and 3 respectively during initial period of the study, to a maximum of 22.34, 24.68 and 20.44 mg/l at the end of the study period. This level was beyond the optimal limits any for surface waters. The seasonal and spatial variation along with increasing trend of this parameter is of critical importance because the addition of organic load into this water body is a continuous process. Reporting lower dissolved oxygen values and higher BOD in the Bellandur lake, Ramesh *et al.* (2014) [14] opined that the presence of chemical pollution in the lake was the main cause for increased BOD levels in the lake waters.

Heavy infestation of aquatic weeds in Bellandur lake results in undesired dissolved gases like carbon-dioxide. The dissolved carbon-dioxide values were high throughout the study period. The carbon-dioxide concentration varied at all the sampled stations, with maximum mean concentration of 33.909 mg/l recorded at station two, where aquatic vegetation was enormous indicating the spatial variation. The winter months also reported high concentration compared to other seasons, with maximum concentration (49 mg/l) during December 2014. The statistical analysis of all the dissolved gases exhibited significant variation between the stations and seasons indicating strong influence on the health condition and production and productivity of the water body.

The nitrate nitrogen concentration in Bellandur lake was beyond optimal range all throughout the study period with maximum concentration being in the year 2017. The concentration levels increased over the period of time, with minimum of 0.04 mg/l during July, 2014 and maximum of 0.97 mg/l in March, 2017. This increasing trend was due to indiscriminate addition of nitrogenous waste into the water body in the form of untreated sewage, industrial effluents or solid waste containing heavy organic load. The mean concentration 0.41, 0.40 and 0.45 mg/l was respectively reported at station 1, 2 and 3. The seasonal highest variation reported during summer months could be due to the fast decomposition of organic matter. The statistical analysis indicated significant variation between stations and seasons. This trend of higher concentration of nitrate nitrogen in Bellandur lake was also reported by Helen *et al.* (2008) [7].

The phosphate phosphorous concentration is essential, in any

water body, to support the primary productivity. However, higher concentrations may lead to eutrophic condition with uncontrolled growth of aquatic vegetation and blooming of phytoplankton. Once this condition sets in, the diffusion of atmospheric oxygen into the water body ceases. Meanwhile, the demand for dissolved oxygen by various organisms such as fish and microorganisms including for decomposing the organic load becomes rapid. The excess decomposition of organic matter by microbes may create anaerobic condition. Low concentration of dissolved oxygen and high concentration of BOD was evident for this lake in the study area. In general, the phosphate concentration in the lake was beyond the optimal range. Maximum concentrations were recorded in two out flows of the lake compared to the other sampling stations located in between. The mean concentration at three locations was 0.955, 0.905 and 0.928 mg/l at station 1, 2 and 3, respectively. Apart from the spatial variation, the monsoon months exhibited highest concentration of phosphate indicating that the inflow water carry phosphate components. The seasonal as well as spatial variation was significantly different.

Regular formation of foam and fire that appears often in Bellandur lake is mainly caused by increased phosphate concentration due to indiscriminate discharge of household waste and industrial effluents containing phosphate components. The churning of water causes formation of foam followed by heat generation at the surface causes fire (Ramachandra, 2017) [13]. Higher concentrations of nitrate nitrogen and phosphate phosphorous in the Bellandur have been reported by Helen *et al.* (2005).

The lead concentration in Bellandur lake was well within the desirable limit except during July, 2014 where its concentration was up to 0.198 mg/l at station 2 where the disposal of solid waste by the public was at rampant. Presence of high concentration of lead at station 2, compared to outflows of the water body clearly indicate the spatial variation with mean concentrations 0.064, 0.083, 0.0576 mg/l at station 1, 2 and 3, respectively. The seasonal variation was more or less uniform except during July and December 2014, when the lead concentrations were high. Analyzing the borewell water at Bellandur village, Helen *et al.* (2008) [7] reported lead concentration upto 0.13mg/l and that the village has fallen prey for this chronic poison.

The mercury concentrations in the lake were beyond the desirable limits at all the sampling stations monitored. The maximum mercury concentration of upto 1.171 mg/l was recorded at station 1, which is the main out flow of the lake. The mean concentration of mercury during the study period was highest at both the outflows when compared to the station situated in between the both with 0.749, 0.702 and 0.769 mg/l at station 1, 2 and 3 respectively. The seasonal variation in mercury concentrations reveal that summer months registered higher concentrations due to inflow of water is minimal during these months. The statistical analysis of both lead and mercury data exhibited significant difference between stations and seasons, making them crucial parameters in understanding the health of an ecosystem.

The presence of high fecal coliforms and total coliform counts in Bellandur lake was evident indicating the existence of high organic load existing in the water body. Higher *E. coli* counts during monsoon season could be due to entry of large quantity of organic load to the lake. Presence of high counts at both the out flows (station 1 and 2) with 614 and 644 MPN/100 ml indicates clear spatial variation. The Total Plate counts were also high throughout the study period and the counts were as high as 17,746 CFU/100ml at station 2 during March, 2014. However, the outflows station 1 and 2 recorded 13,267 CFU/100ml, during June 2016 and 15,743 CFU/100ml, during March 2015 respectively. Spatially, station 2 had the highest mean counts upto 12,509 CFU/100ml compared to the out flows, which might be due to the organic waste disposal at this place. The counts were always high in numbers during summer months compared to other seasons indicating seasonal variation. The statistical analysis of both fecal coliform and total coliform counts reveal significant difference between stations and seasons.

Correlation analysis: The Pearson's correlation (Table 3) between physico-chemical and biological parameters indicate that pH had a moderate correlation with dissolved oxygen, carbon-dioxide, lead and *E. coli* counts, while it had moderately negative correlation with BOD, nitrate nitrogen, phosphate phosphorous, mercury and total plate counts. Dissolved oxygen had strong correlation with BOD, carbon dioxide, phosphate phosphorous, lead, mercury and *E. coli* count. On the other hand, nitrate and total plate counts were negatively correlated to dissolved oxygen. BOD had positive correlation with nitrate and total plate counts and negative correlation to all other parameters. Moderate positive correlation was noticed between carbon dioxide and phosphate, dissolved oxygen and mercury and negative weak correlation with nitrate, *E. coli* and total plate count. Nitrate nitrogen had strong positive correlation with total plate counts and BOD, while strong negative correlation was registered with phosphate, lead and mercury. Phosphate phosphorous and dissolved oxygen were highly positively correlated while strong negative correlation was exhibited between mercury, phosphate phosphorous and total plate counts. Lead exhibited a strong positive correlation with dissolved oxygen, phosphate and *E. coli* counts while moderate negative correlation with BOD, nitrate, and total plate count. Moderate positive correlation was registered between mercury, lead, dissolved oxygen while moderate negative correlation with BOD and phosphate was noticed. *E. coli* counts had moderate positive correlation with pH, dissolved oxygen, phosphate and lead while moderate negative correlation with total plate count. The total plate count had strong positive correlation with nitrate and strong negative correlation with phosphate content. For analysis of variance, the seasons with different months were separated and put to test. The analysis of variation resulted in significant variation between the parameters and less significant variation between the seasons.

Table 1: Temperature, pH, dissolved oxygen, BOD and Carbon dioxide content of water from Bellandur Lake

Particulars	Mar 14	Jul 14	Dec14	Mar 15	Mar 16	Jun 16	Sep 16	Dec 16	Mar 17	Sep 17	Dec 17	Mean
Water Temperature (^{0}C)												
Station 1	25.5	28.5	28.1	28.5	26.1	27.5	26.5	24.9	28.1	31.5	26.1	27.391
Station 2	25.1	28.5	28.2	28.3	26.8	27.8	26.4	25.3	26.5	31.9	26.3	27.373
Station 3	25.6	28.3	28.15	28.2	26.7	27.5	26.4	25.1	27.7	31.9	25.9	27.405
pH												
Station 1	7.2	6.85	7.28	7.1	6.7	6.96	7.04	7.45	6.53	7	6.71	6.984
Station 2	7.3	6.76	6.44	7	6.9	7.01	7.15	7.19	6.62	7.12	6.99	6.953
Station 3	7.3	6.71	6.89	6.9	7.1	6.96	7.11	7.26	6.91	6.68	6.8	6.965
Dissolved oxygen (mg/l)												
Station 1	0.1	6.4	0.1	0	0.34	0	0	2.2	0	1.25	0	0.945
Station 2	0.6	7.12	0.1	2.62	1.24	0	1.06	2.36	0.67	2.16	1.66	1.781
Station 3	0.4	8.18	0.51	1.87	1.04	1.98	0	2.66	0	1.01	0.57	1.656
BOD(mg/l)												
Station 1	9.12	6.13	10.35	9.97	9.9	14.28	13.2	12.28	24.67	16.37	22.34	13.510
Station 2	8.77	5.81	10.45	7.54	8.56	12.3	11.05	10.96	20.09	18.64	24.68	12.623
Station 3	9.72	4.37	9.67	8.29	8.34	10.09	13.26	11.03	26.48	21.26	20.44	12.995
Carbon-dioxide(mg/l)												
Station 1	36	32	49	32	44	38	24	22	24	28	32	32.818
Station 2	32	32	45	38	32	42	48	20	28	24	32	33.909
Station 3	32	28	38	38	28	29	44	28	20	24	28	30.636

Table 2: Heavy metal and microbial counts of water from Bellandur Lake

Particulars	Mar 14	Jul 14	Dec14	Mar 15	Mar 16	Jun 16	Sep 16	Dec 16	Mar 17	Sep 17	Dec 17	Mean
Nitrate Nitrogen (mg/l)												
Station 1	0.216	0.048	0.275	0.418	0.501	0.638	0.5631	0.4867	0.497	0.5413	0.4015	0.417
Station 2	0.193	0.05	0.306	0.341	0.401	0.511	0.4966	0.3966	0.646	0.695	0.4596	0.409
Station 3	0.203	0.049	0.199	0.219	0.357	0.421	0.561	0.487	0.972	0.8974	0.6654	0.457
Phosphate Phosphorous (mg/l)												
Station 1	0.125	2.648	2.845	0.216	0.317	0.399	0.2964	0.3106	1.081	1.2164	1.0579	0.956
Station 2	0.21	2.59	2.827	0.357	0.397	0.424	0.3265	0.2981	0.697	0.9647	0.8794	0.906
Station 3	0.091	2.62	2.328	0.385	0.401	0.36	0.3016	0.2644	1.114	1.2447	1.1002	0.928
Lead												
Station 1	0.04	0.197	0.088	0.063	0.046	0.031	0.0963	0.0645	0.027	0.0332	0.0266	0.065
Station 2	0.056	0.198	0.219	0.095	0.084	0.062	0.0846	0.0687	0.012	0.0218	0.0114	0.083
Station 3	0.046	0.19	0.086	0.067	0.052	0.04	0.0463	0.0545	0.011	0.0197	0.0211	0.058
Mercury												
Station 1	1.171	1.076	0.177	1.049	1.064	0.921	0.8436	0.5988	0.346	0.4578	0.5448	0.750
Station 2	1.091	0.945	0.783	1.125	0.459	0.631	0.8016	0.6554	0.235	0.6541	0.3478	0.702
Station 3	1.075	0.874	0.273	1.114	0.965	0.541	1.0145	0.6487	0.649	0.7471	0.5644	0.770
E. coli (MPN/100ml)												
Station 1	453	842	768	389	468	631	864	854	387	654	465	616
Station 2	231	717	715	310	645	412	496	646	749	844	658	584
Station 3	691	916	502	517	659	610	864	961	409	509	455	645
Total Plate Count (CFU/100ml)												
Station 1	11721	8747	6896	10967	12658	13267	11234	12494	10678	10364	11245	10934
Station 2	17746	8371	7341	12348	15267	11559	12045	9648	16790	15248	11245	12510
Station 3	10197	8294	6966	15743	12498	13567	10687	13467	9648	11879	11334	11298

Table 3: Pearson's correlation coefficient between Physico-chemical and biological Parameters

Parameters	WT	pH	DO	BOD	CO_2	NO_3	PO_4	Lead	Mercury	E. coli	TPC
WT	1.0000										
pH	-0.1910	1.0000									
DO	0.1725	0.0275	1.0000								
BOD	0.0980	-0.5363	0.4388	1.0000							
CO2	-0.0027	0.0347	0.1778	-0.4063	1.0000						
NO3	0.0220	-0.1152	-0.6105	0.4973	-0.2641	1.0000					
PO4	0.4447	-0.0591	0.5133	-0.1143	0.3347	-0.5993	1.0000				
Lead	0.1017	0.1370	0.8236	-0.6167	0.0110	-0.6675	0.5861	1.0000			
Mercury	-0.2906	-0.0121	0.2249	-0.5972	0.0660	-0.2054	-0.4605	0.2494	1.0000		
E. coli	-0.0049	0.5051	0.5273	-0.3881	-0.1493	-0.1203	0.3813	0.6375	-0.1444	1.0000	
TPC	-0.4686	-0.1021	-0.3117	0.1660	-0.2877	0.6146	-0.8963	-0.5375	0.4665	-0.2940	1.0000

Where WT- water temperature, TPC-Total plate count

Conclusion

Bellandur lake is facing severe pollution threat with chemicals and organic load being added every day. This lake with minimal dissolved oxygen is not providing a good habitat for aquatic organisms to survive. The presence of high levels of heavy metals not only contaminates the lake ecosystem but also the underground water in the vicinity. There is urgent need to apply management measures to retain this lake free from pollution and also to provide suitable habitat for the organisms associated with this lake ecosystem.

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