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Physicochemical Investigation of Surface Water Quality of Urban Wetlands of Bangalore, India

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Abstract: The urban aquatic ecosystems are strongly influenced by long term discharge of untreated domestic and industrial wastewater, storm water runoff, accidental spills and direct solid waste dumping. In this study, a survey of physico-chemical pollution of surface water of existing water bodies in Bangalore urban region was carried out. The findings show that total and magnesium hardness, total dissolved solids, total alkalinity, dissolved oxygen and biochemical oxygen demand exceeded desirable limits. Magnesium, chlorides and orthophosphates were also excessive. Calcium carbonate saturation indices showed that the water from the surveyed water bodies had a scale forming tendency. Pearson's coefficient correlation between the chemical contaminants showed a very strong and a statistically significant relationship between sodium, potassium, calcium, magnesium, chlorides and fluorides.

Key words: Urban wetlands, surface water pollution, calcium carbonate saturation indices, morpho-edaphic index.

Introduction

The urban aquatic ecosystems are strongly influenced by long term discharge of untreated domestic and industrial wastewater, storm water runoff, accidental spills, and direct solid waste dumping. All these released pollutants have a great ecological impact on the water quality. The fate of urban wetlands is always associated with physical status of its cities. Kumaresan and Riazuddin (2006) described the status of the lakes in Bangalore area as an ecological devastation. The wrong priorities and change in land use created a phenomenon of lakes being turned into landfills and encroached for other domestic and commercial exploitation. These lakes suffered from mud-lifting and sand-mining purposes, deforestation of the surrounding catchment basins causing siltation and sedimentation, and land reclamation. The grave concern in the management part as described by Ramesh (1996) focused on the city's serious civic problems and a failure to provide adequate water supply system and proper sewerage. As a consequence, the lakes had become receptacles of unaccounted sewerage effluents.

The principal causes of degradation and pollution of urban wetlands of Bangalore have been described in detail from previous publications. The major factor in the declining quality of these wetlands can be traced back to an unplanned physical growth of the city. As a consequence, alterations in the hydrologic structure and functioning of wetlands, de-watering of wetland basins by consumptive use of surface water inflows, unregulated draw-down of unconfined aquifers from either groundwater withdrawal or by stream channelization for various human activities have contributed to the recession of the water budget and disruption of the normal water cycle. Nevertheless, an increased sedimentation from the scrapped upper catchments, excessive nutrient inflows, increase in concentration of organic matter, heavy loading of metals from industrial and domestic chemicals, heavy presence of bacterial pathogens and other water pollutant loadings from both point source and non-point sources of pollution have accelerated the environmental pollution

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of these wetlands. The impact can be felt in the loss in the normal wetlands biodiversity structure and the rise of exotic flora and fauna. Another major issue of encroachment of urban watershed basins exacerbated by the problem of sky-rocketing demand for real estate and infrastructure consequent to urbanization of the city has increased the impact of pollution on Bangalore lakes.

The existing management of wetlands relies heavily on the individual restoration of affected lakes rather than in a holistic management of relevant watersheds with respect to protection and conservation of the basins, and wastewater treatment before the drainage enters the lakes. The current practice of lake restoration involves a complete drainage of that lake, diversion of the feeder drains that brings water into that lake, and physical modification of the depths and shorelines of the lakes. This method is more harmful as it destroys the natural biodiversity of the lake systems and cause shift in aquatic flora/fauna balance.

This study was done to assess the status of physico-chemical pollution of surface water, vis-à-vis performance of the existing wetlands management and rejuvenation programmes currently in place in the city. The scope of the study included the following parameters: Temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), suspended solids (SS), total hardness (TH), calcium hardness (CaH), magnesium hardness (MgH), and total alkalinity (TA), and phenolpthalein alkalinity (PA) were measured. Cationic analysis of calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), was done. Anions such as chlorides (Cl), fluorides (F), sulphates (SO_4), phosphates (PO_4), nitrates (NO_3), carbonates (CO_3) and bicarbonates (HCO_3) were determined. In the matters of water quality for irrigation purposes, the residual sodium carbonate (RSC), sodium adsorption ratio (SAR), and percentage sodium (Na%) were calculated from the primary data. The industrial potency of water was measured using calcium carbonate saturation indices; these included Langelier Saturation Index (LSI), and Ryzner Stability Index (RSI). Morpho-edaphic Index for optimum fish yield in inland fresh water fisheries was measured. Finally, the level of organic pollution was estimated using the parameters involved in measurement of dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD).

Materials and Methods

Study Area: Bangalore is located at a latitude 12°59' N and longitude 77°55' E at an altitude of 920 m above mean sea level. The elevation varies from 835 m to 953 m. The region is composed of five local sub-regions: Anekal, Bangalore North, Bangalore South, Bangalore East and Inner Bangalore. The entire urban area is about 709 sq km. The population is approximately 5.8 million—3 million male and 2.8 million female. The mean annual rainfall is approximately 880 mm with a mean 60 rainy days/year. The mean summer temperature ranges from 18ºC–38ºC while the mean winter temperature ranges from 12ºC–25ºC. The mean relative humidity in Bangalore is 63%. The surface winds in Bangalore have seasonal character with the easterly components predominating during one period followed by the westerly in the other. The high wind speed averages 17 km/hour during the westerly winds in the month of July and a minimum of 8–9 km/hour during the months of April and October.

Profile of the City's Wetlands: Latest remote sensing data on the distribution of the urban wetlands of Bangalore shows a total of 2789 water bodies of various sizes and ecological condition. Many are seasonal and a significant number of them are permanent with serious stages of environmental degradation. The water bodies have been categorized in five main groups: those with less than 2 ha of surface area (1260); those between 2 ha and 8 ha (847); between 8 ha and 25 ha (469); between 20 ha and 50 ha (117) and those water bodies with more than 50 ha (96). These lakes are located in three major basins namely Vrishabavathi, Hebbal and Koramangala-Chalagatta. Within these major basins are series of sub-watersheds containing a chain-link of lakes displaying a cascading flow pattern. A total of seventeen individual wetlands located within various sub-watersheds of these three major basins (Figures 1 and 2 and Table 1) were chosen for the study.

Sampling Strategy: A total of seventeen water bodies located in three major valleys of Bangalore–Vrishabavathi, Koramangla-Challagatta, and Hebbal basins with five of its total six lake watershed series within these valley systems were surveyed (Figures 1 and 2). The selected lakes are located around the peri-urban rim of Bangalore–an area between the city's corporation limits known as the BBMP Area and the outer area known as the Bangalore Development Authority (BDA) zone. Between these water bodies, a total of 64 sampling points were selected based upon inflow and outflow regions of the lakes; geographical proximity of industrial units in relation to the direction of their effluent discharges; proximity of residential sites located on the banks of the wetland systems; and easy accessibility towards the lakes. Detailed information on the surveyed lakes is presented in Table 1.

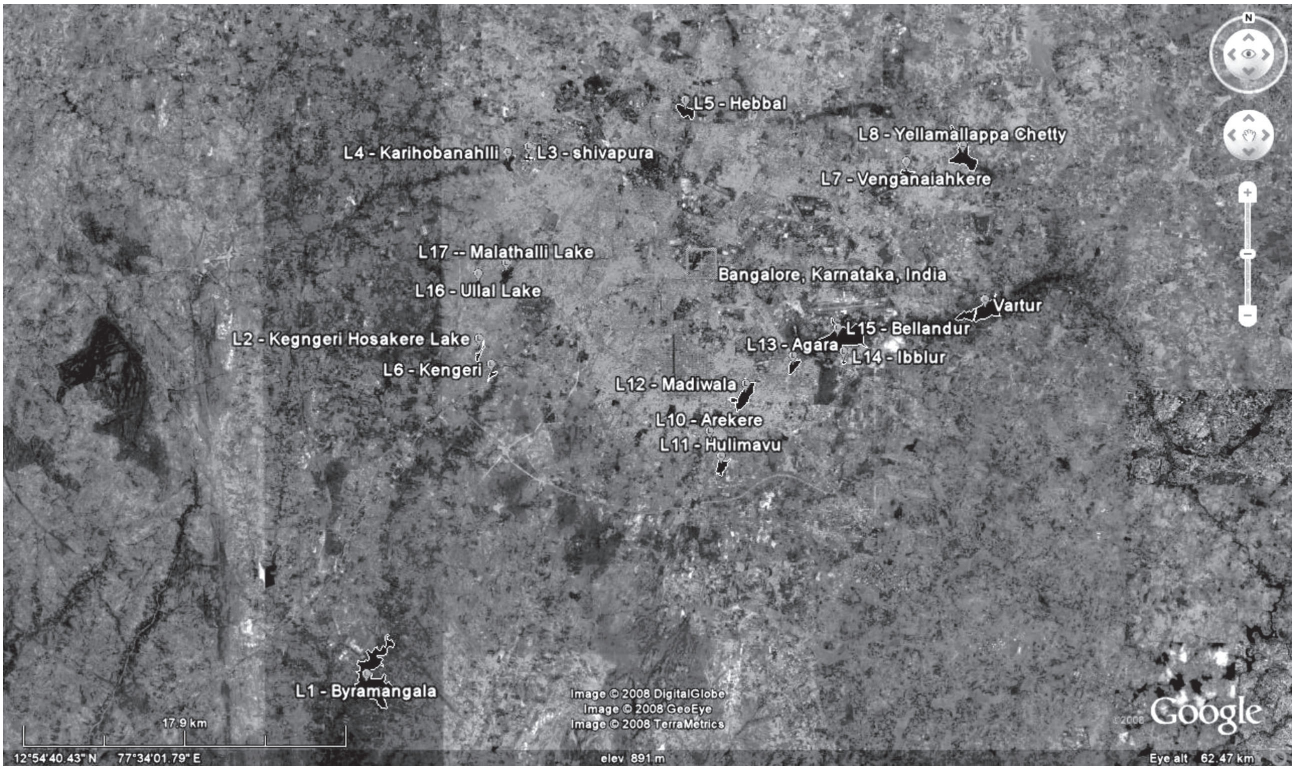

Figure 1: A Google Earth imagery of Bangalore showing selected lakes in the study area.

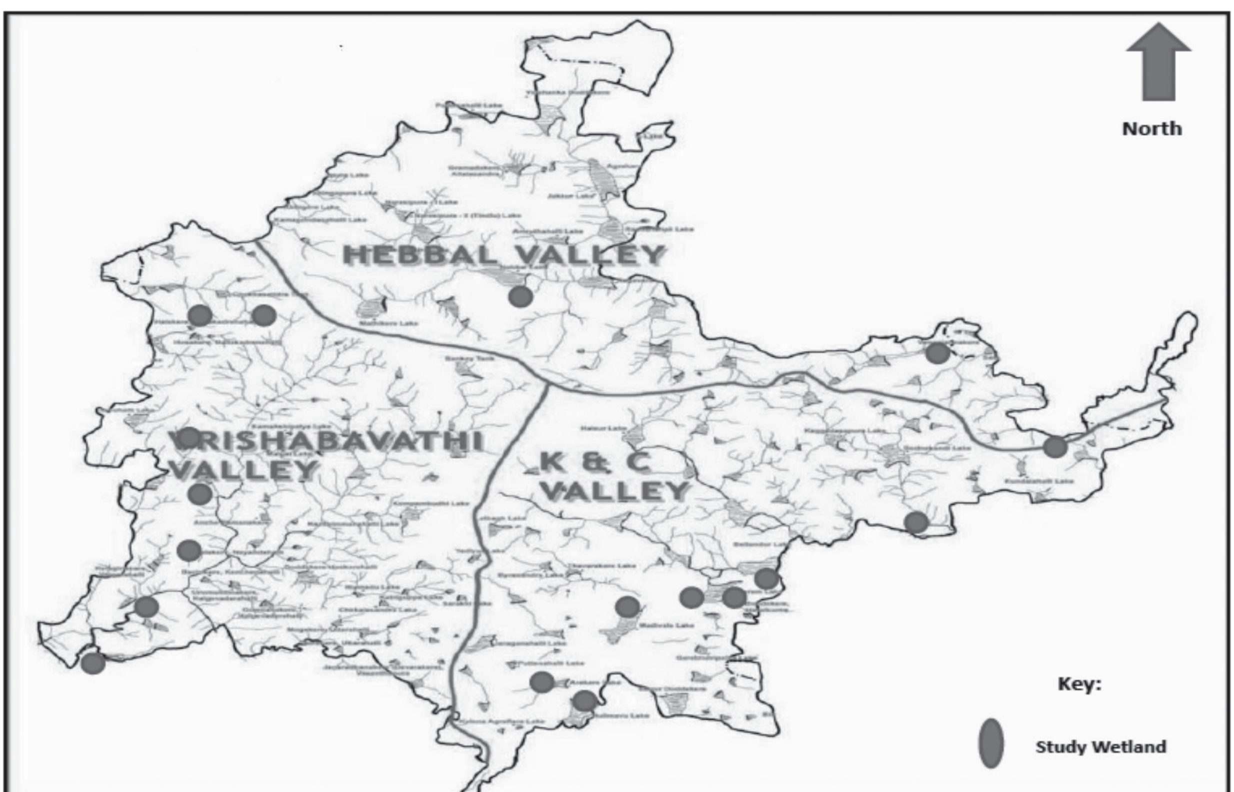

Figure 2: Map of Bangalore Urban Region showing selected lakes in the study area.

Table 1: Sampling locations, position and sampling points

S.No.	*Sampling location (name of the lake)*	*Position*		*Area (ha)*	*Lake series*	*Basin*
		Latitude	*Longitude*			
LI	Byramangala	12°46′02.5″N	77°25′36.0″E	246.64	Byramangala	Vrishabavathi
L2	Hosakere	12°55′41.45″N	77°28′56.58″E	17.20	Byramangala	Vrishabavathi
L3	Shivapura	13°01′23.82″N	77°30′24.04″E	11.39	Madavara	Vrishabavathi
L4	Karihobanahalli	13°01′14.93″N	77°29′50.77″E	22.32	Madavara	Vrishabavathi
L5	Hebbal	13°02′49.17″N	77°35′12.48″E	58.23	Yellamallappa	Hebbal
L6	Kengeri	13°54′56.60″N	77°29′14.17″E	10.73	Byramangala	Vrishabavathi
L7	Venganaiahkere	13°01′00.97″N	77°41′56.28″E	18.87	Yellamallappa	Hebbal
L8	Yellamallappa	13°01′39.39″N	77°43′67.63″E	37.56	Yellamallappa	Hebbal
L9	Vartur	12°56′49.50″N	77°44′10.54″E	165.75	Vartur	Koramangala Challaghatta
L10	Arekere	12°52′58.50″N	77°35′55.86″E	12.43	Hulimavu	Koramangala Challaghatta
L11	Hulimavu	12°52′14.06″N	77°36′20.48″E	23.0	Hulimavu	Koramangala Challaghatta
L12	Madiwala	12°54′22.07″N	77°37′06.82″E	91.87	Puttenahalli	Koramangala Challaghatta
L13	Agara	12°55′10.84″N	77°38′27.33″E	41.08	Puttenahalli	Koramangala Challaghatta
L14	Ibblur	12°55′19.50″N	77°40′00.45″E	8.24	Vartur	Koramangala Challaghatta
L15	Bellandur	12°56′17.62″N	77°40′00.78″E	335.09	Vartur	Koramangala Challaghatta
L16	Ullal	12°57′40.70″N	77°28′53.24″E	11.03	Byramangala	Vrishabavathi
L17	Malathalli	12°57′54.78″N	77°29′42.29″E	50.38	Byramangala	Vrishabavathi

Sampling Strategy: Sampling and analysis of water samples followed the standard methods for examination and water and waste water (APHA, 1995, 2005; KSPCB, 2004). Sampling was carried out on a monthly basis between 2006 and 2007. Water samples were collected in fresh 2-litre plastic containers that had been previously washed with 1:3 HNO_3. On site sample analysis was carried out for dissolved oxygen using Winkler's method. For determination of biochemical oxygen demand (BOD), 1 : 1 dilution of the samples with dilution water was carried out. The sample was carefully added with aerated standard dilution water. About 1 ml each of $CaCl_2$, $Mg_2SO_4.7H_2O$, $FeCl_3.6H_2O$, and phosphate buffer solutions in one litre of good quality distilled water without entrapment of air and the samples were preserved in 300 ml BOD bottle and put in a special freeze box. The samples were brought to laboratory within six hours of collection (Manivasakam, 2003; KSPCB, 2004). The BOD samples were then incubated for three days at 25^{o}C in the BOD incubator before determination of the final dissolved oxygen (DO).

Laboratory Analysis: The pH was done in the laboratory using Digisun Electronics Digital pH Meter 707. Colour, suspended solids and turbidity were also determined using a DR/890 Hach Colorimeter (Hach Manual, 1997). Sodium and potassium concentrations were analysed using a Systronics Flame Photometer. For chemical oxygen demand (COD), an open reflux method using Hach COD Digestion Reactor and titration with ferrous ammonium sulphate (FAS) was carried out.

Nitrates, sulphates and phosphates were determined using Jenway 6300 Spectrophotometer. Nitrates analysis was done using cadmium reduction method. Sulphates were determined using turbidimetric method. Orthophosphates were analysed using stannous chloride method. Estimation of fluorides was done using SPADNS colorimetric method with DR/890 Hach Colorimeter.

Estimation of chlorides was done using silver nitrate method. Estimation for alkalinity (phenolphthalein and total) was done using dilute sulphuric acid (0.02N H_2SO_4) titration method. Hardness (total and calcium) was done using EDTA titration method.

The mean concentrations of the studied parameters of each lake in the study area are presented in Tables 2 and 3. Application of SPSS 12.0 software package for analytical evaluation of the results followed standard statistical methods (Gaur and Gaur, 2006). This included determination of the correlation coefficient measuring the strength of linear relationship between the studied parameters and one way ANOVA analysis of the parameters among sampling sites. These are presented in Tables 4 and 5 respectively.

Table 2: Mean concentrations of the physicochemical characteristics of the surface water samples from the lakes of Bangalore

Lakes	*pH*	*Temp ºC*	*EC*[(a)]	*TDS*	*TH*	*CaH*	*MgH*	*Ca*	*Mg*	*Na*[(b)]	*K*	*Cl*	*F*	PO_4	NO_3	SO_4
Byramangala	7.70	26.3	1274.3	615.0	307.3	178.5	129.0	71.4	31.4	111.6	18.8	153.5	0.76	35.4	22.6	42.2
Hosakere	7.77	26.3	1033.0	514.5	288.5	128.7	159.8	51.4	39.1	109.1	23.7	160.6	0.54	2.9	13.8	31.3
Shivapura	7.46	25.5	3589.4	1772.2	848.0	428.5	419.5	171.4	102.3	495.5	46.9	852.8	1.52	19.7	26.5	203.4
Karihobanahalli	7.62	25.5	3101.7	1301	738.1	379.4	358.7	151.7	87.5	312.3	46.5	813.5	1.86	7.5	31.8	112.6
Hebbal	7.64	25.3	950.1	466.4	250.7	145.5	105.1	58.21	25.5	139.2	16.1	97.9	0.54	3.8	11.3	66.8
Kengeri	8.11	25.5	1269.4	633.1	284.6	118.9	165.7	47.5	40.4	194.7	21.4	185.1	0.76	3.4	10.0	63.0
Venganaiahkere	8.41	25.9	1438.0	732.0	234.1	111.8	122.3	44.7	29.8	203.2	34.7	319.7	0.60	4.18	19.8	49.4
Yellamallappa	8.25	26.2	1356.5	672.9	324.2	176.8	147.4	70.7	35.9	141.4	31.5	214.4	0.70	29.8	51.9	28.9
Vartur	7.73	26.0	1119.1	526.0	288.5	166.2	122.3	66.4	29.8	200.4	34.5	147.9	0.77	28.0	66.3	29.0
Arekere	7.90	26.0	1480	708.1	330.2	193.3	136.8	77.3	33.4	162.7	38.0	273.8	0.87	37.2	23.1	21.7
Hulimavu	7.81	26.3	942.6	460	200.2	116.8	83.35	46.7	20.3	151.8	29.9	190.4	0.46	2.3	13.3	12.3
Madiwala	7.60	26.0	874.5	422.1	202.2	105.3	96.97	42.1	23.6	162.7	26.2	108.1	0.55	6.1	16.7	28.3
Agara	7.96	26.0	1217	584	213.9	110.1	103.8	44.0	25.3	170.3	34.3	218.6	0.53	2.6	9.7	24.9
Ibblur	7.90	26.6	1273.4	622.9	233.3	122.1	111.2	48.8	27.1	158.0	28.3	239.1	0.72	3.0	10.9	78.4
Bellandur	7.6	27.0	1149	546.7	271.8	154.3	117.5	61.7	28.6	113.0	31.7	120.4	0.55	34.0	16.7	39.2
Ullal	8.18	25.6	601	294	190.2	92.7	97.45	37.1	23.7	158.1	19.6	73.7	0.49	3.8	12.1	17.1
Malathalli	8.46	25.6	1285	594	262.2	120.3	141.9	48.1	34.6	225.7	30.8	270.7	0.64	5.7	12.2	45.9
IS drinking limits	6.5-8.5	-		500	300	187.5	125	75	30	-	-	250	1.0	5(P)	45	200
ICMR	6.5-9.2	-	-	500	300	-	-	75	50	-	-	200	1.0	-	20	200

Note: The above IS and ICMR values are under the desirable limit.

(a) WHO's recommended limit is 1500 μmhos/cm.

(b) The US Drinking Water Guidelines for Na is less than 60 ppm while the WHO's recommended limit is 200 mg/L.

Table 3: Mean concentrations of the physicochemical characteristics of the surface water samples from the lakes of Bangalore (cont.)

Lake	*T.Alk*	*P.Alk.*	CO_3[a]	HCO_3	*LSI*[b]	*RSI*[b]	*RSC*[c]	*%Na*[c]	*SAR*[c]	*MEI*[d]	*SS*	*DO*	*BOD*	*COD*
Byramangala	327.3	1.17	2.35	325.0	0.57	6.57	1.0	41.6	4.8	41.0	91.3	3.2	37.8	256.0
Hosakere	230.7	5.49	10.9	219.8	0.34	7.08	0.1	42.2	5.1	57.1	18.6	5.9	16.3	194.5
Shivapura	367.4	13.52	27.0	340.3	0.73	5.99	Nil	53.5	13.4	354.4	36.9	2.8	40.4	282.4
Karihobanahalli	253.9	0.14	0.31	253.6	0.72	6.16	Nil	43.4	8.7	216.8	28.3	2.9	43.0	274.5
Hebbal	197.0	1.61	3.23	193.8	0.25	7.13	0.1	50.9	6.6	62.1	49.7	6.8	7.29	149.0
Kengeri	243.5	8.08	16.1	227.3	0.64	6.83	0.1	56.7	9.1	158.2	29.9	3.5	31.5	160.0
Venganaiahkere	185.2	5.52	11.0	174.2	0.73	6.94	0.2	59.5	10.5	122.0	57.5	4.3	26.9	236.8
Yellamallappa	280.8	4.41	8.82	272.0	1.04	6.17	0.4	44.6	6.0	56.0	67.5	3.1	38.3	191.3
Vartur	283.2	2.20	4.41	278.8	0.49	6.73	0.6	52.0	8.6	40.0	49.0	3.6	45.8	210.2
Arekere	328.5	3.23	6.47	322.0	0.78	6.34	0.5	46.5	6.6	126.2	52.9	3.1	43.0	290.2
Hulimavu	212.3	2.20	4.41	207.9	0.44	7.16	0.6	57.0	8.0	33.8	25.1	8.0	15.5	120.8
Madiwala	206.4	3.23	6.47	200	0.07	7.45	0.5	57.8	8.7	32.1	58.4	3.9	22.6	178.8
Agara	196.0	6.02	12.0	183.9	0.41	7.14	0.2	56.8	8.7	97.3	22.1	7.5	15.2	127.0
Ibblur	126.7	1.17	2.35	124.4	0.20	7.50	Nil	51.9	7.7	88.9	54.3	4.3	30.6	268.2
Bellandur	293.8	11.0	22	271.8	0.41	6.79	0.9	43.8	5.2	33.3	105.	3.5	35.3	260.4
Ullal	182.7	9.80	19.6	163.1	0.57	7.03	0.4	57.4	8.9	58.8	41.7	7.2	18.0	157.0
Malathalli	172.5	25.6	51.3	121.1	0.87	6.71	0.06	60.0	11.2	66.0	47.7	3.5	40.0	257.2
IS standard limits	200	-	-	-	-	-	-	-	-	-	100	6-8	30	250
Manivasakam:2003					Zero = Neutral	6 - 7	<1.25 meq/L	<60%	8.0		-	-	-	-

The above IS values are under the desirable limit.
[a]The US EPA guidelines recommends carbonates levels to be less than 20 mg/L. [b]Interpretation is based on the water quality for industrial use in terms of its scale forming and corrosive tendencies. [c]Interpretation of guidelines based on water quality for irrigation purposes. [d] FAO's guidelines for optimum conditions supporting aquatic life and excellent fish yield is between 50 and 200.

Table 4: Pearson's correlation coefficient between chemical contaminants in the lakes

	Na	*K*	*Ca^{2+}*	*Mg^{2+}*	*Cl^-*	*F^-*	*SO_4*	*PO_4*	*NO_3*	*CO_3*	*HCO_3*
Na	1										
K	.712(**)	1									
Ca^{2+}	.821(**)	.716(**)	1								
Mg^{2+}	.883(**)	.682(**)	.950(**)	1							
Cl^-	.893(**)	.812(**)	.915(**)	.945(**)	1						
F^-	.783(**)	.715(**)	.938(**)	.926(**)	.926(**)	1					
SO_4	.880(**)	.515(*)	.836(**)	.887(**)	.845(**)	.778(**)	1				
O_4	−.051	.215	.290	.080	.005	.159	−.031	1			
NO_3	.174	.386	.341	.211	.171	.314	.034	.564(*)	1		
CO_3	.311	.102	−.007	.145	.104	−.062	.167	−.083	-.237	1	
HCO_3	.281	.352	.617(**)	.462	.339	.467	.295	.799(**)	.509(*)	−.237	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 5: Pearson's correlation coefficient between cumulative indicators of chemical contaminants in the lakes

	Temp	*pH*	*EC*	*TDS*	*TH*	*CaH*	*MgH*	*TA*	*RSC*	*SAR*	*Na%*	*MEI*	*DO*	*BOD*	*COD*
Temp	1														
pH	−.144	1													
EC	−.330	−.340	1												
TDS	−.318	−.326	.991(**)	1											
TH	−.357	−.436	.974(**)	.960(**)	1										
CaH	−.303	−.499(*)	.957(**)	.939(**)	.988(**)	1									
MgH	−.403	−.361	.967(**)	.957(**)	.987(**)	.950(**)	1								
TA	.048	−.466	.498(*)	.522(*)	.576(*)	.633(**)	.503(*)	1							
RSC	.582(*)	−.212	−.428	−.426	−.374	−.272	−.468	.388	1						
SAR	−.588(*)	.207	.495(*)	.524(*)	.409	.335	.474	−.107	−.566(*)	1					
Na percent	−.398	.449	−.197	−.160	−.299	−.363	−.226	−.545(*)	−.313	.727(**)	1				
MEI	−.490(*)	−.211	.911(**)	.932(**)	.872(**)	.822(**)	.901(**)	.396	−.575(*)	.637(**)	.041	1			
DO	−.032	.063	−.504(*)	−.500(*)	−.490(*)	−.493(*)	−.474	−.537(*)	−.018	−.110	.337	−.369	1		
BOD	.066	.001	.513(*)	.492(*)	.500(*)	.525(*)	.461	.575(*)	.090	.162	−.308	.343	−.884(**)	1	
COD	.156	−.129	.570(*)	.560(*)	.533(*)	.554(*)	.498(*)	.416	−.041	.102	−.400	.417	−.788(**)	.772(**)	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Results

Temperature ranges in this study (25.3°C–27.0°C) are within optimum range of aquatic life support system. The mean was 27.0°C (±0.5). There was no significant statistical difference among the sampling sites. ($F = 1.596$; $p > 0.05$). The pH ranged 7.5–8.5. The mean was 8.0 (±0.3) and the significant statistical difference among sampling sites in different seasons ($F = 6.219$; $p < 0.001$). The EC values of the lakes ranged 601–3589 micromhos/cm. The mean was 1409 micromhos/cm (±73.1) and the one-way ANOVA analysis among sampling site showed a statistically significant relationship ($F = 57.217$; $p < 0.001$) . Total dissolved solids ranged 294 –1772 mg/L. The mean was above the desirable level at 674.4 mg/L (±50.1). There was a significant statistical difference among sampling sites in different periods ($F = 30.141$; $p < 0.001$).

Total hardness of the samples ranged 190.2 to 848.1 mg/L as $CaCO_3$.The mean was above the desirable limit at 321.7 mg/L as $CaCO_3$. Standard deviation was (±24.3) with coefficient of variation 8.1%. One-way ANOVA analysis between sampling sites showed a statistically significant relationship ($F = 74.369$; $p < 0.001$). Moreover, Ca Hardness ranged 92.8–428.5 mg/L as $CaCO_3$. The mean was 168 mg/L as $CaCO_3$ (±18.1); the coefficient of variation 11.5% and ($F = 66.671$; $p < 0.001$). Mg hardness exceeded the desirable limits with the mean 154.1 mg/L as $CaCO_3$ (±21.2) and the coefficient of variation of 15.4%. There was a significant difference among sampling sites in different periods ($F = 55.242$; $p < 0.001$).

Dissolved oxygen ranged 2.1–8.1 mg/L. The mean was 4.6 mg/L (±1.5) which was below the optimum level. Coefficient of variation was 33.6%. The biochemical oxygen demand ranged 7.3–46.0 mg/L. The mean was 30.0 mg/L (±10.2). The mean exceeded the BOD limit for inland surface water required for irrigation purposes. Chemical oxygen demand (COD) ranged 120.8 –290.2 mg/L. The mean was 212.6 mg/L (±79.0) and CV = 38.4%.

The ionic concentrations of Na, K, Ca and Mg showed that sodium ranged 109.2–496.0 mg/L. The mean was 189.0 (±15.5), CV = 8.3% and ($F = 18.503$; $p < 0.001$). There is no specific limit in the amount of Na in surface water samples in India. Potassium ranged 16.2–47.0 mg/L. The mean was 30.2 mg/L (±4.0), CV = 13.4%; ($F = 9.516$; $p < 0.001$). The mean exceeded the European Union limit of 10 mg/L. Calcium's mean concentration was within the desirable limit at 67.0 mg/L (±7.4) and a coefficient of variation 11.6%. One-way ANOVA analysis showed ($F = 66.644$; $p < 0.001$). The range was 37.1–171.4 mg/L. Magnesium exceeded the desirable limit of 30 mg/L with a mean of 37.6 mg/L (±6.8) and a coefficient of variation 17.3%. The range was 20.3–102.4 mg/L. There was a statistically significant relationship between groups at ($F = 55.266$; $p < 0.001$).

The anionic characteristics of the surface water samples showed that chloride concentrations were above the desirable limit of 250 mg/L. The mean was 261.2 mg/L (±23.2) and CV = 11.0%; ($F = 75.695$; $p < 0.001$). The range was 73.7–852.8 mg/L. Fluorides mean were within the desirable level and ranged 0.5–1.9 mg/L. The mean was 0.8 mg/L (±0.1) and CV = 16.0%; ($F = 21.990$; $p < 0.001$). Sulphates also were within the desirable level. The mean was 53.0 mg/L (±7.1) and the range was 12.3–203.4 mg/L. Coefficient of variation was 16.0%; (F = 30.237; $p < 0.001$). Orthophosphates ranged 2.3 mg/L–37.2 mg/L as PO_4. The mean was 13.5 mg/L as PO_4 (±2.8) or 4.5 mg/L as P. The coefficient of variation was 26.0%. The maximum limit for phosphates as P is 5.0 mg/L as P; (F = 38.638; $p < 0.001$).

Total alkalinity ranged 126.8–366.0 mg/L. The mean exceeded the desirable limit of 200 mg/L. The mean was 240.5 mg/L (±20.9); CV = 9.0%; (F = 15.663; $p < 0.001$). Carbonates ranged 0.3–51.4 mg/L with a mean of 12.3 mg/L (±5.0); ($F = 6.657$; $p < 0.001$). The US EPA guidelines suggest that carbonates in normal fresh water resources should not go beyond 20 mg/L. Bicarbonates alkalinity ranged 121.2–340.4 mg/L with a mean of 228.2 mg/L (±23.5) and coefficient of variation of 11.0% ($F = 12.238$; $p < 0.001$).

The quality criteria of water for agricultural purposes were surveyed. The results for residual sodium carbonate, sodium adsorption ratio and percentage sodium was as follows: the RSC's mean was 0.4 meq/L (±0.2); ($F = 72.136$; $p < 0.001$). The SAR ranged 4.8–13.4. The mean was 8.1(±0.7) and CV = 9.2%. SAR was slightly above the desirable guideline ($F = 6.495$; $p < 0.001$). As for percentage sodium, the mean was 51.6% (±2.9) and a coefficient of variation 6.0%. The range was 42.0–60.0% ($F = 8.351$; $p < 0.001$). This shows that the Na% was on the threshold limit of 50–60%.

In the assessment of calcium carbonate saturation indices for the surface water potential to be used for industrial purposes, the mean Langelier Saturation Index I_{sat} was +0.5 or the water had the scale forming tendencies. The statistical accuracy in sampling sites was ($F = 3.603$; $p < 0.001$). The Ryzner Stability Index (I_{stab}) had the mean of 6.8 ($F = 7.011$; $p < 0.001$). On the analysis of the MEI in determining the productivity of the water bodies in relation to the fresh water aquaculture and inland fresh water fish yield, the MEI ranged between 32.2–354.4 with a mean of 96.8 (±7.3). One-way ANOVA analysis between sampling sites was ($F = 55.715$; $p < 0.001$). This shows that many water bodies still had the capacity to accommodate optimum aqua-cultural conditions as it was suggested as the best MEI range to support aquatic life that is 50–200.

Discussion

The physicochemical parameters measured in this study provide an interesting depiction of the patterns of effects of pollution in the lakes of Bangalore. Thermal structure and circulation of the lakes are not uniform but depend on the surface area, depth and the volume of the body concerned (Rao and Murthy, 2007). The pH is largely governed by CO_2, CO_3 and HCO_3 and this is probably caused by increase in total dissolved solids. High levels of EC of the industrial effluents could be attributed to the high levels of conducting species such as SO_4, Cl^-, PO_4 and heavy metals (Fakayode, 2005).

Total dissolved solids (TDS) refer to solid matter dissolved in water. High solids may adversely affect water or effluent quality and may cause transient gastrointestinal distress in non-acclimatized consumers. High mineral content in water may also limit its use in many industries. Most of the lakes in the study area are exposed to different forms of chemical species caused mainly by sewage pollution and other waste water inflows.

Dissolved oxygen is the fundamental fuel of life in water. DO in water is of great importance to all aquatic organisms and is considered to be the factor that reflects the biological activity taking place in a water body and determines the biological changes, which are brought about by the aerobic or anaerobic organisms (Dixit et al., 2007). Biochemical oxygen demand (BOD) is directly linked with decomposition of dead organic matter present in the lake and hence the higher values of BOD can be directly co-related with pollution status and an inverse relation with dissolved oxygen concentration and biological oxygen demand values (Dixit et al., 2007).

Piispanen (1993) suggests that some heart ailments have been associated with hardness of water. Other studies suggest that the incidence of kidney stones and mortality from cardiovascular disease are inversely correlated with water hardness (Shariatpatanahi and Anderson, 1987).

In similar context, calcium is exacerbated through leaching of limestone, dolomite, gypsum and gypsiferous slate. Magnesium is a common constituent of natural water. Like calcium, magnesium contributes to water hardness and scale formation in boilers. Sodium is much more soluble than most other cations. Problems to fish life from maximum Na amounts are typically associated with intolerance by fish to extremely high sodium levels in the lake. Excess sodium has a detrimental influence on liming efforts and can cause liming to have little positive effect (Johnson, 1985).

Moreover, Johnson (1985) explains that normal fresh inland surface water contains less than 50 mg/L of sulphates and chlorides. They are considered harmless except where acidity is especially influenced. Another aspect, phosphates, is critical in the lake's eutrophication process. Phosphates, like nitrates, are usually present in slight amounts (less than 0.1 mg/L) in natural surface water. From a conservation perspective, understanding how anthropogenic alterations of the environment may influence competitive interactions is important to evaluate fully the impacts of such changes (Geoffrey et al., 2005).

Similarly, nitrogen in groundwater is ultimately oxidized to nitrates. Consumption of water high in nitrates (or nitrites) can result in induction of infant methaemoglobinaemia. The interim standard of 10 mg/L as nitrogen appears to be protective against infant methaemoglobinaemia; however, there is a narrow margin of safety for some particularly receptive infants.

Total alkalinity is a measure of the basic substances of water. Because in natural water these substances are usually carbonates and bicarbonates, the measurement is expressed as mg/L of equivalent calcium carbonate. It is also important here to note that total alkalinity is often synonymous with the amount of bicarbonates in relation to carbonates and hydroxide alkalinity. In waters having high concentration of bicarbonate, there is a tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated (Kumaresan and Riyazuddin, 2005). This is bad for irrigation schemes that use lake water such as those found in the study area. This is where residual sodium carbonate (RSC), sodium adsorption ratio (SAR) and percentage sodium (Na%), come about in determining a combination of factors crucial for salinity of the water and their potential effects on irrigated soils. The most important characteristics of irrigation water in determining its quality include the relative proportion of sodium to other principal cations (Kumaresan and Riyazuddin, 2005).

Residual sodium carbonate (RSC) can be used as a criterion for finding the suitability of irrigation waters. It is therefore defined as twice the concentration of carbonate or bicarbonate that water would contain after subtracting an amount equivalent to the calcium plus the magnesium, and is a measure of potential hazard which exists when waters high in carbonate and bicarbonate and relatively low in calcium and magnesium are used for irrigation.

Langelier Saturation Index (LSI) and Ryzner Stability Index (RSI) help in determining the scale forming and corrosive tendencies of water vis-à-vis irrigation and industrial usage. Otherwise known as the calcium carbonate saturation index, these indices are influenced by pH, total dissolved solids, Ca, temperature, and phosphates and nitrates alike. The scale forming properties are also influenced by low carbonates levels which gives a positive impact on growth of algae and other phytoplanktons (Mahadev and Hosmani, 2002).

There is a relationship between MEI and fish yield and that is why MEI is a valuable tool for the management of lakes for inland fishery resources. According to Food and Agricultural Organization (2008), many attempts have been made to equate some aspect of productivity of lakes with independent limnological variable and two factors, mean depth and water chemistry. FAO (2008) have shown inverse relationship between mean depth and fish production in lakes. It is important to note that an optimum MEI range is between 50–200 for a favourable aquatic life.

Conclusion

Total and magnesium hardness, total dissolved solids, total alkalinity, dissolved oxygen and biochemical oxygen demand exceeded the Indian standards desirable limits. Magnesium, chlorides and orthophosphates were also excessive. Potassium was above the European Union limit while sodium adsorption ratio was on the threshold. Calcium carbonate saturation indices showed that the water from the surveyed water bodies had a scale forming tendency. Finally, an integrated approach in lake rejuvenation programmes in Bangalore city is critical if the ongoing programmes were to succeed in the mainstream of the economic activities that support a comprehensive water resources management. An increased interaction and co-operation among the various agencies is necessary to enhance protective and restoration measures for Bangalore city lakes. This interaction should primarily focus on the introduction of sewage pumping facilities to replace the current system of sewage transport through natural drainage which is responsible for contamination of various urban water bodies on a large scale. Sewage treatment plants and the creation of sizeable artificial wetlands should be improved and modified in relation to the volume of the inflowing waste water. Creation of wetlands buffer zones with vegetation cover that limit anthropogenic activities (siltation, pollution, etc.) around the demarcated corridor of the wetland should be instituted in any lake rejuvenation programme in the city.

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