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Nutrient Enrichment and Proliferation of Invasive Macrophytes in Urban Lakes

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ABSTRACT Sewage generated in urban households is either untreated or partially treated, which finally let into water bodies through storm water network. Sustained inflow of sewage into water bodies though maintained the water levels in the system of interconnected lakes has contributed to the nutrient enrichment of surface as well as groundwater sources. Nutrient enrichment in urban water bodies has become one of the major environmental concerns in rapidly urbanizing towns and cities in India. In this context, the current study carries out comparative analysis of water quality and ecological health of twelve urban wetlands in Bangalore. Principal component analysis (PCA) and Cluster analysis (CA) were done to assess the ecological integrity of wetlands based on the data of 15 physico-chemical parameters. The loadings of the first and second principal components explain the pollution. CA grouped the wetlands into four distinct clusters: less polluted, moderately polluted, highly polluted and severely polluted based on the water quality parameters. This analyses brings out the importance of regular monitoring and the need to restore and sustainable management of wetlands. The sustained inflow of untreated and partially treated sewage, urban runoff, etc. are the drivers of wetlands quality deterioration.

INTRODUCTION

Wetlands play a pivotal role in supporting extensive food webs and biodiversity. These fragile ecosystems being the interface between terrestrial and aquatic ecosystems, function as kidneys of landscape as it helps in the removal of contaminants. They are biologically rich, productive and support people's livelihood through provision of fish, fodder, etc. They are susceptible to small changes and have become endangered ecosystems in rapidly urbanizing landscapes. India, with highly diverse physiography, monsoon climate with extremes of temporal and spatial variability, and high biotic diversity, is gifted with numerous and equally diverse inland and coastal wetlands (Ramachandra 2001, 2005). These wetlands cover a wide range of ecosystem types and support a rich diversity of flora and fauna (Mitsch and Gosselink 2000; Prasad 2002). It is estimated that fresh water ecosystems support about 20 per cent of the known biodiversity in India (Deepa and Ramachandra 1999; Ramachandra and Solanki 2007). India has a total of 67,492 wetlands, covering about 4.1 million hectares. Out of which, natural wetlands accounted to 2,715, covering about 1.5 million hectares and 65,254 man-made wetlands, occupying about 2.6 million hectares (Ramachandra 2005). Wetlands in India are increasingly facing several anthropogenic pressures due to rapid urbanization consequent to globalization and opening up Indian markets. Unplanned urbanization has led to large scale land use/land cover changes posing threat to the sustainability of wetland resources. Expansion of urban centers, agricultural and industrial settlements, have altered hydrological regime and also has contaminated numerous water bodies (Krishne and Sridhara 2007). Rapid urbanization and economic developments have extensively impacted wetlands and has transformed them to other land uses for short term economic gains (Gopal 2013). The anthropogenic activities, like unplanned urban and agricultural development,

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industries, road construction, impoundments, resource extraction, and dredge disposal had transformed the wetlands leading to economic and ecological losses (Ramachandra 2005). Wetlands have been relegated into sinks of domestic sewage and industrial effluents which have threaten the existence of dependent biota. Heavy loads of nutrients have paved the way for many invasive exotic species affecting the native species and altered the community composition. This necessitates regular monitoring to evolve appropriate management strategies to maintain ecological health of wetlands. The assessment of nutrient enrichment and ecological health of wetlands is a complex process because large no of interrelated variables are involved including both physico-chemical and biological factors (Ignatiades et al. 1985; Vollenweider et al. 1992). Principal Component Analysis (PCA) and Cluster Analysis (CA) helps in the evaluation of environmental data. These techniques helps in reducing dimensions of the data and new variables are uncorrelated (Sharma 1996; Kazi et al. 2009; Najar and Khan 2012). These techniques helped in prioritizing wetlands based on environmental parameters.

Objectives

The objective of this study was to characterize urban wetlands through physico-chemical monitoring of selected lakes and identification of possible factors affecting water quality in wetlands.

MATERIAL AND METHODS

Study Area

Bangalore city, Karnataka, India is located between 12°39´ - 13°18´N and 77°22´ - 77°52´ E. Bangalore (Fig. 1) city with a large number of lakes, ponds and marshy wetlands, which maintains ground water table and pleasant climate. Bangalore has no natural lakes but large numbers of manmade lakes that were built for various hydrological purposes and to meet the needs of drinking water and irrigation. Land use dynamics show 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Analyses of the temporal data reveals an increase in urban built up area of 342.83% (during 1973 to

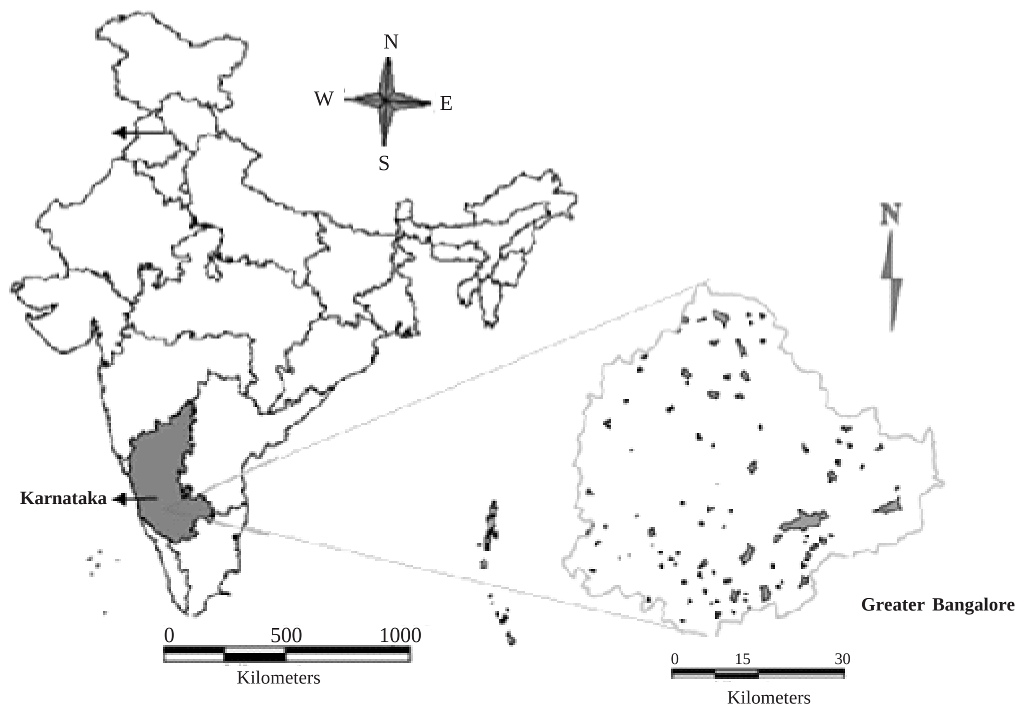

Fig. 1. Study area Bangalore, Karnataka, India.

1992), 129.56% (during 1992 to 1999), 106.7% (1999 to 2002), 114.51% (2002 to 2006) and 126.19% from 2006 to 2010 (Ramachandra and Kumar 2008; Ramachandra et al. 2012) due to rapid and unplanned urbanization and expansion. Now, many of the existing lakes are reduced to cesspools due to direct discharge of industrial effluents, sewage and unregulated dumping of solid wastes (Ramachandra et al. 2003). Figure 2 depicts lakes chosen for the study in Bellandur catchment. Table 1 lists lake wise number of sampling sites and spatial extent of monitored wetlands.

Analysis of Various Physico-chemical Parameters

Water samples were collected in disinfected plastic polyethylene bottles from identified locations in lakes (Table 1, Fig. 2) between 7:30 a.m. and 2:00 p.m. Water samples were preserved in the laboratory at 4°C for further analysis. At respective sampling locations, parameters such as temperature, dissolved oxygen, total dissolved solids, electrical conductivity and pH were measured. While, chloride, alkalinity, total hardness, calcium hardness, magnesium hardness, sodium, potassium, nitrate and phosphate were quantified at laboratory as per the standard protocol (Trivedy and Goel 1986; APHA 2005) listed in Table 2.

Data Analyses

Multivariate statistical analysis of the water quality variables was done through Principal Component Analysis (PCA) and Cluster Analysis (CA).

Table 1: Urban wetlands with spatial extent and location

Lake ID	*Name*	*Location (Lat./Long.)*	*Area (ha)*	*No. of Sampling sites*
1	Lalbagh	12°94´/77°58´	14.27	3
2	Sankey	13°008´/77°57´	15.00	3
3	Yediyur	12°97´/77°57´	4.28	2
4	Begur	12°87´/77°63´	79.24	2
5	Doddakalsandra	12°88´/77°56´	6.23	2
6	Kothnur	12°87´/77°57´	5.38	2
7	Chunchunghatta	12°88´/77°57´	7.69	1
8	SubbrayanKere	12°86´/77°58´	5.00	1
9	Hulimavu	12°87´/77°60´	51.41	1
10	Arekere	12°88´/77°60´	10.57	1
11	Madivala	12°90´/77°61´	100.60	1
12	Kodagisingasandra	12°87´/77°64´	3.04	1

Table 2: Methods used for water quality analysis

Parameters	*Method used*	*Inland waters tolerance limit*	*References*
Te	Mercury thermometer	40	
EC	Digital meter	-	
TDS	Digital meter	500 mg/l (BIS 1998)	
pH	Digital meter	6.5–8.5 BIS (IS: 10500, 1992)	
DO	Digital meter	3	
Cl	Titrimetric method	1000	APHA 2005
Al	Titrimetric method	500 mg/l (BIS 1998)	APHA 2005
Ha	Titrimetric method	600 mg/l (BIS 1998)	APHA 2005
Ca	Titrimetric method	200 mg/l (BIS 1998)	APHA 2005
Mg	Titrimetric method		APHA 2005
NO	Spectrophotometric method	45 mg/l	Brown and Bellinger 1978
PO	Spectrophotometric method	0.3 mg/l	Edwards et al. 1965
Na	Flame photometric method	200 mg/l	APHA 2005
K	Flame photometric method	10 mg/l (BIS 1998)	APHA 2005
COD	Dichromate method		APHA 2005

Te-Water Temperature (°C), EC-Electrical Conductivity (ìS/cm), TDS-Total Dissolved Solids, DO-Dissolved Oxygen (mg/l), COD-Chemical Oxygen Demand (mg/l), Al-Total Alkalinity (mg/l), Cl-Chloride (mg/l), Na-Sodium (mg/l), K-Potassium (mg/l), Ha-Total Hardness (mg/l), Ca-Calcium Hardness (mg/l), Mg-Magnesium Hardness (mg/l), NO-Nitrate, PO-Phosphate (mg/l).

Fig. 2. Spatial distribution of lakes

RESULTS AND DISCUSSION

Physico-chemical Monitoring of Selected Lakes

Table 3 lists physico-chemical properties of water samples across 12 lakes chosen for the current study, which showed marked variations in all the physico-chemical parameters due to seasonal variations and anthropogenic activities.

Water Temperature

Water temperature is one of the important factor in an aquatic environment influencing all the metabolic and physiological activities and life processes (like feeding, reproduction, movements and distribution) of aquatic organisms (Rani et al. 2012). Water temperature showed both the seasonal and diurnal variations with higher values in Begur, Doddakalsandra, Chunchunghatta, Subbrayankere, Hulimavu, Madivala, and Kodagisingasandra lakes (sampled during the afternoon). The average water temperature ranged from 23.05°C-28.07°C.

pH

pH of water changes with time due to exposure to air, variation in temperature and due to biological activities. pH is governed by the equilibrium between carbon dioxide, carbonate and bicarbonate ions. pH in most of the lakes except Arekere was alkaline due to the excessive growth of algae. Average pH ranged from 7.8-9.38 except Arekere and beyond the limits of BIS (IS: 10500, 1992; guidelines of 6.5–8.5). Relatively lower pH in Arekere is due to the luxuriant growth of emergent (*Typhaangustata***,** *Alternanthera-phyloxeroides*) macrophytes, similar to the earlier report of Yamoussoukro's lake system by Parinet et al. (2004).

Table 3:Physico-chemical properties of water samples across 12 lakes

Lake ID	*Summary*	*Te*	*pH*	*EC*	*TDS*	*DO*	*COD*	*Al*	*CI*	*Na*	*K*	*Ha*	*Ca*	*Mg*	*NO*	*PO*
1	Mean	23.05	9.30	560.80	249.50	8.50	48.00	143.10	85.20	141.10	41.04	92.90	16.90	18.50	0.43	0.09
	SD	1.50	0.53	43.20	19.80	2.60	45.22	10.90	10.24	31.20	8.60	4.90	2.70	1.10	0.05	0.01
	Range	21.5-26.2	8.2-10.3	493-611	220-275	4.9-13.7	16-160	120-160	68.16-97.58	38.4-169.6	27.6-52	84-100	13.62 -23.25	16.71- -20.48	0.37 -0.51	0.08-0.1 0.08-0.1
2	Mean	22.98	9.30	472.88	211.64	9.80	44.78	149.67	66.10	106.96	19.99	94.61	16.74	18.95	0.38	0.09
	SD	2.11	0.55	24.42	10.62	4.65	36.96	12.33	3.16	27.81	7.15	4.67	3.43	0.96	0.08	0.02
	Range	21.1- 26.5	8.2 -10.3	420.33 504.00	-197 -228	4.90- 18.78	16- 160	130- 174	58.22 - 70.29	21.6 - 156.8	12.4- 35.6	87 -106	12.83- 24.85	16.80- 21.26	0.278 -0.504	0.068- 0.119
3	Mean	24.09	8.68	702.88	317.63	5.45	31.67	213.33	93.64	140.44	32.44	185.25	42.28	30.88	0.43	0.16
	SD	1.91	0.17	91.91	43.64	1.90	20.73	39.99	12.72	29.10	8.89	45.97	5.90	5.37	0.17	0.09
	Range	22.3- 27.2	8.4 -8.9	575- 848	259- 382	2.31- 8.66	8 -80	154- 284	71.0 - 113.6	100.8- 193.2	16.8 -41.6	120-284	32.06 50.50	20.98 -41.04	0.291 -0.685	0.085 - 0.277
4	Mean	27.15	9.37	2589.95	1319.67	9.30	176.00	214.83	714.29	1142.95	190.00	194.67	43.43	36.75	0.86	0.31
	SD	4.71	0.46	776.14	479.94	1.54	10.37	85.13	41.06	56.23	14.25	68.53	14.95	7.23	0.11	0.09
	Range	23.3 -33.4	8.9-9.7	1786-3380	845-1804	8-8.46	80-520	160-464	310-12 72.32	446.4- 1800.8	94.4- 304.8	148- 246	36.67 -54.5	26.03- 46.72	0.73- 1.00	0.19- .41
5	Mean	26.82	9.38	1706.33	836.67	13.55	50.00	442.50	310.36	475.62	72.54	330.72	76.29	61.90	0.47	0.68
	SD	3.78	0.33	80.93	22.90	6.58	20.68	57.62	47.07	203.09	7.27	39.70	10.29	7.93	0.01	0.19
	Range	24.3-31.7	8.9-9.81	570-1786	807-855	6.06- 21.53	20-96	384-548	227.2- 357.84	210.4- 743	59-78	284- 381	61.72 -88.18	53.62 -74.72	0.45- 0.49	0.49- 0.94
6	Mean	24.56	9.18	1266.95	594.71	8.07	58.00	230.86	229.18	330.14	31.14	182.86	37.53	35.36	0.34	0.09
	SD	2.00	0.51	309.30	155.57	2.32	53.30	16.34	40.97	26.69	8.07	8.44	3.61	2.77	0.16	0.02
	Range	22.5-27.7	8.4-9.8	575-1544	259-752	4.88- 1156	12-200	196-248	180.34 -284	300.4 -376	22-44.4	62-1921	32.87 -45.69	29.63- 38.43	0.14- 0.51	0.06- 0.11
7	Mean	25.35	8.68	1347.25	635.25	7.64	84.00	406.67	171.13	246.20	57.60	286.83	70.00	52.77	0.42	0.94
	SD	1.47	0.39	38.64	23.66	3.11	80.12	52.58	12.35	50.74	6.50	23.28	3.79	5.92	0.08	0.07
	Range	24.2-27.5	8.3-9.1	1294-1382	602-685	4.88- 11.63	24-232	304-444	157.62- 186.87	169.6- 300	46.4-64	256-320	64.12 -74.55	45.26- 61.65	0.36- 0.47	0.9- 0.99
8	Mean	28.43	8.85	859.50	398.75	13.38	58.67	217.33	148.86	222.23	29.12	173.20	45.42	31.09	0.40	0.10
	SD	2.87	0.40	127.42	71.19	5.33	42.83	46.92	47.57	48.35	6.86	32.17	8.81	5.78	0.08	0.00
	Range	25.8-31.8	8.5-9.4	701-970	309-464	9.43- 20.95	20-136	164-284	82.36- 201.64	152.4- 271.2	22- 37.6	134- 207.2	33.66- 54.25	23.89- 37.25	0.34- 0.45	0.094- 0.099
9	Mean	26.70	8.70	1495.00	755.50	6.28	332.00	344.00	243.85	300.57	58.22	309.17	61.40	60.30	0.34	0.09
	SD	2.00	0.42	191.10	35.14	4.70	16.97	28.09	47.24	114.24	6.75	18.29	17.63	5.82	0.05	0.01
	Range	25.2-29.6	8.3-9.3	1211-1609	710-794	1.89- 12.05	320-344	314-384	184.4- 297.49	164-449	45.2-64.4	294-340	32.86- 80.16	52.74- 68.95	0.304 -0.37	0.082- 0.95
10	Mean	24.26	7.80	1420.13	675.25	1.87	90.00	441.43	242.82	293.91	44.37	316.14	81.76	55.14	0.28	0.81
	SD	4.00	1.04	536.22	263.19	0.52	75.93	151.05	13.60	43.66	11.95	18.73	3.44	9.20	0.20	0.07
	Range	20.53-29.9	6.8-8.7	623-1761	282-827	1.17-2.31	16-200	116-560	214.42- 254.18	224.6- 341.6	22.2-52.8	278-334	75.35- 84.97	38- 64.86	0.052- 0.44	0.73- 0.86
11	Mean	27.95	8.78	1290.00	608.50	8.58	81.00	301.71	182.98	243.77	30.89	201.63	44.34	39.63	0.31	0.08
	SD	3.05	0.61	191.80	87.55	3.79	70.23	51.28	29.56	29.52	7.00	7.33	4.57	4.40	0.24	0.02
	Range	24.6-31.3	8-9.4	1111-1553	508-710	3.05- 11.39	16-160	208-360	149.1- 221.52	216.4- 282	22-39	188- 210	36.07- 50.5	33.41- 47.90	0.04- 0.5	0.06- 0.11
12	Mean	27.78	9.30	1509.50	727.50	15.40	123.33	236.67	395.11	594.46	74.06	216.17	41.34	40.16	0.44	0.12
	SD	2.51	0.59	543.63	286.58	4.02	112.72	30.92	44.95	267.89	15.31	15.56	12.41	4.39	0.23	0.02
	Range	25.6-30.1	8.5-9.8	701-1869	309-954	9.43- 18.16	40-320	192-268	333.28 -454.4	297.2- 912.8	59.6- 95.2	200-235	33.67- 65.73	31.12- 44.74	0.25 -0.7	0.09- 0.14

Electrical Conductivity (EC)

Electrical conductivity (EC) depends on the concentration and nature of the ionized substances dissolved in water representing the total ion content (Zacheus and Martikainen 1997). EC in sampled lakes ranged from 472.88-2589.95 µS/cm. Average EC of Doddakalsandra, Begur and Kodagisingasandra exceeded the WHO (2004) guidelines of 1500 µS/cm denoting the high inputs of sewage and domestic waste waters, comparable to Yamoussoukro's lake system (Parinet et al. 2004). Increased evaporation during the dry period has concentrated the ionic contents in water which also raised the conductivity values. Electrical conductivity of 2589.95 µS/cm was recorded at Begur due to sodium ion concentrations with excessive use of detergents for washing clothes and vehicles in the lake.

Total Dissolved Solids (TDS)

TDS indicate the concentrations of common ions (for example, sodium, potassium, calcium, magnesium, chloride, sulfate, and bicarbonate) in freshwaters. TDS of most lakes excluding Lalbagh, Sankey, Yediyur and Subbrayankere exceeded the limits of 500mg/l according BIS and ICMR standards. TDS ranged from 211.64mg/l-1319.67mg/l. Highest TDS at Begur Lake was due to the presence of high concentrations of major cations as well as anions in the lake. A high content of dissolved solids elevates density of water, influences osmoregulation, and reduces gas solubility and utility of water for drinking, irrigation and industries (Manivasakam 2003).

Dissolved Oxygen (DO)

Dissolved oxygen in aquatic systems is a very important as it affects physical, chemical and biological processes in the system. The depletion of oxygen also indicates the presence of high organic loads in the lake (Trivedy and Goel 1986). DO range from 1.87mg/l -15.47mg/l in the studied lakes. The lowest DO was observed in Arekere due to the excessive growth of floating macrophytes in the lake that prevented light penetration into the water, resulting in lower rates of photosynthesis by phytoplankton. Invasive macrophytes covering the water surface of a lake induces anaerobic conditions by deprivation of air water interface (Durga et al. 2010). This leads to the decline of algal growth due to lack of photosynthesis with deprivation of sun light. The high DO in Kodagisingasandra and Doddakalsandra is mainly due to the high photosynthetic activities in algae. Algal mats were seen floating in Doddakalsandra Lake.

Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is the measure of total oxygen required for the complete oxidation of organic matter present in the water body by using a strong chemical oxidant such as dichromate (APHA 2005). COD is an indicator of organic pollution in aquatic ecosystems (Siraj et al. 2010). COD values ranged from 31.67 mg/l in Yediyur to 332 mg/l in Hulimavu. The highest COD was observed in Hulimavu due to the inflow of sewage into the lake as well as high anthropogenic activities on the lake banks. Khuhawari et al. (2009) associated higher values of COD with increased anthropogenic pressures on lakes and it is evident from the results that COD values of all the lakes were very high, an indication of flooded organic matter.

Alkalinity

Alkalinity is a measure of the ability of water to neutralize acids. It is due to the presence of bicarbonates, carbonates and hydroxide of calcium, magnesium, sodium, potassium and salts of weak acids and strong bases as borates, silicates, phosphates, etc. (APHA 2005). Large amount of alkalinity imparts a bitter taste, harmful for irrigation as it damages soil and hence reduces crop yields (Sundar and Saseetharan 2008). The alkalinity ranged from 143.1 mg/l (in Sankey) to 442.50 mg/l (in Doddakalsandra). The alkalinity values were well within the permissible limit of 500 mg/l (BIS 1998) in all lakes.

Chloride

Chloride ions are generally present in natural waters in the form of salts of sodium, potassium and calcium. The main sources of chlorides in lakes are the dissolution of salt deposits, discharges of effluents from industries, sewage discharges, irrigation, etc. (Manivasakam 2003). The average chloride concentration in sampled lakes ranged from 66.10 mg/l (Sankey) to 714.29 mg/l (Begur) and the values were within the permissible limit of 1000mg/l.

Total Hardness

Hardness primarily due to the presence of calcium and magnesium ions measures the capacity of water to precipitate soap. Some cations (like iron, strontium and manganese) and anions (such as carbonates, bicarbonates, sulphate, chloride, nitrate and silicates) contribute to hardness in aquatic ecosystems (APHA 2005). The hardness ranged from 92.9 mg/l (Lalbagh) to 330.72 mg/l (in Doddakalsandra). The degree of hardness of drinking water has been classified (WHO 2004) in terms of its equivalent $CaCO_3$ concentration and accordingly Lalbagh and Sankey fall in medium hard category (75 mg/l –150 mg/l), Yediyur, Begur, Kothnur, Subbrayankere, Chunchunghatta, Madivala and Kodagisingasandra in hard category (150 mg/l –300 mg/l) and Arekere, Hulimavu, and Doddakalsandra in very hard category (Above 300 mg/l). The calcium hardness ranged from 16.9 mg/l (Lalbagh) to 76.29 mg/l (Doddakalsandra) and was well below the permissible limits of 200 mg/l (BIS 1998) in all the lakes. The magnesium ranged from 18.5 (Lalbagh) to 61.90mg/l (Doddakalsandra).

Sodium and Potassium

The average concentration of major cations Na and K ranged from 106.9 mg/l 6 (Sankey) to 1142.95 mg/l (Begur) and 19.99 mg/l (Sankey) to 190 mg/l (Begur) respectively. The average Na concentrations of all lakes except Lalbagh, Sankey and Yediyur are above the permissible limit of 200 mg/l. The average K concentration of all the lakes is above the permissible limit of 10 mg/l (BIS 1998). The high sodium and potassium concentration shows that the lakes are fed by sewage (Bhat et al. 2001).

Nitrate

Nitrate concentration in groundwater and surface water is normally low but can reach high levels as a result of agricultural runoff or contamination with human or animal wastes (Nas and Berktay 2006). The average nitrate content ranged from 0.28 mg/l (Arekere) to 0.86 mg/l (Begur). All lakes showed nitrate values below the permissible limit of 45 mg/l.

Phosphate

The average phosphate concentration ranged from 0.09 mg/l (Sankey) to 0.94 mg/l

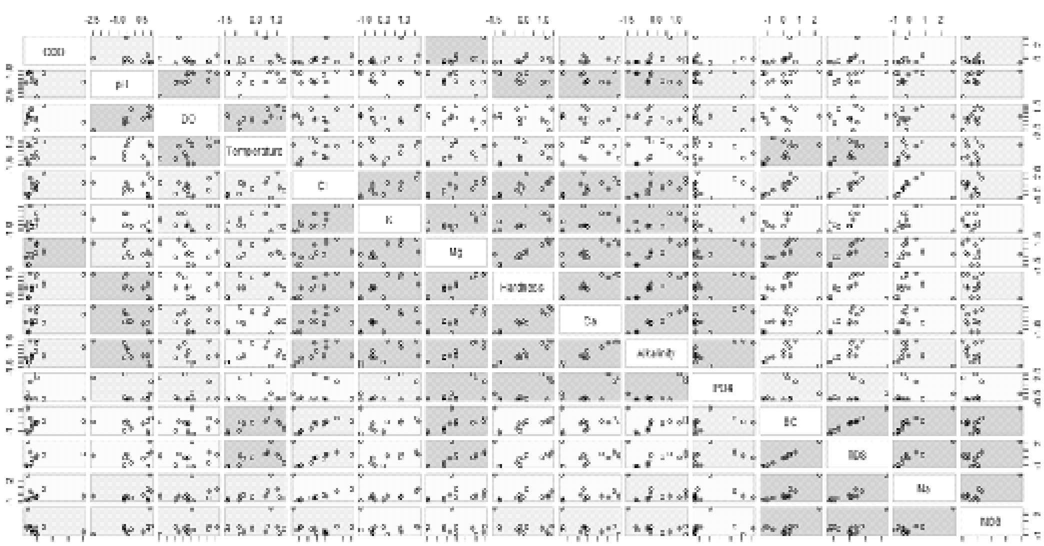

Fig. 3. Scatter matrix showing the correlation strength between variables

(Chunchunghatta). Average phosphate concentration of Begur, Arekere, Chunchunghatta, Doddakalsandra was above the permissible limit of 0.3 mg/l. The surplus amount of phosphate along with nitrate results in nutrient enrichment in aquatic ecosystems and enhances phytoplankton growth (Pandit and Yousuf 2002).

Identification of Possible Factors Affecting the Water Quality of Lakes

Wetlands in Bangalore are interconnected, allowing the transaction of water from wetlands at higher gradient to subsequent low gradient ones. All sampled wetlands are located in the Bellandur catchment. Correlation (Table 4) and Scatter matrix (Fig. 3) were computed in order to analyze to correlation among the variables. In scatter matrix pink box show high and significant degree of correlation between the variables, the blue boxes show moderate degree of correlation and the yellow boxes show no correlation between the variables. From the scatter matrix and the Pearson's correlation matrix, variables in the data set are correlated. Considering the large no of interrelated variables PCA (Principal Component Analysis) was applied to reduce the dimensionality of the variables by transforming the data into a new set of variables—the principal components (PCs), which are orthogonal (non-correlated) and are arranged in decreasing order of importance.

Principal Component Analysis (PCA)

PCA provides information on the most meaningful parameters, which describes a whole data set affording data reduction with minimum loss of original information (Helena et al. 2000; Sarbu and Pop 2005).

The data set of the physico-chemical parameters was first standardized by taking the z-scores (Table 5). The standardization tends to minimize the influence of difference on variance of variables and eliminates the influence of different units of measurements and renders the data dimensionless. PCA was done with these normalized data sets of 15 physicochemical parameters across 12 lakes**.**

Table 6 provides the results of PCA are indicated in the Table 6. The principal component analysis showed that the eigen values of first two principal components accounted for 69.2%

Table 4: Correlation matrix of the physico-chemical parameters

	Te	*pH*	*EC*	*TDS*	*DO*	*COD*	*Al*	*Cl*	*Na*	*K*	*Ha*	*Ca*	*Mg*	*NO*	*PO*
Te	1														
pH	0.1	1													
EC	0.55	0.08	1												
TDS	0.54	0.1	1*	1											
DO	0.54	0.73*	0.09	0.09	1										
COD	0.36	-0.11	0.51	0.53	-0.15	1									
Al	0.24	-0.54	0.42	0.4	-0.25	0.21	1								
Cl	0.49	0.26	0.93*	0.94*	0.22	0.43	0.12	1							
Na	0.47	0.35	0.9*	0.91*	0.27	0.37	0.04	0.99*	1						
K	0.35	0.31	0.86*	0.88*	0.15	0.42	0.04	0.94*	0.96*	1					
Ha	0.36	-0.48	0.55	0.54	-0.19	0.41	0.95*	0.28	0.2	0.19	1				
Ca	0.32	-0.59#	0.49	0.48	-0.25	0.25	0.96*	0.22	0.15	0.15	0.97*	1			
Mg	0.39	-0.41	0.58#	0.56	-0.15	0.48	0.94*	0.29	0.21	0.2	0.99*	0.93*	1		
NO	0.22	0.51	0.62#	0.64#	0.27	0.15	-0.25	0.78*	0.84*	0.91*	-0.13	-0.13	-0.13	1	
PO	-0.08	-0.43	0.34	0.31	-0.27	-0.11	0.8	0.13	0.1	0.18	0.68#	0.79*	0.63#	0.03	1

* $p<0.01$
\# $p<0.05$

Table 5: Z scores of physico-chemical parameters

Lake ID	*Te*	*pH*	*EC*	*TDS*	*DO*	*COD*	*Al*	*CI*	*Na*	*K*	*Ha*	*Ca*	*Mg*	*NO*	*PO*
1	-1.39	0.77	-1.22	-1.19	-0.13	-0.47	-1.06	-0.94	-0.74	-0.08	-1.24	-1.25	-1.47	0.04	-0.63
2	-1.43	0.77	-1.37	-1.32	0.22	-0.51	-1.00	-1.12	-0.86	-1.19	-1.22	-1.26	-1.44	-0.31	-0.65
3	-0.86	-0.58	-0.98	-0.97	-0.94	-0.67	-0.47	-0.86	-0.75	-0.54	-0.22	-0.15	-0.63	0.06	-0.42
4	0.72	0.92	2.28	2.33	0.08	-0.60	-1.47	-1.32	2.77	-1.21	-1.48	-1.35	-0.23	2.93	0.03
5	0.54	0.95	0.76	0.74	1.21	-0.45	1.47	1.19	0.43	1.58	1.39	1.33	1.48	0.29	1.20
6	-0.62	0.50	0.00	-0.05	-0.24	-0.35	-0.32	0.42	-0.08	-0.60	-0.25	-0.36	-0.32	-0.59	-0.65
7	-0.21	-0.58	0.14	0.08	-0.36	-0.03	1.17	-0.13	-0.38	0.79	0.90	1.06	0.86	-0.06	2.01
8	1.37	-0.20	-0.71	-0.70	1.17	-0.34	-0.43	-0.34	-0.46	-0.71	-0.35	-0.01	-0.61	-0.16	-0.62
9	0.48	-0.52	0.39	0.48	-0.72	3.01	0.64	0.56	-0.18	0.82	1.15	0.68	1.37	-0.59	-0.65
10	-0.77	-2.47	0.26	0.21	-1.89	0.04	1.46	0.55	-0.21	0.09	1.23	1.57	1.02	-0.95	1.59
11	1.13	-0.36	0.04	-0.01	-0.11	-0.07	0.28	-0.01	-0.38	-0.62	-0.04	-0.06	-0.03	-0.77	-0.66
12	1.04	0.77	0.42	0.38	1.71	0.45	-0.27	2.00	0.85	1.66	0.12	-0.19	0.00	0.12	-0.56

Table 6: Eigen values of the first three principal components

Parameters	*PC1*	*PC2*	*PC3*
Te	-0.133	0.295	-0.253
pH	0.206	0.249	-0.344
EC	-0.158	0.421	0.197
TDS	-0.150	0.425	0.196
DO	0.059	0.235	-0.532
COD	-0.200	-0.013	-0.161
Al	-0.377	-0.117	0.041
CI	-0.295	0.052	-0.377
Na	-0.010	0.472	0.141
K	-0.300	0.047	-0.320
Ha	-0.390	-0.088	-0.039
Ca	-0.380	-0.105	0.056
Mg	-0.384	0.094	0.069
NO	0.134	0.412	0.204
PO	-0.261	0.005	0.338
Standard deviation	2.500	2.038	1.438
Proportion of Variance	0.415	0.277	0.138
Cumulative Proportion	0.415	0.692	0.830

of total variance (PC1 41.52%; PC2 27.2%) in the data set. The percentage of the explained variability rises up to 83.01% when taking into account three components. However, considering large number of variables (15) studied, PC1 and PC2 were considered for further analysis.

The PC1 which accounted for 41.2% of the variability in the data set with strong positive loadings for pH, DO and Nitrate. The positive values of these variables for this component indicate the colonization of the lakes by phytoplanktons. Nitrate facilitates the growth of phytoplanktons in tropical lakes which in turn result in an increase in pH and DO.

PC2 accounted for 27.2% of variability in the data set with strong positive loadings for T, Na, K, EC, TDS, Cl, Mg, nitrate and phosphate. The positive values for these variables for this component show allochthonous inputs due to urban pollution in lakes. This component mainly represents the anthropogenic pollution of sewage and domestic waste waters into the lakes. These are in consistent with those observed for Yamoussoukro's lake system (Parinet et al. 2004).

The scores of 12 lakes and the loadings of 15 variables are shown in Figure 4. A close look at this figure shows that well correlated variables of pH, DO and NO_3^- contribute to the construction of PC1. The observation of the data shows that these variables are linked to the dominance of algae in lakes number 4 and 12. Strong loadings of TDS, EC, Na, T, and moderate loadings of Mg, K, Cl and PO_4^{3-} contribute to the con-

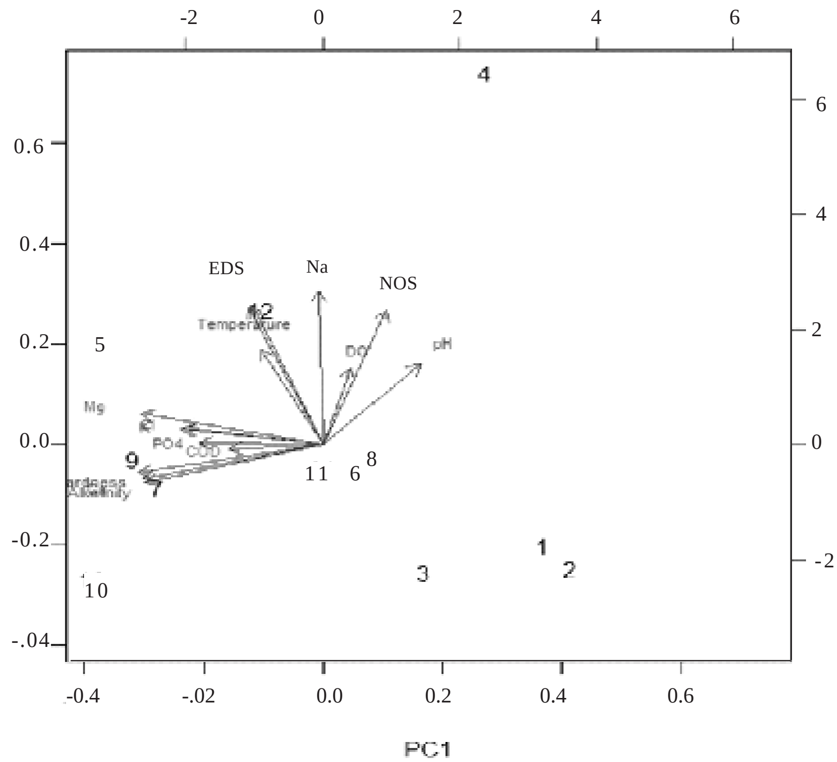

Fig. 4. Loadings of the 15 experimental variables and scores of the lakes (1-12) on the plane defined by principal components 1 and 2

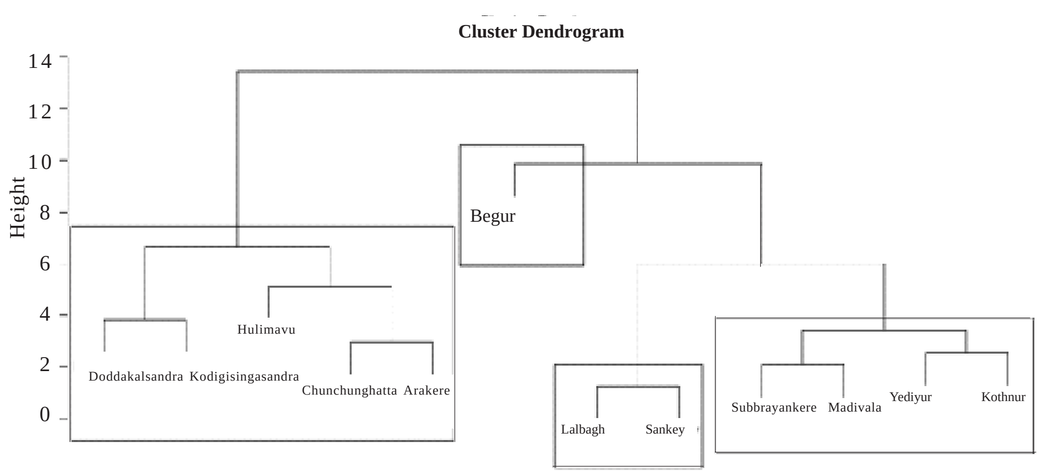

Fig. 5. Dendrogram of cluster analysis based on surface water quality of 12 lakes.

struction of PC2. These variables are linked to the discharge of sewage, domestic and industrial wastes in lakes (sampled lakes at 4, 5, 9 and12)

Cluster Analysis

The Cluster Analysis (CA) clusters variables based on internal (within-cluster) homogeneity and high external (between-cluster) heterogeneity. Hierarchical agglomerative clustering, illustrated by a dendrogram (tree diagram) provides similarity relationships between any one sample and the entire data set (McKenna 2003). The dendrogram depicts various groups and their proximity, with a reduction in dimensionality of the original data. The Euclidean distance provides the similarity between two samples, and a distance can be represented by the difference between analytical values from the samples (Otto 1998; Varol et al. 2009).

In the present study, hierarchical agglomerative CA was performed on the normalized data set by means of the Ward's method, using squared Euclidean distances as a measure of similarity. Cluster analysis resulted in a dendrogram, grouping all the 12 lakes into four statistically significant clusters (Fig. 5). The cluster 1 comprises less polluted lakes like Lalbagh and Sankey. Subbrayankere, Madivala, Yediyur and Kothnur were grouped into the second cluster, which corresponds to the moderately polluted lakes. Cluster 3 includes Doddakalsandra, Kodagisingasandra, Chunchunghatta, Hulimavu, and Arekere corresponds to highly polluted lakes. Begur showed an abnormal behavior because of its relatively higher value of variables which contributed to the construction of both PC1 and PC2 and thus is classified in a separate, very highly polluted cluster 4. This lake is characterized by extreme degree of physical and biological pollution. The CA had grouped the restored (Lalbagh and Sankey) and maintained lakes (Madivala, Yediyur and Kothnur) into the same cluster of low and moderately polluted lakes respectively. Thus, more attention is to be paid on lakes in cluster three and four through regular monitoring of their water quality and by adopting restoration measures in order to prevent their degradation as well as disappearance from the landscape. Immediate steps need to be taken by the policy makers to prevent these ecologically sensitive habitats as well as the associated diversity from becoming extinct.

CONCLUSION

The current study based on sampling of water in twelve urban wetlands in Bellandur catchment showed that some lakes are highly contaminated due to the sustained inflow of untreated or partially treated sewage and effluents. The physico-chemical parameters in water samples collected from lakes exceeded the permissible limits set by BIS and ICMR standards for drinking quality and inland waters. PCA analysis further substantiate anthropogenic pollution, evident from the extent of respective variables loadings of the first and second Principal components. CA grouped the lakes into four separate clusters: less polluted, moderately polluted, highly polluted and very highly polluted based on the different water quality parameters. The sustained inflow of sewage and dumping of wastes have degraded the water quality. The present study urges the need for the restoration of degrading lakes in Bangalore to ensure sustainability of a healthy ecosystem. Appropriate aquatic conservation strategy is necessary to maintain and conserve spatial connectivity within and between the watersheds and also to preserve the quality of water necessary to support biotic components of wetland ecosystems.

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