

Limnology of Kandy Lake before the outbreak of cyanobacteria bloom in May 1999. I. Physicochemical characteristics

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Abstract

The Kandy Lake, a man-made water body, located in the heart of the second largest city of the island adjoining the world-renowned Buddhist temple, was examined for its physicochemical characteristics. Monthly sampling was carried out at four sites for a period of two years (September 1996-August 1998) and physicochemical characteristics and nutrient concentrations were analyzed to determine the spatial and temporal patterns of the basic limnological features. Physicochemical characteristics of surface water in the Kandy lake did not show significant spatial variability depicting a homogeneous nature but, marked vertical gradients of some parameters were noted in the deeper basin. Although, annual range of surface temperature varied within the tropical range, a temperature/density micro-stratification was prominent under calm conditions.

Bicarbonate and calcium dominant alkaline lake water was about three fold conductive than the inland surface waters found at similar elevations. Alkaline water becomes acidic in the deeper layers and the water column of the deep basin was characterised with a clinograde oxygen profile with the incidents of anoxia. The ratio of total inorganic-N to total-P indicated phosphorous limiting conditions but concentrations of reactive phosphorous were available for rapid uptake by phytoplankton. The dynamic fluctuations of $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ and the upper limit of $\text{NH}_4\text{-N}$, the most dominant nitrogen species indicate extremely high heterotrophic potential in the bottom water under less oxygen conditions.

Introduction

The island Sri Lanka which has no natural lakes, is fairly well documented in limnological literature for its planktonic flora and fauna since the first quarter of the last century. Basic limnological characteristics of man-made water bodies had been examined since 1960s. This includes the studies on Beira Lake located in the heart of the capital of the country (Costa & De Silva, 1996). An ecological study

on meso and macro fauna of the littoral region of the Kandy lake was conducted during the latter part of 1970s' (De Silva and De Silva 1984). Studies launched on Parakrama Samudra in 1980 shed light on limnological processes and functions of a dry zone man-made lake which is primarily used for irrigation of rice paddy (Schiemer 1983). Since then various aspects of limnology of irrigation tanks, hydropower reservoirs etc., had been examined by Sri Lanka as well as foreign limnologists (see Costa and de Silva 1996; Silva and Schiemer 2001). Beira lake became a nuisance water body with a permanent bloom of two co-existing cyanobacteria species and the Kandy lake, which is one of the most aesthetic water bodies in the country located in the second largest city and the hill capital was labeled as a polluted water body (Dissanayake et al. 1982, 1986). Subsequently Silva (1996) categorized the Kandy lake as a eutrophic water body which is susceptible to hyper-eutrophication because of very high anthropogenic pressures from riparian communities

Man-made water bodies in the tropical latitudes are reported to be poorly studied with respect to their present density throughout the world (Talling and Lemoalle 1998). The poor knowledge on Asian limnology is coincided with the low density of natural lakes in the region and poor development of inland fisheries until quite recent (Fernando 1984) but, lack of expertise also seems to be a crucial factor. Besides, the available information has little deviation from predictable limnological studies and holistic approaches integrating land-water interactions have still received little attention (Schiemer 1983; Amarasinghe et al. 2003). Silva and Schiemer (2001) highlighted that unwarranted human interventions on water bodies in the tropics result unforeseen limnological consequences. The manipulation of water level of eutrophic water bodies could lead to outbreaks of algal blooms (Silva 2003). Nevertheless, limnological studies on man-made water bodies subjected to gross human pressures in the tropics are becoming an increasingly important issue since inland waters are not only being subjected to progressive eutrophication and pollution but also there are evidences for catastrophic collapse of reservoir ecosystems. Therefore, updating the limnological knowledge on a regular basis of a water body is of prime importance for management and conservation purposes. Spatial and temporal characteristics of physicochemical limnology of Kandy Lake was determined for a period of two years with a view to understanding the behaviour of the water body with respect to autochthonous and allochthonous environmental dynamics.

Materials and Methods

Kandy Lake: The Kandy Lake (7° 18' N; 80° 39' E) located at 510 m above mean sea level in Kandy, the second largest city in Sri Lanka, was constructed by the

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last King of the Sinhalese monarchy between 1810 and 1812 by forced labor to enhance the panoramic beauty of the royal palace complex and surrounding temples. It is 18 ha in area and has a maximum depth of 13 m and a capacity of 0.348 MCM within a perimeter of 3.25 km. Being located adjoining to the most esteemed religious centre in the country, the temple of tooth, fishing and bathing are prohibited in the lake. Further, the lake water is used neither for irrigation nor other domestic purposes. Two small brooks feed the lake and water spills over only during the rainy season (October - December) and evaporation losses are high during the dry months (February - March). In addition, wastewater drains into the lake via 12 perennial inlets. The Lake which has two morphologically distinct basins (deep and shallow), but has no prominent littoral zone and the entire perimeter is surrounded either by public roads or cement/concrete walls.

Field sampling and laboratory analysis: Four sampling stations were fixed with more or less equal distance intervals along the middle of the water body representing the entire water mass of the lake (Fig. 1). Sampling was carried out monthly, for a period of two consecutive years from September 1996 to August 1998. Water samples were collected using a 1 l Rutner sampler from the surface and just above the bottom at each sampling station. Water temperature was measured *in situ* using a Barnant-100 thermocouple thermometer. Water samples from each station were also collected in clean Nalgene bottles for laboratory analysis of chemical parameters.

In the laboratory, a known volume of water samples were filtered through Whatman GF/C circles (0.45 μm pore size and 47 mm in diameter) using a Millipore filtering manifold. The filtrate was used to determine the concentrations of $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, dissolved phosphorous, Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- and SO_4^{2-} . Unfiltered samples were used to determine pH, alkalinity, conductivity, turbidity, and total phosphorus. The pH measurements were taken using a Genway 3030 pH meter calibrated with two buffer solutions (pH 7 and pH 9.2). Total alkalinity, which is the acid neutralizing capacity of lake water was determined by titrating with 0.1N HCl using methyl orange as an indicator. Specific conductance was measured using portable ATI Orion conductivity-1 tester (Model 116) and turbidity was measured using a Nephelometer (Model-800). Dissolved oxygen fixed in the field as Mn(OH)_x , was dissolved in 1:1 H_2SO_4 and the equivalent amount of iodine liberated was determined by iodometric titration with 0.025N $\text{Na}_2\text{S}_2\text{O}_3$ solution using starch as an indicator (APHA 1989).

Nutrients: All forms of phosphorous in raw lake water were converted into orthophosphate by persulfate digestion. Then orthophosphate concentration was determined spectrophotometrically by ascorbic acid method (APHA 1989). Same

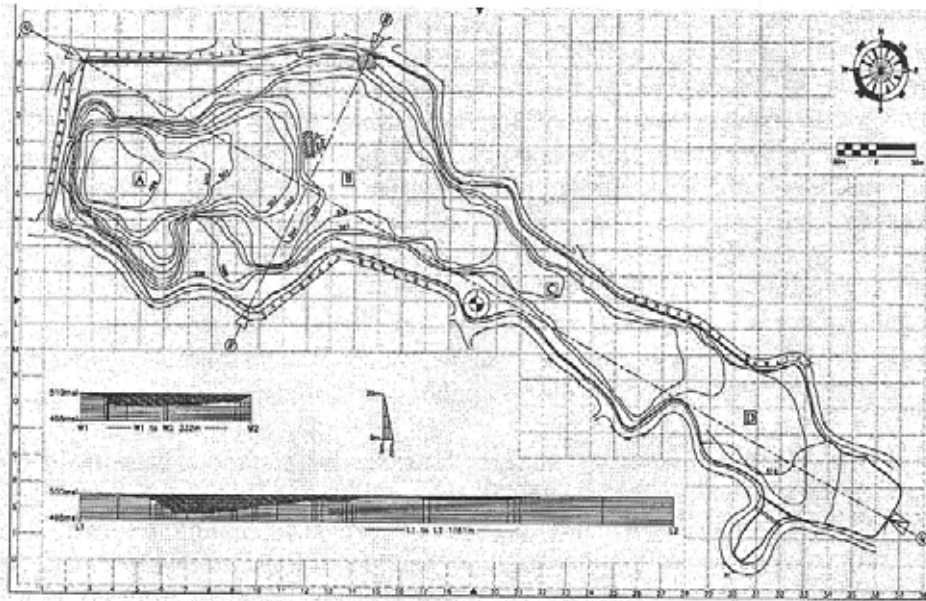


Figure 1. Map of Kandy Lake showing sampling sites (A-D) with depth contours

method was used to determine dissolved orthophosphate in unfiltered samples without digestion. Concentration of nitrite-N in lake water was determined colorimetrically by diazotization (APHA 1989). The colour intensity was measured using a Shimadzu spectrophotometer (model 6100) at 543 nm. Nitrate ions were reduced into nitrite (Cu/Cd reduction) and subsequently the concentrations of nitrate-N were determined following the diazotization method described below. Concentration of $\text{NH}_4\text{-N}$ was measured colourimetrically by indo-phenol blue method (APHA 1989).

The concentrations of major cations (Na^+ , K^+ , Ca^{2+} and Mg^{2+}) in lake water were analyzed by means of atomic absorption spectrophotometer in flame emission mode (Shimadzu GBC 933AA). Sulphate ion concentrations were determined spectrophotometrically after precipitating with gelatin-barium chloride in an acid medium (APHA 1989). An ion selective electrode (Model 96-17B) coupled with Double Junction Reference Electrode (Model 90-02) and Expandable ion analyzer (EA 920) was used to determine chloride ion concentration.

*Limnology of Kandy Lake***Results**

The mean values (\pm SD) of physicochemical parameters of surface and bottom waters of four sites are given in Table 1. The results of the one-way ANOVA and Student's t-test employed to determine the inter-site variations in sampling site A and intra-site variations of surface and bottom waters are given in Table 2. There was no significant inter-site variation in surface temperature and it was lowest (24.5°C) in December 1996 and highest (32.0°C) in April 1998 (Fig. 2). Monthly changes in surface temperature did not show a marked seasonal patterns but a gradual decline in temperature was found from surface to bottom at site A resulting in a mean difference of 2.6°C between surface and bottom (Fig. 2).

The pH was uniform in the surface water but inter-site variability was significantly different for the bottom water. Surface water pH ranged from 7.37 to 8.76 with a mean value of 8.18 ± 0.40 and it was significantly higher than the bottom water at site A (7.04 ± 0.36) ($t = 4.88$; $p < 0.000$). Monthly fluctuation of pH showed no marked seasonal pattern but the surface pH was always higher than the bottom (Fig. 3) and pH was significantly correlated with monthly rainfall at $p < 0.05$ (Table 3). A more or less similar trend was found with respect to inter-site variability of total alkalinity of surface water but Tukey's pair-wise comparison showed significant differences between A and C; A and D; and B and C for the bottom water (Table 2). Total alkalinity ranged from 1.50 meq l^{-1} to 2.33 meq l^{-1} with mean value of 1.82 meq l^{-1} during the study period. Except in a few occasions, monthly values of total alkalinity of surface water were significantly less than the bottom values at site A ($t = 3.44$; $p < 0.001$) (Fig. 3).

Electrical conductivity (EC) of surface water ranged from $180 \mu\text{S cm}^{-1}$ to $260 \mu\text{S cm}^{-1}$ with mean value of $215 \mu\text{S cm}^{-1}$ and it was between $190 \mu\text{S cm}^{-1}$ and $385 \mu\text{S cm}^{-1}$ for the bottom water with a mean value of $252 \mu\text{S cm}^{-1}$. EC of neither surface nor bottom water showed a significant inter-site variability during the period under investigation (Table 2). Similar to total alkalinity, surface water EC in site A was less than the bottom water and the mean values were significantly different ($t = 2.13$; $p < 0.04$). The general trend of EC in Kandy lake was increasing towards the end of the study period.

Turbidity varied between 2.60 NTU and 18.20 NTU with a mean value of 9.43 NTU (Table 1). There was no significant difference in inter-site variation of turbidity for both surface and bottom water (Table 2). However, the surface turbidity was significantly less than the bottom values at site A ($t = 8.66$; $p < 0.001$). Monthly variation of mean turbidity values shows that the turbidity was less than 10.0 NTU but more than 5 NTU during most months with no marked seasonal pattern even with the rainfall (Fig. 3).

Table 1. Mean values (\pm SD) of physicochemical parameters of surface and bottom waters of four sites of Kandy Lake for first twelve-month of the study period.

Parameter	Site A		Site B		Site C		Site D	
	Sur.	Bot.	Sur.	Bot.	Sur.	Bot.	Sur.	Bot.
Temp. ($^{\circ}$ C)	27.2 \pm 1.5	25.8 \pm 0.7	27.5 \pm 1.4	217 \pm 23	27.7 \pm 1.2	202 \pm 40	27.6 \pm 1.3	209 \pm 25
EC (μ S cm^{-1})	212 \pm 23	238 \pm 34	209 \pm 24	7.38 \pm 0.23	207 \pm 23	7.63 \pm 0.28	208 \pm 25	7.88 \pm 0.44
pH	8.18 \pm 0.40	7.04 \pm 0.36	8.08 \pm 0.42	1.98 \pm 0.24	8.14 \pm 0.39	1.88 \pm 0.13	8.13 \pm 0.39	1.80 \pm 0.24
Alk. (meq l^{-1})	1.88 \pm 0.19	2.19 \pm 0.44	1.85 \pm 0.16	26.2 \pm 19.0	1.86 \pm 0.15	20.7 \pm 16.4	1.88 \pm 0.10	23.6 \pm 12.2
Turb. (NTU)	8.26 \pm 2.2	23.5 \pm 18.9	10.3 \pm 4.4	2.44 \pm 2.25	13.3 \pm 7.17	5.52 \pm 1.47	11.5 \pm 4.7	6.47 \pm 1.89
DO (mg l^{-1})	7.59 \pm 1.78	1.33 \pm 1.53	7.51 \pm 1.60	0.51 \pm 0.06	7.55 \pm 1.71	0.54 \pm 0.07	7.14 \pm 1.68	0.56 \pm 0.07
Na ⁺ (meq l^{-1})	0.54 \pm 0.07	0.52 \pm 0.07	0.53 \pm 0.08	0.14 \pm 0.02	0.52 \pm 0.06	0.14 \pm 0.03	0.56 \pm 0.08	0.14 \pm 0.03
K ⁺ (meq l^{-1})	0.14 \pm 0.02	0.14 \pm 0.02	0.14 \pm 0.02	0.14 \pm 0.02	0.13 \pm 0.03	0.72 \pm 0.23	0.13 \pm 0.02	0.73 \pm 0.17
Ca ²⁺ (meq l^{-1})	0.73 \pm 0.19	0.82 \pm 0.17	0.77 \pm 0.16	0.79 \pm 0.17	0.71 \pm 0.18	0.59 \pm 0.05	0.71 \pm 0.20	0.59 \pm 0.05
Mg ²⁺ (meq l^{-1})	0.57 \pm 0.05	0.59 \pm 0.07	0.58 \pm 0.07	0.59 \pm 0.06	0.60 \pm 0.06	0.08 \pm 0.05	0.59 \pm 0.05	0.078 \pm 0.06
SO ₄ ²⁻ (meq l^{-1})	0.07 \pm 0.04	0.08 \pm 0.06	0.07 \pm 0.05	0.07 \pm 0.06	0.07 \pm 0.05	0.08 \pm 0.05	0.08 \pm 0.06	0.078 \pm 0.06
Cl ⁻ (meq l^{-1})	0.83 \pm 0.15	0.95 \pm 0.20	0.83 \pm 0.13	0.83 \pm 0.15	0.85 \pm 0.13	0.86 \pm 0.14	0.89 \pm 0.19	0.95 \pm 0.34

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Table 2. Results of statistical analysis for inter-sites and intra-site variability of physicochemical characteristics of surface and bottom water in Kandy Lake during the study period.

Parameter	Inter-site (Sur.)		Inter-site (Bot.)		Intra-site (A)	
	F-ratio	p-value	F-ratio	p-value	t-value	p-value
Temp.	0.11	0.952				
pH	0.14	0.933	14.33	0.000	4.88	0.000
Alkl.	0.06	0.993	10.25	0.000	3.44	0.001
EC	0.04	0.990	3.18	0.330	2.13	0.039
DO	0.70	0.971	21.85	0.000	12.73	0.000
Turb.	2.69	0.057	2.71	0.560	8.66	0.000
Na ⁺	0.67	0.578	1.19	0.326	0.19	0.850
K ⁺	0.31	0.820	0.07	0.973	0.02	0.980
Ca ²⁺	0.37	0.774	0.34	0.796	0.73	0.470
Mg ²⁺	0.64	0.591	0.00	1.000	0.89	0.380
Cl ⁻	0.35	0.786	0.85	0.475	1.72	0.092
SO ₄ ²⁻	0.20	0.897	1.17	0.331	0.14	0.890

Table 3. Relationships of independent and dependent physicochemical variables examined using least square model (N = Number of observations; r = Correlation coefficient).

Parameter	N	r	p-value
EC vs Na ⁺	190	0.203	<0.050
EC vs Ca ²⁺	190	0.164	>0.050
EC vs Mg ²⁺	114	0.200	<0.050
EC vs Cl ⁻	84	0.605	<0.001
EC vs SO ₄ ²⁻	167	0.441	<0.001
EC vs Alk.	168	0.308	<0.001
pH vs RF	24	0.420	<0.050
pH vs DO	24	0.568	<0.010
DO vs Temp.	21	0.475	<0.050

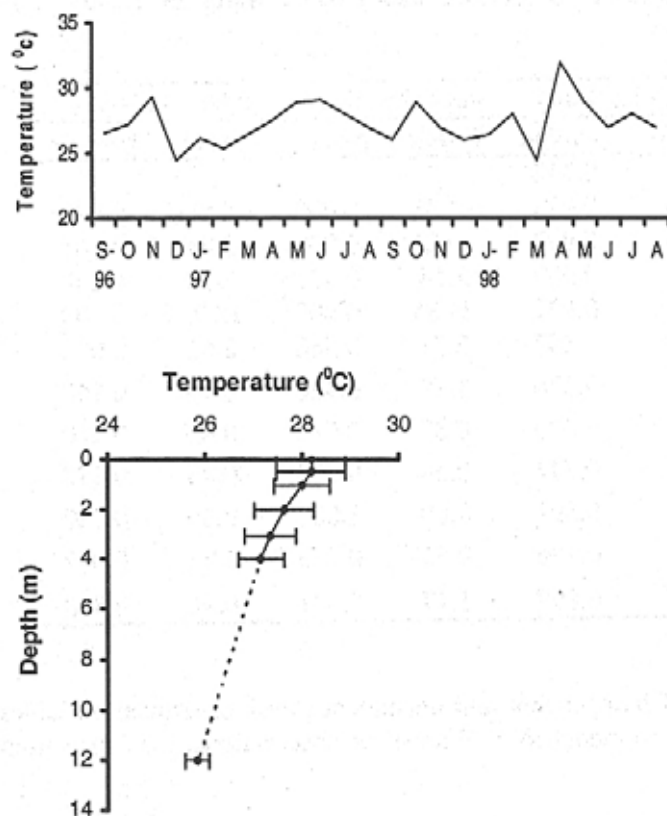


Figure 2. Seasonal changes of surface temperature (upper) and vertical temperature profile at site A (lower).

The DO content of surface water ranged from 4.02 to 12.72 mg l⁻¹ with a mean value of 7.53 (± 1.91) mg l⁻¹ during the study period with no significant inter-site variability in the mean values (Table 2). However the mean DO concentrations of bottom water were significantly different and the lowest mean of 1.33 (± 1.53) mg l⁻¹ was computed for site A which had the range of 0.00-5.80 mg l⁻¹. A prominent oxygen gradient was consistent at site A throughout the study period but the monthly concentration did not show a marked seasonal pattern (Fig. 4). The DO concentration of surface water was above 6.00 mg l⁻¹ except in September and December 1996, September 1997 and May and June 1998. Further it was more than 10.00 mg l⁻¹ in April, May, June, and August 1997, January, February, March, July and August 1998. The DO content had statistically significant linear correlations with water temperature and pH (Table 3).

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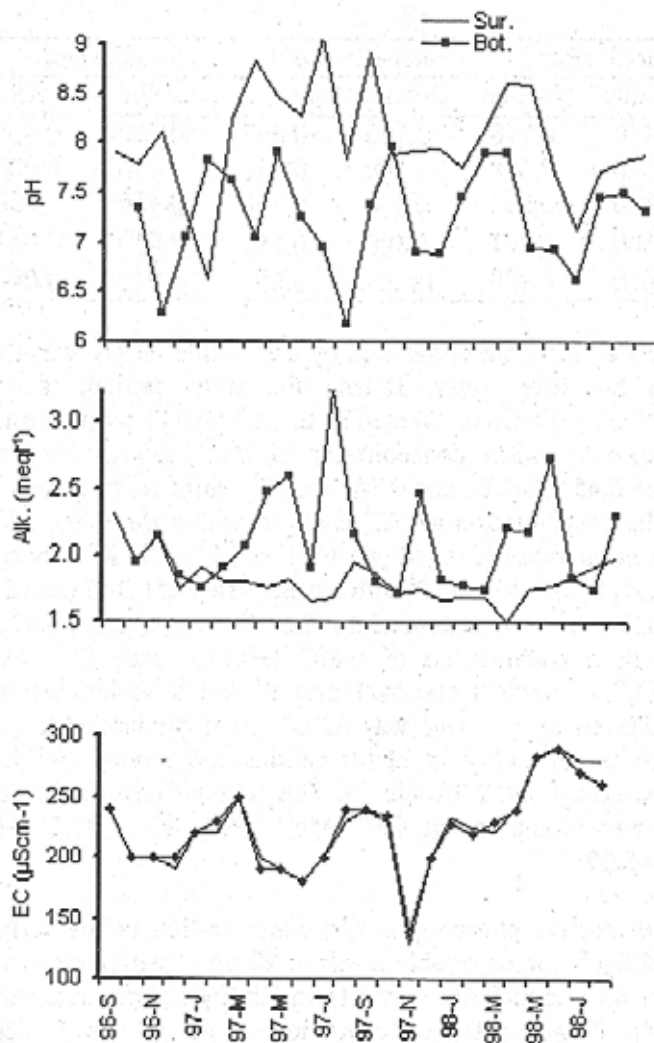


Figure 3. Monthly changes of pH, Alkalinity (Alk) and electrical conductivity (EC) at surface and bottom waters in Kandy Lake at site A.

Table 4. Results of statistical analysis for inter-site and intra-site variability of nutrient concentrations of surface and bottom waters at site A in Kandy Lake.

Parameter	Inter-site (sur.)		Inter-site (bot.)		Intra-site (A)	
	F-value	p-value	F-value	p-value	t-value	p-value
dP	0.410	0.748	0.560	0.647	0.710	0.410
tP	0.510	0.678	1.100	0.359	4.210	0.000
NO ₂ -N	0.210	0.946	0.360	0.779	0.450	0.660
NO ₃ -N	0.360	0.781	1.400	0.255	2.010	0.051
NH ₄ -N	0.010	0.998	11.220	0.000	5.910	0.000

Cations and anions: Cations were dominated by Ca²⁺ while HCO₃⁻ was the most dominant anion in the lake water. During the study period, the overall concentration of Ca²⁺ ranged from 0.106 meq l⁻¹ to 1.07 meq l⁻¹ with a mean value of 0.775 (±0.001) meq l⁻¹ while concentration of Mg²⁺, the second dominant cation varied between 0.451 meq l⁻¹ and 0.745 meq l⁻¹ with a mean value of 0.586 (±0.056) meq l⁻¹. The concentration of Na⁺ changed within the range of 0.402–1.076 meq l⁻¹ with a mean value of 0.548 (±0.103) meq l⁻¹ while K⁺ concentration ranged from 0.078 meq l⁻¹ to 0.30 meq l⁻¹ with a mean value of 0.143 (±0.038) meq l⁻¹. The concentration of the second dominant anion, Cl⁻ ranged from 0.42 meq l⁻¹ to 1.21 meq l⁻¹ with a mean value of 0.802 (±0.173) meq l⁻¹. The mean concentration of SO₄²⁻ was 0.078 (±0.047) meq l⁻¹ and it varied between not detectable levels and 0.002 meq l⁻¹. One-way ANOVA and Student's t-test showed no significant inter-site variability in major cations and anions and intra-site variability in site A except HCO₃⁻ (Table 2). The relative ionic ratio of major cations and anions were computed as Ca²⁺: Mg²⁺: Na⁺: K⁺ = 37:29:27:7 and HCO₃⁻: Cl⁻: SO₄²⁻ = 68:29: 3.

Nutrients: Dissolved reactive phosphorus (dP) concentration in the surface and bottom water ranged from non-detectable levels to 22 µg l⁻¹ with a mean value of 4.6 µg l⁻¹ but did not show significant inter-site variability or intra-site variability in site A (Table 4). However the concentration of dP at site A decreased significantly with increasing pH (t = 8.62; p<0.01) while a significant negative correlation was computed with DO. Monthly concentration of dP in surface water fluctuated with no marked seasonal pattern and it was more than 15 µg l⁻¹ only during two months (Fig. 5). The concentration of dP in the bottom water exceeded 5 µg l⁻¹ during six occasions and it was more than 10 µg l⁻¹ only twice (Fig. 5). The concentration of total phosphorus (tP) ranged from 14 µg l⁻¹ to 216 µg l⁻¹ with

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a mean value of $51 (\pm 46) \mu\text{g l}^{-1}$ but with no significant inter-site variability (Table 3). However, the results of Student's t-test showed a significant intra-site variability for the site A. Monthly concentration of tP in both surface and bottom water at site A did not show a marked seasonal pattern and was less than $50 \mu\text{g l}^{-1}$ except in June, July, October and December 1997 and more than $100 \mu\text{g l}^{-1}$ only in June 1997. Monthly fluctuation of tP in surface water was more prominent than in the bottom and it was more than $200 \mu\text{g l}^{-1}$ in November and December, 1996 and June and December, 1997 and less than $50 \mu\text{g l}^{-1}$ during four occasions (Fig. 4).

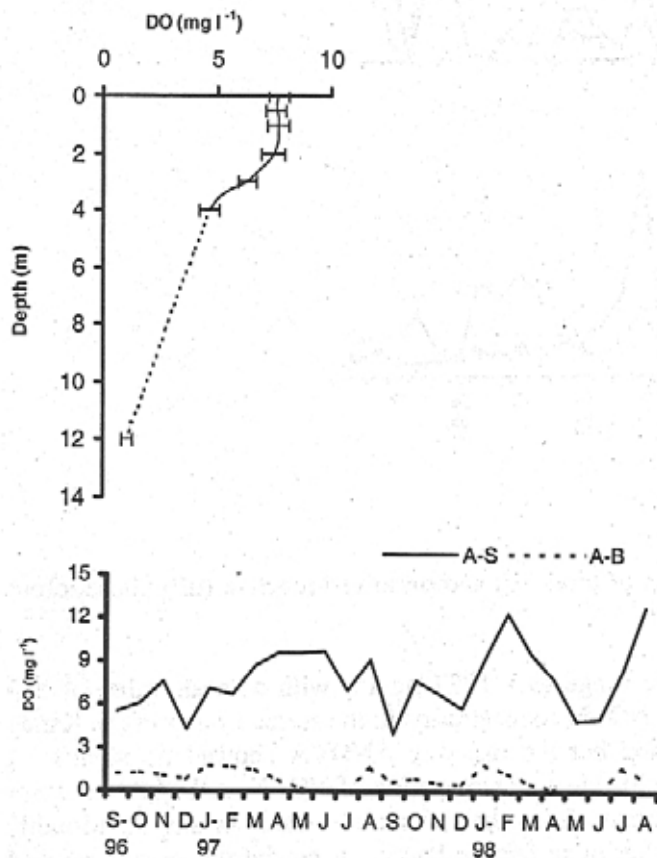


Figure 4. Vertical distribution of dissolved oxygen (upper) and its monthly variation (lower) in surface and bottom water at site A.

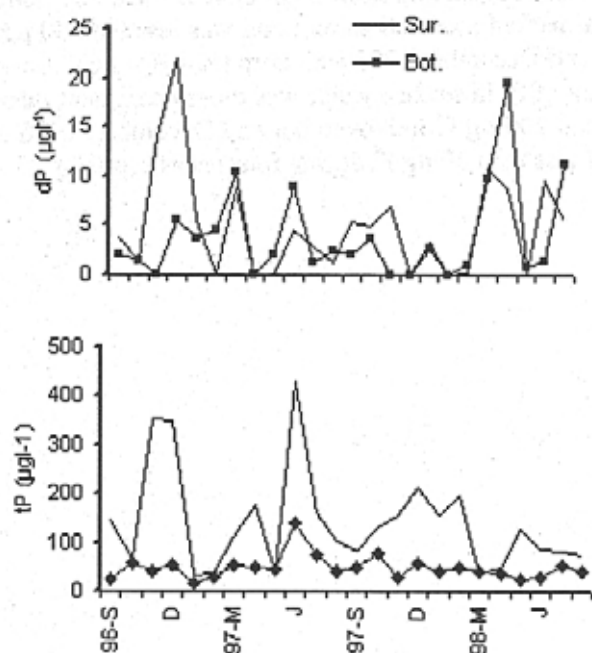


Figure 5. Monthly variation of total (tP) and dissolved reactive (dP) phosphorous in surface and bottom water.

An extremely wide range ($3 - 1277 \mu\text{g l}^{-1}$) with a mean value of $337 (\pm 319) \mu\text{g l}^{-1}$ was found for $\text{NO}_3\text{-N}$ concentration in the surface water of the Kandy lake during the study period but the one-way ANOVA showed no significant inter-site variability (Table 3). Mean concentration of $\text{NO}_3\text{-N}$ in the bottom water showed a significant difference from that of surface water at site A. Monthly concentration of $\text{NO}_3\text{-N}$ either in surface or bottom water did not show a marked seasonal pattern (Fig. 6). Although surface concentrations were generally higher than the bottom concentrations, there were instances of higher bottom concentrations (Fig. 6). Of the 24 sampling occasions, only six occasions had more than $500 \mu\text{g l}^{-1}$ $\text{NO}_3\text{-N}$ and extremely high concentration of $1227 \mu\text{g l}^{-1}$ was found in November 1997. The highest bottom concentration of $968 \mu\text{g l}^{-1}$ was determined in December 1996 and the bottom values were relatively low in June, July, and November 1997 and from March to May 1998.

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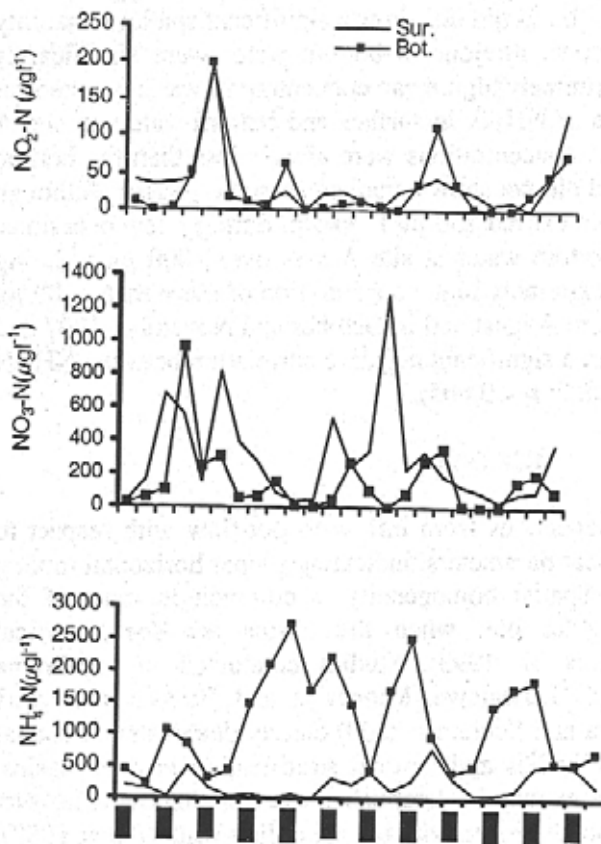


Figure 6. Monthly variation of $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ in surface and bottom water.

Spatial distribution and temporal pattern of $\text{NO}_2\text{-N}$ in Kandy Lake were more or less similar to those of $\text{NO}_3\text{-N}$ but $\text{NO}_2\text{-N}$ concentration ranged from non detectable level to $192 \mu\text{g l}^{-1}$ with a mean value of $42 (\pm 48) \mu\text{g l}^{-1}$. Monthly concentration in surface water was less than $25 \mu\text{g l}^{-1}$ except for September 1996, January and December 1997 and May and June 1998. It was more than $50 \mu\text{g l}^{-1}$ in January and February 1997 and in June 1998 (Fig. 6). A more or less similar trend was found in the bottom water but the concentration was less than the surface water except in few occasions.

The ranges of $\text{NH}_4\text{-N}$ concentrations in both surface and bottom waters of Kandy Lake were also extremely wide during the study period. Irrespective of the site, surface concentration ranged from non-detectable levels to $774 \mu\text{g l}^{-1}$ with a mean value of $177 (\pm 150) \mu\text{g l}^{-1}$ but it did not show a significant spatial variability (Table 4). However, $\text{NH}_4\text{-N}$ concentrations in bottom water were significantly different among sites and an extremely high mean concentration was computed for site A. Monthly concentrations of $\text{NH}_4\text{-N}$ in surface and bottom waters in site A are shown in Figure 6. Surface concentrations were always less than the bottom throughout the study period and did not show a marked seasonal pattern. Although the surface concentration did not exceed $250 \mu\text{g l}^{-1}$ except during a few occasions, $\text{NH}_4\text{-N}$ concentration in the bottom water at site A was over $1000 \mu\text{g l}^{-1}$ during twelve occasions (Fig. 6). An extremely high concentration of more than $1500 \mu\text{g l}^{-1}$ was determined from March to August and in October and November 1997 and in April and May 1998. Further, a significant negative correlation between $\text{NH}_4\text{-N}$ and DO was also found ($r = -0.552$; $p < 0.005$).

Discussion

Kandy Lake was homogeneous from inflow to out-flow with respect to most of the physical and chemical parameters, indicating proper horizontal mixing throughout the study period. Spatial homogeneity is common in most of the shallow reservoirs in Sri Lanka but, when the basins are deep, vertical stratification occurs (Duncan et al. 1993). Studies conducted in Parakrama Samudra (Schiemer 1983) and Udawalawe, Minneriya and Victoria reservoirs (Silva and Gamlath 2000; Silva and Schiemer 2000) clearly demonstrated spatial homogeneity in shallow water bodies and vertical stratification in deep basins. However, micro-thermal gradients may be established even in shallow reservoirs under calm condition, which can be broken with the prevailing wind (Bauer 1983). Although Kandy Lake is shallow in comparison to the highland reservoirs in Sri Lanka, the deeper basin i.e. at site A showed a permanent stratification throughout the study period. This has resulted in the establishment of significant vertical gradients in some physical and chemical parameters such as pH, temperature, electrical conductivity, alkalinity and dissolved oxygen in the deep basin. Stratification of the deeper basin may be attributed to several characteristics such as basin morphology, fetch, inflow and outflow, hydrological residence time, flushing rate and the occurrence of topographic barriers and physical structures as windbreakers in the surrounding.

Surface water temperature was slightly low during rainy months (October-January) compared to dry months (February-April), but a marked seasonality was not very prominent during the study period. However, vertical gradient of temperature in the deep basin was significantly narrow although it was not

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established as a thermocline with noticeable temperature zones (epilimnion, metalimnion and hypolimnion). Slight seasonal changes of surface temperature in Kandy Lake may be attributed to global climatic pattern to a greater extent whereas relatively wide temperature range compared to lowland reservoirs may be resulted from altitudinal location of the water body.

Lake water was alkaline throughout the study period and surface water was more alkaline than the bottom water. There were instances where bottom water in the deeper basin became acidic. In general, shallow reservoirs in Sri Lanka show a marked seasonality in pH in relation to annual rainfall pattern and slightly acidic pH occurs in downstream irrigation tanks during the northeast monsoon (Silva and Davies 1987). When photosynthetic organisms consume free carbon dioxide, bicarbonate concentration will increase in the water while microbial activities under anoxic condition may results in acidic pH (Wetzel 1985). This indicates that heterotrophic microbial processes occurring in the bottom layer of the deep basin of the Kandy Lake may be quite different form the surface waters. Sharaff (2003) found extremely large numbers of acid producing facultative bacteria species in the bottom waters of the deep basin in Kandy Lake. Seasonal and spatial trends in bicarbonate alkalinity is more of less similar to that of pH, but the pattern at site A is reversed, bottom water being more alkaline in terms of bicarbonate ion concentration than the surface water.

EC, which is essentially a function of bicarbonate concentration in soft inland waters was relatively high in Kandy Lake compared to the other water bodies located in similar elevations (Silva 1991; De Silva 1993; Silva and Gamlath 2000). The lowest value coincidences with high rainfall and it increased significantly under dry whether conditions due to high evaporation losses. EC was significantly related to the concentration of bicarbonate ions and relatively high EC in bottom water of deeper basin may also be attributed to relatively high concentration of bicarbonate. Relatively high EC may be attributed to high amount of wastewater discharged into the lake and eutrophic nature of the water body. In general, urban water bodies contain more cations and anions as a result of release of wastewater with no treatment. EC reflects the total amount cations and anion and temperature shows a highly significant linear relationship with total dissolved salts for irrigation reservoirs in Sri Lanka (Silva 2003). In Kandy Lake, the relationship between EC and TDS can be expressed by $EC = 196 + 0.221 TDS$. Turbidity was relatively high during moderately rainy periods compared to dry and wet periods. Particles suspended in the water are either inorganic or planktonic and the concentration of inorganic particles is extremely high in the inflow area during the wet season due to sediment loading and they settle down on the bottom within a few days.

Kandy Lake demonstrated intermittent fluctuations in dissolved oxygen concentration in both surface and bottom water within a wide range. Horizontal

gradient was not prominent during the sampling but vertical gradient at the deep basin was prominent throughout the study period. Vertical gradient is a result of high photosynthetic rate at surface layer, poor mixing and high consumption of oxygen by heterotrophic bacteria (Sharaff 2003). This is a common phenomenon in eutrophic tropical water bodies (Talling and Lemoalle 1998). It should be mentioned that permanent stratification occurred in the deep basin collapsed only in few occasions due to high wind during southwest monsoons. Since the bottom layer of the deep basin was anoxic or contained less oxygen during most of the year, only *Chaoborus*, a dipteran larvae was found in the bottom of the deep basin. Stratification of Kandy Lake cannot be compared with temperate water bodies since there is no prominent vertical zonation such as epilimnion, metalimnion and hypolimnion. However, anaerobic processes occur in the bottom layers of the deep basin perhaps significantly affecting the biogeochemical processes and nutrient dynamics of the entire lake ecosystem.

Ca^{+2} was the most dominant cation and Mg^{+2} concentration was higher than that of Na^{+} . The lowest concentration of cations was recorded for K^{+} . Among the anions, bicarbonate is dominant in tropical freshwaters. With regard to composition of anions, chloride ion was subdominant while sulphate was the least abundant among the anions during the study period. Most of the surface waters in Sri Lanka are rich in sodium ions, and the concentrations of calcium and magnesium ions are more or less similar while the concentration of potassium ions is the lowest (Dissanayaka and Weerasooriya 1986). Even though the concentration of bicarbonate ions is always higher compared to chloride and sulphate ion concentrations, a substantial concentrations of chloride are present in some waters (Silva and Gamlath 2000). Ionic composition and relative ionic ratios in lowland dry zone reservoirs are also more or less similar to that of the highland water bodies although the concentrations are relatively high. Catchment geochemistry has been shown to be the most important determinant of surface water chemistry (Douglas 1968; Webb and Walling 1974; Maybeck et al. 1989). Gibbs (1970) had explained the chemical composition of inland water with respect to rock dominance, precipitation and evaporation-crystallization processes. Altitude can also influence the surface water chemistry due to variation in water balance (Vitousek 1977). However, nothing is definitive and the spatial and temporal variations in water chemistry are regulated by the overall framework within which the hydrogeochemical system functions. However, within a particular climatic region, rainfall, watershed characteristics, vegetation and soil are the most significant factors (Gower 1980). Relatively higher concentrations of calcium and magnesium ions in Kandy Lake compared to that of sodium ions may be attributed to watershed characteristic, especially to its urbanized nature without waste treatment facilities together with geochemical characteristics. Concentrations of calcium and magnesium ions are higher in Sri Lankan waters

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when drain watershed is dominated by dolomite. In general, sodium ion concentration is high when the water body is receiving urban waste water. Upper limit of the dissolved phosphorous concentration in Kandy Lake was slightly higher than the reported values for Sri Lankan reservoirs (Gunatilaka and Senaratne 1981; Gunatilaka 1983) but the mean value was within the acceptable range for tropical eutrophic water bodies. Undetectable concentrations of dissolved phosphorous indicate a rapid turnover within the water body. Eutrophic water bodies with higher algal biomass uptake dissolved phosphorous from the nutrient pool very rapidly (Wetzel 1983). However, mobilization of dissolved phosphorous from the anoxic bottom is also extremely rapid. Silva (2003) hypothesized that rapid nutrient uptake by non-nitrogen fixing cyanobacteria when the water level was reduced has resulted in an outbreak of *Microcystis aeruginosa* bloom in 1999 in the Kandy Lake. Extremely high concentration of total phosphorous was found in the bottom waters of the lake, which indicates accumulation of organic matter in the bottom. This may have resulted from sinking of dead algal biomass as well as faeces of fish and droppings by birds and bats. When fish biomass is extremely high in non-harvesting water bodies, their contribution to the nutrient pool is colossal. Relatively low concentration of total phosphorous in the surface layer compared to the bottom of the water body may be attributed to rapid uptake by phytoplankton. Dynamic fluctuation of phosphorous species without a particular seasonal trend may be an indication of rapid biogeochemical processes occurring in the lake or otherwise the lake may be receiving high loads of phosphorous containing waters intermittently through waste water drains.

Dominance of $\text{NH}_4\text{-N}$ among the nitrogen species in Kandy Lake is an indication of conversion of organic nitrogen into ammonia through the process of ammonification. This transformation may be carried out by all heterotrophic microorganisms. Sharaff (2003) reported the occurrence of nitrification and denitrifying bacteria in high densities in Kandy Lake. Planktonic algae prefer to uptake $\text{NH}_4\text{-N}$ as their nitrogen source over $\text{NO}_2\text{-N}$ or $\text{NO}_3\text{-N}$ (Brezonik 1972; Zervenboon and Mur 1981). When the concentration of $\text{NH}_4\text{-N}$ or other nitrogen species is high in the water body, it results in the colonization of non-nitrogen fixing cyanobacteria such as *Microcystis* spp., *Merismopedia* spp. etc.. Relatively high concentrations of nitrogen species and their intermittent fluctuation in Kandy Lake during the study period indicate organic pollution of the water body. This may have resulted either from allochthonous or autochthonous organic loading. Seepage of $\text{NO}_3\text{-N}$ into the water body may be extremely high from the surrounding watershed, which has schools, nursing homes and hotels with no proper wastewater treatment facilities. It has been observed that some hotels release their waste and even night soils, to the lake directly during night through underground outfalls. Further, slight increase in total phosphorous and total

inorganic nitrogen concentrations in the surface water in the lake was found after the rains although there was no marked seasonal pattern in nutrient concentrations. This suggests that the wastewater generated in the watershed also contribute to a substantial amount of nutrients loading to the water body. Furthermore, the droppings of aquatic birds such as roosting cormorants and pelicans and the visiting birds such as egrets and the bats residing on trees around the lake will certainly contribute to the nutrient loading of the lake. In addition, the foliage parts (e.g. leaves) fallen from the trees around the lake would also contribute as a nutrient source. The lake ecosystem is also adapted to recycle nutrients within the water body and enhances the microbial activity. Particularly, the feeding behaviour of cichlid fish, i.e., tilapia, the most dominant fish in the water body stir up bottom sediment when they browse on the bottom. The vertical gradient of nutrient in the deep basin of the lake may be attributed to the chemical gradients in physicochemical parameters such as temperature, pH, DO and also to distribution the pattern of the microbial populations.

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