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PHYSICO-CHEMICAL ENVIRONMENTAL COMPLEX OF A COMMERCIALLY EXPLOITED TROPICAL FRESHWATER SYSTEM WITHIN A WILDLIFE SANCTUARY, KERALA, INDIA

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The present work deals with comprehensive and systematic analysis of the physico-chemical environmental complex of a unique tropical high altitude fresh water ecosystem, the Periyar Lake. It is a freshwater reservoir of global significance. Regular monthly investigations for three years were carried out to collect baseline data on the ecosystem structure and function of the Lake. Environment characteristics of the Lake system such as seasonal changes in climate, hydrology, water temperature, secchi depth, electric conductivity, pH, total dissolved solids, total solids, total alkalinity, hardness, dissolved oxygen and carbon dioxide$_2$, dissolved mineral ions such as Ca, Mg, K, Na and Cl are described. The major climatic factor of the Lake system was identified as precipitation. Temperature, total solids, total dissolved solids, and all the other physical and chemical characteristics of the waters remained quite normal and similar to an oligotrophic freshwater system and never exceeded the standard values during the entire period of study. Comprehensive plans with an integrated holistic approach were found essential to protect this type of unique tropical freshwater system which may be considered as a ‘common human heritage’.

Keywords: Periyar Lake; tropical system; environmental complex, physico-chemical factors, seasonal changes, holistic approach.

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ФІЗИКО-ХІМІЧНІ ВЛАСТИВОСТІ ПРІСНОВОДНОЇ ТРОПІЧНОЇ СИСТЕМИ ЯК ЧАСТИНИ ПРИРОДНОГО ЗАПОВІДНИКА (КЕРАЛА, ІНДІЯ), ЯКА ВИКОРИСТОВУЄТЬСЯ З КОМЕРЦІЙНОЮ МЕТОЮ

Робота присвячена комплексному та систематичному аналізу фізико-хімічних властивостей унікальної тропічної прісноводної екосистеми, яка знаходиться високо над рівнем моря, – озера Періяр. Це озеро – запас прісної води світового значення. Щомісячні дослідження, які виконувалися протягом трьох років, дозволили зібрати дані про структуру та функціональні особливості названої екосистеми. Результати досліджень показали крайню необхідність у захисті цієї унікальної водної екосистеми, яка є надбанням усього людства.

Ключові слова: озеро Періяр, тропічна система, фізико-хімічні фактори, сезонні зміни, глобальний підхід.

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ФИЗИКО-ХИМИЧЕСКИЕ СВОЙСТВА ПРЕСНОВОДНОЙ ТРОПИЧЕСКОЙ СИСТЕМЫ, ИСПОЛЬЗУЕМОЙ В КОММЕРЧЕСКИХ ЦЕЛЯХ, ЯВЛЯЮЩЕЙСЯ ЧАСТЬЮ ПРИРОДНОГО ЗАПОВЕДНИКА (КЕРАЛА, ИНДИЯ)

Настоящая работа посвящена комплексному и систематическому анализу физико-химических свойств уникальной, находящейся высоко над уровнем моря, тропической пресноводной экосистемы – озера Перияр. Это озеро – запас пресной воды мирового значения. Ежемесячные исследования, проходившие в течение трех лет, позволили собрать данные о структуре и функциональных особенностях названной экосистемы. Результаты исследований показали крайнюю необходимость в защите этой уникальной водной экосистемы, которую нельзя назвать иначе как «достояние всего человечества».

Ключевые слова: озеро Перияр, тропическая система, физико-химические факторы, сезонные изменения, глобальный подход.

Physico-chemical factors within all the natural biological systems interact among themselves and with the biotic factors resulting in the formation of a complex relationship, the biotic complex. Individual analysis of different physico-chemical environmental factors of a commercially exploited freshwater ecosystem, which is integral to a wildlife sanctuary, is useful in analyzing the interrelationships of management problems of both the systems. Natural ecosystems in the tropics in general are under the pressure of developmental activities in and around. In the conservation of precious wildlife communities in these complex natural systems, thorough investigations of the physico-chemical environmental complex are inevitable. Hundred years over Periyar reservoir (Periyar Lake) system offers a model for discussing crucial aspects of ecosystem management in general.

Periyar Lake is the first constructed Mega Water reservoir of India. It is situated in one of the eighteen biodiversity hotspots of the world, the Western Ghats, Idukky District, Kerala, India, and is an ecologically unique water body of global significance. The Lake is central to the Periyar Tiger Reserve (PTR), which represents 35% of the total of all protected areas in the State (Manoharan, 2000), and the largest of all Indian wildlife sanctuaries (Waller, 1972). Many have identified the Lake as the focal point of the sanctuary (Kurup, 1971) and the key attraction for tourists (Ramachandran et al., 1987). It forms the core environment of the PTR which is a 'Project Tiger' and 'Project Elephant' area. The Lake may be considered as a 'common human heritage'. A large number of tribal populations depend on the resources of the Lake (Arun, 1999). All the wild animals of this system directly depend on its water. The Periyar Lake gives the PTR some wetland characteristics as well. The Lake is a unique and diverse *ichthyofaunal* regime in South India, supporting more than 56% of the total endemic fishes in Kerala (Arun, 1998; Lal, 2000). But in a fifty-year period (1948 to 1997) sixteen species of fishes became extinct in the Lake (CED report, 2000). This fact suggests that though PTR is one of the most protected sites of India, the Lake and its resources are not managed properly.

Though believed as one of the very clean waters of the country, the Lake is presently subjected to the pressure of tourism activity in and around. Annually more than four hundred thousand people of both natives and foreigners visit the Lake (Management Plan, 2001). The increase in the number of tourists each year to the Lake causes increased direct disturbance to the system via boat journey and the waste generated in the region. A perusal of literature on Lakes in Kerala revealed that freshwater reservoirs in the Western Ghats in general are oligotrophic (Khatri, 1992). Sugunan (1995) stressed that detailed investigations of the reservoirs in the Western Ghats are necessary. Long-term studies on pollution status and hydrobiology of Lakes in this region are negligible. Therefore, regular monthly investigations for three years were carried out to collect baseline data on the ecosystem structure and function of the Periyar reservoir which may be considered as a model system for analyzing problems of lake management as well as wildlife management in the world, especially in tropics in general. Environment characteristics of the Lake system such as seasonal changes in climate, hydrology, water temperature, secchi depth or transparency, electric conductivity (EC), pH, total Alkalinity (TA), total hardness (TH) total dissolved solids (TDS), total solids (TS), dissolved oxygen (DO), free carbon dioxide (CO_2), dissolved mineral ions such as Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na) and Chlorine (Cl) are described in this first part. Discussion of the nutrient status and Phytoplankton characteristics of the system will be followed.

MATERIALS AND METHODS

(a) Location map of Periyar Lake

Periyar Lake lies in the Periyar Plateau of the Western Ghats at 9^0 18^1 to 9^0 40^1 northern latitude and 76^0 55^1 to 77^0 25^1 eastern longitude. The PTR forms the major watershed of the Lake consisting of undulating hills, varying in altitude and the elevation around the Lake is about 800-1200 m. The water-spread area of the Lake is 26 km^2 with steep shoreline and a maximum depth of 46 M at the dam site. The lake extends from *Thekkady* boat landing to the Periyar River at *Thannikkudy* with diverticula extensions, and has an approximate distance of 30 km from end to end. Two streams, the *Periyar* and *Mullayar*, join near the beginning of the reservoir. The only outlet of the reservoir is the drainage pipes laid down from the lake to the plain of Tamil Nadu.

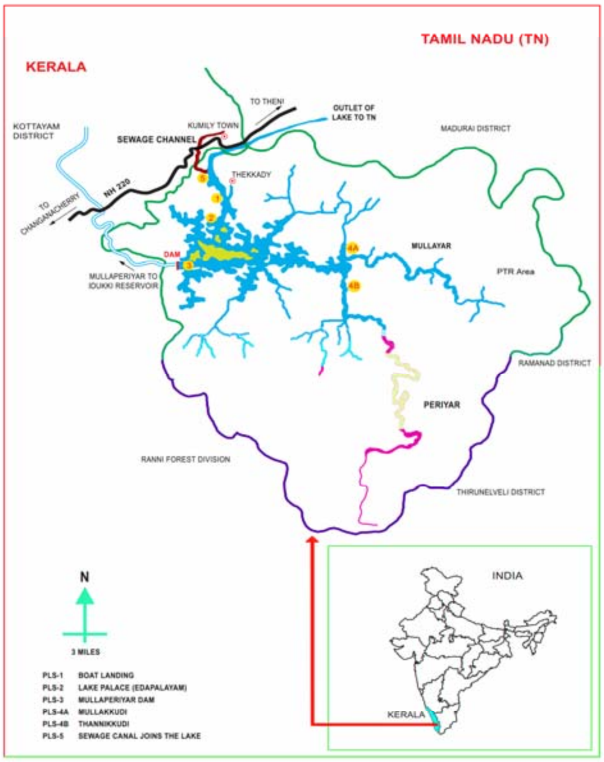

Fig. 1. **Location map of Periyar Lake**

(b) Filed Stations

Since the morphometry of Periyar Lake is complex with a lot of dendritic structures along its whole length, and the base of the flooded plane in the reservoir in general has an undulating topography, accounting of spatial variation was not easy in this system. However, six permanent sampling stations were fixed in the lake (Fig. 1) for convenient monitoring and systematic field study and regular sampling of waters. These stations were fixed after preliminary survey in the lake and according to differences in degrees of human interactions. The stations were designated as Periyar Lake Stations (PLS) - PLS-1, PLS-2, PLS-3, PLS-4a, PLS-4b, and PLS-5 respectively.

PLS-1 station was the boat jetty at *Thekkady* where boat trips begin in the Lake. This station is a place of high human impact. PLS-2 was the station near the star hotel, 'the Lake Palace', which is about 3 km away from the boat jetty towards the south of the lake. The area around the hotel is called 'Deer Island', and tourists reaching the hotel are able to vew frequently grazing of *Sambar* deer population quite common there. Water at this place is subjected to medium anthropogenic impact. PLS-3 was the site at the *'Mullaperiyar'* dam. It is about 15 km away from the boat jetty towards the south of the lake and represents the deepest zone of the Lake. PLS-4 (a) station was located at a place called the '*Mullakkudi'*, the site at which "*Mullayar*" (a tributary of Periyar River) merges with the lake. It is about 30km away from the boat jetty in the eastern direction. Naturally it is one of the regions of the Lake with low human impact and represents a zone of influence of '*Mullayar*' on the Lake. PLS-4(b) was located at a place called '*Thannikkudy'* where '*Periyar*' (the major river across which the dam is constructed) enters the reservoir and is about 5 km away from the '*Mullakkudi'* station, in the southeast direction of the lake. This region represents the core area of the reserve where tiger is available evidenced by its pugmarks on the riverbanks. It is therefore a virgin zone representing the influence of '*Periyar'* on the Lake. PLS-5 was the water tunnel way to Tamil Nadu, where the sewage channel from Kumily Township enters the lake. It is 1km away from the main Lake towards west direction from the boat landing site. The rate of flow of wastewater from the sewage channel to the tunnel varied according to the season. Field studies were conducted at three separate spots at each station every month and the average of the three measurements was taken as the monthly reading of a site.

(c) Field Measurements

Air temperature, monthly precipitation, monthly water level of the Lake, the rate of average monthly inflow and outflow were the climatic and hydrologic characteristics analyzed during this study. Details of precipitation, monthly inflow, outflow and water storage were collected from the records of the climate stations of the Tamil Nadu PWD at Thekkady. But water level of the Lake was measured directly from the measuring scale available at the PLS-1 Recording of air temperature and water temperature (of both the surface and bottom) was simultaneously done at all stations using a glass thermometer. The pH, DO, TDS and salinity of both surface and bottom samples were measured on the spot using a portable water and soil analysis kit (EI-microprocessor no.1160E). EC and pH were measured using separate pocket testers (Eutechscan-3). Transparency was measured at each station using a 20cm diameter painted iron plate with alternate bands of black and white (secchi dick).

(d) Sampling and Laboratory Analysis

Water samples were collected from the lake approximately between 15^{th} and 20^{th} of every month, from April 2002 to April 2005. Direct field measurements and sampling started at 9AM. The order of sampling was PLS-5 first and then PLS-1 to PlS-4 in regular order. The sampling of waters at PLS-5 and PLS-1 were done from the shores and PLS-2 to PLS4 (b) were carried out from motor boat. Samples were collected from surface (1-2cm) and bottom (2-10m) regions of the lake. The depth from which the bottom water sample collected was not uniform at all stations. In different seasons the depth varied from 1-3 meters at Stations 1 and 4b, 2-6 meters at station 5; it varied from 6-10 m at Station-2 but it was almost uniformly 10 meters at Station-3 and station 4b. Two liter of water of both surface and bottom were collected from each spot at all stations for physico-chemical analysis. Samples were collected in well cleaned polythene bottles of two liter capacity. The bottom samples were collected using a Meyer's water sampler. Bottom samples were transferred to the polythene bottles using a plastic tube. The bottles were packed appropriately in well-insulated boxes filled with ice cubes and were kept in darkness in iceboxes at 4 ^{0}C till the samples reached the laboratory for analysis. After reaching the laboratory the samples for BOD measurements were immediately incubated and others were kept in a refrigerator for next day's analysis.

Sample collection and incubation for BOD and the final analysis for the same were done according to methods of APHA (1995). DO was measured following Winkler iodometric method (Trivedy & Goel, 1986). CO_2, TA, Hardness, Ca, Mg, Cl and bicarbonates were measured titrimetrically (APHA, 1995; Golterman et al., 1978, and Trivedy & Goel 1986). Na and K were measured in the laboratory using a Flame Photometer (APHA, 1995). TS was measured as per Trivedy & Goel (1986). Results of the descriptive measures (average and variance) for all the climatic and water quality parameters were calculated station wise, season wise and year wise. The data used for seasonal analyses were the average of the four monthly values in each season. The variations of each particular parameter across stations and that over seasons or years and correlation analysis were analyzed using the ANOVA (Microsoft Excel).

RESULTS

Monthly readings of all the climatic, hydrological and physico-chemical parameters were grouped into different seasonal averages in each year. The averages of three different years were grouped into three-year average of all the seasons. Thus comparisons of the parameters were done in two different ways. Comparison of seasonal reading of each parameter over years and across stations helped to assess the degree of variability of these different environmental characteristics over years in different seasons and at different places of the Lake in each season. Comparison of the three-year average helped to assess the long-term variability over seasons and across stations. The purpose was to identify the degree of fluctuations in each quality parameter in relation to climate and hydrology annually, and in the three-year term at different places in the Lake. Ultimately, ecological status of the Lake as a whole and the route of environmental damage affecting the system could be traced.

(a) Climate of the area and Hydrology of the Lake

Air temperature and precipitation were the climatic factors monitored. Total inflow, outflow and water-level were the parameters monitored to assess hydrology of the lake. The maximum seasonal air temperature recorded in the Lake area was 30 ^{0}C during pre monsoon at Station-3 and 4-(a) in noon time and the minimum recorded temperature was 24 ^{0}C in the morning (at 8 AM) during northeast monsoon in Station -1. Only in the southwest monsoon, the fluctuations in air temperature across stations and over years were found significant. Therefore, this season appeared to be of maximum yearly fluctuations of air temperature in the system. A comparison of the three- year average value of air temperature showed significant difference in temperature over different seasons and across different stations at all seasons (Table 1).

Table 1

Three-year average of air temperature in the Lake area (2002-2005)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre monsoon	27.3	28.3	28.3	28	28	26.7
Southwest monsoon	25	27.3	26	26.6	27.6	25.6
Northeast monsoon	24.3	25	24.6	26.3	25.6	25

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	20.843333	2	10.42167	32.26522	4.35E-05	4.102816
Columns	6.431667	5	1.286333	3.982456	0.030062	3.325837
Error	3.23	10	0.323			
Total	30.505	17				

There were fluctuations in the monthly and seasonal precipitations over years during the period of study. In general, southwest monsoon remained the season of highest rainfall. The fluctuations in precipitation over years were very high during this season (695mm in 2002, 609mm in 2003, and 1190mm in 2004). The month of highest rainfall (203-511mm) during southwest monsoon varied from June to August during the three years of study. The month of lowest rainfall during southwest monsoon was May in both 2002 (134 mm) and 2004 (41 mm); but it was July during 2003 (145 mm). Thus fluctuations in monthly precipitations over years were quite evident in the southwest monsoon season. The precipitations during northeast monsoons varied between 422mm (in 2002) to 648mm (2003). Throughout the entire period of study December remained the month of lowest rainfall (1-41mm) and October remained the month of highest fall (249 mm to 488 mm) in the northeast monsoon. Monthly fluctuations in precipitation over years were quite low during northeast monsoon. The pre-monsoon rainfall was the lowest (13mm-20mm) throughout the period of study. Compared to the other seasons, fluctuations in rain fall of pre-monsoon over years were quite narrow. In the pre-monsoon period January remained the month of lowest rain fall (0-2mm) during the entire period of study. The month of highest rain fall of pre-monsoon was April (2003 and 2004) or March (2002).

Monitoring of the inflow, out flow, storage and water-level of the Lake are given in Table-2. Field observations showed that water level of Lake continuously fluctuate diurnally and monthly, and the fluctuations were quite unpredictable. However, these short duration fluctuations were not visible in the recorded seasonal average values. This was due to continuous fast drawing of water to the eastern planes through the drainage pipes permitting very low retention time of water in the Lake.

Table 2

Yearwise and Seasonwise Comparison of Hydrology (2002-2005)

season	year	Precipitation (mm)	Inflow (mcft)	Outflow (mcft)	Storage (mcft)	Water level (ft)
Pre-monsoon	2003	193	1060	40	1101	111
	2004	126	751	137	888	110
	2005	237	1662	1552	1130	111
Southwest	2002	695	3487	2292	1195	112
	2003	610	2474	1001	1473	113
	2004	1190	10677	8273	2404	118
Northeast	2002	422	6737	4580	2157	117
	2003	647	6051	4050	2000	115
	2004	537	10997	7872	3124	122

PHYSICAL AND CHEMICAL PARAMETERS

(a) Water temperature

Comparison of temperature of different years showed significant variations in surface water temperature across stations and over years in the southwest monsoon. However, comparison of the three-year average of surface water temperature during the period of study showed that temperature variations over different seasons were significant but across stations were insignificant (Table 3). The monthly variations in bottom water temperature of different years were significant across stations during the pre-monsoon period alone. However, in the three-year average of bottom water temperature, significant variations were found over different seasons at all stations.

Table 3

Three-year average of surface water temperature – ^{0}C (2002-05)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	27	27.6	27.3	27	28	26.3
Southwest monsoon	26	26	25.3	27	25.3	25
Northeast monsoon	25	26.3	24.3	25.3	25	25.3

ANOVA: Two-Factor Without Replication

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	12.75111111	2	6.375556	17.34583	0.000561	4.102816
Columns	2.797777778	5	0.559556	1.52237	0.26696	3.325837
Error	3.675555556	10	0.367556			
Total	19.22444444	17				

(b) Transparency

In general the secchi depth was found least during the pre-monsoon, highest during the northeast monsoon and moderate during the southwest monsoon at all stations. Three-year average of transparency at different stations showed that the variations in transparency over seasons and across stations were significant in the Lake (Table 4).

Table 4

Three-year average of Seasonal Secchi Depth or transparency -m (2002-05)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	1	1.4	2	1.5	1.2	0.85
Southwest monsoon	1.2	1.5	1.7	1.5	1.5	1.2
Northeast monsoon	1.3	1.7	2.2	1.7	1.5	1.2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.230277778	2	0.115139	7.28471	0.011169	4.102816
Columns	1.514027778	5	0.302806	19.15817	7.83E-05	3.325837
Error	0.158055556	10	0.015806			
Total	1.902361111	17				

(c) Electric Conductivity (EC)

In Periyar Lake, the highest average seasonal EC of surface waters observed during this study was 80 µS from Station-5 during the pre-monsoon of 2004 and the lowest value was just 15.2µS at Station 4(b) during the northeast monsoon of the same year. Highest average seasonal EC of bottom water during this study was 86.7 µS from Station-5 (southwest monsoon, 2004) and lowest conductivity reported was just 15.6 µS at Station 4(b) (northeast monsoon, 2004). Except at Station-5, the surface and bottom water at all the other five stations showed more or less the same EC always. The EC of both the bottom and surface water were quite similar in the Lake. Moreover, apart from slightly random spatial and yearly fluctuations, water in this Lake did not express definite seasonal trends in EC value. There were no significant variations in EC of surface water over years during all the seasons. Across stations the variations were insignificant during pre-monsoon but significant during both the monsoon periods. In the three year average EC of both surface and bottom waters also there were no variations over seasons but the variations were significant across different stations (Tables 5 and 6).

Table 5

Three year average E C of surface waters -µS (2002-05)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	29.3	27.2	26.7	30	21.7	63
Southwest monsoon	22.8	28.3	23.4	18.2	19.4	60.9
Northeast monsoon	29.3	31.6	24.1	21.8	21.8	52.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	53.49	2	26.745	2.121553	0.170599	4.102816
Columns	2986.031667	5	597.2063	47.37352	1.22E-06	3.325837
Error	126.0633333	10	12.60633			
Total	3165.585	17				

Table 6

Three year average of E C of bottom waters - μS (2002-05)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	29.5	26.7	29.8	23.9	22.5	53.8
Southwest monsoon	28.3	25.4	26.5	23	22.2	64.2
Northeast monsoon	28.9	29.6	32.1	22.6	22.5	32.9

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	42.35111111	2	21.17556	0.429848	0.662082	4.102816
Columns	1576.004444	5	315.2009	6.398344	0.006452	3.325837
Error	492.6288889	10	49.26289			
Total	2110.984444	17				

(d) Salinity

In surface water, the highest salinity range of 16-24 ppm was found at Station-5 and the lowest salinity range of 11-17 ppm was noticed at station 4b. Surface water at station 1 showed the 2nd highest salinity. The lowest recorded average seasonal salinity of surface waters during the period of this investigation was 11.4 ppm at station 4b during northeast monsoon of 2003 and the highest recorded salinity was 24 ppm at Station-5 during the southwest monsoon in 2002. There were significant correlations between salinity and EC of waters at all stations. The general increase in salinity at station-5 during southwest monsoon might be due to the influence of increased amount of sewage waters joining the system at this site. Variations in salinity of surface waters over years during pre-monsoon were slightly significant whereas that across different stations were insignificant. In both the monsoon seasons there were very significant variations in salinity of surface water across stations; but the variations of salinity over years during these seasons were insignificant. A comparison of the three year average salinity of surface water (Table 7) showed that similar to the trends in EC the variations of salinity across different stations were significant whereas that over different seasons were insignificant in the Lake. Unlike surface water, fluctuations in salinity of bottom water over different years were insignificant during all the seasons. But the fluctuations across different stations were significant during both the monsoons seasons.

Table 7

Three year average salinity of surface water – mg L^{-1}(2002-05)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	16.3	13.3	15.4	17	16.1	17.8
Southwest monsoon	15.5	13.7	13.2	12.6	12.8	21.8
Northeast monsoon	16.5	12.6	13.3	12.5	11.8	17.2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	12.01	2	6.005	2.137264	0.16873	4.102816
Columns	71.9133333	5	14.38267	5.118994	0.013774	3.325837
Error	28.0966667	10	2.809667			
Total	112.02	17				

(e) Total Solids (TS)

TS of surface waters varied from 110 mg L^{-1} (at Station-4b during northeast monsoon of 2004) to 530 mg L^{-1} (at Station-5 during southwest monsoon of 2002). The TS values of surface waters of Station-5 remained higher than that of the other stations during the entire period of study. Similarly the 2nd highest TS were noticed at Station-1. TS across different stations and over years were significantly different during all the seasons. The highest content of total solids at both these stations was observed in the southwest monsoon of 2002. Three year average of TS across stations and that over different seasons were also significantly different in the Lake.

(f) Total dissolved solids (TDS)

TDS is a direct measure of all the dissolved substances, both organic and inorganic in waters. In Periyar Lake the TDS of surface waters varied from 19 mg L^{-1} (pre-monsoon of 2004 at Station-2) to 44.2 mg L^{-1} (southwest monsoon of 2003 at Station-5) and that of bottom waters varied from 47.2 mg L^{-1} (northeast monsoon of 2003 at Station-5) to 18.8 mg L^{-1} (northeast monsoon of 2002 at Station-2). The TDS at Station-5 was the highest among all stations (29.8 mg L^{-1} to 44.2 mg L^{-1} for surface waters and 29.8 to 47.2 mg L^{-1} for bottom waters) and in general, were significantly higher than that of other stations during the entire period of study. The 2nd highest TDS was noticed at Station-1 (20 to 28.2 mg L^{-1} for surface waters and 18.5 to 28.2 mg L^{-1} for bottom waters), during most of the seasons. However, in the northeast monsoon, the TDS at this station was almost equal to that at other normal stations. At the other stations (2, 3, 4-a, and 4-b) the variations in TDS were quite narrow (19-24.4 mg L^{-1}) during the entire period of study. Fluctuations in TDS of both surface and bottom waters over years during all seasons were found insignificant, but that across the different stations were very significant.

(g) Total Alkalinity (TA)

TA varied between 13.1 mg L^{-1} (at Station-4a & 4b during southwest monsoon of 2004) to 22.5 mg L^{-1} (at Station-5 during the pre-monsoon of 2005).

The fluctuations in TA of surface water over years were very significant during pre-monsoon and southwest monsoon, but that was insignificant during northeast monsoon. During all the seasons, fluctuations in TA of surface water across different stations were insignificant. A comparison of the three-year average of TA of surface water showed that variations in this factor over seasons and across different stations were always significant; but that of bottom waters was significantly different over seasons and insignificant across stations. TA of both the surface and the bottom water in general showed a decreasing tendency from the pre-monsoon to the northeast monsoon at all stations during the entire period of study. It may be assumed that as the monsoon progresses TA decreases in the Lake.

(h) Hardness

The highest hardness noticed was during the pre-monsoon season (12.5 mg L^{-1} at Station-5 in 2003), moderate during the southwest monsoon (6.5 mg L^{-1} at Station-4b in 2004) and lowest during the northeast monsoon season (5 mg L^{-1} at Station-5 and the same at Station-3 in 2004). In general, the surface water at Station-5 showed comparatively higher hardness than that at other stations in all seasons during entire period of study except during the northeast monsoon of 2004.

(i) Free Carbon Dioxide (CO2)

The CO_2 of surface waters varied from 1.6 mg L^{-1} (at Station-3) to 3.4 mg L^{-1} (at Station-5). In general, both the surface and bottom water at Station –5 showed a comparatively higher CO_2 than that at the other stations during the entire period of study. Another significant trend observed was a slight increase in CO_2 in the surface water at Station 4 (a) during the northeast monsoon. In other stations during the entire period of study the CO_2 of surface waters did not show much fluctuation. CO_2 of bottom waters showed a slight increase from pre-monsoon to northeast monsoon at all stations. There were no fluctuations in CO_2 content of surface waters over different years and across different stations in each season. Comparison of three-year average CO_2 content (Table 8.) showed that the variations in CO_2 in surface waters were significant over different seasons but insignificant across different stations. There were no fluctuations in CO_2 of bottom waters over different years and across different stations in southwest and northeast monsoon seasons. But in the pre-monsoon, the fluctuations in CO_2 of bottom water were found significant over years and not significant across stations. However, comparison of three-year average of dissolved CO_2 of bottom water (Table 9) showed that the variations in this factor were significant over different seasons and across different stations in Periyar Lake.

Table 8

Three-year average Total dissolved CO_2 of surface water mg L^{-1} (2002-05)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	2.5	2.4	2.4	2.4	2.2	2.5
Southwest monsoon	2.4	2.2	2	2.1	2.1	2.8
Northeast monsoon	2.5	2.7	2.8	2.7	2.5	2.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.497777778	2	0.248889	8.818898	0.006201	4.102816
Columns	0.304444444	5	0.060889	2.15748	0.140805	3.325837
Error	0.282222222	10	0.028222			
Total	1.084444444	17				

Table 9

Three-year average Total dissolved CO_2 of bottom water - mg L^{-1} (2002-05)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	1.3	1.7	1.8	1.5	1.3	1.8
Southwest monsoon	2.2	2.6	2.6	2.9	2.2	2.8
Northeast monsoon	2.6	3.3	3.1	3.3	2.5	2.9

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	6.081111111	2	3.040556	117.4464	1.14E-07	4.102816
Columns	1.044444444	5	0.208889	8.06867	0.002766	3.325837
Error	0.258888889	10	0.025889			
Total	7.384444444	17				

(j) Dissolved Oxygen (DO)

DO in surface waters of Periyar Lake varied from 4.6 mg L^{-1} (at Station-2, during pre-monsoon of 2004) to 8.3 mg L^{-1} (at Station 4b during pre-monsoon of 2005). There was no significant difference in DO between surface and bottom waters at all stations 1, 4-(a), 4-(b) and 5 but the difference was significant in stations 2, 3 and 4a. The uniform DO at certain stations was because of the low bottom sample depth (below 3 meters) at all those stations. At Stations-2, 3 and 4a, where the average sample depth was consistently around 10 meters, a difference in DO between both surface and bottom waters was quite evident. At the dam site (Station-3) where the depth of bottom sample was consistently 10 meters in all seasons throughout the entire period of study, the bottom DO was also consistently lower than that of its surface content; 2.1 to 5 mg L^{-1} during pre-monsoon, 4.9 to 7.2 mg L^{-1} during southwest monsoon and 4.4 to 6.9 mg L^{-1} during northeast monsoon.

(k) pH

The three year average pH during pre-monsoon at the inlets was 7.5 and that at the outlet was 7.6. The three year average pH during southwest monsoon at the inlet and outlet were 7.5. The three year average pH during northeast monsoon at the inlet was 7.6 and that at the outlet was 7.8. Comparison of the three-year average of pH (Table 10 & 11) of both surface and bottom water showed that the variations in pH across different stations were insignificant whereas that over different seasons were significant always.

Table 10

Three-year average pH of surface water (2002-05)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	7.5	7.3	7.5	7.5	7.5	7.7
Southwest monsoon	7.7	7.6	7.6	7.6	7.4	7.5
Northeast monsoon	7.9	7.7	7.7	7.6	7.6	7.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.147778	2	0.073889	6.584158	0.014981	4.102816
Columns	0.089444	5	0.017889	1.594059	0.247742	3.325837
Error	0.112222	10	0.011222			
Total	0.349444	17				

Table 11

Three-year average pH of bottom water (2002-05)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	7.4	7.4	7.4	7.4	7.4	7.7
Southwest monsoon	7.7	7.5	7.5	7.4	7.3	7.7
Northeast monsoon	7.8	7.5	7.6	7.6	7.7	7.7

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.124444	2	0.062222	6.086957	0.018655	4.102816
Columns	0.156111	5	0.031222	3.054348	0.062604	3.325837
Error	0.102222	10	0.010222			
Total	0.382778	17				

(l) Calcium ions in Water (Ca)

In Periyar Lake the seasonal average of Ca content in waters varied from 2 mg L^{-1} (during monsoon) to 3.5 mg L^{-1} (during summer). The fluctuations in Ca of surface water over years and across stations were insignificant during southwest and northeast monsoons, whereas it was significant during the pre-monsoon. However, comparison of the three year average of Ca of surface water showed that the variations in it over seasons and across stations were very significant (Table 12).

Table 12

Three-year average of Ca of bottom water mg L^{-1} (2002-05)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	2.6	2.4	2.9	2.9	2.7	3
Southwest monsoon	2.6	2.6	2.8	2.8	2.6	3.2
Northeast monsoon	2.4	2.4	2.3	2.5	2.4	2.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.341111111	2	0.170556	12.89916	0.001701	4.102816
Columns	0.549444444	5	0.109889	8.310924	0.002473	3.325837
Error	0.132222222	10	0.013222			
Total	1.022777778	17				

(m) Magnesium ions in Water (Mg)

The seasonal average of Mg in Periyar waters varied from 3.1 to 6.6 mg L^{-1}, which is quite below the standards prescribed. The maximum Mg reported from bottom water was 7.3 mg L^{-1} (at station 5 during the Pre-monsoon 2003 and the minimum amount reported was 3.1 mg L^{-1} (at station 3 during the Pre-monsoon of 2003).

(n) Potassium ions in Water (K)

K ions in both the surface and bottom waters did not vary much. In both surface and bottom waters, the K varied from 1.9 mg L^{-1}(at Station-5 and 1 during southwest monsoon of 2002) to 0.8 mg L^{-1} (at Station-4b during northeast monsoon of 2002). A comparison of the three year average of K ions of both surface and bottom water showed that there were no significant fluctuations in K ions in the Lake over different seasons and across different stations during all the seasons.

(n) Sodium ions in Water (Na)

In Periyar Lake the seasonal average of Na ions varied from 1.9 mg L^{-1} (at Station -4b during Southwest monsoon) to 6.1 mg L^{-1} (at Station-5 during Pre-monsoon). There were not much difference in Na ions in both surface and bottom waters. There were significant fluctuations in the Na ions over different years during all the seasons but the fluctuations across stations were significant during the southwest and northeast monsoon seasons only. The fluctuations in the three year average of Na in the surface and bottom water were significant over different seasons and across different stations during all the seasons.

(o) Chloride ions (Cl)

The Cl ranged from 5 mg L^{-1} (at Station-4b during southwest monsoon of 2003) to 9.9 mg L^{-1} (at Station-5 during pre-monsoon of 2005). At the major inlet stations (4a & 4b) Cl varied from 5 to 6.4 mg L^{-1} where as the same at Station-5, varied from 6.3 to 9.9 mg L^{-1}. At Station-1 the Cl ranged from 6.2 to 9.9 mg L^{-1} and at the other stations lying in between Station-5 and the major inlet stations, the range of Cl was intermediary between the two. Another important trend noticed was that of increase in Cl at Station-1 than that at Station-5 during the southwest monsoon of both 2003 and 2004.

Comparison of Cl in surface water during different years of study showed that the fluctuations in it over years were significant in the pre-monsoon and northeast monsoon but it was insignificant during the southwest monsoon. However, such fluctuations across different stations were significant during all the seasons. The three-year average of Cl in surface water showed that fluctuations over seasons were insignificant whereas that across stations were significant (Table 13).

Table 13

Three-year average of Total dissolved Cl of surface water mg L^{-1} (2002-05)

	Station 1	Station 2	Station 3	Station 4a	Station 4b	Station 5
Pre-monsoon	7.6	6.6	5.6	6	5.6	8.3
Southwest monsoon	7.2	6	5.8	5.5	5.2	6.5
Northeast monsoon	6.4	6.3	5.9	5.9	5.5	7.1

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1.101111111	2	0.550556	3.094941	0.089905	4.102816
Columns	8.611111111	5	1.722222	9.681449	0.00137	3.325837
Error	1.778888889	10	0.177889			
Total	11.49111111	17				

DISCUSSION

Natural lakes in temperate latitudes usually have a relatively stable water regime but this is not the case in some natural lakes in the tropics, particularly those that occur in areas where the climate is divided into distinct wet and dry seasons (Osborne et al., 1987). Periyar Lake is a ‘high altitude’ tropical Lake with constant and much frequent diurnal and monthly fluctuations in rain fall, inflow as well as out flow. The three-year monitoring, as was carried out in Periyar, was found minimal to assess the general ecological tendencies of such tropical Lake Systems in general.

In monitoring investigations of aquatic systems in Kerala, monthly data are usually pooled and divided into three seasons for getting reliable trends for explaining the features (Koshy, 2002). In previous studies of freshwaters in Kerala (Koshy & Nair, 1999; Jayaraman et al., 2003; Radhika et al., 2004), the three seasons usually recognized are post monsoon (Nov – Dec – Jan) pre monsoon (Feb – March – April – May) and monsoon (June – July – August – Sept – Oct). However, there exist two monsoon seasons in Kerala, the southwest and northeast monsoons, which quite often differ in the nature and amount of precipitation. Though the gap between these two monsoon seasons is quite narrow and sometimes they overlap, they represent climatically quite distinct periods. Moreover, there is a recognizable gap in between the northeast monsoon of one year and the southwest monsoon of the next year, which is the pre-monsoon. Therefore, monthly observations of each year were grouped into three seasons in the present study; the pre-monsoon (Jan – Feb – March – April), southwest monsoon (May – June – July – August) and northeast monsoon (Sept. - Oct. – Nov. – Dec.) which enabled a better comparison of the seasonal changes of the Lake system between years.

Seasonal difference in air temperature was a clear indication that the pattern of division of monthly observations into the three seasons followed in the present study did correspond to differences in air temperature regimes of the Lake area. However, stationwise fluctuations in temperature during a particular season might be due to differences in the timing of collection of water samples because the weather quite fluctuates diurnally in the Periyar Lake. Jayaraman et al. (2003) recorded similar fluctuations in air temperature in different stations in a river in Thiruvananthapuram District, Kerala. The comparison of rainfall between different seasons showed that precipitation is the major atmospheric factor which contributes to seasonal variations of climate in the system. Since the southwest, northeast and pre-monsoon seasons showed statistically significant differences in precipitation rate and air temperature, the present division of the monthly data of a year to develop the three seasonal trends, the two different monsoon trends and the pre-monsoon trend, was found to be quite reasonable.

According to Osborne et al. (1987) the implications of fluctuations of water level on chemical composition and productivity of water body as a whole is not obvious. Becht & Harper (2002) found that an optimum water level is essential in Lakes in terms of biodiversity, ecology and conservation. Such an ecological concern was not found in the management of water level in Periyar Lake.

Water temperature is of enormous significance as it regulates various abiotic characteristics and biotic activities of an aquatic ecosystem which is recognized by many authors (Kataria et al., 1995; Iqbal & Kataria, 1995; Sharma & Sarang, 2004; Radhika et al., 2004). Kataria et al. (1995) reported a temperature variation of 21.4^0C to 34.2 ^{0}C in Tawa Reservoir in North India. Jayaraman et al. (2003) observed a difference in surface water temperature of 25^0C (post-monsoon or northeast monsoon) to 30.6^0C (pre-monsoon) in *Karamana* River near Thiruvananthapuram, in Kerala. The season of lowest and highest temperature in Periyar Lake area was similar to that of aquatic systems elsewhere in Kerala, but the range of temperature fluctuation in Periyar Lake was narrower than that of other water bodies in the State. Moreover, the maximum surface water temperature in Periyar Lake was found lower than that of other fresh water systems in the State. This is on account of the high altitude location of the lake as well as the presence of thick forests around. The present observation of surface water temperature in Periyar Lake agrees with the observations of Kaul et al (1980) that surface water temperature usually remains close to the air temperature.

The spatial and vertical difference in temperature of water in a Lake in general is influenced by the temperature of inflowing waters, extend of vertical mixing as well as process like exchange of heat with the atmosphere and other localized phenomena also influence the distribution of temperature. Unlike the surface water, the variations in the three year average temperature of bottom water across all the stations were also significant during all the seasons. This might be due to differences in depth of measurement at different sites. At Station 3, where the depth was constantly 10 meters, the bottom temperature was constantly 24 ^{0}C in the pre-monsoon, 22-25^{0}C in the southwest monsoon and 22-24^{0}C in the northeast monsoon, during the entire period of study. As in the case of surface water, the bottom waters also exhibited a slight seasonal trend in temperature with a slight increase in the pre-monsoon, a decrease during northeast monsoon and moderate values during southwest monsoon. Radhika et al., (2004) made a similar observation in water temperature in *Vellayani* Lake, in Kerala.

Unlike the observations in other tropical freshwater by Suvarna & Somashekar (1997), the transparency of waters in Periyar Lake was found only increased during the monsoon seasons. This is owing to undisturbed watershed which keeps the soil system intact during the monsoon. Increase in turbidity due to higher impact of boat activity combined with low water level is responsible for less transparency in the pre-monsoon. Radhika et al. (2004) also observed an increase in turbidity during pre-monsoon in *Vellayani* Lake, Kerala, which they attributed to high productivity coupled with excessive planktonic growth; they assumed that the high transparency during monsoon is because of dilution of water in excess precipitation. In Periyar Lake, the increase in transparency during monsoons is definitely due to excessive inflow which is not muddy due to undisturbed watershed around.

The highest secchi depth noticed during the study period was 250 cm at station –3 (dam site) during the northeast monsoon of 2004 and the lowest measure was 70 cm at Station –5 during the pre-monsoon, 2003. This observation agrees with that of Bhade et al. (2001) that turbidity is 3 to 4 times higher in the riverine stretch compared to dam site. Sharma and Sarang, (2004) observed transparency of 22- to 167 cm in *Jaisamand* Lake, Udaipur; in a Forest Lake in Kashmir, Kaul et al., (1980) observed a transparency of 80 cm to 200 cm and the same observed in *Vellayani* lake in Kerala (Radhika et al., 2004) is only 28cm to 58.5 cm. In Periyar Lake, the higher transparency at Station-3 did correspond to higher depth and lesser turbulence. Amarasinghe & Viverberg (2002) reported a similar influence of depth on increased transparency in waters of a tropical reservoir in Sri Lanka. The lowest transparency at Station-5 was due to the combined effect of both sewage inflow as well as the impact of turbulence due to boat activity at Station-1, which is close to it. The second lowest transparency at Station-1 was definitely due to lower depth and highest boat turbulence at this site. Hilton & Philips, (1982) reported a similar increase in turbidity due to boat activity in a river.

Tiwari (1999) reported EC of 230 to 300 µS at 30^{0}C in Upper Lake water of Bhopal. Kataria et al. (1995) found EC of 150 to 256 µS in *Tawa* Reservoir, India. Garg (2002) observed average EC of 769.62 µS in River *Mandakini, Chitrakoot* and the author also found a seasonal trend in EC in the same river; minimum in monsoon due to addition of rain water but maximum in post monsoon (northeast monsoon). Radhika, et al. (2004) reported that in *Vellayani* Lake, Kerala, the EC of surface waters varied from 91.2 to 320 µS during pre-monsoon, 76.3 to 230µS during southwest monsoon and 96 to 226.6 µS during northeast monsoon. Suvarna and Somashekar (1997) reported that EC usually decrease after rainfall following increase in inflow, culminating in dilution. Taheruzzaman & Kushari (1995) observed an increase in EC in water bodies of Burdwan, West Bengal, during monsoon which according to them is due to voluminous runoff carrying diverse types of electrolytes from the nearer as well as distant areas. But according to Sarojini (1996) seasonal fluctuations in EC are closely related to evaporation and concentration of soluble salts. Compared to these previous reports on EC of Indian waters, Periyar waters showed a very low EC. Low ionic content in natural waters is generally attributed to slow chemical weathering in the catchments area (Blakar et al., 1990**).** Mortimer (1941) reported that mineralization of organic matter under the influence of reducing conditions prevailing in the bottom water is accompanied by a release of minerals. Kaul et al. (1980) finds this as the reason for higher EC in bottom waters than surface waters and also observed mixing of water results in the prevalence of the same EC values throughout the vertical profile of water. Since no significant difference in conductivity of both surface and bottom waters was observed in Periyar Lake, it may be concluded that there exist quite good vertical mixing of waters to the depth examined in the Lake.

The salinity, TS and TDS measured for Periyar Lake was quite low and there was no significant difference in salinity between the surface and bottom waters. Tiwari (1999) observed a TDS of 150 to 192 mg L^{-1} (mean value 170 mg L^{-1}) in the 'Upper Lake' of Bhopal. Dwivedi & Sonar (2004) reported a TDS of 150 mg L^{-1} in a small reservoir in northeastern State of Arunachal Pradesh, India. Gupta & Gupta (1999) reported a TDS of 175-414 mg L^{-1} in drinking waters in Satna, MP State, India. Compared to these reports TDS at Periyar Lake was found very low at all the stations during the entire period of study. However, a general increase in salinity, TS and TDS of surface water at Station-5 and its reflection on salinity range of Station-1 are trends suggesting inflow of sewage content to the general Lake system.

Sharma and Sarang (2004) observed TA of 190 to 350 mg L^{-1} in *Jaisamand* Lake, Udaipur, Rajastan State, India. Bhatt et al (1999) reported TA variation of 156 to 191 mg L^{-1} in *Taudaha* Lake in Katmandu. When compared to these reports it became clear that the TA in surface as well as bottom waters of Periyar Lake remained within the very safe level at all stations during the entire period of Study. In Periyar Lake, TA was solely due to bicarbonates and no carbonate alkalinity could be traced at any station during the entire period of study. However, when the TA level is used as a criterion for assessing the nutrient status (Moyle, 1949 and Sorgensen, 1948) the Periyar Lake water is moderately nutrient rich. The observations of seasonal difference in TA in Periyar Lake in general agrees with the opinions of Bhatt et al. (1999) and Trivedy and Goel (1986) who argued that TA is usually higher during pre-monsoon than monsoon. Venkateswarlu (1969) observed that TA is affected by rain fall. Radhika et al. (2004) observed an increase in alkalinity during summer in *Vellayani* Lake, Kerala. Garg (2002) observed that total alkalinity in river *Mandakini, Chitrakoot*, decreases in summer and increases at winter. Iqbal & Katariya (1995) reported that in the Upper Lake of Bhopal, MP State, India, the maximum TA was during monsoon and the minimum value was during summer. As in the case of other parameters, the surface water of Station-5 showed a higher TA in all seasons during entire period of study. But such a clear tendency was not found in the TA of bottom waters.

Reid (1961) observed that hard water lakes have little or no carbonate alkalinity and the bicarbonate alkalinity results in high buffer capacity which keep the pH relatively constant. In *Vellayani* Lake, Kerala, Radhika et al (2004) observed hardness in surface waters of 16.25 to 30.75 mg L^{-1} whereas in bottom waters the hardness was slightly higher, which varied from 17 to 37.25 mg L^{-1}. According to Durfer and Baker's classification when hardness is less than 75 mg L^{-1} of $CaCO_3$, water is soft (Adak et al., 2002). According to Moyle (1949) and Pandey & Soni (1993) a lake with an alkalinity value over 90 mg L^{-1} is hard. Prasanth et al. (1996) reported a hardness of 82 mg L^{-1} to 344 mg L^{-1} in waters of Temple Tanks in and around Madras city. Compared to hardness of similar fresh waters in the country, the Periyar water was soft throughout the period of study. Higher hardness of river water is probably due to the regular addition of sewage, detergents and huge human activities (Jain et al., 2002). It is at the Station-5, the sewage of *Kumily* Township joins the surface water of the Lake and hence the slight increase in hardness in surface waters at this site is a sign of anthropogenic impact on the system just as in the case of alkalinity.

CO_2 in Periyar Lake waters remained quite normal for an oligotrophic freshwater system and never exceeded the standards during the entire period of study. The limit of CO_2 as per acceptable standards is 10 mg L^{-1} of surface water and increase in CO_2 above this level indicates increase in pollution load (Koshy & Nair, 1999). Dwivedi and Sonar (2004) observed an average of 2 mg L^{-1} of free CO_2 in water of reservoirs in Arunachal Pradesh State, India. Radhika et al. (2004) reported an annual variation of 2.42 to 10.47 mg L^{-1} of CO_2 in *Vellayani* Lake in Kerala. The same author found that there was a gradual change in concentration of CO_2 in the Lake from pre-monsoon to monsoon to post monsoon; the maximum being in the post monsoon, minimum during monsoon and moderate during pre-monsoon. Significant fluctuations in CO_2 over seasons were observed in Periyar Lake which agrees with similar findings in North Indian waters (Sharma & Mathur, 1992).

The minimum limit of DO required for freshwaters as per ICMR (1975) and the ISI (1991) standards is 5 to 6 mg L^{-1}. Therefore, the DO of Periyar Lake (4.6 mg L^{-1} to8.3 mg L^{-1}) can be considered almost normal for a natural Lake except at certain points during certain seasons and years. Kaul, et al (1980) observed DO value of 5.7 to 11.7 mg L^{-1} in *Nilnag* Lake, Kashmir. Koshy and Nair (1999) observed a DO content of 3.1 mg L^{-1} to 12.6 mg L^{-1} in *Pampa* River, Kerala. Garg (2002) reported DO of a minimum of 6 mg L^{-1} (during summer) and maximum 8.12 mg L^{-1} (during Monsoon) in river *Mandakini*, Chitrakoot. Singh & Rai (1999) reported DO variation of 9.83 mg L^{-1} to 0.9 mg L^{-1} in *Ganga* River at Varanasi. Jayaraman et al., (2003) observed that DO vary monthwise and stationwise in waters of *Karamana* River, Kerala and maximum DO is observed in rainy season. Unlike the above reports, Periyar Lake waters remained stable with only meager fluctuations in DO during the entire period of study. The fluctuations in DO observed in Periyar Lake were quite random. There were no visible seasonal trends in the average dissolved oxygen content of surface waters and bottom waters at all the stations in Periyar Lake. However, a slight general reduction in DO was observed at Station-5, which may be due to the impact of organic load through sewage from Kumily Township reaching the site. In Lakes depletion of oxygen in the lower layers near the bottom is an indication of eutrophication (Kaul, 1977). In Periyar Lake since the bottom depletion of oxygen was much more intense during the summer (pre-monsoon) season, the monsoon influence was positive than negative, and hence the bottom depletion in the pre-monsoon can be attributed to lowering of general water level and to the deposit of organic matter which may be existing at the extreme bottom. Moreover, there is the chance of re-oxygenation of water during monsoon due to circulation and mixing by inflow after monsoon rains (Hannan, 1979). Northeast monsoon corresponds to the winter season during which cooling down of water body enable much more dissolution of oxygen in waters than during warm seasons.

pH balance in an ecosystem is maintained when pH is within the range of 5.5 to 8.5 (Chandrasekhar et al 2003). pH of a water body is a diurnally variable property according to temperature variation in the system (Ojha & Mandoli, 2004). According to ICMR (1975), safe pH limit is 7 to 8.5. But the safe range according to ISI (1991) is 6.5 to 8.5. A pH range of 6 to 8.5 is normal according to the United States Public Health Association (De, 1999). When compared to all these standards, pH observed in Periyar Lake waters in general, was within the safe limits of standard values fit for aquatic life. The pH in a lake clearly demonstrates the stabilizing effect when the yearly variation is smaller at the outlet than at the inlet, and the stabilizing effect is related to the retention time as well (Halvorsen, 2004). The maximum variation of pH noticed during the three year period of study was 7.4 to 8 and 7.1 to 7.7 at the two major inlets (Stations 4-a & 4-b) respectively whereas at the outlet (Station-5) the variation was 7.3 to 7.9. The fluctuations between the inlet and the outlet were quite insignificant in Periyar Lake. The retention time of water in Periyar Lake is very short as it is continuously drawn downwards to Eastern Plains for electricity generation and irrigation purpose. Therefore, it is better to assume that pH of waters in the entire Periyar Lake remain stable during each season.

The Ca level was found quite normal at all stations and the fluctuations noticed were quite irregular between seasons throughout the period of study. The general acceptable limit of Ca in waters is usually 75 mg L^{-1} whereas its maximum permissible limit is 200 mg L^{-1} (ICMR, 1975). Annual average amount of 30 mg L^{-1} of Ca is found in *Nilnag* Lake in Kashmir and the amount decreased in summer (Kaul, et al., 1980). But in a Norwegian mountain Lake the annual variation in Ca reported is from 0.62 to 0.93 mg L^{-1} (Halvorsen, 2004). Summer decrease of Ca in waters is attributed to photosynthetic activity of macrophytes attaining their peak growth and production during the season (Kaul et al., 1978). Unlike this findings, an increase in Ca was observed during summer in Periyar Lake, which agrees with the observations of Osborne, et al., (1987) who found that in Lake *Murray* of Papua New Guinea Ca was inversely proportional to water level; increased during low water levels and decreased during high levels. In general, there was a slight increase in Ca ion in waters at Station-5 (the outlet) from that at the dam site or Station-3 (the culmination of all inlets). The order of the major cations in waters is generally a progression of Ca>Mg>Na>K, typical of fresh water (Rhode 1949). In Periyar Lake the Calcium ions were found lesser than that of Magnesium ions.

Unlike the mineral composition of other lakes, the water of Periyar Lake was characterized by a higher amount of Mg than Ca. As in the case of Ca, there was a general increase in the average amount of Mg at Station-5 than at all other stations during the entire period of study. The general acceptable limit of Mg in water is usually 50 mg L^{-1} whereas its maximum permissible limit is 100 mg L^{-1} (ICMR, 1975). Halvorsen (2004) reported 0.12 to 0.16 mg L^{-1} of Mg in a Norwegian mountain Lake. In Lake Murray of Papua New Guinea, concentration of Mg (6 to 16 mg L^{-1}) varied according to water level; increased during low water levels and decreased during high levels (Osborne et al., 1987). The fluctuations of Mg in surface water over years were significant only during the southwest monsoon but that across stations were insignificant in all seasons. In the bottom samples, the fluctuations of Mg over years and across stations were insignificant in all seasons.

In Rivers *Mandakini and Chitrakoot*, seasonal variation in K content (2 to 12 mg L^{-1}) was not same at all stations; at certain stations the maximum content recorded was during summer and at certain others during monsoon (Garg 2002). Comparison of K content of surface water in the three-year period showed that the fluctuations in it over years were significant in all seasons whereas the fluctuations across different stations were significant during the northeast monsoon alone. But fluctuations over years or across stations were not visible in the three year average.

Na in the Lake was quite low and similar in both surface and bottom waters. Cl was more or less similar in both the surface and bottom water and it varied from 5 to 9.9 mg L^{-1}. The lowest amount of Cl was recorded at station 4 (b) throughout the study period. Gowd et al (1998) reported Cl of 11-514 mg L^{-1} during northeast monsoon and 10-418 mg L^{-1} during pre-monsoon season at *Pedavanka* watershed, *Ananthapur* District, Andhra Pradesh Sate, India. Dwivedi and Sonar (2004) observed a variation of Cl in reservoirs in Arunachal Pradesh from 21 mg L^{-1} during pre-monsoon to 29.6 mg L^{-1} during monsoon. Cl serves as an indicator of pollution by sewage (Trivedi & Goel 1986). But compared to other Indian Lakes Cl in Periyar Lake was negligible. However, an increase in Cl at Station-5 and 1 is obviously an indication of the sewage inflow from the town as was observed by Chandrasekhar, et al (2003) in other systems.

A general examination of the different physical and chemical parameters suggested that the Lake still remains in an oligotrophic state. However, the ecological trend in a complex ecosystem cannot be explained on the basis of physical or chemical environmental characteristics alone. Nutrient status and biotic structure are essential to understand its structure and functions completely. Moreover, the ecology of Periyar Lake cannot be discussed as an isolated system ignoring its importance to the existence of wildlife in the PTR. Its association with the PTR necessitates analysis of other pollutants such as oil and grease and other toxins in the water which has deleterious impact on the wildlife depending on the waters. Discussion of such details formed crucial part of the present research.

CONCLUSIONS

One of the very important general observations was the comparatively stable physico-chemical environmental characteristics of the hundred years over freshwater system, owing to its characteristic position within an undisturbed watershed, the PTR. Linking of reservoirs and wildlife sanctuaries appeared beneficial to commercial exploitations of water bodies but dangerous to wildlife if precautionary measures to even slight changes in quality management are not adequate. The studies offered certain specific information useful in the better management of Periyar Lake system. This Lake system is important to whole humanity as it is central to one of the richest wildlife resources of Asia, 'common human heritage', the PTR.

Since the fluctuations in air temperature across seasons was quite narrow, but that of precipitation rate of different seasons were very wide, it became evident that the major climatic factor dominating the Periyar Lake system is precipitation. The southwest, northeast and pre-monsoon seasons were found quite distinct in precipitation rate. Therefore, the present pooling of monthly data to develop the three seasonal trends, the two different monsoon trends and the pre-monsoon trend in a year was quite reasonable and fruitful. Southwest monsoon season was the season of maximum fluctuations in precipitation over years followed by the northeast monsoon and the season of least fluctuations was pre-monsoon. Analysis of hydrology of the Lake showed that the major management concern in this Lake is to tap as much water as possible as and when the inflow increases. Consequently the water level continuously fluctuates diurnally and monthly, and the fluctuations were quite unpredictable. Therefore, determination and maintenance of a constant water level is essential for the sustainable existence of Lakes as natural biological systems supporting wildlife sanctuaries, their economic uses as water bodies supporting tourism, as water reservoirs for irrigation and power generation purposes and as the water resources to sustain the viability of Rivers down the dams.

The maximum surface water temperature in Periyar Lake was found lower than that of other fresh water systems in the State. Both the surface and bottom water exhibited a seasonal trend in temperature with a slight increase in the pre-monsoon, a decrease during northeast monsoon and moderate values during southwest monsoon. Unlike the observations in different tropical freshwaters by many authors, the transparency of waters in Periyar Lake was found only increased during the monsoon seasons, which explains the significance of maintaining wildlife sanctuaries in association with reservoirs as a measure to keep the watersheds undisturbed.

The surface and bottom water in Periyar Lake in general showed a neutral or slightly alkaline pH and the pH of surface waters changed only once below the neutral value. Compared to the previous reports on EC of Indian waters, Periyar Lake showed a very low EC. Moreover, apart from slight random spatial and yearly fluctuations, water in this Lake did not express any definite seasonal trends in the EC value. In general, the salinity range of Periyar Lake is quite normal. TDS for surface water and that of bottom waters was found very low at all the stations during the entire period of study. TS of surface waters varied from 110 mg L^{-1} to 530 mg L^{-1}. The total alkalinity in surface as well as bottom waters remained within safe limit at all stations during the entire period of study. In the Periyar Lake, total alkalinity was solely due to bicarbonates. Hardness of water varied from 6.5 to 12.5 mg L^{-1}. In general, the free CO_2 level in Periyar Lake waters remained quite normal similar to an oligotrophic freshwater system and never exceeded the standard values during the entire period of study. DO in the surface water of the Periyar Lake varied from 4.6 mg $L^{-1}$to 8.3 mg L^{-1}. The water remained stable with only meager fluctuations in DO throughout the entire period of study. There were no visible seasonal trends in the average DO of surface waters and bottom waters at all the stations in Periyar Lake. All these factors explain the degree of resilience of freshwater systems in general, in association with undisturbed terrestrial forest ecosystems.

In general, the amount of mineral ions such as Ca, Mg, K, Na and Cl, and TA, CO_2 and hardness in the Lake were very low. Unlike the mineral composition of other lakes, the water of Periyar Lake was characterized by a higher amount of Mg than Ca. There were no significant differences in Ca and Mg ions in both surface and bottom waters. There was a general increase in the average amount of TA, salinity, CO_2, Ca, Mg, K, Na and Cl ions in water at Station-5 than all other stations during the entire period of study. This is evidently an impact of the sewage waters from the Kumily Township joining at this site. Thus the stationwise analysis of individual factors enables us to understand the way the disturbances affect freshwater systems in general. Such information is essential to take precautions sufficiently earlier for the sustainable maintenance of natural biological systems. Moreover, overall analysis of physico-chemical environment complex point to the development of comprehensive plans with an integrated holistic approach to protect tropical fresh water systems, in general. The Periyar model of keeping watersheds of reservoirs as sanctuaries may be accepted us a universal model, of course, with necessary precautions and proper monitoring.

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REFERENCES

Adak, M. D., S. Adak, & K.M. Purohit (2002), Studies on water quality of village Timjor, Orissa – Part-I Physico-chemical parameters, International Journal of Environment and Pollution, 22 (9), pp. 1040-1046.

Amarsinnghe, B.P. & J. Vijverberg (2002) Primary production in a tropical reservoir in Sri Lanka, Hydrobiologia, 487, pp. 85-93.

Arun, L.K., (1999) Patterns and processes of fish assemblages in Periyar Lake Valley system of South Western Ghats, KFRI Research Report No. 172, ISSN 0970-8103, pp. 1-57.

Arun, L.K. (1998), Status and distribution of fishes in PTR Lake Stream system of Southern Western Ghats, Fish Genetic Biodiversity Conservation, pp.77-87.

Becht, R. & D.M Harper (2002) Towards an understanding on Hydrobiology of Lake Naiwasha, Kenya, Hydrobiologia, 488, pp. 1-11.

Bhade, C., K.S. Unni & S. Bhade, (2001). Limnology and Eutrophication of Tawa Reservoir, MP, India; Verh Internat Verein Limnol, 27, pp.3632-3635.

Bhatt, L.R., P. Lacoul, H. D. Lekhak & P.K. Jha (1999) Physico-chemical characteristics and phytoplanktons of Taudaha Lake, Kathmandu, Pollution Research, 18 (4), pp. 353-358.

Blakar, I. A., I. Digernes, & H.M Seip, (1990). Precipitaion and stream water chemistry at alpine catchments in central Norway. *In* Mason, B.J. (ed.), The surface waters acidification programme, Cambridge University Press, Cambridge, UK, pp. 69-73.

CED (Centre for Environment and Development) Report (2000). Conflicts in Biodiversity Conservation – Traditional tribal fisheries in the PTR, Final Report, Research Report submitted by Centre for Environment and Development, Trivandrum, to Kerala Research Programme on Local Level Development, Centre for Development Studies, Thiruvananthapuram, pp. 5-88.

Chandrasekhar, J. S., K. Lenin Babu & R. K. Somasekar, (2003). Impact of Urbanization on *Bellandur* Lake, Bangalore – a case study, Journal of Environment Biolology, 24 (3), pp. 223-27.

De, A.K, (1999) Environmental Chemistry, New Age International (P) Ltd., Publishers, New Delhi, p.364.

Dwivedi, P. & S. Sonar (2004) Evaluation of physico-chemical and biological characteristics of water samples in water reservoir around Rono Hills, Doimmukh (Dist. Pampum Pare), Arunachal preadesh, Pollution Research, 23 (1) pp. 101-104.

Garg, S.S., (2002). Seasonal fluctuation on physico-chemical parameters of river Mandakini, Chitrakoot, International Journal of Environment and Pollution, (9), pp.986-991.

Golterman, H. L. (1975) Physiological Limnology- An Approach to the Physiology of Lake Ecosystems. Elsevier Scientific Publishing Company, Amsterdam, Oxford, New York.

Gowd, S. S., A.S. Sudheer & S. Srinivasulu (1998) Assessment of water quality for domestic and irrigation purposes in Peddavanka watershed, Anantapur district, International Journal of Environment and Pollution, 19 (9), 689-97.

Gupta, B.K. & R.R.Gupta (1999) Physico-Chemical and Biological study of drinking water in Satna, M.P – 485 001 (India), Pollution Research, 18 (4), pp. 523-525.

Halvorsen, G. (2004) Some physical and chemical characteristics of Lake Atnssjoen, Hydrobiologia, 521, pp. 129-140.

Hannan, H., (1979). Chemical modification in reservoir regulated streams; In: The Ecology of Regulated streams, Ward. J.W. and Stanford, J.A, Plenum (Ed.), Corporation Publication, pp. 75-94.

Hilton, J. & G. L. Phillips (1982) The effect of boat activity on turbidity in a shallow broad land river, Journal of applied Ecology, 19, pp.143-50.

ICMR (1975) Manual of standards of quality for drinking water supplies, Special report series No.44, 2nd edition.

Iqbal & H.C. Katariya, (1995) Physico-chemical analysis and water quality assessment of upper lake of Bhopal, International Journal of Environment and Pollution, 15 (7) pp. 504-509.

ISI, (1991). Indian standard specification for drinking water IS: 10500, ISI, New Delhi.

Jain, C. K., Singhal D. C., & M. K. Sharma, (2002). Survey and characterization of waste effluents polluting river Hindon, International Journal of Environment and Pollution , 22(7) pp. 792-799.

Jayaraman, P. R., T. Ganga Devi & T. Vasudevan Nayar (2003) Water quality studies on Karamana River, Trivandrum District, South Kerala, India, Pollution Research 22 (1) pp. 89-100.

Katariya, H.C. Iqubal S. A. & A.K. Sandilya (1995) Limno- chemical studies of Tawa Reservoir, International Journal of Environment and Pollution 16 (11) 841-846.

Kaul, V. (1977), Limnological survey of Kashmir Lakes with reference to trophic status and conservation, International Journal of Environment Science, 3, pp.29-44.

Kaul, V., J. K. Handoo & R. Raina, (1980). Physicochemical characteristics of Nilmnag – a high altitude forest lake in Kashmir and its comparison with valley lakes; Proceedings of the Indian National Science Academy, B. 46 No.4, pp.528-541.

Kaul, V., C.L.Trissal, & J. K. Handoo (1978) Distribution and production of macrophytes in some aquatic bodies of Kashmir, In Concepts of Ecology (Ed) J.S. Singh and B Gopal, pp. 313-334.

Khatri, T.C. (1992) Hydrobiology of Idukki Reservoir of Kerala, India, Oikassay, 9: pp. 41-46.

Koshy M. & T. V. Nair (1999) Water quality aspects of River Pampa, Pollution Research, 18(4), pp.501-510.

Koshy M. (2002) Study of carbon, phosphorus and Nitrogen in the sediments of River Pamba, Asian Journal of Chemistry, Vol. 14, No. 3-4, 1660-1666.

Koshy M.& T V. Nair (2000) Water quality of River Pamba at Kozencherry, Pollution Research 19 (4), pp.665 – 668.

Kurup, G.U. (1971), A preliminary ecological survey of the Periyar wildlife sanctuary, Kerala State, *Cheetal*, 13 (2) pp. 5-18.

Lal, M. S. (2000) Conservation of fish fauna of Periyar Lake, Thekkady, Kerala, p.160, In: Ponniah, A.G. Gopalakrishnan, A. (Eds) Endemic fish diversity of Western Ghats, NBPGR – NATP Publication – 1, National Bureau of Fish Genetic resources, Lucknow, UP, India, 347 p.

Management Plan (2001) PTR – 2001—02 to 2010-11 – Final Draft, Forest and Wildlife Department, Govt. of Kerala, Thiruvananthapuram.

Manoharan T. R. (2000), A Status paper on the linkages between the conservation of PTR and benefits of Mullaperiyar Dam – prepared as per a short-term assignment provided by the Field Director (PTR), Kottayam, pp.1-23.

Mortimer, C.H. (1941) The exchange of dissolved substances between and the water in lakes I & II, Journal of Ecology, 29, pp. 280-329.

Moyle, J. B. (1949) Some indices of Lake Productivity, Transactions of the American Fisheries Society, 76: pp. 322-334.

Ojha, P. & A. K. Mandoli (2004) Diurnal variation of pH in freshwater fish culture pond, Ecology, Environment & Conservation, 10 (1), pp.85-86.

Osborne, Patrick L., James H Kyle & Michael S. Abramski (1987) Effects of seasonal water level changes on the chemical and biological Limnology of Lake Murray, Papua New Guinea, Australian Journal of Marine and Freshwater Research. 38, 397-408.

Pandey, D. K. & P. Soni (1993) Physico-Chemical quality of *Naukuchiyatal* Lake water, International Journal of Environment and Pollution, 13 (10), 726-728.

Prasanth, A., K.S. Rao, V. Kothandaraman, J. Kumar & S. Narasimhan (1996), Evaluation of physico-chemical and bacteriological quality of water from temple tanks in and around Madras City, International Journal of Environment and Pollution, 16 (7), pp. 494-498.

Radhika, C. G., Mini I. & T. Gangadevi (2004) Studies on Abiotic parameters of a tropical fresh water lake – Vellayani Lake, Trivandrum, Kerala, Pollution Research, 23(1), 49-63.

Ramachandran, K.K, Easa P.S & Nair P.V. (1987), Management of PTR – Problems and Perspectives, *Tiger Paper*, Vol. XIV, No.1, pp.25-32.

Reid, G.K (1961) Ecology of inland waters and estuaries, Reinhold Pub. Corp., New York, 375pp.

Rodhe, W (1949) The ionic composition of Lake waters; Verhandlungen der Internationalen Vereinigung fur Theoretische und Angewandte Limnologie, 10, pp. 377-386.

Sarojini, Y. (1996) Physico-Chemical characteristics and phytoplankton assemblages of sewage entering harbour water at Visakapatanam, East Coast of India, International Journal of Environment and Pollution, 16 (9) pp. 645-650.

Sharma, S. & R. Mathur (1992), A comprehensive study of Entomo fauna in Mesosaprobic systems in Gwalior, Journal of Nature Conservation, 4 (2), pp.39-54.

Sharma, L. L. & N. Sarang (2004) Physico-chemical limnology and productivity of Jaisamand Lake, Udaipur, (Rajasthan), Polltion Research, 23 (1) pp. 87-92.

Singh, B.N. & Seema Rai (1999) Physico-chemical studies of Ganga River at Varanasi, Journal of Environment & Pollution, 6 (1) pp. 43-46.

Sorgensen, H (1948) Studies on the ecology of Danish water and bog mosses, Dansk. Bot. Ar.K., 12, p.10.

Sugunan, V.V. (1995), Reservoir fisheries of India. FAO Fish. Tech. Pap. No. 345 Rome, FAO. pp. 423.

Suvarna, A.C. & R. K. Somasekar (1997), Ecological study on the riverine ecosystem of Karnataka, 1. Physico-chemical characteristics of river Cauvery, Journal of Environment and Pollution, 4 (1) pp. 57-63.

Taheruzzaman, Q. & D. P. Kushari (1995) Study of some physico-chemical properties of the different water bodies in Burdwan with special reference to effluents resulting from anthropogenic activities, International Journal of Environment and Pollution, 15 (5), pp.344-349.

Tiwari, D. R. (1999) Physico – Chemical studies of the Upper Lake water of Bhopal, MP India, Pollution Research, 18(3) 323-26.

Trivedy, R.K.& P. K. Goel (1986) Chemical and Biological Methods for Water Pollution Studies, Environmental Publications, Karad 415 110, India, P.244.

Venkiteswarulu, V., (1969) An ecological study of the river Moosi, Hyderabad (India) with special reference to water pollution – III. The algal periodicity, Hydrobiologia, 34, pp. 533-560.

Waller, R. H. (1972) Observations on the wildlife sanctuaries of India, Journal of Bombay Natural History Society, Vol. 69 (3), pp.575-590.

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