CHAPTER 3

PHYSICO-CHEMICAL PARAMETERS

INTRODUCTION

A healthy environment is necessary for any organism, since life depends upon the continuance of a proper exchange of essential substances and energies between the organisms and its surroundings (Welch, 1952). Water has a unique place on planet as it supports life on earth. The entire fabric of life is woven around it. Man uses this important resource collected in depressions on earth or creates depressions by blocking the streams and constructing reservoirs, because of industrial development and unplanned urbanization. This important resource for life has been polluted to a point of crisis (Singh *et al*., 2002).

The adverse impact is felt on the unique physical and chemical properties of water. The fish and other organisms that inhabit these reservoirs are also affected which in turn influence the functions of the reservoir. Quality of water is important for drinking, irrigation, fish production, recreation and other purposes. The water quality deterioration in reservoirs usually results from acidification, heavy metal contamination, organic pollution, obnoxious fishing practices and excessive nutrient input that leads to eutrophication. The effects of these imports into the reservoir not only affect the socio-economic functions of the reservoir negatively, but also lead to the loss of structural biodiversity of the reservoir. The physico-chemical properties of water quality assessment give a proper indication of the status, productivity and sustainability of a water body (Djukie *et al*., 1994). The changes in the physico-chemical characteristics like temperature, transparency and chemical elements of water such as dissolved oxygen, nitrate and phosphate provide valuable information on the quality of the water, the source (s) of the variations and their impacts on the functions and biodiversity of the reservoir.

Hence, the consideration of the physico-chemical factors in the study of limnology is basis for the understanding of trophic dynamics of the water body. The physical and chemical properties of water immensely influence uses of a water body for the distribution and richness of biota (Unanam and Akpan, 2006). Each factor plays its own role but at the same time the final effect is the actual result of the interactions of all the factors. These factors serve as a basis for the richness or otherwise biological productivity of any aquatic environment (Imevbore, 1970). Looking at the importance of understanding physico-chemical properties of water in a waterbody for supporting various biota, a study was planned to find out physico-chemical status of water of Lotus Lake, a perennial Lake present at Toranmal. Following parameters are considered:

Temperature

Temperature is a measure of the intensity (not the amount) of heat stored in a volume of water measured in calories and is the product of the weight of the substance (in gms), temperature (ºC) and the specific heat (Cal g - $^{o}C^{-1}$)

In general atmospheric and water temperature depend on geographical location and meteorological conditions such as rainfall, humidity, cloud cover, wind velocity, *etc*. The atmospheric and water temperature go more or less hand in hand (Macan, 1958). Water temperature is of enormous significance as it regulates various abiotic characteristics and activities of an aquatic ecosystem (Hutchinson, 1957; Alabaster and Lloyd, 1980; Kataria *et al*., 1995; Singh and Mathur, 2005; Ramchandra and Solanki, 2007).

Total Solids (TS), Total Suspended Solids (TSS) and Total Dissolved Solids (TDS)

Total solids is the term applied to the materials left in a vessel after evaporation of a water sample on its drying in the oven at a defined temperature. While TSS is the material left in a vessel after filtration of a water sample. Total suspended solids range in size from colloidal to coarse dispersions and range from pure organic substances to those that are highly organic in nature. The TDS consist of the material left in a vessel after evaporation of filtered sample and include different kinds of nutrients and minerals which are considered as useful parameters in determining the productivity of reservoir (Reid, 1961).

Transparency

Secchi disk transparency is essentially a function of the reflection of light from its surface and is therefore influenced by the absorption characteristics both of the water and of its dissolved and particulate matter. Water transparency determines the depth of the photic zone and consequently affects the lower limit of light penetration that influences the primary productivity of a lake. Plankton also reduces transparency in natural waters (Ramachandra and Solanki, 2007).

Water Cover/Spread

Water cover of any fresh water body is influenced by climatic factors such as rainfall and evaporation in Indian tropical climatic conditions. The water cover can be correlated to the shore line and ultimately with littoral formation. Percentage of littoral formation is also an indicator of productivity of the lakes (Sugunan, 2000). Water cover provides spatial heterogeneity from pelagic to littoral zone and provides habitat space for colonization of communities and hence an important parameter in assessing status of a water body.

pH (Potentia Hydrogenii)

Hydrogen ions (acidic) as well as hydroxyl ions (alkaline) are the result of the ionization of water. Any change in the concentration of any one of these ions bring about a change in the concentration of the other. Therefore, a single scale of numbers, called the pH scale (measured on a scale of 0-14) is used to measure the acidity or alkalinity of water and the number expresses the concentration of hydrogen ions indirectly (Michael, 1984).

The pH changes in water are governed by the amount of free CO_2, Carbonates and Bicarbonate. These changes are accompanied by the changes in other physico-chemical aspects that in turn influence quality of water.

Oxygen (O_2)

Dissolved oxygen is essential to the respiratory metabolism of most aquatic organisms. The dynamics of oxygen distribution in inland waters are governed by a balance between inputs from the atmosphere and photosynthesis and losses from the chemical and biotic oxidations. DO is a very important parameter for the survival of fishes and other aquatic organisms. It is also needed for many chemical reactions that are important for Lake functioning (Oxidation of metals, decomposition of dead and decaying matter, *etc*.). (Ramchandra and Solanki, 2007).

Carbon dioxide

Free CO_2 in water accumulates due to microbial activity and respiration of organisms. It imparts the acidity to the water because of the formation of carbonic acid. Photosynthesis and respiration are two major processes that influence the amount of CO_2 in water. Algae and submerged macrophytes require an abundant and readily available source of carbon for high sustainable growth. The dissolved carbon dioxide influences water quality properties such as acidity, hardness and related characteristics. Thus, it is essential that the rudiments of dissolved inorganic carbon reactivity be evolved. Hence, CO_2 forms an important component in aquatic ecosystem.

Total Hardness

Total hardness (Calcium and Magnesium) is an important parameter in the detection of water pollution. It exists mainly as bicarbonates of Ca^{++} and Mg^{++} and to a lesser degree in the form of sulphates and chlorides. Calcium is an essential nutritional element for animal life and also aids in maintaining the structure of plant cells and soil. Magnesium possesses no major concern with public health. Limits of concentration of hardness set for water are based mainly on palatability, corrosion and incrustation.

Chlorides (Cl^-)

The concentrations of four major cations Ca^{++}, Mg^{++}, Na^+ and K^+ and four major anions, HCO_3^-, CO_3^-, SO_4^- and Cl^-, usually constitute the total ionic salinity of the water for all practical purposes. Of these Chloride influences, in general, osmotic salinity balance and ion exchange. However, metabolic utilization does not cause large variations in the spatial and seasonal distribution of chlorides within most lakes, but high chloride content may indicate the pollution by sewage/ industrial waste or intrusion of the saline water (APHA, 1998).

Nitrogen is a major nutrient that affects the productivity of fresh water. Dominant forms of nitrogen in fresh waters include dissolved molecular N_2, ammonia (NH_3), nitrite (NO_2^-), nitrate (NO_3^-) and large number of organic compounds (*e.g.* amino acids, amines, nucleotides, proteins and refractory humic compounds of low nitrogen content) (Wetzel, 2006).

Nitrite (NO_2)

Nitrite is an intermediate stage in oxidation of nitrogen, both the oxidation of ammonia to nitrate as well as in reduction of nitrate.

Nitrate (NO_3^-)

Nitrate is the most highly oxidized form of nitrogen compound commonly present in natural waters. It is a product of aerobic decomposition of organic nitrogenous matter. Significant sources of nitrates are fertilizers, decaying vegetation and animal matter, domestic and industrial effluents and atmospheric fall out. Excessive concentration of Nitrate in drinking water is considered hazardous for infants because in their intestinal tract nitrates are reduced to nitrites, which may cause blue baby syndrome. Hence, nitrate levels needs to be maintained in a water body. Nitrate is assimilated by algae and larger hydrophytes. It is reduced to ammonia when molybdenum is provided in the enzyme system associated with the reduction.

Phosphate (PO_4^{-3})

Phosphorus plays a major role in biological metabolism. In comparison to other macronutrients required by biota, phosphorus is the least abundant and commonly the first element to limit biological productivity. The deposition of phosphorus into lake sediments occurs by mechanisms such as a) sedimentation of phosphorus minerals imported from the drainage basin, b) adsorption or precipitation of phosphorus with inorganic compounds c) uptake of phosphorus from the water column by algal and other attached microbial communities (Williams and Mayer, 1972; Bostrom *et al*., 1988; Wetzel, 1990). The quantities of phosphorus entering the surface drainage vary with the amount of phosphorus in catchment soils, topography, vegetative cover, quantity and duration of runoff flow, land use and pollution.

MATERIALS AND METHODS

The study site was visited at an interval of fifteen days from December 2006 to November 2008. Total 48 visits were made during the study period. To collect water samples for analysis, plastic containers of two liters capacity were used. Surface water samples were collected from three sites at Lotus Lake (LL) namely LL-A, LL-B and LL-C between 8 a.m. to 10 a.m. in three separate clean containers and labeled station wise to indicate date and location, and brought to the laboratory for analysis. The parameters such as Atmospheric Temperature (AT), Water Temperature (WT), Transparency (Trans.), Water Cover (WC) and Carbon-dioxide were analyzed at the field station itself while Dissolved Oxygen (DO) was fixed in separate BOD sample bottles. Analysis of other parameters such as Total Solids (TS), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total Hardness (TH), Chlorides (Cl^-), pH, Nitrate (NO_2^-), Nitrite (NO_3^-) and Phosphate (PO_4^{-3}) were carried out in the laboratory. To retain the chemical properties, all the samples were protected from heat and direct sunlight during transportation and until estimated.

PHYSICAL PARAMETERS

Temperature

Both Atmospheric and Water Temperature were measured using Mercury thermometer and noted in °C.

Water Cover

The water cover was estimated visually in terms of percentage as compared to maximum filled level.

Transparency

Transparency was determined using Secchi disc, a metallic disc of 20 cm diameter with four alternate black and white quarters on the upper surface. The disc with centrally placed weight at the lower surface is suspended with a graduated cord at the centre. Transparency was measured by gradually lowering the Secchi disc at respective sampling stations. The depths at which it disappears (A) and reappears (B) in the water were noted. The transparency of the water was computed as follows,

Secchi disc light penetration = A + B / 2

Where, A = depth at which Secchi disc disappears.

B = depth at which Secchi disc reappears.

Total Solids (TS)

Total solids were determined as the residues left after evaporation of the unfiltered sample. An evaporating dish of 100 ml capacity was ignited at 550 ± 50 °C in muffle furnace for half an hour, cooled in desiccators and weighed. 100 ml of unfiltered sample was taken and evaporated in an evaporating dish on a hot plate at 98 °C. The residues left were heated at 103-105 °C in an oven for one hour. The evaporating dish was then cooled in desiccators and weighed. TS was calculated as,

$$\text{Total Solids in mg/l} = \frac{(\text{A} - \text{B}) \times 1000}{V}$$

Where, A = Final weight of the dish in gm.

B = Initial weight of the dish in gm.

V = Volume of sample taken in ml.

Total Dissolved Solids (TDS)

Total dissolved solids were determined as the residues left after evaporation of the filtered sample. As reported for TS, an evaporating dish of 100 ml capacity was ignited at 550 ± 50 °C in muffle furnace for half an hour, cooled in desiccators and weighed. 100 ml of filtered sample was added to it and evaporated in a pre-weighed evaporating dish on the hot plate at 98 °C. The residues collected were heated at 103-105 °C in an oven for one hour and final weight was taken after cooling the evaporating dish in a desiccators. TDS was calculated as,

$$\text{Total Dissolved Solids in mg/l} = \frac{(\text{A} - \text{B}) \times 1000}{V}$$

Where, A = Final weight of the dish in gms.

B = Initial weight of the dish in gms.

V = Volume of sample taken in ml.

Total Suspended Solids (TSS)

It is the difference between the total solids and total dissolved solids.

TSS (mg/l) = TS (mg/l) – TDS (mg/l)

CHEMICAL PARAMETERS

pH (Electrometric method)

The pH of water sample was measured by electronic portable pH meter. The pH meter was calibrated with phosphate buffer of known pH. It uses electrodes that are free from interference. At constant temperature, a pH change produces a corresponding change in the electrical property of the solution. This change was read by the electrode and the accuracy was the greatest in the middle pH ranges.

Dissolved Oxygen (DO) (Winkler's method – APHA, 1998)

For the estimation of Dissolved Oxygen the water samples were collected with care in BOD bottles without bubble formation. The DO was then fixed at the station itself by adding 1 ml each of Manganese Sulphate ($MnSO_4$) and Alkali-iodate azide (KI) reagents and brought to the laboratory. The precipitates formed were dissolved by adding 2 ml. of concentrated Sulphuric acid (H_2SO_4). 100ml sample was taken from this and titrated against 0.1N Sodium thiosulphate. Starch is used as an indicator to estimate iodine generated and the end point is noted as the solution turns from blue to colourless. The DO is calculated using following formula,

$$\text{DO mg/l} = \frac{\text{B. R.} \times \text{N} \times 1000}{\text{Amount of sample taken (ml)}}$$

Where, B. R. = Burette Reading (Amount of titrant used).
N = Normality of Sodium thiosulphate.

Free Carbon dioxide (APHA, 1998)

The method is based on the principle that free carbon dioxide (CO_2) in water reacts with sodium hydroxide (NaOH) to form sodium bicarbonate (Na_2CO_3) and the end point is indicated by development of pink colour using phenolphthalein an indicator at pH 8.3. To estimate CO_2 in water in 100 ml. sample 2 to 3 drops of phenolphthalein were added and the sample was titrated against 0.05N Sodium hydroxide until a pink colour was obtained. The free carbon dioxide was calculated using following formula:

$$\text{Free carbondioxide mg/l} = \frac{\text{B.R.} \times \text{N} \times 44 \times 1000}{\text{Amount of sample taken (ml)}}$$

Where, B.R. = Burette Reading (Amount of titrant used).
N = Normality of Sodium Hydroxide (0.05N).
44 = Equivalent weight of CO_2.

Total Hardness (EDTA Titrimetric Method, APHA, 1998)

For the estimation of total hardness, in 100 ml. of sample, 1 to 2 ml of buffer solution and a pinch of Eriochrome Black-T (used as an indicator) were added. After the appearance of wine red colour, the mixture was titrated against EDTA stirring continuously till end point change of wine red to blue is achieved. The total hardness is calculated using following formula:

$$\text{Total hardness expressed as mg } CaCO_3/l = \frac{\text{A} \times \text{N} \times 1000}{\text{Amount of sample taken (ml)}}$$

Where A = ml of titrant (EDTA) used.
N = Normality of EDTA.

Chlorides (Cl^-) (Argentometric Titremetric method, APHA, 1998)

In 100 ml. of sample, 1 ml. of K_2CrO_4 indicator was added and titrated against 0.02N $AgNO_3$ till brick red precipitates were formed. The formula used to calculate mg. of Cl^-/l is as follows:

$$\text{mg of } Cl^-/l = \frac{\text{B.R.} \times \text{N} \times 35.45 \times 1000}{\text{Amount of sample taken (ml)}}$$

Where, B.R. = Burette reading (Amount of titrant used).
N = Normality of Silver Nitrate.
35.45 = Equivalent weight of Chloride.

Nitrites (NO_2^-): (Colorimetric Method, APHA, 1998)

To estimate Nitrites, 100 ml of sample was taken in a beaker and 2 ml. of colour reagent was added to it. The colour developed was read immediately at 543 nm using colorimeter model Photochem 5 indicating O.D. A standard graph was plotted to obtain the factor. A reagent blank was run to set the instrument. The Nitrites were calculated as:

$$NO_2^- \text{ mg/l} = \frac{\text{O.D.} \times \text{Factor}}{\text{Amount of sample taken (ml)}}$$

Where, O.D. = Optical Density

Nitrates (NO_3^-): (Cadmium Reduction Method, APHA, 1998)

Nitrite (NO_2^-) is reduced to nitrate (NO_3^-) in the presence of Cadmium (Cd). This method uses commercially available Cd granules coated with 2% copper sulphate ($CuSO_4$) packed in a glass column. The Nitrate (NO_3^-) produced is determined by diazotizing it with colour reagent containing sulfanilamide coupled with N-(1-naphthyl)-ethylenediamine dihydrochloride (NEDD) to form highly coloured azo dye. The colour developed is measured colorimetrically at 410 nm. A correction was made for any NO_3^- present in the sample by analyzing the sample without the reduction step. A standard graph was plotted to obtain the factor. Nitrates were calculated as:

$$\mathrm{NO_3^-\ mg/l} = \frac{\mathrm{O.D.} \times \mathrm{Factor}}{\text{Amount of sample taken (ml)}}$$

Where, O.D. = Optical Density

Phosphates (PO_4^{-3}) (APHA, 1998)

In a conical flask containing 100ml. of sample, 4ml of strong acid and 4 ml of ammonium molybdate were added followed by 10 drops of $SnCl_2$. The blue colour developed was measured after 10 minutes at 690 nm with colorimeter model Photochem 5.0. It is necessary to make a standard graph before the analysis of sample to obtain the factor. The instrument was set by running a reagent blank. The Phosphates were calculated as,

$$\mathrm{PO_4^{-3}\ as\ mg/l} = \frac{\mathrm{O.D.} \times \mathrm{Factor}}{\text{Amount of sample taken (ml)}}$$

Where, O.D. = Optical Density

Analysis

For the convenience of analysis the bimonthly data was pooled as four seasons: Summer (March, April and May), Monsoon (June, July and August), Postmonsoon (September, October and November) and Winter (December, January and February). The results given are in the form of Mean ± SEM. The data is subjected to ANOVA across the season with the help of Prism 3 software (Graphpad software, San Diego, California U.S.A.). The p value for ANOVA is non significant if $P > 0.05$ (ns), significant if $P < 0.05$(*), significantly significant (**) if P is < 0.001 and highly significant (***) if $P < 0.0001$. The Pearson Correlation between various parameters was also calculated with the help of SPSS 7.5 for windows. At (**) Correlation is significant at the 0.01 level (two-tailed), whereas at (*) correlation is significant at 0.05 level (two-tailed).

RESULTS

For convenience, the results are presented into three groups: Group I (Physical Parameters) Ambient Temperature (AT), Water Temperature (WT), Water Cover (WC), Transparency (Trans), Total Solids (TS), Total Dissolved Solids (TDS) and Total Suspended Solids (TSS). Group II (Chemical Parameters) pH, Dissolved Oxygen (DO), Carbon Dioxide (CO_2), Total Hardness (TH) and Chlorides (Cl^-) : Group III (Nutrients) Nitrite (NO_2^-), Nitrate (NO_3^-) and Phosphate (PO_4^{-3}).

Group I: Physical Parameters

1. Atmospheric Temperature (AT)

Atmospheric Temperature showed highly significant seasonal variations ($P < 0.0001$ $F_{3\ 44}$ 51.72) around Lotus Lake. In accordance to Indian climatic conditions maximum temperature (Table 3.1 Fig. 3.1) was recorded in summer (23.96 ± 0.56 ºC) and minimum in winter (17.21 ± 0.33 ºC), while it was 22.83 ± 0.38 ºC and 20.75 ± 0.32 ºC in monsoon and post monsoon respectively. It administered positive significant correlation (Table 3.4) with Cl^-, CO_2, pH, PO_4^{-3}, TDS, TSS, TS and WT while it was negatively correlated at 0.05 level with DO, Transparency and WC.

2. Water Temperature (WT)

Similarly, maximum water temperature (Table 3.1 Fig. 3.1) was also recorded in summer (21.67 ± 0.37 ºC). It slightly decreased in monsoon (20.88 ± 0.26 ºC) and post monsoon (19 ± 0.18 ºC) and was minimum in winter (18.38 ± 0.15 ºC) with highly significant seasonal variations (P < 0.0001 $F_{3\ 44}$ 35.82).

Water temperature showed significant positive correlations (Table 3.4) with AT, Cl^-, CO_2, pH, PO_4^{-3}, TDS, TS and TH (at 0.01 level, two-tailed), while it showed negative significant correlations with DO, Transparency and water cover at the same level.

3. Water Cover (WC- %)

Maximum percentage of water cover (Table 3.1 Fig. 3.1) was recorded in post-monsoon (91.83 ± 0.8 %) and minimum in summer (54.58 ± 2.1 %), while it was 78.58 ± 4 % and 75.67 ± 1.8 **%** in monsoon and winter respectively (P< 0.0001, $F_{3\ 44}$ 80.26). Water cover administered positive significant correlations (Table 3.4) with NO_3^- and TSS while it showed negatively significant correlations with AT, Cl^-, CO_2, pH, TDS, TH, TSS and WT at 0.01 level.

4. Total Solids (TS)

Total Solids also showed highly significant seasonal variations (P< 0.0001, $F_{3\ 44}$ 65.61). Maximum mean TS (Table 3.1 Fig. 3.1) was recorded in monsoon (203.2 ± 1.02 mg/l) and minimum in winter (160.5 ± 2.72 mg/l), while it was 188.5 ± 1.68 mg/l and 162.8± 3.82 mg/l in summer and post monsoon respectively. TS showed positive significant correlations (Table 3.4) with AT, Cl^-, CO_2, pH, PO_4^{-3}, TDS, TSS, and WT and negative to transparency and water cover at the 0.01 level.

5. Total Dissolved Solids (TDS)

With highly significant seasonal variations (P< 0.0001, $F_{3\ 44}$ 53.80) mean TDS was maximum (Table 3.1 Fig. 3.1) in summer (160.4 ± 0.84 mg/l) and minimum in post-monsoon (122.6 ± 1.63 mg/l), while it was 136.3 ± 3.47 mg/l and 151± 2.25 mg/l in winter and monsoon respectively. TDS was positively significantly correlated (Table 3.4) with AT, Cl^-, CO_2, pH, PO_4^{-3}, TH, TS and WT while negatively significantly with water cover at 0.01 level and DO at 0.05 level.

6. Total Suspended Solids (TSS)

Total Suspended Solid showed highly significant seasonal variations ($P< 0.0001$, $F_{3\ 44}$ 72.75). Mean TSS was maximum (Table 3.1 Fig. 3.1) in monsoon (52.25 ± 1.39 mg/l) and minimum in winter (24.25 ± 0.91 mg/l), while it was 28.08 ± 0.91 mg/l and 40.25± 2.28 mg/l in summer and post monsoon respectively. Total suspended solids administered positive significant correlations (Table 3.4) with PO_4^{-3}, TS and WC at the level of 0.01 and AT, CO_2 at 0.05 while they were significantly negatively correlated with TH and Transparency at 0.01 level.

7. Transparency (Trans)

Transparency also showed highly significant seasonal variations ($P< 0.0001$, $F_{3\ 44}$ 80.26). Transparency of Lotus Lake water was maximum in winter (127.5 ± 0.9 cm) and minimum in monsoon (84.92 ± 1.3 cm) (Table 3.1 Fig. 3.1). Transparency showed significant negative correlations (Table 3.4) with AT, CO_2, PO_4^{-3}, TS, TSS and WT at 0.01 level and positive significant correlation with TH at 0.01 level.

Group II: Chemical Parameters

1. pH

pH showed highly significant seasonal variations ($P< 0.0001$, $F_{3\ 44}$ 53.62) with maximum 8.45 ± 0.097 in summer and minimum 7.48 ± 0.02 in winter, while it was 7.9 ± 0.03 and 7.68 ± 0.03 in monsoon and post monsoon respectively (Table 3.2, Fig. 3.2). It showed positive significant correlations (Table 3.4) with AT, Cl^-, CO_2, PO_4^{-3}, TDS, TS, TH and WT while it showed significant negative correlations with DO and WC, both at 0.01 level.

2. Dissolved Oxygen (DO)

Dissolved Oxygen also showed highly significant seasonal variations ($P< 0.0001$, $F_{3\ 44}$ 32.03). Maximum mean DO was recorded in winter (14.83 ± 0.57 mg/l) and minimum in summer (8.5 ± 0.43 mg/l), while it was 12.33 ± 0.41 mg/l and 10.67± 0.44 mg/l in monsoon and post-monsoon respectively (Table 3.2, Fig. 3.2). Dissolved Oxygen showed positive significant correlations (Table 3.4) with water cover at the 0.05 level while, it was negatively correlated with AT, CO_2, pH, TH and WT at 0.05 level.

3. Free Carbon dioxide (CO_2)

Free CO_2 showed highly significant seasonal variations ($P < 0.0001$, $F_{3\ 44}$ 74.81). Maximum mean CO_2 was recorded in summer (4± 0.19 mg/l) and minimum in winter (0.5 ± 0.12 mg/l), while it was 3.2 ± 0.2 mg/l and 1.99± 0.16 mg/l in monsoon and post-monsoon respectively (Table 3.2, Fig. 3.2). It showed positive significant correlations (Table 3.4) with AT, Cl^-, pH, PO_4^{-3}, TDS, TS and WT while negative correlations with DO, Trans and WC, both at 0.01 level.

4. Total Hardness (TH)

Total Hardness also showed highly significant seasonal variations ($P < 0.0001$, $F_{3\ 44}$ 90.6). Maximum mean TH was recorded in summer (114.6 ± 2.37 $CaCO_3$ mg/l) and minimum in monsoon (67.17 ± 2.69 $CaCO_3$ mg/l), while it was 75.17 ± 1.47 $CaCO_3$ mg/l and 88.92 ± 1.99 $CaCO_3$ mg/l in post-monsoon and winter respectively (Table 3.2, Fig. 3.3). It showed positive significant correlations (Table 3.4) with Cl^-, pH, TDS, Trans. and WT while it showed significant negative correlations with DO, TSS, WC, NO_2^- and NO_3^- at 0.01 level.

5. Chlorides (Cl^-)

Chloride showed highly significant seasonal variations ($P < 0.0001$, $F_{3\ 44}$ 64.71). Maximum Chlorides were recorded in summer (50.5 ± 1.79 mg/l) and minimum in post-monsoon (24.33 ± 0.94 mg/l), while in winter and monsoon the levels were 34.67 ± 1.16 mg/l and 44.5 ± 1.63 mg/l respectively (Table 3.2, Fig. 3.3). Chloride showed positive significant correlations (Table 3.4) with AT, CO_2, pH, PO_4^{-3}, TDS, TS, TH and WT while significant negative correlations with WC, both at 0.01 level.

Group III: Nutrients

1. Nitrites (NO_2^-)

The Nitrites showed highly significant seasonal variations ($P < 0.0001$, $F_{3\ 44}$ 41.67) with maximum mean Nitrite level recorded in monsoon (0.31 ± 0.010 mg/l) and minimum in summer (0.08 ± 0.005 mg/l) while it was 0.17 ± 0.002 mg/l and 0.21 ± 0.016 mg/l in winter and post-monsoon respectively (Table 3.3, Fig. 3.4). The Nitrites showed positive significant correlations (Table 3.4) with PO_4^{-3}, TSS, TS and WC while it showed significant negative correlations with TH and Trans. at 0.01 level.

2. Nitrates (NO_3^-)

The Nitrates showed highly significant seasonal variations ($P < 0.0001$, $F_{3\ 44}$ 64.27). Maximum mean Nitrate values were recorded in monsoon (0.14 ± 0.008 mg/l) and minimum in winter (0.054 ± 0.002 mg/l), while it was 0.08 ± 0.003 mg/l and 0.12 ± 0.007 mg/l in summer and post-monsoon respectively (Table 3.3, Fig. 3.4). Nitrates showed positive significant correlations (Table 3.4) with NO_2^-, PO_4^{-3}, TSS, TS and WC while significant negative correlations with TH and Trans. both at the 0.01 level and with DO at the 0.05 level.

3. Phosphates (PO_4^{3-})

Phosphates showed highly significant seasonal variations ($P < 0.0001$, $F_{3\ 44}$ 56.8). Maximum Phosphate values were recorded in monsoon (0.20 ± 0.004 mg/l) and minimum in winter (0.06 ± 0.007 mg/l), while it was 0.14 ± 0.009 mg/l and 0.12 ± 0.007 mg/l in summer and post-monsoon respectively (Table 3.3, Fig. 3.4). Phosphate showed positive significant correlations (Table 3.4) with AT, Cl^-, CO_2 NO_2^-, NO_3^-, pH, TDS, TS, TSS and WT while significant negative correlations with Trans. at the 0.01 level.

Table: 3.1 Seasonal variations in physical parameters of Lotus Lake over the period of two years from December 2006 to November 2008 (Mean ± SEM)

Sr.No	Parameters	Winter	Summer	Monsoon	Pt. Mon.
1	AT °C	17.21 ± 0.33	23.96 ± 0.56	22.83 ± 0.38	20.75 ± 0.32
2	WT °C	18.38 ± 0.15	21.67 ± 0.37	20.88 ± 0.26	19 ± 0.18
3	Water Cover %	75.67 ± 1.8	54.58 ± 2.18	78.58 ± 4.24	91.83 ± 0.83
4	Total Solids (TS) mg/l	160.5 ± 2.72	188.5 ± 1.68	203.2 ± 1.02	162.8 ± 3.82
5	Total Dissolved Solids mg/l	136.3 ± 3.47	160.4 ± 0.84	151 ± 2.25	122.6 ± 1.63
6	Total Suspended Solids (TSS) mg/l	24.25 ± 0.91	28.08 ± 0.91	52.25 ± 1.39	40.25 ± 2.28
7	Transparency (Trans) Cm.	127.5 ± 0.99	111.8 ± 1.98	84.92 ± 1.38	100.7 ± 3.03

Table: 3.2 Seasonal variations in Chemical parameters of Lotus Lake over the period of two years from December 2006 to November 2008 (Mean ± SEM)

Sr. No.	Parameters	Winter	Summer	Monsoon	Pt.Mon.
1	pH	7.48 ± 0.02	8.45 ± 0.09	7.9 ± 0.03	7.6 ± 0.03
2	Dissolved Oxygen (DO)	14.83 ± 0.57	8.5 ± 0.43	12.33 ± 0.41	10.67 ± 0.44
3	Free Carbon dioxide (CO_2)	0.5 ± 0.12	4 ± 0.19	3.2 ± 0.20	1.99 ± 0.16
4	Total Hardness (TH)	88.92 ± 1.99	114.6 ± 2.37	67.17 ± 2.69	75.17 ± 1.47
5	Chloride (Cl)	34.67 ± 1.16	50.5 ± 1.79	44.5 ± 1.63	24.33 ± 0.94

Table: 3.3 Seasonal variations in nutrients of Lotus Lake over the period of two years from December 2006 to November 2008 (Mean ± SEM)

Sr. No.	Parameters	Winter	Summer	Monsoon	Post-monsoon
1	NO_2^- mg/l	0.17 ± 0.012	0.08 ± 0.005	0.31 ± 0.010	0.21 ± 0.016
2	NO_3^- mg /L	0.054 ± 0.002	0.084 ± 0.003	0.14 ± 0.008	0.12 ± 0.007
3	PO_4^{-3}mg /L	0.06 ± 0.007	0.14 ± 0.0095	0.20 ± 0.004	0.12 ± 0.007

Table: 3.4 Physico-chemical Correlations of Lotus Lake during December-2006 to November-2008.

	AT	CL	CO2	DO	NO2	NO3	PH	PO4	TDS	TH	TRANS	TS	TSS	WC	WT
AT	1.000														
CL	.624**	1.000													
CO2	.961**	.686**	1.000												
DO	-.643**	-.364*	-.643**	1.000											
NO2	.349*	-.203	.310*	-.194	1.000										
NO3	.028	-.195	-.034	.301*	.706**	1.000									
PH	.812**	.729**	.857**	-.665**	.062	-.325*	1.000								
PO4	.754**	.401**	.740**	-.296*	.650**	.436**	.479**	1.000							
TDS	.645**	.903**	.711**	-.306*	-.118	-.108	.719**	.383**	1.000						
TH	.282	.551**	.338*	-.462**	-.659**	-.826**	.613**	-.221	.522**	1.000					
TRANS	-.590**	-.072	-.533**	.182	-.877**	-.698**	-.247	-.869**	-.101	.551**	1.000				
TS	.754**	.694**	.779**	-.256	.450**	.409**	.612**	.784**	.795**	-.007	-.661**	1.000			
TSS	.367*	-.077	.320*	-.007	.900**	.820**	.034	.772**	-.044	-.717**	-.951**	.572**	1.00		
WC	-.484**	-.830**	-.555**	.358*	.543**	.548**	-.668**	-.085	-.807**	-.836**	-.294*	-.381**	.465**	1.000	
WT	.887**	.791**	.919**	-.553**	.106	-.196	.894**	.628**	.809**	.475**	-.353*	.751**	.141	-.678**	1.00

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

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

Fig. 3.1 Seasonal variations in physical parameters of Lotus Lake over the period of two years from December 2006 to November 2008 (Mean ± SEM)

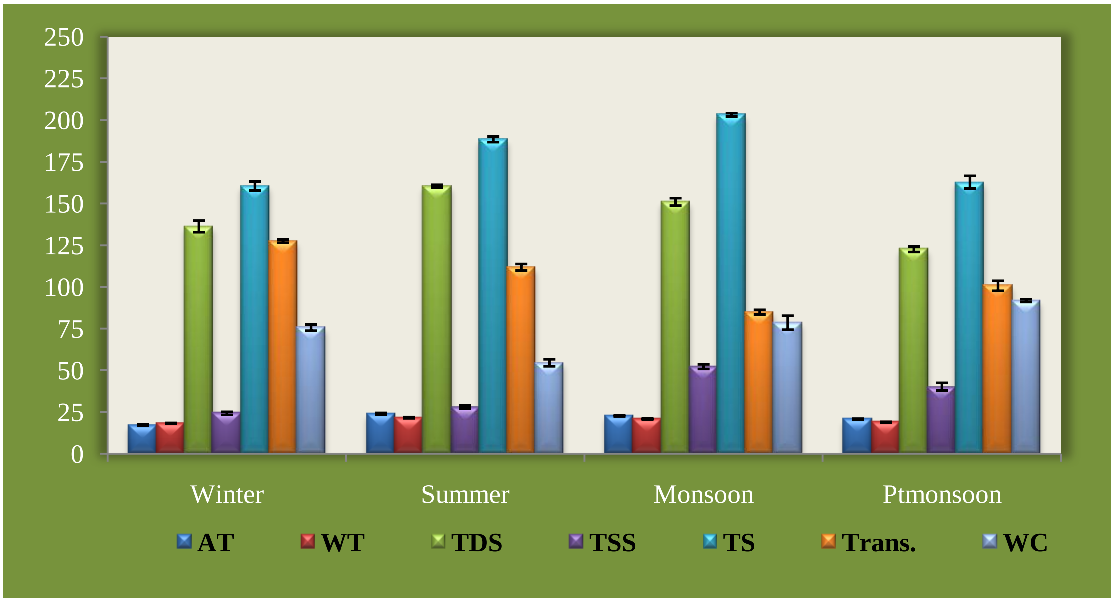


Fig. 3.2 Seasonal variations in chemical parameters of Lotus Lake over the period of two years from December 2006 to November 2008 (Mean ± SEM)

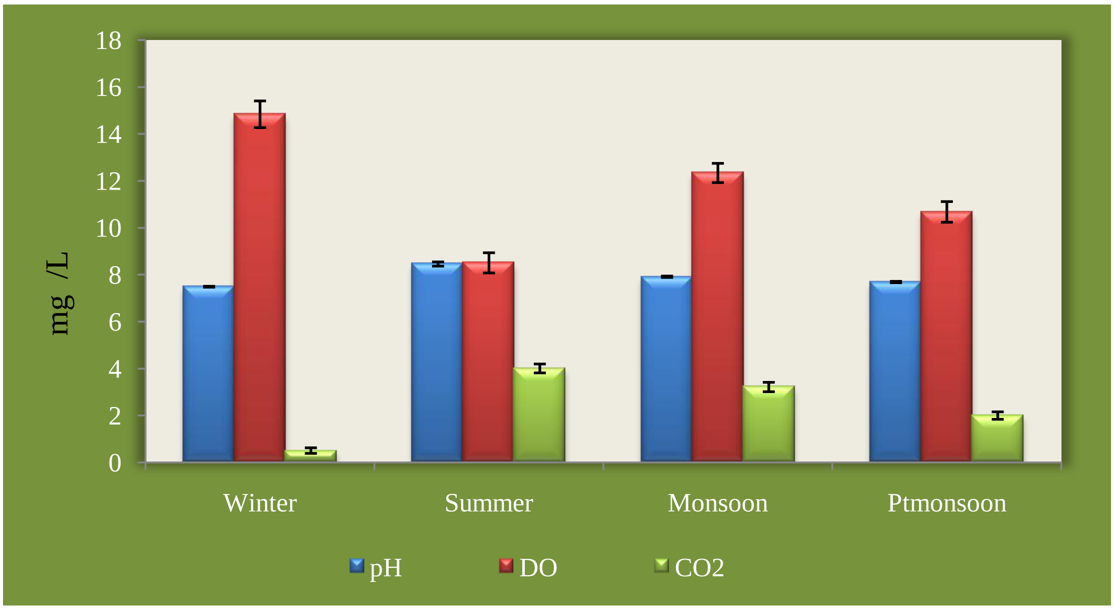


Fig. 3.3 Seasonal variations in chemical parameters of Lotus Lake over the period of two years from December 2006 to November 2008 (Mean ± SEM)

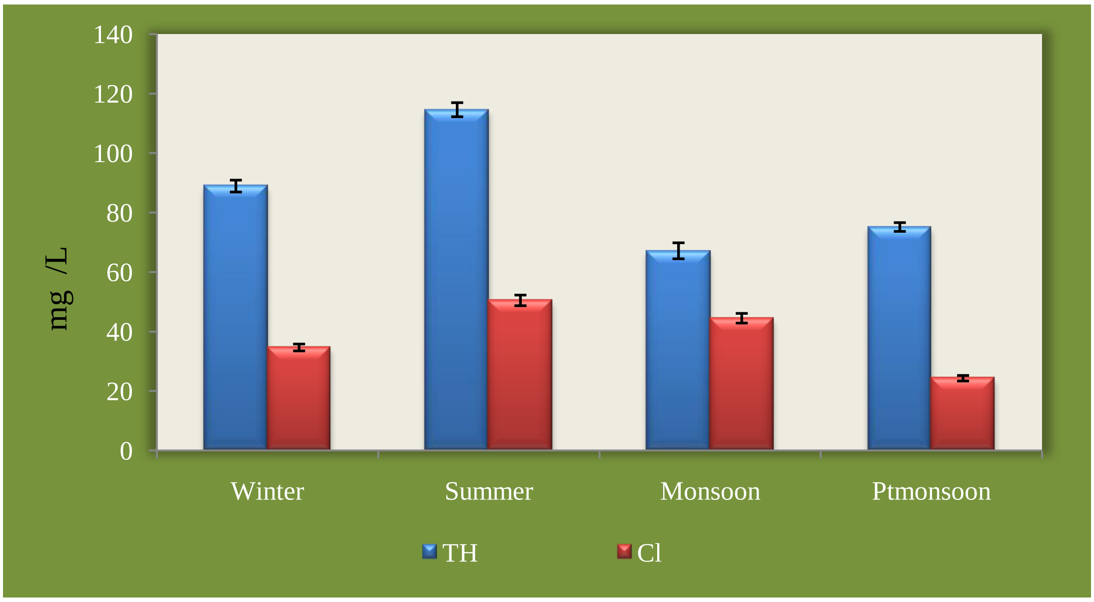
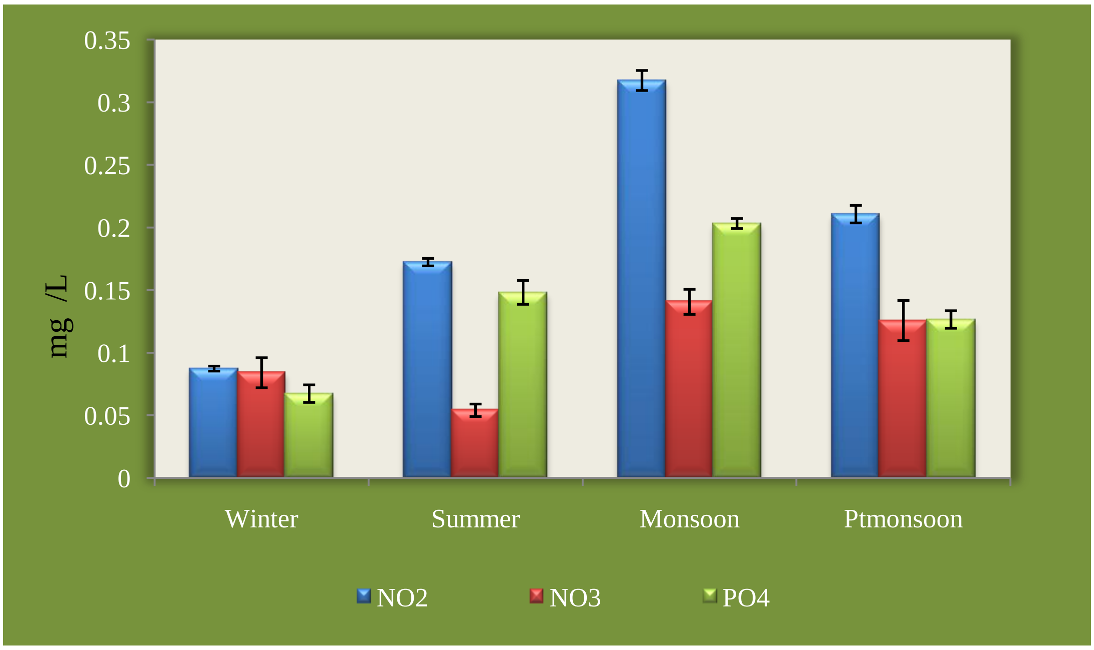


Fig. 3.4 Seasonal variations in nutrients of Lotus Lake over the period of two years from December 2006 to November 2008 (Mean ± SEM)



DISCUSSION

Temperature:

Atmospheric temperature and water temperature were the only climatic characteristics assessed in the present study of Lotus Lake. Since changes in atmospheric temperature show a close proportionality to that of the water (Kaul and Handoo, 1980), a simultaneous measurement of both is important. Maximum atmospheric temperature recorded in summer and minimum in winter may be attributed to the subtropical climatic conditions. A comparison of mean values of atmospheric temperature in different seasons showed significant variations over the seasons. This is a clear indication of the Indian climatic pattern of four seasons, also at the higher altitude in Satpura range, influenced by altitudinal effect, as temperature was always lower than the plains.

Variations in water temperature are usually governed by the climatic conditions. Rainfall and solar radiations are the major climatic conditions that influence most of the physicochemical parameters of water bodies (Odum, 1992; Kadiri, 2000). Solar radiation is dependent on the duration and intensity or iridescence received daily by the water body. The intensity of solar radiations may be naturally modified by variations in cloud cover, water flow, phytoplankton species composition and diversity, surface area, depth, wind velocity, solid matter suspension, *etc*. All these factors influence daily fluctuations in water temperature (Atoma, 2004). However, the comparatively narrow range of maximum and minimum water temperature with 21.67 ± 0.37 °C recorded in summer and minimum 18.38 ± 0.15 °C in winter clearly indicates the absence of pronounced seasonal variations in surface water temperature of Lotus Lake. Water has a great specific heat capacity. At Lotus Lake, present at higher altitude, the daily radiations may hardly bring about significant fluctuations as is also observed by Imoobe and Obon (2003).

The range of temperature fluctuation in Lotus Lake is narrower than that of other water bodies from other regions in India (Tawa reservoir, N. India - Kataria *et al*., 1995; Kasamana river, Kerala - Jayraman *et al*., 2003; Mohari reservoir, Ahmednagar, Maharashtra –Walujkar, 2005), but similar to the results reported by Ekhande (2011) at Yashwant Lake in neighbouring area as well as Deshkar (2008) in central Gujarat. The lower water temperature can be accounted for the higher altitudinal location of the lake as well as the presence of forest around it. The difference in the WT and AT was also narrower supporting the findings of Kaul and Handoo (1980) that surface water temperature usually remains close to the atmospheric temperature.

Temperature is known to influence water chemistry, specially the parameters like dissolved oxygen, solubility, pH, conductivity, *etc*. (Ramachandra and Solanki, 2007). The solubility of oxygen in water increases when water temperature decreases (Joshi and Singh, 2001; Awasthi and Tiwari, 2004). In present study also similar results was found with inverse relationship between water temperature and DO. Temperature is one of the most important factors in the aquatic environment (Singh and Mathur, 2005) that plays a crucial role in physico-chemical and biological behaviour of an aquatic system (Dwivedi and Pandey, 2002). Aquatic organisms depend on certain temperature range for their optimal growth (APHA, 1992).

Water Cover/Spread

The availability of space for colonization is essential, and it markedly affects the composite productivity of the periphytic communities (Wetzel, 2006). Large lakes are typical repositories of the greatest numbers of species because their greater surface area provides more opportunities for colonization. They contain a greater variety of microhabitats and their internal environmental conditions are more stable compared to smaller water bodies (Pip, 1987). These opportunities for development of various organisms are provided by water cover that in turn determines the extent of littoral formation. As far as producers like algae are concerned spatial heterogeneity in their rates of production is usually very high because of the great variability in littoral habitats within freshwater ecosystem. Most lakes of the world are shallow and possess large littoral zone. Such shallow lakes with a well developed littoral habitat can function as a refuge for zooplankton from fish and invertebrate predation that prevails in the open water.

Maximum water cover recorded at Lotus Lake in the post-monsoon and minimum in the summer indicates that the area receives rainfall mainly during south-west monsoon. The water is brought to the lake by stream coming from higher elevation till post-monsoon. Hence, the increased water cover then stabilizes by post monsoon and starts declining as input through streams decreases and reaches to minimum cover by summer when evaporation is high with no percolation as well as usage for domestic purpose. The seasonal variation in the percentage of water cover with the contour of water body determines the littoral formation; it is an indicator of productive nature of the lakes (Sugunan, 2000). An irregular shoreline encompasses more littoral formation produces more area of land and water interface. At Lotus Lake the shoreline is less irregular and hence less littoral formation with only about 40 % fluctuation in water cover.

Total Solids (TS)

TS is a very useful parameter indicating the chemical constituents of the water and can be considered as a generator of edaphic relations that constitute to productivity within the water body (Goher, 2002). Maximum total solids in Lotus Lake water in the monsoon reflects the input of rain water which brings large amount of dissolved solids and suspended solids with it as well as agitation of lake water due to water current. As the rain stops the solids settle down minimizing their levels by post-monsoon and winter. TS were lower during the lean months of post-monsoon and winter when the interferences due to flood and precipitation are low. However, comparatively higher levels during summer may be due to concentration due to evaporation. Similar conditions are also observed Taherazzaman and Kushari (1995), Deshkar (2008), Rathod (2009) and Ekhande (2010).

Total Dissolved Solids (TDS)

TDS, the sum of cations and anions concentration expressed in mg/l. elevates the density of water influencing osmoregulation in fresh water organisms. It reduces solubility of gases (like oxygen), utility of water for drinking purpose and also enhances eutrophication of the aquatic ecosystem (Mathur *et al*., 2008). As discussed for TS, maximum TDS recorded during hot period may be correlated to the elevated water temperatures which lead to the increase in rate of evaporation as well as increase in dissolved salts in water. Indeed, high concentration of TDS enriching the nutrient status of water body (Singh and Mathur, 2005) beyond limit may enhance eutrophication (Mathur *et al*., 2008). Minimum values of TDS at Lotus Lake were evident with the high water level of post monsoon due to the excessive dilution, stagnation and low rate of evaporation.

Water with elevated levels of dissolved solids is of inferior potability and may induce an unfavourable physiological response on the body of consumer (Bhanja *et al*., 2000). Highly mineralized waters are unsuitable for many industrialized applications too (APHA, 1992). However, the TDS values at Lotus Lake were within the permissible limits of 500 mg/l (BIS, 1991) suitable for drinking purpose.

Total Suspended Solids (TSS)

In accordance to TS, maximum TSS were recorded in monsoon as a result of water runoff from the catchment area which brings various suspended matter. TSS also increases due to decaying vegetation. When the products of decaying vegetation at the surface start sinking, it may increase the TSS as well as TDS (Khan and Khan, 1985; Iqbal and Kataria, 1995). Such processes are minimum in winter hence the minimum TSS in winter when the water of the lake is stabilized and most of the suspended matter settles down. Increased level of suspended solids results in increased turbidity and lower photosynthesis, rise in water temperature and decrease in dissolved oxygen (Sharma *et al*., 2008).

Transparency (Secchi Depth)

The lower limit of Transparency is the limit of algal photosynthetic activity, which has a major influence on the primary productivity of the lake. Increase in the turbulence of water usually agitates all the suspended materials, especially in shallow waters. In a lake the transparency can be affected by factors such as time of the day, clarity of the sky at the time of measurement (Cloudy or not) and suspended solids in water including plankton. The Secchi depth measurement at the Lotus Lake is subjected to all these factors.

Lower transparency is recorded during rainy season when there is turbulence and high turbidity (USEPA, 1991; APHA, 1992). Higher TS, TDS and TSS, resulted in minimum transparency in monsoon. This complies with the reports on several water bodies especially in Indian climatic conditions (Zafar, 1964; Singhai *et al*., 1990; Kaur *et al*., 1995; Ekhande, 2010) as well as other tropical country like Nigeria (Olele and Ekelemn, 2008). At Lotus Lake water transparency varied directly with rainfall. Dry season was characterized by absence of flow velocity, flood, surface runoff, settling effect of suspended particles and non-organic/detritus transport. These are the factors that give rise to high transparency, increased food abundance, high photosynthetic activity and vice-versa (Biswas, 1984; Baijot and Baunda Sana, 1997). Lotus Lake receives around 1600 mm annual rainfall during South-West monsoon (June to August) which brings silt and other matter to the lake from the catchment area (forest), lowering the transparency of Lake. The heavy rain, deforestation, human activities, *etc*. are the main causes of soil runoff that lowers transparency (Coker, 1954). As discussed earlier, maximum total solids were also recorded in monsoon which is also responsible for increasing turbidity and decreasing transparency. As the silt start settling down moderate transparency was recorded in post monsoon at Lotus Lake reaching to maximum level in winter when all the solids settled down. However, lowering in transparency during following season *i.e*. in summer may be attributed to higher planktonic growth and hardness. Welch (1986) has recorded lower transparency due to higher hardness of water.

pH (Potentia Hydrogenii)

pH regulates most of the biological processes and bio-chemical reactions. In a balanced ecosystem pH is maintained within the range of 5.5 to 8.5 (Chandrasekhar *et al*., 2003). Due to diurnal variations in the water temperature of a system, pH of a water body is a diurnally variable property (Ojha and Mandloi, 2004). Kaul and Handoo (1980) and Satpathy *et al*. (2007) have reported that increased surface pH in water bodies is due to increased metabolic activities of autotrophs, because in general they utilize the CO_2 and liberate O_2 thus reducing H^+ ion concentration. However, pH, with free CO_2 and ammonia are more critical factors in the survival of aquatic plants and fishes than the oxygen supply (Sculthorpe, 1967).

The surface water of Lotus Lake was always alkaline (Table 3.2) with maximum pH in summer. High value of pH in the summer can be due to utilization of bicarbonate and carbonate buffer system (Bohra, 1976; Mehrotra, 1988). The results are well comparable with other workers (Bhatt *et al*., 1999; Krishnan *et al*., 2003) in their studies on water bodies at higher altitude. Different reports have given different pH ranges as ideal for supporting aquatic life. However all these ranges fall around same point between 6 to 8.5 (ICMR, 1975; Boyd and Lichtkoppler, 1979; WHO, 1985; De, 1999) and pH of Lotus Lake water fall in ideal range.

Dissolved Oxygen (DO)

Oxygen content of a water body is important for direct need of many organisms. Majority of chemical and biological processes undergoing in the water body also depend on the presence of oxygen. It is also essential to maintain the higher forms of biological life and balance the populations of various organisms. Further, Oxygen is also known to affect the solubility and availability of many nutrients and hence, it is one of the most significant parameter affecting the productivity of aquatic systems (Wetzel, 1983). The factors affecting oxygen content in natural waters include input from atmosphere and photosynthesis and output from respiration, decomposition and mineralization of organic matter as well as losses to atmosphere. The oxygen balance in water bodies becomes poorer when the input and photosynthetic activity decrease and the metabolic activities of heterotrophs enhance.

There is an increased chance of oxygen depletion after heavy rains (monsoon) in lakes that receive inflow of organic matter from watersheds (Kaul *and Handoo* 1980). But in Lotus Lake, depletion of DO is moderate during monsoon indicating that inflow of organic matter is probably low because of presence of forest around it. However, depletion of DO during summer may be attributed to the increase in surface water temperature that increases the mineralization of non-living matter which also demands more oxygen (Kumar *et al*., 2005) resulting in lowering DO levels. According to Rabalais (2002), the water body where excess carbon is produced, carbon accumulates in waters producing secondary effects of eutrophication such as noxious algal blooms (including toxic ones), decreased water clarity, and low DO. A low DO content is a sign of pollution (Bhatt *et al*., 1999). However, at Lotus Lake the depletion of DO during summer is not that low to produce effects of eutrophication.

In the present study, at Lotus Lake, the annual mean dissolved oxygen differed non-significantly, the phenomenon can be correlated with increasing altitude. It is well known fact that with increase in altitude there is a decrease in atmospheric pressure implying that oxygen saturation will be lower. However, compensation occurs, because decreasing temperature at higher altitude enhances the solubility of oxygen. Hence, the observed DO levels in the Lake is probably the result of these opposing trends, besides biological and other interacting factors as discussed by Green *et al*. (1996) and Murugavel and Pandian (2000). The oxygen cycle in water involves a rapid decrease during summer, a steady increase through autumn till maximum content is reached in winter following the well known theory of solubility of gases (Kaul and Handoo, 1980).

Ideal dissolved oxygen for the fish, the final stage of productivity in the fresh water ecosystem, is assumed to be between 6 and 7 mg/l (Edmondson, 1960). Low oxygen concentration will also affect the types of fish and invertebrates that inhabit the area (Anonymous, 2005). The minimum limit of DO required for freshwaters as per ICMR (1975) standards is 5 to 6 mg/l therefore, the DO of the Lotus Lake can be considered almost normal for a natural non polluted Lake.

Free Carbon dioxide (CO_2)

Though carbon dioxide is readily soluble in water, very little carbon dioxide is present in sample because of the small amount of it being present in the atmosphere. Apart from this, decomposition of organic matter and the respiration of aquatic plants and animals also contribute to the free carbon dioxide.

CO_2 levels of Lotus Lake water ranged between 0.5 mg/l to 4 mg/l similar to the reports of Ekhande (2010) at the neighbouring Yashwant Lake and Deshkar (2008) in central Gujarat. However, Dwivedi and Sonar (2004) observed an average of 2 mg/l of free carbon dioxide in water of reservoirs in Arunachal Pradesh while Radhika *et al*. (2004) reported an annual variation of 2.42 to 10.47 mg/l of CO_2 in Vellayani Lake in Kerela.

This probably indicates geographical variation in the free CO_2 levels in water. The free carbon dioxide limit values for drinking water have not been prescribed but the permissible limit for fish culture is 6 mg/l.

The maximum free CO_2 in summer may be attributed to higher rate of decomposition of organic matter due to comparatively higher temperature. During daytime due to photosynthesis water is generally CO_2 free (Sahu and Behera, 1995) hence while measuring CO_2 of water time of measuring is also important.

An inverse relationship exist between Dissolved Oxygen and Carbon dioxide, pH, alkalinity and temperature the parameter that are directly related to each other since the pH depends upon the free CO_2 and bicarbonate-carbonate levels (Michael, 1984).

Organic decomposition, respiration, photosynthesis, diffusion and runoffs could also account for the variations seen in the CO_2 levels.

Total Hardness

Hardness of water, mainly governed by the Ca^{++} and to a lesser extent by Mg^{++} contents with ions such as Fe^{++}, is a measure of the capacity of water to precipitate soap. Waters with hardness below 60 mg $CaCO_3$/l are soft, between 61 to 120 mg $CaCO_3$/l are moderately hard; between 121 to 180 mg $CaCO_3$/l are hard and more than 181 mg $CaCO_3$/l are very hard (Durfor and Becker, 1964). Considering this classification the water of Lotus Lake having hardness ranging between 67.17 ± 2.6 mg $CaCO_3$/L to 114.6 ± 2.3 mg $CaCO_3$/l (table 3.3) fall in the category of moderately hard water. According to Spence (1964) waters with more than 60 ppm which is equivalent to 60 mg.$CaCO_3$/l hardness are classified as 'nutrient rich' waters. The desirable limit of hardness in drinking water according to ISI standards is below 300 mg/l. While hardness levels above 500mg/l are generally considered to be aesthetically unacceptable (WHO, 1996).

In the present study the total hardness is negatively correlated with water cover at the 0.01 level. In the summer total hardness is reported to be maximum, when water cover decreases due to evaporation concentrating the calcium and magnesium salts (Moundiotiya *et al*., 2004; Lentz-Ciplani and Dunson, 2006). Hence, the excessive dilution by heavy rains in the following season – monsoon, is responsible for lowering the hardness of water. High value of Hardness in summer and low in monsoon observed in the present study are in agreement with Iqbal and Kataria (1995); Bhatt *et al*. (1999); Awasthi and Tiwari (2004) and Radhika *et al*. (2004). Further, geological setting of various reservoirs is also responsible for variations in the hardness (Jindal and Kumar, 1993; Jhajhria, 2003).

The correlation between hardness and chloride (Table 3.4) of Lotus Lake was positive at 0.01 level. Chlorides occur mainly in the form of sodium chloride which is concentrated in the summer due to evaporation. The presence of major cations or hardness of calcium and magnesium in the biotic dynamics are of ecological significance. Calcium is essential mainly for fauna while magnesium is essential for flora for chlorophyll biosynthesis and enzymatic transformations, particularly for phosphorylation in algae, fungi and bacteria.

Chlorides (Cl^-)

Chloride is one of the most important parameter in assessing the water quality. Higher concentration of chlorides indicates higher degree of organic pollution (Munawar, 1974; Ramakrishna, 1990). Concentration of Cl in sea water is around 20,000 mg/l, in unpolluted rivers between 2-10 mg/l and in rain water 2 mg/l. When it is above 200 mg/l the water is unsuitable for human consumption (Koshy and Nayar, 1999). Maximum permissible limit with regard to chloride content in natural freshwaters according to ICMR (1975) and ISI (1991) is 250 mg/l.

The higher chlorides in summer again may be attributed to the concentration due to the increased rate of evaporation with to rise in temperature. This results in minimum water cover. Both are negatively significantly correlated with each other at 0.01 level. Moundiotiya *et al*. (2004); Kumar *et al*. (2006) and Ekhande (2010) have reported positive relation between chlorides and water temperature. In addition, numerous studies have confirmed that ground water inputs also tend to increase the concentrations of chlorides (Cengiz Koc, 2008; Allen *et al*., 1999). At Lotus Lake seepage from the rocks is also expected. As noted for hardness, normally lowering of chloride concentrations in monsoon may be attributed to the dilution effects and the domestic waste and agricultural runoff. However, in post monsoon due to maximum water cover and the effect of dilution is most prominent with lowest Cl^- concentration.

Higher chloride concentration serves as an indicator of pollution by sewage (Munawar, 1970; Trivedy and Goel, 1986). In natural water excessive Cl^- ions are usually found associated with Na^{++}, K^{++} and Ca^{++} which produce salty taste when concentration is 100 mg/l (Kataria *et al*., 1995; Gowd *et al*., 1998). However, the water of Lotus Lake has Cl^- ion concentration much lower than the permissible limit as per ISI (250 mg/l).

Nitrite (NO_2^-)

Nitrogen, the major constituent of protein and nucleic acids, occupies a predominant place in aquatic system. Kudesia *et al*. (1986) reported that nitrites along with some toxic aromatic compounds impart brown colour and offensive odour to water which becomes unfit for irrigation, fish culture and drinking.

The water of Lotus Lake showed maximum nitrite level in the monsoon probably due to fresh input through water runoff as well as the agitation of water that helps in oxidation and release of ammonia from sediment. In winter though the photoperiod is short, wetlands occurring in subtropical belt receive adequate sunlight which favours growth of plants. The utilization of nitrites as nitrogen source by autotrophs (Yang *et al*., 2001) can be a reason for low level of nitrites in winter. Ekhande (2010) and Deshkar (2008) have also reported low NO_2^- level in winter in higher altitude as well as subtropical water body of plains respectively. However, the lowest NO_2^- concentration was noted in summer. The low concentration of NO_2^- is in consonance with its insignificant role in the environment and also with its short residence time in water (Malhotra and Zanoni, 1970). According to Riordan (1993) maximum acceptable permissible concentration of nitrite for humans, as well as animals including wildlife either for drinking or for recreation and aesthetics is 10 mg/l to 100 mg/l (nitrite and nitrate together).

Nitrate (NO_3^-)

The accumulation of N in reservoirs and water bodies due to intensive human activity has become a common phenomenon which alters ecological process in many parts of the world. Increased nutrients along with altered nutrient ratios cause multiple and complex changes in the aquatic ecosystem. One of the forms of N that affects aquatic ecosystems is Nitrate (NO_3^-). It is the most highly oxidized form of nitrogen, which is the product of aerobic decomposition of organic nitrogenous matter. NO_3^- is a plant nutrient that enters the system as inorganic fertilizer from septic systems, animal feed, agricultural fertilizers, manure, industrial waste water, sanitary landfills and garbage dumps (Saxena, 1998).

The effect of monsoon can be noted for Nitrate nitrogen content in the surface water of Lotus Lake too. The increased activity such as agitation of water due to southwest monsoon probably adds nitrate in water. According to Boqiagn *et al*., 2004, due to the degradation of organic matter, the nutrient is separated out and comes into the pure water where because of wave and wind forces the sediments are resuspended. The nutrient in pure water would leak into the super adjacent waters accordingly. The higher levels of nitrate in monsoon have been correlated to more nitrate in rain water from the catchment area (Manikya Reddy, 1984; Kousar and Puttaiah, 2008). Nitrate is also generated from agricultural fertilizers and mixing of human and animal wastes to the lake (Murugavel and Pandian, 2000; Cengiz Koc, 2008).

The content of dissolved oxygen (DO) at the water sediment interface is the main factor that affects the degradation of nitrate and its outcome (Boquiagn *et al*., 2004). Minimum dissolved oxygen recorded in Lotus Lake in the summer may be the reason for the minimum nitrate in the same season. Further, it can also be due to the denitrification of NO_3^- into NO_2^- and NH_3 by denitrifying bacteria (Merck, 1980) and growth of aquatic plants which utilize the nitrate for growth (Kannan, 1978). The nitrate levels of Lotus Lake water, within the range of 0.31 ± 0.01 to 0.087 ± 0.005 mg/l are in the permissible limit given by WHO *i.e*. 45 mg/l for human consumption.

Phosphates (PO_4^{-3})

The cycling of phosphorus within lakes and rivers is dynamic and complex process, involving adsorption and precipitation reactions, interchange with sediments and uptake by aquatic biota (Borberg and Persson, 1988). The studies have shown that the release of this nutrient from the sediments, that are under disturbance is far greater (20 – 30 times) than that under static conditions (Sondergaard *et al*., 1992) and has been correlated with its resuspension process mainly caused by waves (Sheng and Lick, 1979). All forms of phosphates such as orthophosphates, condense phosphates and organically bound phosphates are found in water. In natural waters phosphorus exists as soluble phosphate. Phosphate is one of the critical major limiting nutrient that triggers eutrophication of fresh water systems (Rabalais, 2002). It is required by algae in small quantities (Bandela *et al*., 1999). Each P ion promotes the incorporation of seven molecules of N and 40 molecules of CO_2 in algae (Wetzel, 1983).

At Lotus Lake, maximum phosphate recorded in monsoon (0.20 ± 0.004 mg/l) may be related to the releases of phosphate in the water just above the sediments. Disturbance due to wind and current increases in the monsoon when mainly wind forces the wave action in water that can resuspends sediments. Further, in the monsoon rain water also contributes phosphorus to the Lake (Wen, 1992). Higher values of phosphate are also reported by Murugavel and Pandian (2000) in Kodiyar reservoir during monsoons.

Minimum phosphates recorded in winter at Lotus Lake may be correlated to its locking by macrophytes and phytoplankton during their bloom decreasing their levels in water as is reported by Kant and Raina (1990). Further, most active organic substance in shallow lakes at higher dissolved oxygen levels are easily oxidized (Boqiagn *et al*., 2004). However, the condition of oxidation at the sediment water interface is not advantageous for the degradation and release of P and N (Sondergard, 1992). The sufficient supply of oxygen is in favour of oxidation of Fe and Mn and enhances the absorption at the sediment water interface and finally retards the release of nutritent (phosphate) to overlaying water (Gachter *et al*., 1988). The Lotus Lake was well oxygenated in winter and it may be another reason for least phosphate level. (The Pearson correlation between DO and PO_4 is negatively significantly correlated at 0.05 level).

According to Welch (1980) a water body may be considered as eutrophic if total PO_4^{-3} value ranged in between 20 to 30 mg/l. The phosphate value of Lotus Lake fluctuating between 0.06 to 0.2 mg/l is much below this level. However, it crossed the permissible limit of drinking water (0.1 mg/l) as given by US Public Health Standards (De, 2002) in monsoon. This indicates that phosphates in the Lotus Lake water are under the permissible limit but if care is not taken its condition can deteriorate. Hence, a continuous monitoring of Lotus Lake has become essential.

From the analysis of physico-chemical factors of Lotus Lake water over a two year study period it can be said that in this higher altitudinal lake Toranmal area of North Maharashtra maintains the balanced ecosystem. Care should be taken to manage the system so that its condition does not deteriorate under the pressure of ecotourism.