CHAPTER 3

ABIOTIC PARAMETERS

INTRODUCTION

Fresh water is one of the basic needs of the mankind and is vital to all forms of life. It exists in lentic and lotic habitats. All the lentic habitats, such as reservoirs, ponds and lakes, are extremely important as they are endowed with abundance of other natural resources too.

For limnological studies understanding physico-chemical factors influencing the trophic dynamics of the aquatic system is fundamental. Each factor plays its unique role in the system but at the same time the final effect is the actual result of the interaction of these factors. All the physico-chemical variables influence gross primary productivity (GPP) of aquatic system but the magnitude of their influence differ significantly (Murugavel and Pandian, 2000). The metabolic activities of phytoplanktons-the primary producers depend on the physico-chemical factors of the aquatic environment (Hulyal and Kaliwal 2009), and the changes in physico-chemical parameters lead to changes in the plankton density which in turn influence faunal diversity and presence of some immigrant species in the lentic zone of reservoir (Ayoade *et al.,* 2009). The physical and chemical properties of a fresh water body are characteristic of the climatic, geochemical, geomorphological and pollution conditions prevailing in the drainage basin and the underlying aquifer (Ramchandra *et al.,* 2002). The monitoring of the surface water quality by hydrobiological parameters is among fundamental environmental priorities, because it also permits direct estimation of the conditions of the aquatic ecosystems exposed to deleterious anthropogenic factors.

Eutrophication has become a widely recognized problem of water quality deterioration (Kim *et al.*, 2001). Phosphorus and Nitrogen inputs from domestic wastes and fertilizers accelerate the process of eutrophication (Rao *et al.,* 1994). Discharge of urban, industrial and agricultural wastes have increased the quantum of these chemicals considerably altering physico-chemical characteristics of an aquatic ecosystem. Over the time, many countries have regulated the point sources of nutrients, such as municipal and industrial discharges. However, Non-point sources of nutrients, such as runoff from agricultural or urban lands have replaced point sources as the driver of eutrophication in many regions (Carpenter, 2005). Thus, the anthropogenic activities with sewage and fertilizers used in agricultural fields appear to be the major causes of the eutrophication (Kudari *et al.,* 2006). As a major element in aquatic biota, among plants, the algal community exhibits dramatic changes in response to changes in physico-chemical properties (Ramchandra and Solanki, 2007), whereas among animal biota the rotifer community structure is shaped by a variety of environmental factors that in addition influence the biological parameters such as predation or competition (Anna and Natalia, 2009).

A Lake is a sizable water body that is fed by rivers, springs or local precipitation. It may be natural or manmade. Its structure has a significant impact on its biological, chemical and physical features. Lack of ecosystem approach in the management of these resources has led to several current chaos. Hence, it is necessary to study and manage a water system as a part of broader environment through a system approach. A true ecosystem approach recognizes the individual component as well as the linkages between them. A disturbance of one or the other component of the system may indirectly dampen out the natural reliance. Sometimes the effect is direct, significant and may increase the degree as it moves through the system (Ramchandra *et al.,* 2006).

The demand of water requirements has increased with burgeoning human population coupled with agricultural and industrial developments. Hence, the restoration, conservation and management of the water resources require thorough understanding of the system. Understanding of environmental changes is also necessary for the protection for remediation. Thus, monitoring and assessment of a system can provide basic information on the condition of the water bodies. With the help of study the interaction of all physical, chemical and biological components, one can design restoration methods towards conservation, management and sustainable use of a habitat. This may be useful in characterizing water bodies and their integrity too.

The physical parameters define those characteristics of water that respond to the sense of sight, touch, taste, odor and temperature; chemical parameters are related to the solvent capabilities like Total dissolved solids, Alkalinity, Hardness, Chlorides, Metals and nutrients while biological parameters measure density and diversity of various biota. Though physico-chemical approach to monitor water pollution is most common and plenty of information is available on these aspects, it may not provide all the information required at the local level and thus assessment of water quality of all the water bodies becomes essential. Hence, a study of physical and chemical parameters was carried out at 'The Yashwant Lake' of Toranmal area. These parameters are as follows:

Temperature

Temperature is one of the most important parameter that influences almost all physical, chemical and biological characteristics and thus the chemistry of water. In general air and water temperature depend on geographical location and meteorological conditions such as rainfall, humidity, cloud cover, wind velocity, *etc*. The air and water temperature go more or less hand in hand (Macan, 1958). The measurement of ambient temperature in surface water is of vital importance for calculating the solubility of oxygen, carbon dioxide, bicarbonate and carbonate equilibria (Shivanikar *et al.*, 1999). It also influences the dynamics of alkalinity, salinity, electrical conductivity, *etc*. in a water body. In Indian subcontinent, the temperature in most of the water bodies ranges between 7.8 – 38.5 °C (Sinha, 1986).

Further, the minimum temperature difference between the atmospheric temperature and water temperature plays a major role in the productivity of shallow water body in the form of fish life (Oomachan, 1981; Mehta, 1999). Hence, water temperature is important in relation to fish life too. High density of planktonic groups is observed during the period when temperature is most suitable for growth and reproduction (Bhalla, 2006). It is one of the important factors influencing the structure of the rotifer community too (Miloslav, 1998). Approximately two fold increase in temperature has strong positive correlation with biomass (Meric and Akcaalan, 2003). Thus, there are clear evidences suggesting a casual relationship between summer temperature, conductivity and density of vegetation cover with species composition, species richness, diversity, equitability and the proportion of individuals in the first rank of the macroinvertebrate assemblages (Savage, 2000).

The peninsular reservoirs in India are characterized by a narrow range of fluctuation in water and air temperature across seasons, a phenomenon which prevents the formation of thermal stratification (Sugunan, 2000).

Water Cover

In Indian climatic conditions the water level of any fresh water body fluctuates seasonally influencing water cover. The rate of inflow and outflow of water with resultant water level have a direct bearing on productivity of water body as the sudden fluctuations directly affect the biotic communities. Plankton, benthos and periphyton pulses coincide with the months of least water fluctuations, that is, all the communities are at their ebb during the months of maximum levels and water discharge (Sugunan, 1980; Sugunan and Das, 1983; Sugunan and Pathak, 1986). The spillway discharge, apart from dislodging the standing crop of plankton, removes the oxygenated clear water of the top layer, leaving the oxygen deficient bottom water. Conversely, the deep drawdown removes the decomposing material including nutrients (Jhingran, 1975). Percentage of shallow area (littoral formation), which varies at different seasons depending on the contour of water body, is also an indicator of productive nature of the Lakes (Sugunan, 2000). An irregular shoreline encompasses more littoral formation and areas of land and water interface. Thus, a high value of shoreline development index is believed to be indicative of productive nature of the water body. High shoreline indices of Hirakud (13.5), Gobindsagar (12.26), Tilaiya (9.12), Konar (8.78), Nagarjunsagar (7.89) and Rihand (7.04) have been correlated to a moderate to rich plankton community (Sugunan, 2000).

Transparency

Transparency is a characteristic of water that varies with the combined effect of colour and turbidity. It measures the depth to which light penetrates in the water body. Transparency gives an idea about the degree of suspended particles in the water, which in turn affect the light penetration (Verma *et al.,* 1980). Clear water Permits light to penetrate more deeply into the lake than does murky water. This light allows photosynthesis and production of oxygen in deeper water while pollution tends to reduce water clarity.

Evaluation of the vertical extinction and spectral characteristics of light in natural waters is commonly accomplished *in situ* with modern underwater quantum sensors. The Secchi disk transparency is essentially a function of the reflection of light from its surface and is therefore influenced by the absorption characteristics of both, the water and its dissolved and particulate matter. The Secchi disc transparencies range from few centimeters in turbid reservoirs to over 40 m in a few rare clear lakes. The Secchi disc transparency correlates closely with the percentage transmission of light. Higher water transparency is recorded at the beginning of dry season as a consequence of reduced rain (Cleber and Giani, 2001). Transparency of water is generally influenced by factors like wind action, plankton concentration, suspended silt particles and decomposition of organic matter at the bottom (Singh, 2000).

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

As per APHA (1998), Solids refer to the matter that is suspended or dissolved in the water or waste water. The total suspended solid (TSS), is a portion of total solids (TS) retained by a filter while the total dissolved solids (TDS) are the infilterable solids, mostly inorganic salts and small amount of organic matter dissolved in the water. These have been proved to be very useful parameters in determining the productivity of water, and of biological and physical waste water treatment processes. A limit of 500 mg/Lit TDS is permissible in drinking water. The concentration of total dissolved solid gives an idea about suitability of this water for various uses including potability of water (Trivedy, 1995).

Water in nature contains both organic and inorganic solids varying both qualitatively and quantitatively with the season. TDS may affect the water quality adversely in a number of ways. Waters with highly dissolved solids are generally of inferior potability and may induce an unfavorable physiological reaction in the transient consumer. Highly mineralized water is not suitable for many industrialized applications (APHA, 1985) as it increases hardness and corrosive properties of the water (EPA, 1976) and may create an imbalance for the aquatic life, whereas the suspended sediments are probably key factors controlling the light availability (Fathi and Flower, 2005).

The amount of hydrocarbonates and corresponding TDS in the water are positively correlated with phytoplankton and zooplankton diversity (Karatayev *et al.*, 2008). The wetlands act as sinks for the nutrient deposition and hence, the high TDS value may also depend on the age of the lake (Anitha *et al.*, 2005) as a result of gradual salt deposition.

pH

pH - the negative logarithm of hydrogen ion concentration, is one of the most important and frequently used test in the water chemistry. It is a valuable indicator for the acid alkali balance of water. Practically every phase of water supply and waste water treatment of acid base neutralization and water softening, precipitation, disinfection and corrosion control are pH dependent. In case of pollution by acidic and alkaline wastes, the pH serves as an index to denote the extent of pollution. pH changes in water are governed by the amount of free carbon-dioxide, carbonate and bicarbonate. The alteration of hydrogen ion concentration of water is accompanied by changes in other physico-chemical aspects. In addition to factors like temperature, salinity, atmospheric pressure, disposal of industrial wastes, *etc.,* biological factors such as respiration and photosynthesis also influence pH.

The pH of water determines the solubility and biological availability of certain chemical nutrients such as phosphorus, nitrogen, carbon as well as heavy metals like lead, copper, cadmium, *etc.* It indicates how much and what form of phosphorus is most abundant in water and whether aquatic life can use the form available. Metals tend to be more toxic at lower pH because they are more soluble in acidic water. Measured on a scale of 0 – 14, pH of natural water usually lies in the range of 4.4 to 8.5. The rise in pH paralleles with the rise in carbonate alkalinity and percentage of oxygen saturation. It is probably not affected by photosynthetic activity of a water body (Kobbia *et al.*, 1992; Kebede, 1996; Fathi *et al.*, 2001). A weak correlation between pH and fresh water gastropod species richness has been established by Sarkar and Hakuriat (1964) whereas, with temperature, pH has been considered to cause summer minima of total phytoplankton density (Hujare, 2005). Further, Sharma *et al.* (2008) have described role of pH in formation of algal bloom too. Thus, pH plays important role in controlling biotic community structure of a water body.

Acidity

Acidity of water is its quantitative capacity to react with a strong base to a designated pH (APHA, 1985). It may be defined as the power of water to neutralize hydroxyl ions and is expressed in terms of calcium carbonate. Acidity is caused by presence of free CO_2, mineral acids like sulphuric acid, weakly dissociated acids, strong mineral acids, weak acids such as carbonic acid, acetic acid *etc.* Hydrolyzing salts of iron or aluminum sulphates may also contribute to the measured acidity depending on the method of determination.

Thus, acidity indicates the total available acids as well as the concentration of hydrogen ions (Michael, 1984). Chemically, pure water is neutral having equal amounts of hydrogen and hydroxyl ions. In acidic waters, productivity is low because acidity not only inhibits nitrogen fixation but also prevents the recirculation of nutrients by reducing the rate of decomposition. Acids contribute to the corrosiveness and influence the chemical reaction rates, chemical speciation as well as biological processes. The measurements of acidity reflect changes in the quality of the source water. Addition of waste waters having acidity producing substances also increase the acidity of waters (Trivedi and Goel, 1986). The acidity may be produced in following way

$$FeSO_4 + 2H_2O = Fe(OH)_2 + H_2SO_4$$

$$Al_2(SO_4)_3 + 6H_2O = 2Al(OH)_3 + 3H_2SO_4.$$

Alkalinity

The alkalinity of water is a measure of its capacity to neutralize acids. The major portion of alkalinity in natural water is caused by hydroxyls, carbonates and bicarbonates, which may be ranked in order of their association with high pH values. The borates, silicates and phosphates along with hydroxyl ions in "free state" also add to alkalinity. Alkalinity values provide guidance in applying proper doses of chemicals in waste water treatment processes, particularly in coagulation, softening and operational control of anaerobic digestion.

Alkalinity is also considered as buffering capacity of the water and is important for aquatic life in a fresh water system because it equilibrates the pH changes that occur naturally as a result of photosynthetic activity of aquatic plants (Kaushik and Saksena, 1989). It has been reported that the total alkalinity of a lake shows significant direct relationship with carbonate alkalinity and total rotifer counts (Meshram, 1996). A number of workers have reported direct correlation between alkalinity and productivity too (Banerjee, 1967; Bhowmic and Utpal, 1994; Jhingran, 1982; Khalil, 1990). But Meshram (1996) did not find such relationship.

Dissolved Oxygen (DO)

Dissolved oxygen is a key parameter reflecting the quality of water, particularly water which receives waste. The consumption of O_2 during decomposition of organic matter may reduce its concentration to zero level and hence reflects the degree of organic pollution in water (Ramchandra *et al.*, 2006).

The oxygen required by plants and animals for respiration is acquired from the atmosphere and the photosynthetic process of green plants. Oxygen from air is absorbed by direct diffusion and agitation of surface water by wind action and turbulence. Hence, the amount of oxygen dissolved in water depends on the surface area exposed, temperature and salinity as well as the amount of oxygen derived from the green plants depending upon their density and the duration and the intensity of effective light. Thus dissolved oxygen levels in the natural waters and waste waters depend upon the physical, chemical as well as biochemical activities in the water body. The content of dissolved oxygen brings about various biochemical changes that affect metabolic activities of organisms (David and Roy, 1966, Adebisi, 1981). Dissolved oxygen shows inverse relationship with temperature (Patil and Goudar, 1985; Gurumayum *et al.,* 2000; Agrawal and Thapliyal, 2005). Oxygen is moderately soluble in water. With increasing altitude there is a decrease in atmospheric pressure, implying oxygen saturation to be lower (Murugavel and Pandian, 2000). The percentage saturation of oxygen in water has been studied extensively by many workers (Wetzel, 2006) while studying biotic and abiotic parameters of water body.

Free Carbondioxide (Free CO_2)

The sources of carbondioxide in an aquatic ecosystem are community respiration and decomposition, while it is consumed during the photosynthesis. Depending on the pH and other biological conditions, carbondioxide is found in any one of the three forms, free carbondioxide, carbonic acid and bicarbonates. It is a normal component of all natural waters. Like oxygen it may enter surface water by absorption from the atmosphere, but only when its concentration in water is less than its concentration in atmosphere. Biological oxidation of organic waste, particularly in polluted water, may be one of the major sources of carbondioxide. In such cases, if photosynthetic activity is limited, the concentration of carbondioxide may exceed in equilibrium with that of atmosphere and escape from water too. Thus, surface water constantly absorbs or gives up carbondioxide to maintain equilibrium with the atmosphere. Carbondioxide is an end product of both aerobic and anaerobic respiration therefore its concentration is not limited by the amount of dissolved oxygen originally present.

Algae obtain carbon from carbondioxide that is dissolved in the water and in equilibrium with bicarbonate buffer system. The absence of free carbondioxide in lentic area is attributed to the presence of larger populations of phytoplankton in these areas (Ayode *et al.,* 2009). Maximum light available at surface also results in higher photosynthetic activity and low levels of CO_2 (Sreenivasan, 1964). However, a vertical distribution of carbondioxide occurs in a waterbody that reflects a qualitative way in the vertical distribution of oxygen deficit (Hutchinson, 1957).

Total Hardness (TH)

The water hardness is a traditional measure of the capacity of water to react with soap. Hard water requires a considerable amount of soap to leather. The hardness (Calcium and Magnesium) is an important parameter in the detection of water pollution. Calcium and Magnesium are the most abundant elements that render hardness to natural surface as well as ground waters. They exists mainly as bicarbonates of (Ca^{++}), (Mg^{++}) and to a lesser degree in the form of Sulphates (SO_4^-) and Chlorides (Cl^-). Hardness caused by, bicarbonates and carbonates of calcium and magnesium is called temporary hardness whereas that caused by their sulphates and chlorides is called permanent hardness. Natural hardness of water depends upon the geological nature of the catchment area. It plays an important role in the distribution of aquatic biota and many species are identified as indicators for hard and soft waters (Ramchandra *et al.*, 2006). In the presence of carbon dioxide, calcium carbonate is dissolved in water. It maintains the pH of the most natural waters between 6.0 to 8.0. However, dissolved magnesium concentrations are lower than calcium for a majority of the natural waters. Because of the high solubility of magnesium salts, this metal tends to remain in solution and is less readily precipitated than calcium. Calcium is an essential nutrient element for animal life that aids in maintaining the structure of plant cells and soils. While, magnesium possesses no major concern with public health or aquatic environment. The hardness may range from zero to hundreds of milligrams per liter depending on the source and treatment to which the water has been subjected.

Hardness has been evaluated and correlated by different workers for different purposes. Kudari *et al.*, (2006) classified water bodies based on the hardness as slightly hard moderately hard and hard. While, Moshood, (2008) states that the utilization of calcium and magnesium ions by organisms probably causes decrease in the concentration of total hardness in the dry season. Higher hardness and conductivity of water in winter has been correlated to more productive during this season (Ayode *et al.,* 2009). Hardness is very important parameter in decreasing the toxic effects of poisonous elements (Jinwal and Dixit, 2008).

Chloride (Cl^-)

Chloride, in the form chloride ion (Cl^-), is one of the major inorganic anion in water and waste water (APHA, 1985). Natural water normally has low chloride content when compared to bicarbonates (HCO_3^{-1}) and sulphates (SO_4^{-2}). High chloride level in fresh water indicates pollution from domestic sewage and industrial effluents. The chloride content normally increases as the mineral content increases. High chloride content may harm metallic pipes and structures as well as growing plants. The origin of chloride in surface and ground water may be from diverse sources such as weathering and leaching of sedimentary rocks and soils, infiltration of sea water, windblown precipitated sea salt, domestic and industrial waste discharges and ground water inputs *etc.* (Allen *et al.*, 1999). Human excreta, particularly urine also contain high amount of chlorides (Goel *et al.*, 1980; Sinha, 1986). According to Walujkar

(2005) there is great reduction in chlorides during monsoon, which gradually built up from post monsoon to maximum during premonsoon.

Bhalla (2006) has reported that high chloride contents have damaging effect on agricultural crops too. The high chlorides, with potassium and sodium are not prefered for irrigation purpose (Ramchandra *et al.*, 2006). While, according to Trivedi and Goel (1986), the concentration of chloride in water serves as an indicator of sewage pollution. Kudari *et al.* (2006) noted almost three time increase in the concentration of chlorides due to increased anthropogenic disturbances like bathing, washing and cattle bathing in Unkal Lake which were correlated with pollution load. Further, Venu and Seshavatharam (1984) have reported the significant relationship of chlorides with primary productivity in Lake Kondakarla while Sharma *et al.,* (2008) have reported a negative correlation of chloride with DO and positive correlation with TSS, BOD, Total coliform and phytoplankton.

Nitrite (NO_2^-)

There are no mineral sources of nitrite in natural waters. Nitrite is an intermediate unstable oxidation state of nitrogen, both in the oxidation of ammonia to nitrate and reduction of nitrate. Such oxidation and reduction may occur in waste water treatment plants, water distribution systems and natural waters. Man has altered the nitrogen cycle through his agricultural and technological practices. Changing patterns in agriculture, food processing, urbanization and industrialization have major impact on the accumulation of nitrate in the environment.

The nitrite form of nitrogen is of concern because of its high water solubility and consequent leaching, diffusion and environmental mobility in soil water. Nitrous acid which is formed from nitrite in acidic solution can react with secondary amine (RR'NH) to form nitrosamine (RR'-N-NO), many of which are known to be carcinogens.

Organic waste, when comes in contact with oxygen in water undergoes biodegradation. First product of such biodegradation is ammonia which is converted to nitrite. Therefore, detection of nitrite is a significant indication of large amount of faecal matter coming from domestic waste, while oxidation of ammonia also points to the higher concentration of effluents (Jha and Bharat, 2003). The presence of nitrites along with some toxic aromatic compounds are said to be imparting brown colour and offensive odour to water which becomes unfit for irrigation, fish culture and drinking for cattle and human beings (Bhalla, 2006). The significant environmental variables identified by Canonical Correspondence Analysis (CCA) have explained maximum variability in zooplankton species at Old Foot Lake due to abiotic factors such as NO_2^-, NO_3^- and PO_4^{-3} (Arora and Mehra, 2009).

Nitrate (NO_3^-)

Nitrates are one of the most important nutrients in an aquatic ecosystem. They are the highly oxidized form of nitrogen compounds commonly present in the natural water. They are the products of the aerobic decomposition of nitrogenous matter received from domestic sewage, agricultural runoff and industrial effluents.

Nitrates generally occur in trace quantities in surface waters but may attain low levels in ground water. However, the high amounts of nitrates are generally indicative of water pollution. The runoff water coming from intensive agricultural activities (including the use of fertilizers) also contribute to significant nitrate contents in surface waters.

Nitrate is found only in small amounts in fresh domestic water. It is an essential nutrient for many photosynthetic autotrophs and in some cases has been identified as growth limiting nutrient. Many workers have reported the presence of nitrates at higher levels in effluent water compared to fresh water. The presence of nitrates in the water samples is suggestive of some bacterial action and bacterial growth (Narayan *et al.*, 2007). Low levels of nitrates and phosphates are not indicative of low productivity as these nutrients are quickly recycled (Sugunan, 2000). The natural concentration of 0.3 mg/L of nitrate may be enhanced by fertilizer in the runoff, industrial and municipal waste waters up to 5 mg/L. In Lakes, concentration of nitrate in excess of 0.2 mg/L of nitrate nitrogen stimulates algal growth leading to eutrophication (Ramchandra and Solanki, 2007). According to Trevisan and Forsberg (2007) phytoplankton of Amazonian system of Lakes is mainly controlled by the availability of nutrients, especially nitrogen, during the dry period. The concentration of nutrients, mainly nitrogen and phosphorus, are the factors which govern the phytoplankton growth and distribution (Naselli-Flores and Barone, 2003). Forbes *et al.,* (2008) could not detect any significant relationship between bioavailable nitrogen (*i.e.* nitrate) and N_2 fixation potentials with the help of both multiple linear regressions and the pruned regression tree analysis. However, the roles of bioavailable nitrogen, as well as temperature are normally revealed in the seasonal N_2 fixation (Scott *et al.,* 2008). A relationship between total nitrogen and total phosphate exist which indicates that both zooplankton biomass and phytoplankton biomass increase with the increase of total Nitrogen and total phosphate concentrations (Chun *et al.,* 2007).

Phosphates (PO_4^{-3})

Like Nitrites and Nitrates in natural waters, phosphates are also present in small quantities. The presence of phosphate in large quantities in freshwater indicates pollution through sewage and industrial waste. In an aquatic ecosystem phosphorus occurs in inorganic as well as organic forms. It is one of the important nutrients required by the biota. Phosphates occur in natural and waste waters, principally as organic orthophosphates, condensed phosphates and organically bound phosphates. Orthophosphates are applied to agricultural land as fertilizers and carried into surface waters with storm runoff. Orthophosphate, the soluble reactive phosphorus which is also termed as organic phosphate, plays a dynamic role in aquatic ecosystem as it is widely taken up by phytoplankton (Goldman, 1965). Phosphates in small concentrations are used in water supply to reduce scale formation. It promotes growth of microorganisms, that are reported to lead to eutrophication in stagnant water bodies. However, phosphorus is essential for the growth of organisms and is one of the major factors limiting primary production and has been reported as most critical single element in maintaining aquatic productivity in reservoirs (Das, 2000). According to Chun *et al.* (2007) contents of total phosphates and total nitrates decrease almost linearly with the increase of macrophytes biomass. Murugavel and Pandian (2000) recorded almost doubled amount of phosphates in the lower Kodayar, as compared to Azhakia Pandipuram ponds of upper Kodayar. Further, Thomas and Azis (1996) have reported higher phosphate contents in the system that receives rain water gushing from adjacent forests and agriculture fields that are moderately fertilized. However, the reservoirs of Rajasthan have particularly high level of phosphates ranging from traces to 0.929 mg/L. Sharma, (1980) and Sugunan, (2000) observed that the phosphate may also be received from the rain washings of the brown hills and the red and yellow desert soils. Phosphate concentration of lotic ecosystem for *e.g.* Panchganga river, increases towards downstream due to influx of domestic sewage, detergents, agricultural effluents and industrial effluents (Mulani *et al.*, 2009). Thus increased input of inorganic phosphates to lakes, bays and other surface water causes eutrophication, resulting in excess growth of phototrophs, depletion of dissolved oxygen, degradation of the recreational value of water and foul tastes to the drinking water on addition. Strong positive correlation between altitude and trophic state (total phosphorus) in the reservoirs has been reported by Sharma *et al.*, (2008).

Hence, while studying ecology and biodiversity of a water body, study of its physico-chemical parameters becomes essential. Therefore, the present chapter deals with the influence of environmental changes in accordance with season on water chemistry of "Yashwant Lake" a higher altitude lake in mid Satpura range of North-West Maharashtra.

MATERIALS AND METHODS

Surface water samples were collected from three selected stations of Yashwant Lake namely YLA, YLB and YLC between 8 a.m. to 10 a.m. The study site was visited at an interval of fifteen days and monthly mean was taken for calculation (December 2006 to November 2008). Total 24 visits were made per year and 48 visits during the study period. To collect water samples for analysis, plastic containers of two litre capacity were used. Containers were thoroughly cleaned, washed and rinsed before every collection. Separate containers were labeled station wise to indicate date and location and brought to the laboratory. The parameters such as Atmospheric Temperature (AT), Water Temperature (WT), Transparency (Trans.), Water Cover (WC) and Carbon-dioxide were analyzed at station itself and 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), Acidity (Aci), Alkalinity (Alk), 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 until estimation.

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 body 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. Then 100 ml of unfiltered sample was evaporated in an evaporating dish on a hot plate at 98 °C. After heating the residues at 103-105 °C in an oven for one hour the evaporating dish was cooled in a desicator and weighed. TS was calculated as,

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

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 a 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 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,

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

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.

$$\mathrm{TSS} = \mathrm{TS} - \mathrm{TDS}$$

CHEMICAL PARAMETERS

pH (Electrometric method, Michael, 1984)

The pH of water sample was measured by electronic portable pH meter. The pH meter was calibrated with phosphate buffer of known pH. pH meter 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.

Acidity (Titrimetric method, APHA, 1998)

Acidity of the water is its capacity to neutralize a strong base to a fixed pH. Hydrogen ions present in a sample as a result of dissociation/ hydrolysis of solutes react with standard alkali added to it. Acidity thus depends on the end-point pH/ indicator used. For routine controlled titrations or rapid preliminary estimates of acidity, the colour change of the indicator is used to find out the end point. In 10 ml. of sample, 2 to 4 drops of phenolphthalein are added as indicator and titrated against 0.02 N NaOH solution. Wherever necessary the sample was made colourless with the help of charcoal. Colour change from colourless to pink is taken as the end point and acidity was calculated using following formula,

$$\text{Acidity as mg } CaCO_3/L = \frac{B.R. \times 1000}{\text{Amount of sample taken (ml)}}$$

Where, B.R. = Burette reading (Amount of titrant used).

Alkalinity (Titrimetric method, APHA, 1998)

Total alkalinity is a measure of the capacity of the water to neutralize a strong acid and is the sum of Hydroxyl alkalinity and Bicarbonate alkalinity. Hydroxyl ions present in a sample as a result of dissociation or hydrolysis of solutes react with additions of standard acid. Thus, alkalinity also depends on the end-point pH.

In 100ml. of sample 3 to 4 drops of Phenolphthalein indicator are added and titrated against 0.1N HCl. If the solution remains colourless, then the hydroxyl alkalinity is considered as zero. Colour change from pink to colourless is noted down as the burette reading (A) for calculation of hydroxyl alkalinity. To estimate bicarbonate alkalinity, few drops of methyl orange indicator were added to 100 ml. of sample in which Phenolphthalein alkalinity has been determined and titrated against 0.1N HCl. The end point was noted with colour change from yellow to orange at pH 4.6 and noted as burette reading (B) and calculated as follows,

$$\text{Hydroxyl alkalinity as mg } CaCO_3/L = \frac{A \times N \times 50 \times 1000}{\text{Amount of sample taken (ml)}}$$

$$\text{Bicarbonate alkalinity as mg } CaCO_3/L = \frac{B \times N \times 50 \times 1000}{\text{Amount of sample taken (ml)}}$$

Where, A= ml of HCl used with only Phenolaphthalein.

B = ml of total HCl used with phenolaphthalein as well as methyl orange.

N = Normality of HCl (0.1N).

50 = equivalent weight of $CaCO_3$.

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

The Manganese sulphate reacts with alkali (KOH) to form a white precipitate of manganous hydroxide. In the presence of oxygen it gets oxidized to form a brown coloured manganese oxyhydrate which is equivalent to the amount of dissolved oxygen present in water. In the presence of iodide ion acidification, oxides of manganese revert to divalent state with the liberation of iodine equivalent to originally dissolved oxygen content in the sample. The iodine is then titrated with standard solution of sodium thiosulphate using starch as an indicator.

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 and Alkali-iodide azide reagents. The precipitates formed were dissolved by adding 2 ml. of concentrated Sulphuric acid. From this 100ml sample was taken and titrated against 0.1N Sodium thiosulphate. To estimate iodine generated starch is used as indicator 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 Carbondioxide (APHA, 1998)

Present method is based on the principle that free carbondioxide in water reacts with sodium hydroxide to form sodium bicarbonate and the end point is indicated by development of pink colour using phenolaphthalein indicator at pH 8.3. 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 carbondioxide 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)

Hardness is generally due to calcium and magnesium ions present in the water. EDTA (Ethylene di-amine tetra acetic acid) and its sodium salts as well as Eriochrome Black-T form a chelated soluble complex when added to a solution of certain metal cations. When a small amount of Eriochrome Black-T Calamite indicator is added to the aqueous solution containing calcium and magnesium ions at pH 10.0 it forms calcium and magnesium ion complexes and the solution becomes wine red. Since EDTA has strong affinity towards calcium and magnesium ions, with the addition of EDTA as titrant, the complex binds to EDTA and Erichrome Black T is released free. As a result the solution turns from wine red to blue, indicating the end point.

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 colour is achieved. The total hardness is calculated using following formula,

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

Where A = ml of titrant (EDTA) used.

N = Normality of EDTA.

Chloride (Cl^-) (Argenometric Titremetric method, APHA, 1998)

Silver nitrate reacts with chloride to form very slightly soluble white precipitates of $AgCl_2$. In a neutral or slightly alkaline solution, chloride is estimated with silver nitrate as titrant using potassium chromate as an indicator. Silver chloride is precipitated quantitatively before red silver chromate is formed.

In 100 ml. 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^-/Lit is as follows,

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

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)

Nitrate (NO_2^-) is determined by the formation of reddish purple azo dye produced at pH 2.0-2.5 with colour reagent.

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 copper sulphate ($CuSO_4$) and 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. Nitrates were calculated as,

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

Where, O.D. = Optical Density

Phosphate (PO_4^{-3}) [APHA, 1998]

The phosphates in water react with ammonium molybdate and form complex molybdophosphoric acid which gets reduced to a complex of blue colour in the presence of $SnCl_2$. The absorption of light by this blue colour can be measured at 690 nm to calculate the concentration of phosphate.

In a conical flask containing 100ml. of sample, 4ml of strong acid and 4 ml of ammonium molybdate were added followed by 10 drops $SnCl_2$. 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,

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

Where, O.D. = Optical Density

For the convenience of analysis the biweekly data were 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 7.5/12 for windows. If (**) Correlation is significant at the 0.01 level (two-tailed), whereas at (*) correlation is significant at 0.05 level (two-tailed).

RESULTS

For the convenience of presentation the physico-chemical parameters were divided into four groups:

Group I: Atmospheric temperature (AT), Water temperature (WT) and Water Cover (WC),

Group II: Transparency (Trans), Total solids (TS), Total dissolved solids (TDS) and Total suspended solids (TSS),

Group III: pH, Acidity, Alkalinity, Dissolved oxygen (DO), Carbon dioxide (CO_2), Total hardness (TH) and Chlorides (Cl^-) and,

Group IV: NO_2^-, NO_3^-, PO_4^{-3}.

Results are mainly considered for YLC and wherever required values for other sites are given.

Group I:

1) Atmospheric temperature (AT)

Atmospheric temperatures were same at all the three stations with minor differences in mean values (Table 3.1, Fig.3.1). They were minimum in winter around 17 °C and maximum in summer around 24 °C, while in monsoon and post-monsoon they were around 23 °C and 20 °C respectively.

2) Water temperature (WT)

The water temperature followed same trend as that of atmospheric temperature (Table 3.1, Fig.3.2). However, during winter water temperature was about 1 °C higher than atmospheric temperature around 18.5 °C while during other seasons it was 1 to 3 °C lower around 22 °C in summer, 21 °C in monsoon and 19 °C in post monsoon. Seasonal variations for AT and WT were noted at $P < 0.0001$.

3) Water Cover (WC)

Percentage of water cover was recorded for whole Lake so the value for all stations was same (Table 3.1, Fig.3.3). It was Maximum in post monsoon (92.5 ± 1.1 %). It slightly decreased in winter (85.8 ± 1.5 %) and was recorded minimum in summer (66.67 ± 2.4 %). With the onset of monsoon it started increasing reaching mean value of 77.50 ± 3.5 % with seasonal variations at $P < 0.0001$.

Table: 3.1 Average seasonal variations in Atmospheric Temperature (AT) (°C), Water Temperature (WT) (°C) and Water Cover (WC) (%) at station YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

Sr. No	Parameters	Station with F-value	Winter	Summer	Monsoon	Pt.Mon.
1	AT °C	YLA $F_{3, 20}$ 27.51	17.25 ± 0.55	24.50 ± 0.65	22.83 ± 0.38	20.75 ± 0.72
		YLB $F_{3, 20}$ 22.57	17.67 ± 0.54	24.08 ± 0.75	22.92 ± 0.50	20.92 ± 0.52
		YLC $F_{3, 20}$ 27.95	17.75 ± 0.62	24.50 ± 0.60	23.08 ± 0.32	20.58 ± 0.62
2	WT °C	YLA $F_{3, 20}$ 12.47	18.42 ± 0.20	21.83 ± 0.45	20.42 ± 0.47	19.17 ± 0.49
		YLB $F_{3, 20}$ 9.073	18.75 ± 0.21	21.58 ± 0.50	20.75 ± 0.44	19.67 ± 0.42
		YLC $F_{3, 20}$ 18.85	18.75 ± 0.30	22.00 ± 0.46	21.17 ± 0.38	19.17 ± 0.24
3	Water Cover %	YL $F_{3, 20}$ 21.95	85.83 ± 1.53	66.67 ± 2.47	77.50 ± 3.59	92.50 ± 1.11

Figure: 3.1 Average seasonal variations of Atmospheric Temperature (AT) °C at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

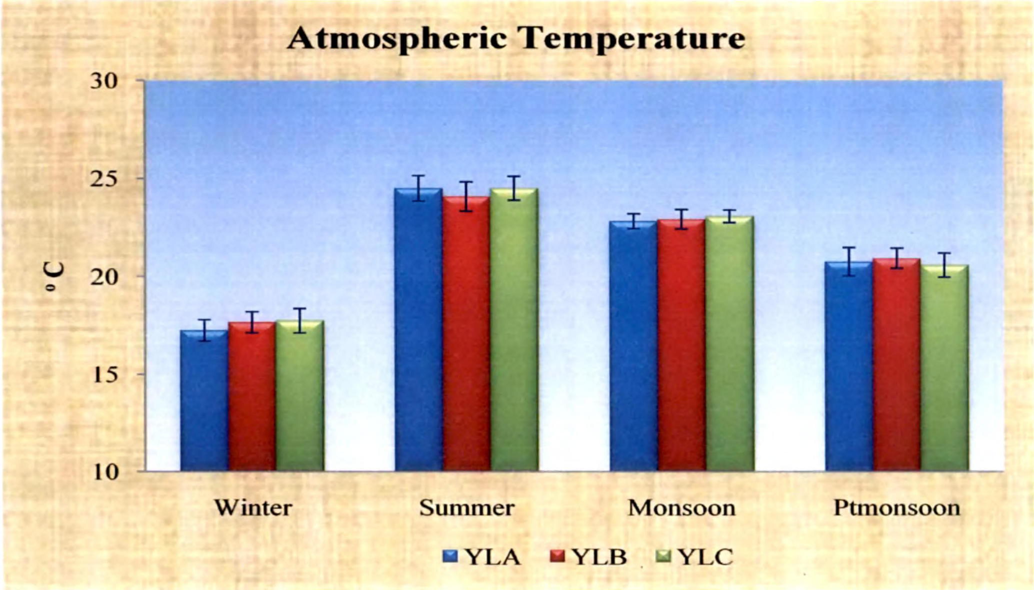


Figure: 3.2 Average seasonal variations of Water Temperature (WT) °C at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

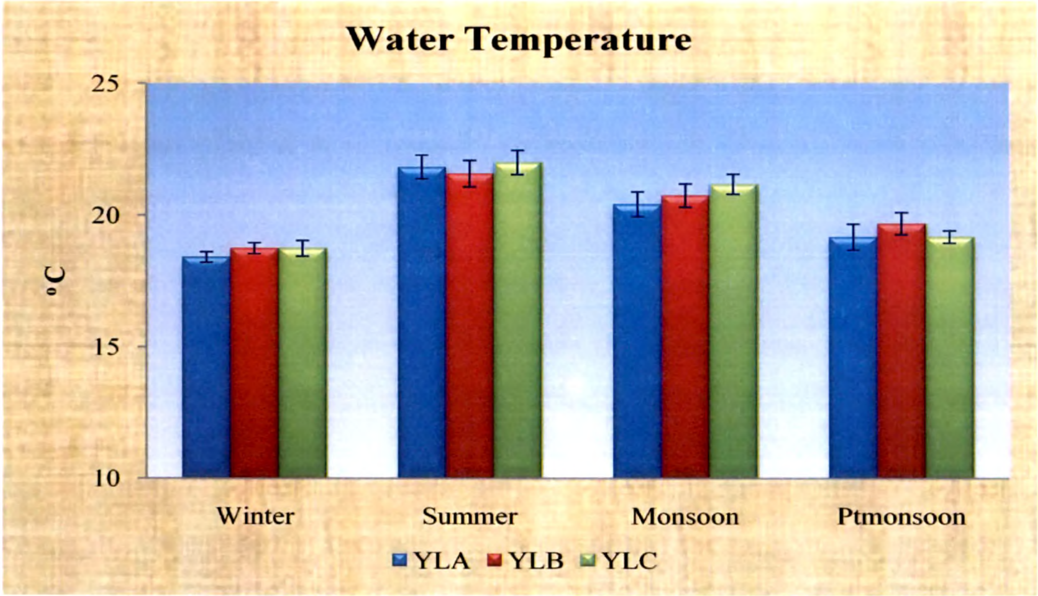
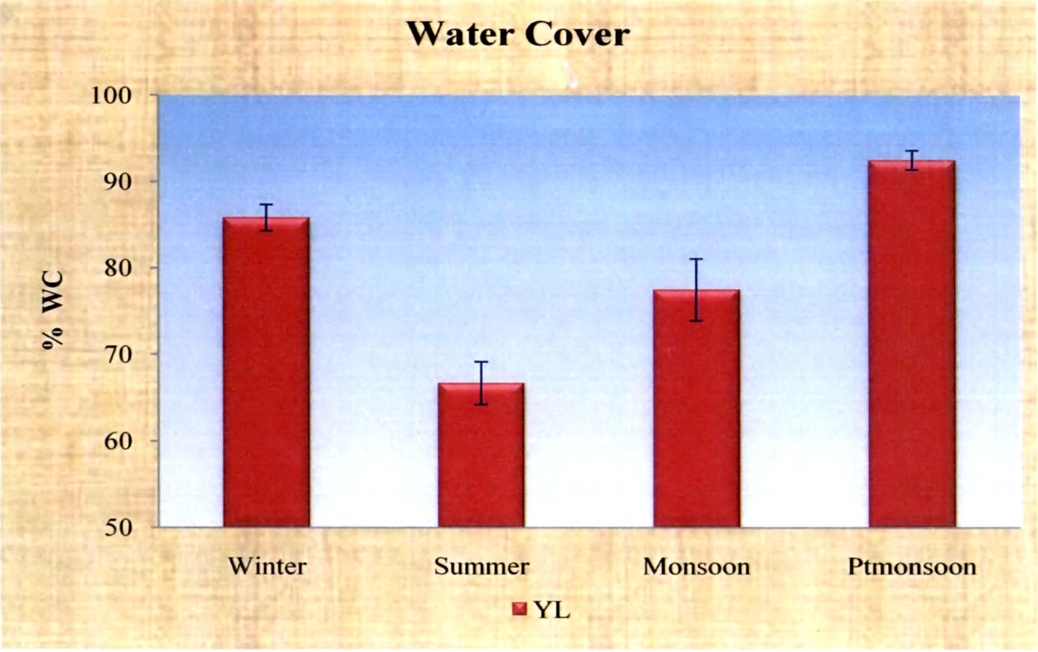


Figure: 3.3 Average seasonal variations of Water Cover (%) at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008



Group II:

4) Transparency (Trans. meters)

With the nonsignificant differences among the three stations, maximum transparency was recorded at YLB (1.48 ± 0.01 m) in the winter and minimum at YLA (1.15 ± 0.01 m) in the monsoon (Table 3.2, Fig.3.4). Compared to winter it decreased marginally in the summer and post-monsoon. Transparency showed variations at $P < 0.0001$.

5) Total Solids (TS mg/L)

Total solids in water were higher at YLC as compared to YLA and YLB (Table 3.2, Fig.3.5) in all the seasons and fluctuated in accordance. They were maximum 170.8 ± 2.33 mg/L during monsoon that decreased to 146.3 ± 4.36 mg/L in post monsoon and further declined to 136 ± 1.7 mg/L in winter but increased to 160 ± 4.52 mg/L in summer at YLC.

6) Total Dissolved Solids (TDS mg/L)

TDS was maximum 133 ± 2.9 mg/L in summer and minimum 108.8 ± 2.79 mg/L in postmonsoon. While it was 112.3 ± 2.26 mg/L in winter and 128.3 ± 2.17 mg/L in monsoon at YLC (Table 3.2, Fig.3.6). The trends were same at other two stations but were nonsignificantly low.

7) Total Suspended Solids (TSS mg/L)

TSS levels showed same trend at all the three stations as that of TS (Table 3.2, Fig. 3.7). However, at YLA and YLC minor differences were noted. At YLC it was maximum 42.5 ± 2.17 mg/L in monsoon and minimum 23.67 ± 1.14 mg/L in winter, while it was 26.5 ± 1.52 mg/L in summer and 37.5 ± 1.6 mg/L in post monsoon, with variations at $P < 0.0001$ across the season.

In short, transparency was higher at YLB and lowest at YLA where as TS, TDS and TSS were higher at YLC and lowest at YLB. TSS showed same results at YLA and YLB during winter and monsoon.

Table: 3.2 Average seasonal variations in Transparency (Trans.), Total Solids (TS), Total Disolved Solids (TDS) and Total Suspended Solids (TSS) at station YLA, YLB and YLC of Lake during November 2006 to December 2008

Sr. No.	Para-meters	Stations with F value	Winter	Summer	Monsoon	Postmonsoon
1	Trans. mts.	YLA $F_{3,\,20}$ 20.12	1.38 ± 0.01	1.277 ± 0.008	1.155 ± 0.01	1.22 ± 0.03
		YLB $F_{3,\,20}$ 34.34	1.48 ± 0.01	1.34 ± 0.017	1.19 ± 0.02	1.27 ± 0.02
		YLC $F_{3,\,20}$ 24.85	1.44 ± 0.01	1.30 ± 0.01	1.168 ± 0.01	1.24 ± 0.03
2	TS mg/L	YLA $F_{3,\,20}$ 22.28	131 ± 0.85	150.3 ± 3.48	161.2 ± 1.35	138 ± 4.16
		YLB $F_{3,\,20}$ 11.89	126 ± 2.03	145.3 ± 3.94	152.8 ± 2.52	131.2 ± 5.06
		YLC $F_{3,\,20}$ 19.50	136 ± 1.71	160 ± 4.52	170.8 ± 2.33	146.3 ± 4.36
3	TDS mg/L	YLA $F_{3,\,20}$ 22.66	109.7 ± 1.74	126.8 ± 2.18	123.7 ± 1.94	105.7 ± 2.71
		YLB $F_{3,\,20}$ 13.83	105.2 ± 2.38	120.2 ± 1.93	115.3 ± 1.70	101 ± 3.21
		YLC $F_{3,\,20}$ 21.24	112.3 ± 2.26	133 ± 2.95	128.3 ± 2.17	108.8 ± 2.79
4	TSS mg/L	YLA $F_{3,\,20}$ 23.74	21.33 ± 1.20	23.50 ± 1.33	37.50 ± 1.92	32.33 ± 1.64
		YLB $F_{3,\,20}$ 14.70	20.83 ± 1.47	25.17 ± 2.16	37.50 ± 1.82	30.17 ± 1.93
		YLC $F_{3,\,20}$ 29.16	23.67 ± 1.14	26.50 ± 1.52	42.50 ± 2.17	37.50 ± 1.60

Figure: 3.4 Average seasonal variations of Transparency (m.) at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

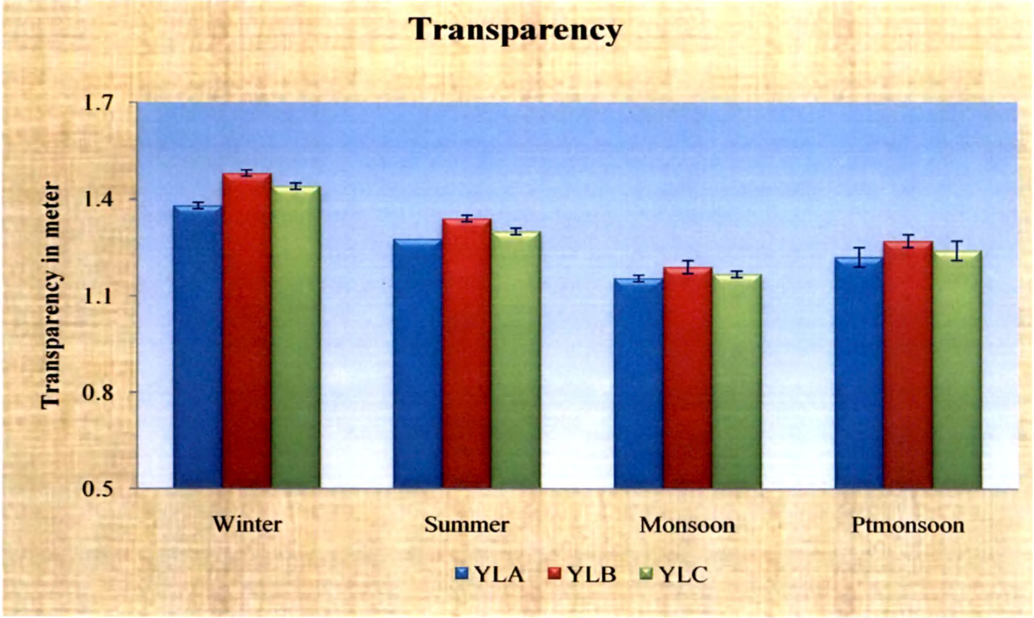


Figure: 3.5 Average seasonal variations of Total Solids (TS) mg/L at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

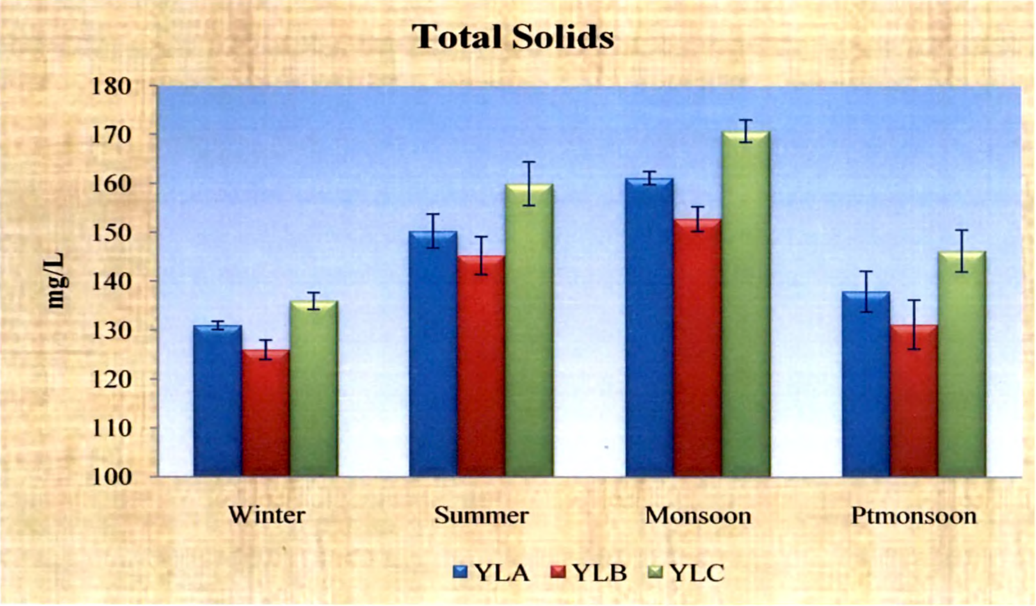


Figure: 3.6 Average seasonal variations of Total Dissolved Solids (TDS) mg/L at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

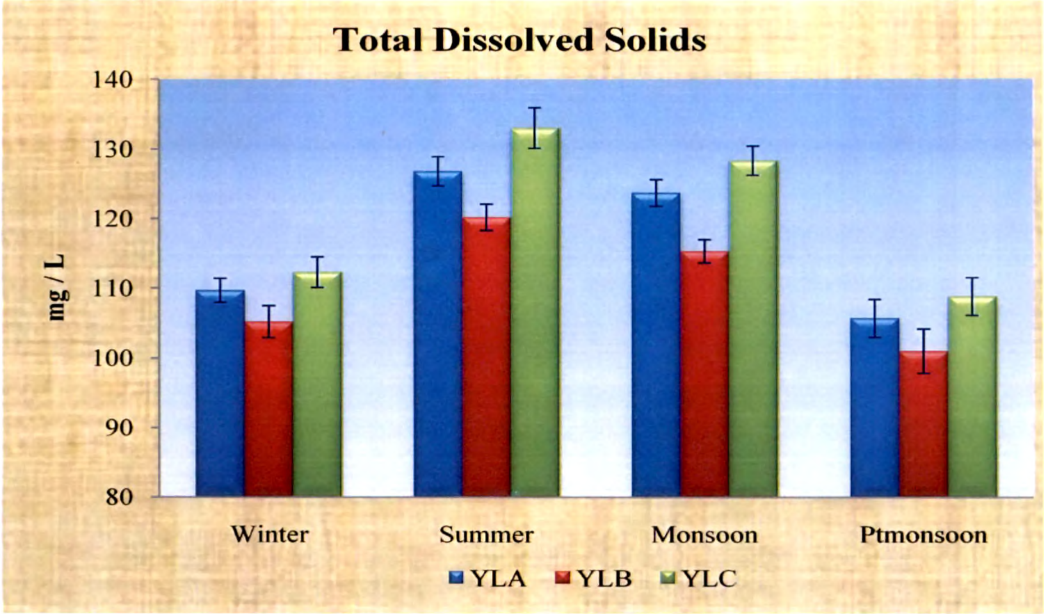
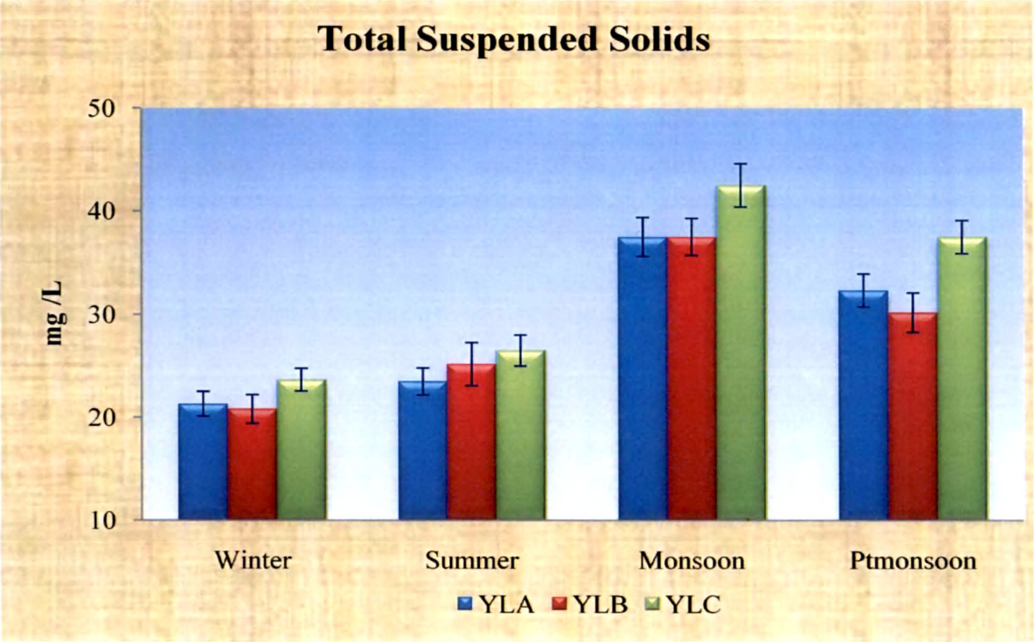


Figure: 3.7 Average seasonal variations of Total Suspended Solids (TSS) mg/L at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008



Group III

8) pH

pH showed parallel fluctuations at the three stations but it was nonsignificantly higher at YLA and lower at YLC as compared to YLB (Table 3.3, Fig.3.8). However, seasonal variations at all the three stations were significant at $P < 0.0001$. pH of water at YLC was highest 8.2 ± 0.09 in summer which declined to 7.9 ± 0.06 in monsoon to 7.5 ± 0.04 in post-monsoon and decreased further in winter to 7.36 ± 0.05.

9) Acidity

Acidity also showed parallel fluctuations at the three stations (Table 3.3, Fig.3.9). It was non-significantly lower at YLB and YLC. Acidity was maximum 18.75 ± 0.3 mg $CaCO_3$/L in summer that declined to 16.17 ± 0.7 mg $CaCO_3$/L during monsoon to 10.5 ± 0.4 mg $CaCO_3$/L in post-monsoon and was maintained in winter at 10.83 ± 1.1 mg $CaCO_3$/L at YLA.

10) Alkalinity

Maximum 115.4 ± 1.6 mg $CaCO_3$/L alkalinity was reported in summer and minimum 85.4 ± 2.8 mg $CaCO_3$/L in post-monsoon at YLC with 89.58 ± 4.1 mg $CaCO_3$/L in winter and 107.9 ± 2.8 mg $CaCO_3$/L in monsoon which was lower than the other two sites (Table 3.3, Fig.3.10). The seasonal variations were significant at $P < 0.0001$ at the three stations.

11) Dissolved Oxygen (DO)

The DO was marginally non significantly higher at YLC compared to YLA and YLB (Table 3.3, Fig.3.11). It oscillated from maximum 12.93 ± 0.41 mg/L in winter to 9.73 ± 0.31 mg/L in summer, 11.6 ± 0.38 mg/L in monsoon and 10.63 ± 0.14 mg/L in post-monsoon. Dissolved oxygen also showed variations at all the three stations at $P < 0.0001$.

12) Carbon dioxide (CO_2)

CO_2 levels were also non-significantly higher at YLC compared to YLA and YLB with maximum 4.23 ± 0.3 mg/L in summer falling to 3.5 ± 0.1 mg/L in monsoon and further declining to 2.75 ± 0.2 mg/L in post-monsoon and reaching to minimum 0.96 ± 0.2 mg/L in winter with $P < 0.0001$ (Table 3.3, Fig.3.12).

13) Total Hardness (TH)

Total hardness of water was lower at YLC as compared to YLA and YLB (Table 3.3, Fig. 3.13). It was minimum 49.33 ± 2.1 mg/L in monsoon, which started increasing in postmonsoon with 52.33 ± 1.2 mg/L and winter with 58.67 ± 0.9 mg/L and reached to the maximum level at 65 ± 0.8 mg/L in summer. Total hardness showed significant variations at all the three stations across the seasons with $P < 0.0001$.

14) Chloride (Cl^-)

At YLC maximum 27.17 ± 0.7 mg/L chloride was observed in summer that declined to 22.83 ± 0.9 mg/L in monsoon and reached to minimum level at 14.0 ± 0.6 mg/L in post- monsoon (Table 3.3, Fig.3.14). It started increasing in winter with 17.33 ± 1.1 mg/L. Though seasonal variations were in accordance to YLA and YLB, the chloride at YLC was lower than the other two stations. Chloride showed variations across the season at all the three stations with $P < 0.0001$.

Table: 3.3 Average seasonal variations in pH, Acidity (Aci.), Alkalinity (Alk.), Dissolved Oxygen (DO), Carbon-dioxide (CO_2), Total Hardness (TH) and Chlorides(Cl^-) at station YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

Sr. No.	Param -eters	Stations with F value	Winter	Summer	Monsoon	Postmonsoon
1	pH	YLA $F_{3,20}$ 31.53	7.51 ± 0.03	8.35 ± 0.10	8.03 ± 0.06	7.70 ± 0.04
		YLB $F_{3,20}$ 19.93	7.48 ± 0.047	8.23 ± 0.11	7.9 ± 0.076	7.65 ± 0.04
		YLC $F_{3,20}$ 28.56	7.36 ± 0.055	8.2 ± 0.096	7.9 ± 0.068	7.53 ± 0.049
2	Aci.	YLA $F_{3,20}$ 28.08	11.92 ± 0.96	18.75 ± 0.72	17.42 ± 0.65	11.08 ± 0.49
		YLB $F_{3,20}$ 31.28	11.17 ± 0.98	18.42 ± 0.56	16.75 ± 0.69	11.08 ± 0.23
		YLC $F_{3,20}$ 25.87	10.83 ± 1.19	18.17 ± 0.38	16.17 ± 0.70	10.50 ± 0.46
3	Alk.	YLA $F_{3,20}$ 14.86	96.25 ± 4.90	120 ± 1.44	113.3 ± 2.86	91.67 ± 3.85
		YLB $F_{3,20}$ 12.09	94.58 ± 5.45	116.3 ± 1.67	110.4 ± 2.98	89.17 ± 3.57
		YLC $F_{3,20}$ 23.19	89.58 ± 4.1	115.4 ± 1.6	107.9 ± 2.8	85.42 ± 2.8
4	DO	YLA $F_{3,20}$ 21.16	12.23 ± 0.26	8.96 ± 0.38	10.80 ± 0.33	9.91 ± 0.17
		YLB $F_{3,20}$ 18.13	12.63 ± 0.34	9.45 ± 0.33	11.28 ± 0.37	10.37 ± 0.18
		YLC $F_{3,20}$ 17.00	12.93 ± 0.41	9.73 ± 0.314	11.60 ± 0.38	10.63 ± 0.14
5	CO_2	YLA $F_{3,20}$ 26.13	0.716 ± 0.37	4.03 ± 0.28	3.35 ± 0.20	2.56 ± 0.22
		YLB $F_{3,20}$ 33.79	0.73 ± 0.26	4.06 ± 0.32	3.38 ± 0.19	2.63 ± 0.18
		YLC $F_{3,20}$ 32.81	0.96 ± 0.27	4.23 ± 0.3	3.51 ± 0.17	2.75 ± 0.21
6	TH	YLA $F_{3,20}$ 26.41	60.33 ± 0.61	67.67 ± 1.40	51.00 ± 1.98	56.33 ± 1.08
		YLB $F_{3,20}$ 47.06	60.67 ± 0.84	66.33 ± 0.95	50.0 ± 1.26	55.67 ± 0.95
		YLC $F_{3,20}$ 25.54	58.67 ±0.98	65 ±0.88	49.33 ±2.1	52.33 ±1.2
7	Cl	YLA $F_{3,20}$ 29.21	19.00 ± 1.31	29.5 ± 1.43	25.33 ± 0.95	15.83 ± 0.70
		YLB $F_{3,20}$ 27.84	18.33 ± 1.40	27.83 ± 1.13	24.83 ± 1.13	14.83 ± 0.70
		YLC $F_{3,20}$ 42.08	17.33 ± 1.14	27.17 ± 0.74	22.83 ± 0.94	14.0 ± 0.68

Acidity and Alkalinity are measured in terms of mg $CaCO_3$/L.

DO, CO_2, TH, and Cl^- are measured in terms of mg/L.

Figure: 3.8 Average seasonal variations of pH at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

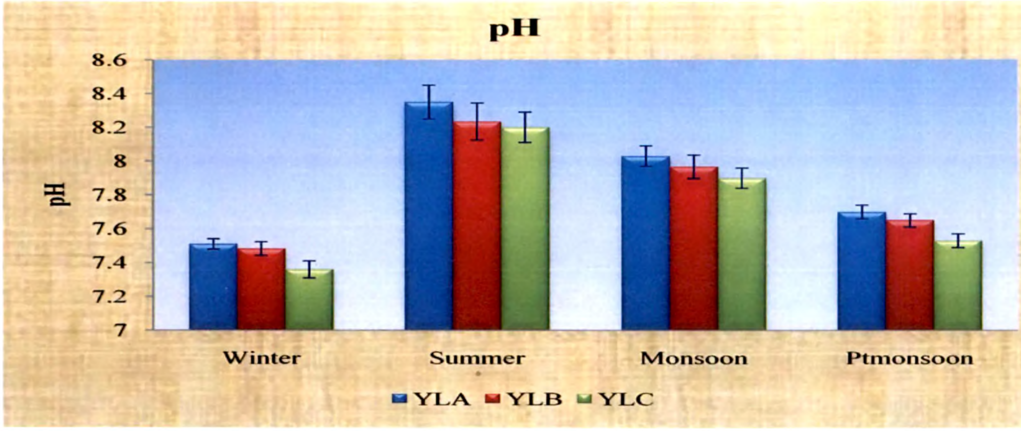


Figure: 3.9 Average seasonal variations of Acidity mg $CaCO_3$/L at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

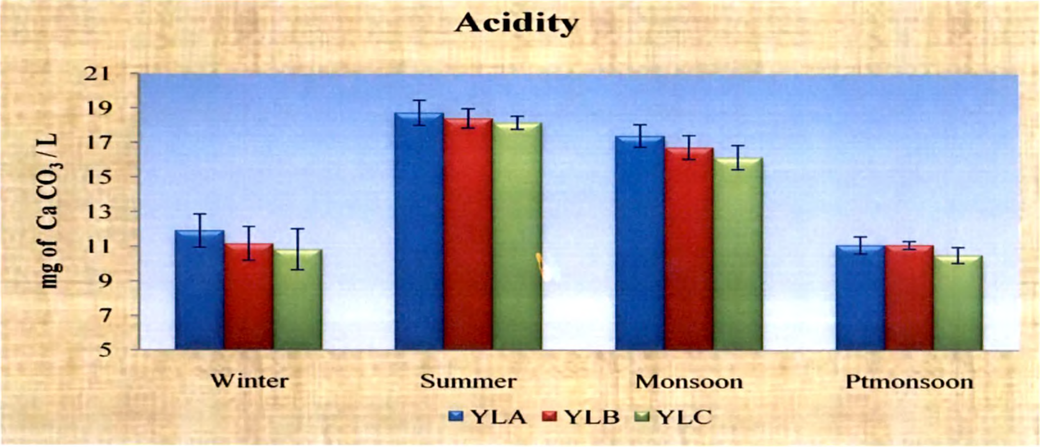


Figure: 3.10 Average seasonal variations of Alkalinity mg $CaCO_3$/L at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

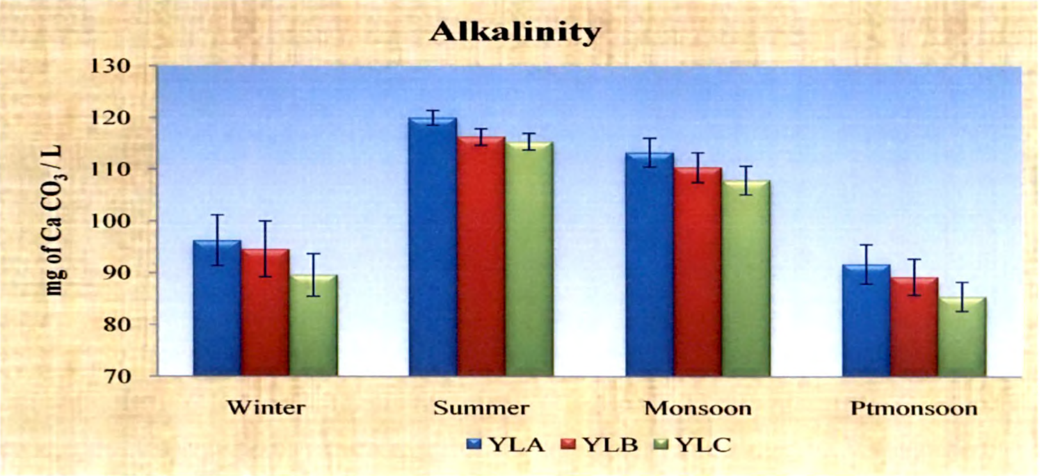


Figure: 3.11 Average seasonal variations of Dissolved Oxygen mg/L at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

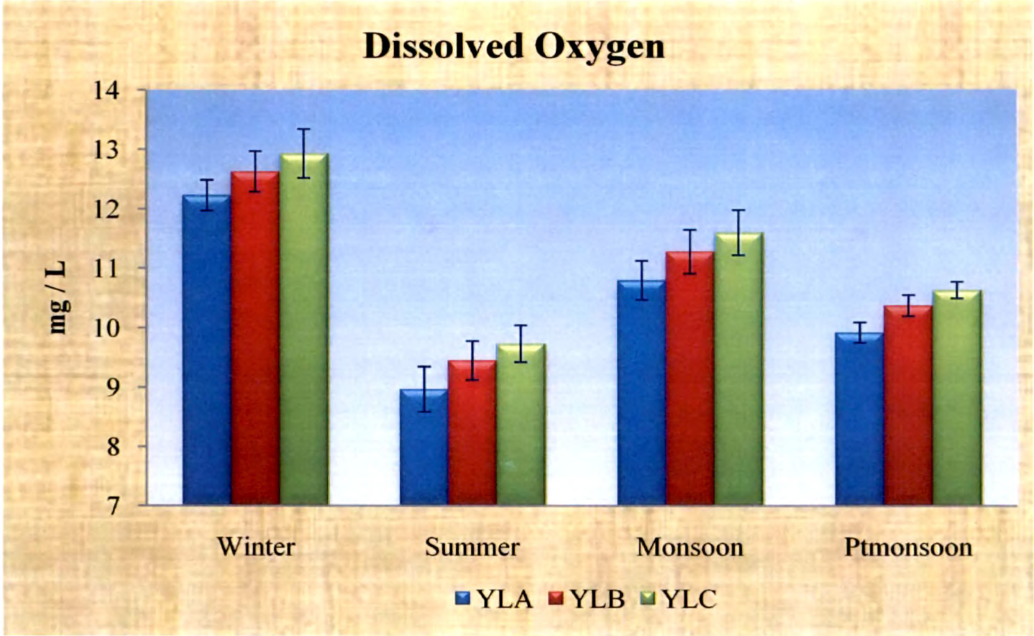


Figure: 3.12 Average seasonal variations of Carbondioxide mg/L at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

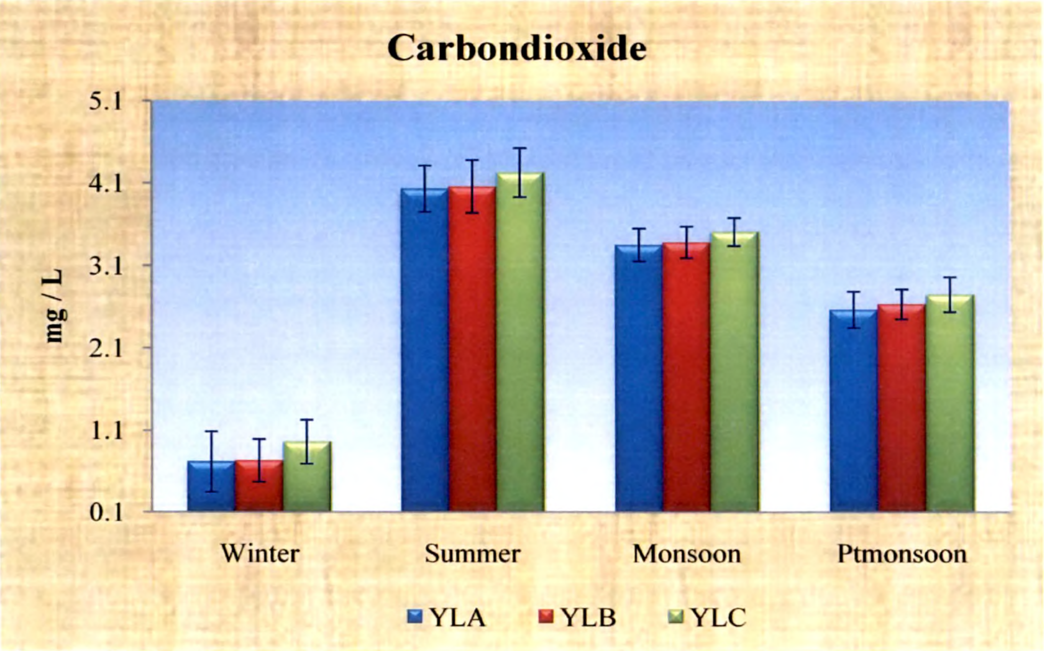


Figure: 3.13 Average seasonal variations of Total Hardness mg/L at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

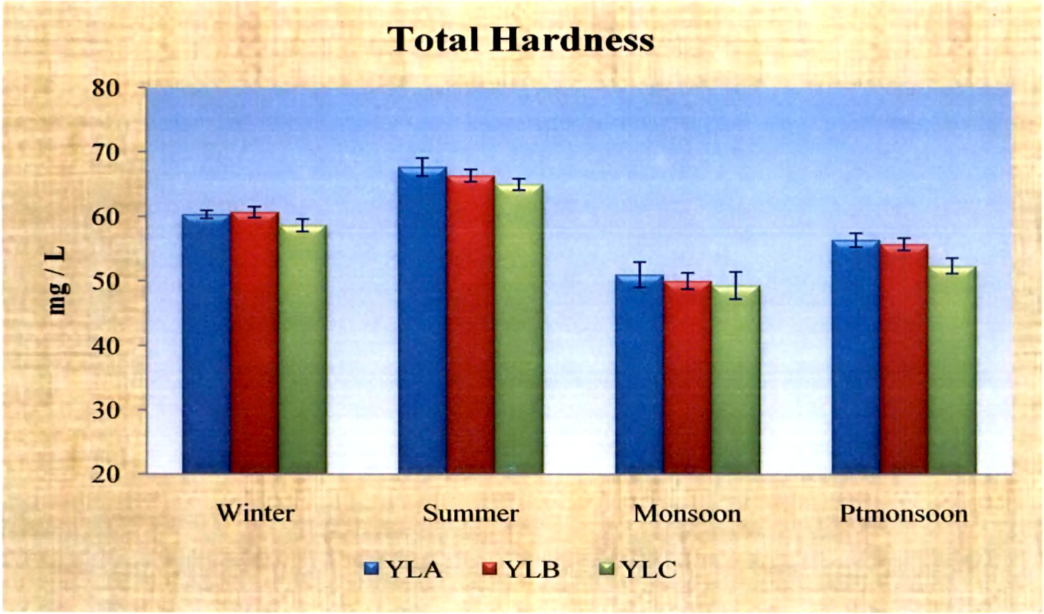
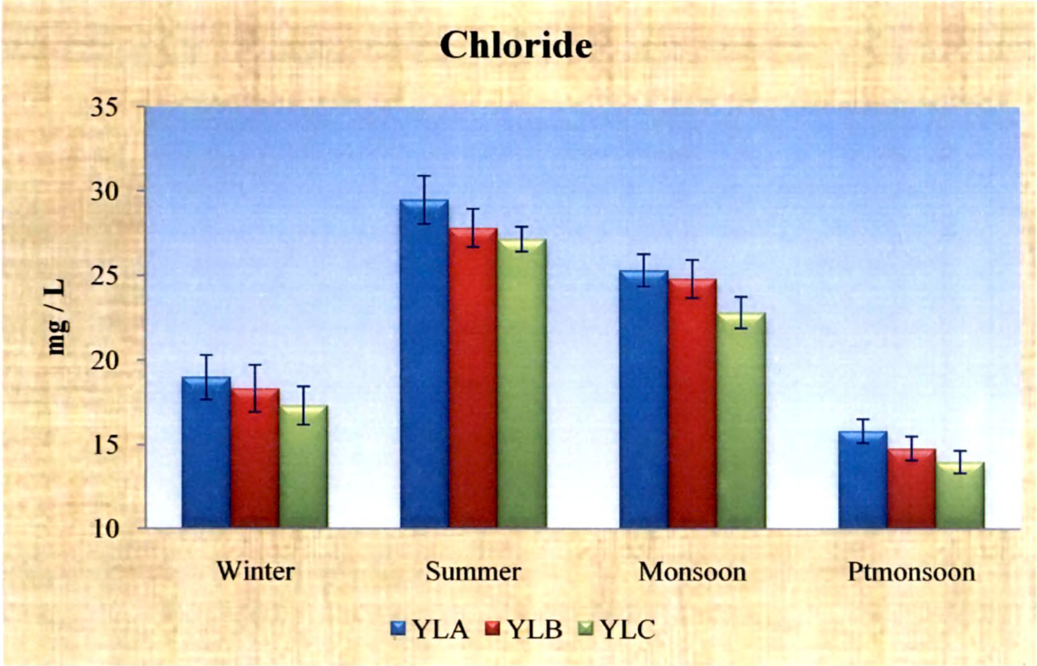


Figure: 3.14 Average seasonal variations of Chloride mg/L at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008



Group IV

15. Nitrite (NO_2^-)

All nutrients (NO_2^-, NO_3^-, and PO_4^{-3}) showed significantly significant seasonal variations at all the three stations with $P < 0.001$.

The nitrite level at YLC were almost same as that of YLA and YLB with maximum 0.38 ± 0.01 mg/L in monsoon that declined to 0.23 ± 0.03 mg/L in post-monsoon and further declined to 0.1 ± 0.005 mg/L in winter which was maintained to 0.175 ± 0.015 mg/L in summer (Table 3.4, Fig.3.15).

16. Nitrate (NO_3^-)

The nitrate content at YLC showed same trend as that of YLA and YLB with maximum nitrate levels in monsoon 0.16 ± 0.013 mg/L, declining to 0.12 ± 0.01 mg/L in post-monsoon and 0.09 ± 0.006 mg/L in winter and minimum 0.046 ± 0.005 mg/L in summer (Table 3.4, Fig.3.16). Though seasonal variations at YLC were similar to station YLA and YLB, the nitrate at YLC was lower than the other two stations in summer but higher during other three seasons.

17. Phosphate (PO_4^{-3})

Phosphate showed parallel variations at the three stations with the maximum phosphate concentrations recorded in monsoon (0.19 ± 0.004 mg/L), that declined non-significantly in post monsoon to 0.12 ± 0.009 mg/L (YLC) to minimum 0.086 ± 0.003 mg/L in winter and increased to 0.156 ± 0.004 mg/L. in summer (Table 3.4, Fig.3.17).

For the convenience of discussion the positive and negative correlations among various physicochemical parameters at all the three stations are considered in common and that too only at the level of 0.01 (**). These are as follows: Acidity was positively correlated with AT, Cl^-, CO_2, pH, PO_4^{-3} TDS, TS, WT and negatively with DO and WC. Alkalinity is positively correlated with AT, Cl^-, CO_2, pH, TDS, TS and WT and negatively with DO and WC; atmospheric temperature is positively correlated with Cl^-, CO_2, pH, NO_2^-, PO_4^{-3}, TS, WT and negatively with DO, Transparency and WC. Chlorides are positively correlated with CO_2, pH, PO_4^{-3}, TDS, TS, WT and negatively with only WC. Carbon dioxide was positively correlated to NO_2^-, pH, PO_4^{-3}, TDS, TS, WT and negatively with DO, Transparency and WC. Dissolved oxygen is only negatively correlated with pH and WT. Nitrate was positively correlated with NO_3^-, PO_4^{-3}, TS, TSS and negatively with only transparency. Nitrite was positively correlated only with TSS and negatively with TH and transparency. pH was positively correlated with PO_4^{-3}, TDS, TS, WT and negatively with WC. Phosphates were positively correlated with TDS, TS and WT and negatively with transperacy only. TDS was positively correlated with TS and WT while TH was positively correlated with Transparency and negatively with TSS. Transparency was only negatively correlated with TSS and TS, and lastly TS was positively correlated with TSS and WT and negatively with WC; and Water cover was negatively correlated with water temperature. Other parameters were variously correlated at various levels at the three stations. Details are given in Annexture 5a, 5b and 5c.

In the present study the water cover was positively significantly correlated with dissolved oxygen and NO_3^- only at YLB (Table 3.6), but dissolved oxygen and transparency are non significant at YLA and YLC (Table 3.5 and 3.7). While, the negative significant correlation was established with Acidity, Alkalinity, AT, Cl, CO_2, NO_2^-, pH, PO_4^{-3}, TDS, TS and WT.

Table: 3.4 Average seasonal variations in Nitrites (NO_2^-), Nitrates(NO_3^-), and Phosphates (PO_4^{-3}) (mg/L) at station YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

Sr. No.	Param -eters	Stations with F value	Winter	Summer	Monsoon	Post-monsoon
1	NO_2^- mg/L	YLA $F_{3,\,20}$ 41.08	0.08 ± 0.01	0.20 ± 0.019	0.35 ± 0.01	0.20 ± 0.022
		YLB $F_{3,\,20}$ 63.34	0.11 ± 0.01	0.18 ± 0.012	0.38 ± 0.013	0.22 ± 0.019
		YLC $F_{3,\,20}$ 37.29	0.1 ± 0.005	0.17 ± 0.015	0.38 ± 0.014	0.23 ± 0.033
2	NO_3^- mg /L	YLA $F_{3,\,20}$ 22.53	0.07 ± 0.004	0.06 ± 0.003	0.15 ± 0.012	0.11 ± 0.01
		YLB $F_{3,\,20}$ 16.62	0.08 ± 0.004	0.05 ± 0.0049	0.14 ± 0.015	0.11 ± 0.006
		YLC $F_{3,\,20}$ 30.54	0.09 ± 0.006	0.04 ± 0.005	0.16 ± 0.013	0.12 ± 0.01
3	PO_4^{-3} mg /L	YLA $F_{3,\,20}$ 56.84	0.08 ± 0.004	0.16 ± 0.0068	0.19 ± 0.004	0.13 ± 0.007
		YLB $F_{3,\,20}$ 53.09	0.07 ± 0.004	0.14 ± 0.0076	0.19 ± 0.004	0.13 ± 0.009
		YLC $F_{3,\,20}$ 62.90	0.08 ± 0.003	0.15 ± 0.004	0.19 ± 0.004	0.12 ± 0.009

Figure: 3.15 Average seasonal variations of Nitrite (NO_2^-) mg/L at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

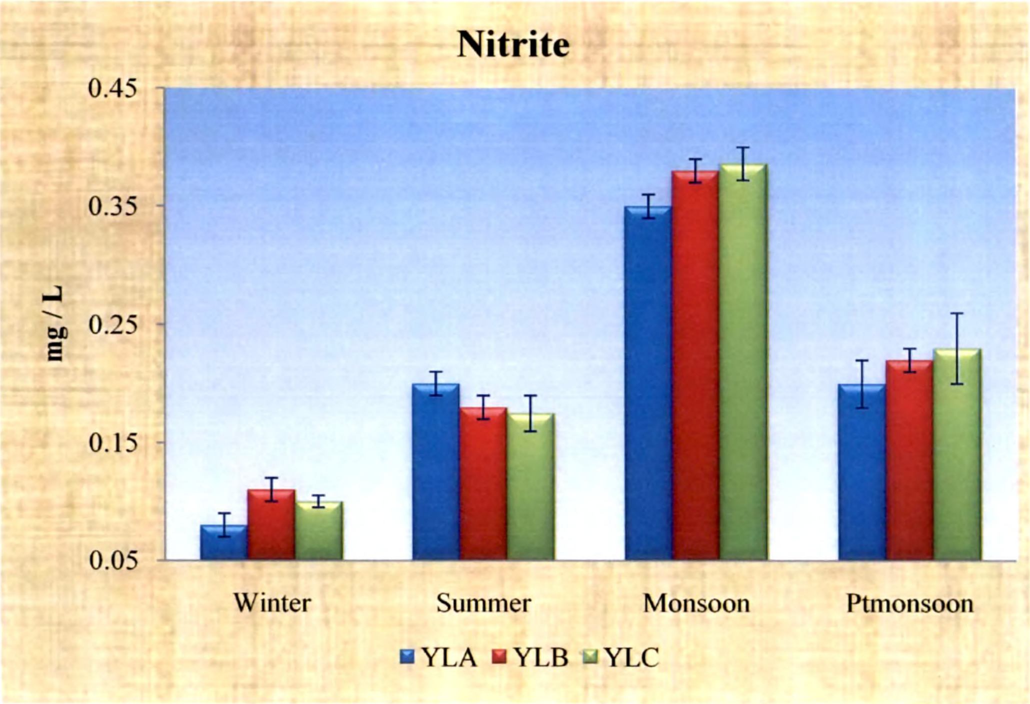


Figure: 3.16 Average seasonal variations of Nitrate (NO_3^-) mg/L at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

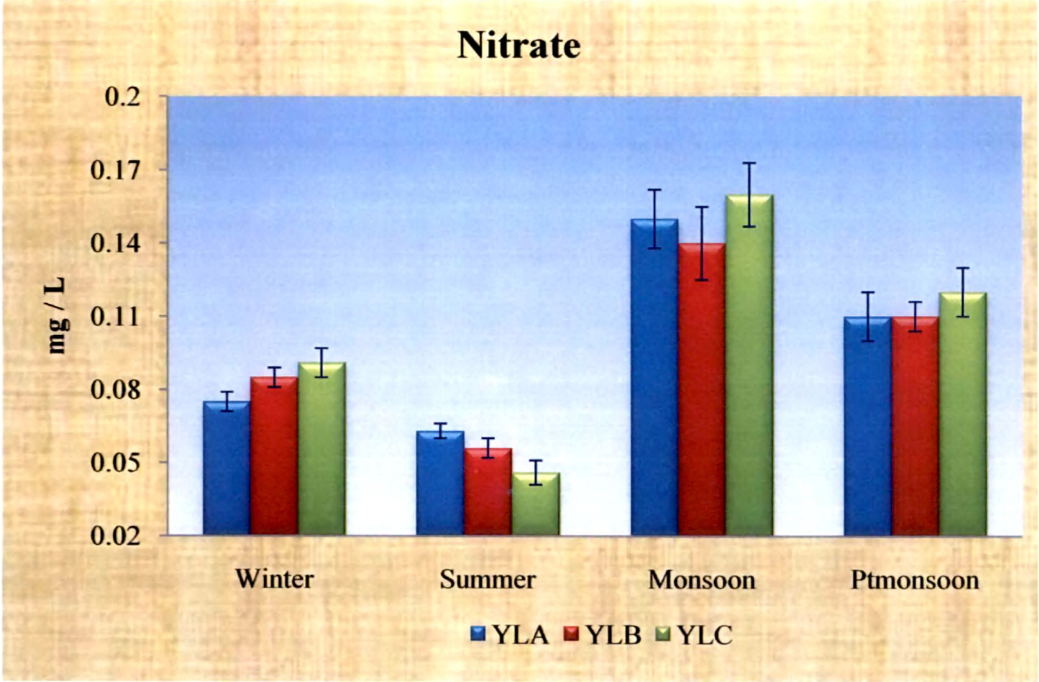


Figure: 3.17 Average seasonal variations of Phosphate (PO_4^{-3}) mg/L at three stations YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

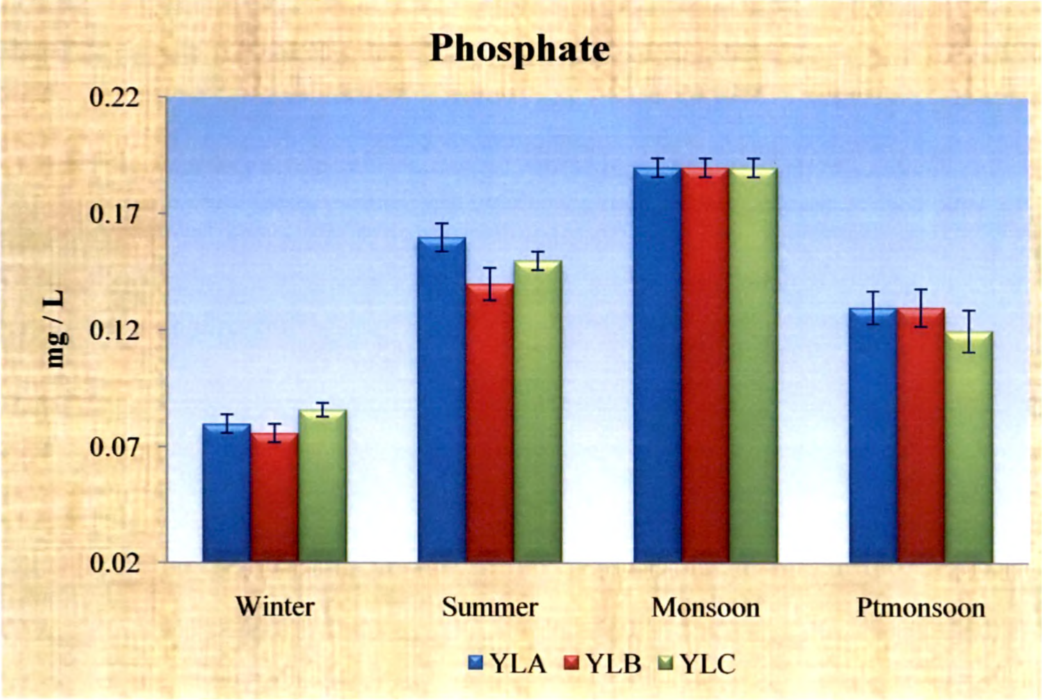


Table 3.5 Intra Pearson Correlation between physico-chemical parameters of YLA at Yashwant Lake during Dec. 2006 to Nov. 2008

	ACI	ALK	AT	Cl	CO_2	DO	NO_2^-	NO_3^-	pH	PO_4^{-3}	TDS	TH	TRANS	TS	TSS	WC	WT
ACI	1																
ALK	.942**	1															
AT	.813**	.707**	1														
Cl	.955**	.864**	.772**	1													
CO_2	.806**	.724**	.965**	.757**	1												
DO	-.574**	-.487*	-.844**	-.556**	-.871**	1											
NO_2^-	.547**	.417*	.670**	.443*	.672**	-0.347	1										
NO_3^-	-0.063	-0.146	0.124	-0.183	0.106	0.14	.749**	1									
pH	.883**	.770**	.897**	.886**	.885**	-.788**	.534**	-0.073	1								
PO_4^{-3}	.682**	.571**	.811**	.581**	.790**	-.488*	.942**	.597**	.701**	1							
TDS	.952**	.854**	.809**	.964**	.771**	-.546**	.570**	-0.013	.873**	.678**	1						
TH	0.304	0.323	0.177	.412*	0.194	-.453*	-.515*	-.885**	.411*	-0.315	0.254	1					
TRANS	-0.379	-0.34	-.620**	-0.228	-.641**	0.388	-.898**	-.750**	-0.386	-.853**	-0.372	.545**	1				
TS	.754**	.602**	.804**	.712**	.765**	-.475*	.910**	.515*	.738**	.919**	.828**	-0.238	-.743**	1			
TSS	0.029	-0.106	0.315	-0.061	0.298	-0.091	.832**	.932**	0.11	.700**	0.095	-.772**	-.808**	.637**	1		
WC	-.882**	-.767**	-.770**	-.848**	-.754**	.495*	-.687**	-0.167	-.815**	-.753**	-.907**	-0.068	.483*	-.857**	-0.273	1	
WT	.810**	.686**	.880**	.849**	.841**	-.764**	.479*	-0.113	.908**	.620**	.849**	0.377	-0.338	.712**	0.095	-.802**	1

** Correlation is significant at the 0.01 level 2-tailed

* Correlation is significant at the 0.05 level 2-tailed

Table 3.6 Intra Pearson Correlation between physico-chemical parameters of YLB at Yashwant Lake during Dec. 2006 to Nov. 2008

	ACI	ALK	AT	Cl	CO_2	NO_2^-	NO_3^-	DO	pH	PO_4^{-3}	TDS	TH	TRNS	TS	TSS	WC	WT
ACI	1																
ALK	.908**	1															
AT	.839**	.741**	1														
Cl	.955**	.890**	.745**	1													
CO_2	.832**	.713**	.974**	.725**	1												
NO_2^-	.408*	0.316	.548**	0.315	.539**	1											
NO_3^-	-0.244	-0.264	-0.098	-0.292	-0.098	.726**	1										
DO	-.638**	-.553**	-.824**	-.512*	-.864**	-0.15	.410*	1									
pH	.916**	.810**	.903**	.876**	.914**	0.371	-0.294	-.788**	1								
PO_4^{-3}	.623**	.513*	.795**	.523**	.776**	.921**	.483*	-.425*	.639**	1							
TDS	.872**	.822**	.723**	.923**	.715**	0.367	-0.178	-.489*	.820**	.554**	1						
TH	0.24	0.217	0.078	0.321	0.091	-.732**	-.918**	-0.369	0.311	-.481*	0.242	1					
TRNS	-0.365	-0.298	-.642**	-0.196	-.653**	-.891**	-.601**	.405*	-.420*	-.883**	-0.254	.631**	1				
TS	.708**	.593**	.729**	.715**	.736**	.751**	0.293	-0.389	.714**	.841**	.844**	-0.213	-.626**	1			
TSS	0.182	0.037	.407*	0.131	.427*	.890**	.749**	-0.087	0.257	.818**	0.266	-.686**	-.806**	.742**	1		
WC	-.895**	-.836**	-.708**	-.933**	-.693**	-0.139	.491*	.573**	-.867**	-0.399	-.848**	-.461*	0.077	-.592**	-0.005	1	
WT	.768**	.629**	.881**	.752**	.836**	0.38	-0.207	-.707**	.848**	.663**	.714**	0.207	-0.383	.670**	0.31	-.735**	1

** Correlation is significant at the 0.01 level 2-tailed

* Correlation is significant at the 0.05 level 2-tailed

Table 3.7 Intra Pearson Correlation between physico-chemical parameters of YLC at Yashwant Lake during Dec. 2006 to Nov. 2008

	ACI	ALK	AT	Cl	CO_2	DO	NO_2^-	NO_3^-	pH	PO_4^{-3}	TDS	TH	TRANS	TS	TSS	WC	WT
ACI	1																
ALK	.944**	1															
AT	.848**	.779**	1														
Cl	.950**	.910**	.790**	1													
CO_2	.827**	.740**	.969**	.736**	1												
DO	-.630**	-.571**	-.769**	-.514*	-.849**	1											
NO_2^-	0.324	0.307	.525**	0.206	.527**	-0.16	1										
NO_3^-	-0.253	-0.27	-0.096	-0.36	-0.097	0.377	.738**	1									
pH	.919**	.869**	.915**	.883**	.908**	-.762**	0.332	-0.272	1								
PO_4^{-3}	.607**	.622**	.759**	.523**	.752**	-.469*	.726**	0.208	.667**	1							
TDS	.930**	.854**	.821**	.954**	.790**	-.516**	0.379	-0.155	.888**	.609**	1						
TH	0.377	0.347	0.181	.515**	0.182	-0.389	-.657**	-.926**	0.37	-0.22	0.36	1					
TRANS	-0.379	-0.346	-.658**	-0.211	-.669**	.413*	-.919**	-.602**	-.444*	-.729**	-0.363	.580**	1				
TS	.726**	.622**	.807**	.673**	.805**	-.428*	.781**	0.348	.747**	.755**	.835**	-0.151	-.745**	1			
TSS	0.004	-0.08	0.292	-0.124	0.333	-0.034	.880**	.852**	0.087	.502*	0.103	-.784**	-.833**	.633**	1		
WC	-.842**	-.809**	-.797**	-.830**	-.764**	.479*	-.587**	-0.06	-.821**	-.664**	-.884**	-0.124	.518**	-.838**	-0.274	1	
WT	.885**	.819**	.904**	.885**	.876**	-.652**	0.387	-0.201	.933**	.686**	.904**	0.339	-.438*	.788**	0.14	-.858**	1

** Correlation is significant at the 0.01 level 2-tailed

* Correlation is significant at the 0.05 level 2-tailed

DISCUSSION

1) Temperature:

Water temperature is one of the most important factors which controls the physiological behavior and distribution of aquatic organisms and has effect on natural environment. This is reflected by lower water temperature at YSL in monsoon due to cloudy weather and influx of rain water while in winter due to cold climatic conditions of higher altitude with shorter sunshine period. A pattern also observed by Zafar (1964); Munnawar (1970); Swarnalatha, (1994); Rajasegar (2003) and Singhai *et al.* (1990). A close correlation is evident between atmospheric and water temperature (Pearson correlation is significant at the 0.01 level Table 3.5, 3.6 and 3.7) with no significant differences in temperature at the three stations (YLA, YLB, YLC) of the Lake (Table 3.1, Fig.3.1 and 3.2). Temperature is also known to influence water chemistry-the parameters like Dissolved Oxygen, Solubility, pH, conductivity, *etc.* (Ramachandra and Solanki, 2007). In general water holds lesser oxygen as the temperature increases (Awasthi and Tiwari, 2004) hence an inverse relationship between the two, but a positive significant correlation with Alkalinity, Acidity, Atmospheric temperature, Chloride, CO_2, pH, Phosphate, TDS, TS and water cover is noted at 0.01 level in the present study.

With reference to thermal lag between AT and WT and annual variations in temperature, Jaychandra and Joseph (1988) recorded maximum difference of 2.7 °C between AT and WT at a tropical Vellayani Lake in Kerala while Kanan and Job (1980) have reported a difference of 5.5 °C, and Sreenivasan (1964) a difference of 6 °C in Bhavani Sagar reservoir. In the present study mean difference between AT and WT were between 2.56 °C to 1.42 °C respectively in summer and winter with Atmospheric temperature lower than Water Temperature in winter and *vise a versa* in summer. It is a well established fact that land heats up and cools down faster than water, the same effect is produced at YSL. Water temperature is an important factor which regulates the biogeochemical activities in the aquatic environment. All metabolic and physiological activities and life processes such as feeding, reproduction, movements and distribution of aquatic organisms are greatly influenced by water temperature.

2) Water Cover:

Large lakes are typically 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). However, ponds are the examples of a patchily distributed habitat whose biodiversity has to cope up with conditions and events such as the physico-chemical changes, resource availability, biotic interactions, *etc.* The potential of surrounding landscape also influences the conditions within a patch and effects the dispersal between patches (Andrew and Michael, 2009).

The high DO in the reservoirs compared to the tanks are related to slightly lower temperatures, more water level, larger surface area (water cover) and therefore, more dissolution of atmospheric oxygen (Hegde and Hudder, 1995). Hence, water cover was positively correlated to DO at YSL. At YSL water cover starts increasing in monsoon due to rain water and continues to rise slowly upto post-monsoon as water is brought to Lake via streams present in the forest surrounding the Lake (Table 3.1). It is minimum in summer due to the evaporation, percolation of water as well as due to the usage for domestic purpose by the people of Toranmal village. This creats an irregular shoreline that encompasses more littoral formations at the area of land and water interface. A high value of shoreline development index is believed to be indicative of productive nature of the water body (Sugunan, 2000).

3) Transparency:

The transparency of water reflects seasonal variations with maximum transparency in winter when water level has stabilized and (Table 3.2) minimum in monsoon when the rain water run off brings soil particles like silt and mud with other inorganic matter from catchment area making the water turbid. This is a common phenomenon noted for several waterbodies especially in Indian climatic condition. (Zafar, 1964; Kanungo and Naik, 1987; Singhai *et al.,* 1990; Kaur *et al.,*1995). The area around YSL receives around 1600 mm annual rainfall during South West monsoon (June to August). The heavy rains, deforestation, human activities, *etc.* are main causes of soil runoff that lowers transparency of water (Coker, 1954). This is reflected by high total solids in monsoon, obstructing light penetration in water. (The transparency and total solids are negatively significantly correlated at YLA, YLB and YLC) (Table 3.5, 3.6 and 3.7). The turbidity of this type is temporary as the particles settle down due to gravitation of their own weight. Low transparency affects the aquatic ecosystem influencing its productivity, as the rate of photosynthesis by submerged macrophytes decreases. Further, the excess amount of hardness in water also reduces the penetration of light (Welch, 1986; Shukla and Bais, 1990). The water of the YSL is soft (At YLA: Maximum 67.6 ± 1.4 mg $CaCO_3$/L and Minimum 51 ± 1.9 mg $CaCO_3$/L). Here, the transparency is positively correlated with total hardness at 0.05 levels, while it is negatively correlated with Atmospheric Temperature, CO_2, NO_2^-, NO_3^-, PO_4^{-3}, TS and TSS at 0.01 level.

Non-significant increase in transparency was observed from post-monsoon onwards as the silt started settling down increasing transparency to maximum level in winter. (Decrease in transparency during summer may be attributed to increase in hardness noted in present study.) Increased hardness during summer indicates increase in amount of dissolved solids that decreases light penetration leading to decrease in transparency.

Studies of Eggermont, *et al.*, (2007) using redundancy analysis (RDA) showed that the transparency is also affected due to different types of vegetation in catchment area. However, in the present study the Lake is surrounded by deciduous forest for which the correlation is still to be evaluated.

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

As discussed earlier higher concentration of TDS increases water turbidity which in turn decreases the light penetration in water. This affects the photosynthesis thereby suppressing the primary production in the form of algae and microphyte. Positive significant correlation is expected between TDS, TS and TSS as is noted at all the three stations YLA, YLB and YLC (Table 3.5, 3.6 and 3.7). However, the significantly negative correlations between TDS and DO at YLA and YLC and positively significant correlation with CO_2 at all the three stations indicate decline in photosynthetic activity due to lower light penetrance. The TDS is positively significantly correlated with Acidity, Alkalinity, AT, Cl^-, NO_2^-, NO_3^-, pH, PO_4^{-3} and WT at all the three stations except NO_2^- at YLB and YLC.

The highest TDS recorded in summer at all the three stations may be due to decaying vegetation (Table 3.2). The products of decaying vegetation at the surface when starts sinking may increase the TSS as well as TDS (Khan and Khan, 1985; Iqbal and Kataria, 1995). The wetlands acts as sinks for nutrient deposition hence, the high TDS values may also depend on the age of the Lake (Anitha *et al.*, 2005) as a result of gradual salt deposition, an observation not always applicable for monsoonal wetlands. However, at YSL all the values of TDS were within the permissible limits of 500 mg/L (BIS, 1991).

The higher TSS during monsoon reflects the addition of suspended solids from the runoff water, which starts settling down slowly in post-monsoon and results in minimum TSS during winter (Table 3.2). Increased level of suspended solids, result in increased turbidity and decreased photosynthesis, rise in water temperature and decreased dissolved oxygen (Sharma, *et al.*, 2008). The TSS at YSL of the three stations ranged between 20.8 ± 1.4 to 42.5 ± 2 mg/L which are within the permissible limits of WHO standards *i.e.* below 500 mg/L. Total solids being TSS + TDS correspond to changes in both these parameters too.

5) pH:

Natural waters are usually alkaline due to presence of high concentration of carbonates. However, considerable fluctuations in pH can be observed in natural waters during day, as well as over the month and the year, caused by exposure to air and biological activities. In present investigation pH varied between 7.3 ± 0.05 at YLC to 8.3 ± 0.1 at YLA (Table 3.3). The higher value of pH during summer may be due to increased photosynthetic activity by phytoplankton and macrophytes decreasing CO_2 levels that are known to lower the pH towards acidity. Higher the photosynthesis more O_2 production and more CO_2 utilization, increasing the pH (Satpathy *et al.,* 2007). According to Boyd and Pillai (1984) photosynthetic activity leads to following reaction,

$$2HCO_3 \rightarrow CO_2 + CO_3^{2-} + H_2O$$

As plants remove CO_2 from water for use in photosynthesis, carbonates accumulate and subsequently undergo hydrolysis as follows:

$$CO_3^{2-} + H_2O \rightarrow HCO_3^- + OH^-$$

With reference to accumulation of OH^- that causes the pH to rise, (Sarwar and Wazir, 1991), YSL can be categorized as 'slightly alkaline' due to the predominance of calcium, carbonates as well as bicarbonates, the ions that influence the pH of water (Pearsall, 1930 and Zafar, 1966).

Variation in pH may also be due to the human activities (addition of sewage and industrial effluent *etc.*) as well as natural processes such as ground water leaching of carbonate minerals (Skoulikidis *et al.,* 1998).

The pH of Lake water is positively correlated with hardness as is also reported by Rao, (1955); Zafar, (1964); David and Savita, (1995). The pH was observed to decline during winter and increase during summer as is evident from the observations. Studies on the pH under present investigation did not reveal much variation at different sampling stations and alkaline trend was maintained all throughout the year.

Further, in the present study the pH is also positively correlated with nitrite and phosphate (Table 3.5, 3.6 and 3.7). The pH is controlled by the chemical state of many nutrients including phosphate and nitrite (Goldmann and Horne, 1983) which regulates most of the biological processes and biochemical reactions (Verma *et al.*, 2006).

The water which has a pH value of more than 9.6 or less than 4.5 becomes unsuitable for most living organisms and for other uses (Dwivedi and Sonar, 2004a). In the present study the pH levels were within the limits set for the protection of aquatic life *i.e.* 6.5 to 9 (U.S. EPA, 2002), irrigation 5.5 to 9 and for drinking water ISB standard 6.5 to 8.5. This indicates that the pH of the Yashwant Lake is well in the permissible limit for various uses.

6) Acidity:

As higher acidity causes corrosion and influences the chemical and biochemical reactions its determination is important. The threshold value of acidity is about 200 mg/L (Dwivedi and Sonar, 2004b). Higher acidity at irrigation reservoirs has been proposed due to initial acidic rains as well as agricultural runoff during monsoon (Deshkar, 2008). However, at Yashwant Lake acidity was minimum during post-monsoon at all the three stations as this is the period immediately after precipitation which leads to dilution. The maximum acidity recorded was 18.7 mg $CaCO_3$/L at YLA in summer much below the threshold value (Table 3.3, Fig. 3.9). Hence, the acidity in water of Yashwant Lake is very low. Here a positive significant correlation of acidity is established with Alkalinity, AT, Chloride, Carbon dioxide, pH, NO_2^-, PO_4^{-3}, TDS, TS, WT and negative correlation with DO and WC (Table 3.5, 3.6 and 3.7). The analysis of soil may provide better correlation of acidity with other components of water chemistry.

7) Alkalanity:

In the present study, alkalinity ranged from 120 ± 1.4 mg $CaCO_3$/L at YLA in summer to 85.4 ± 2.8 mg $CaCO_3$/L at YLC in post monsoon (Table 3.3, Fig. 3.10). Seasonal variations in alkalinity with higher values in summer and lower in post-monsoon indicate the concentration of salts in water as a result of evaporation and dilution respectively. As the area is surrounded by forest erosion from rocks is probably low as is also reported by Agrawal and Kanchan (2004) and Radhika *et al.*, (2004). Low values of alkalinity conform to the lower pH. There is no standard set for total alkalinity. Alkalinity and pH are the factors responsible for determining the amenability of water to biological treatment (Manivasakum, 1980). Spence (1964) suggested that a water body with alkalinity values above 60 mg/L is nutrient rich and is good for the production of fish-food organisms, while Sugunan (1989) observed that reservoirs having total alkalinity value between 40 – 90 mg/L were medium productive and above 90 mg/L were highly productive. Accordingly, the average total alkalinity of the Lake studied indicates its good productive nature.

(Further, positively significant correlations of alkalinity are established with AT, Cl^-, CO_2, acidity, pH, PO_4^{-3}, TDS, TS, WT and negative significant correlation with Dissolved Oxygen and water cover at all the three sampling stations.)

The alkalinity is also contributed from the soaps and detergents. Results of present study confirm this at YLA where because of domestic washing activities, maximum alkalinity is noted compared to YLB and YLC. Some amount of alkalinity is used by phytoplankton as carbon source (Ahmad and Singh, 1993 and Wani, 1998).

In the water with moderate to high alkalinity (good buffering capacity) and similar hardness levels, pH is neutral or slightly basic (7.0 to 8.3) and does not fluctuate widely. The pH of well buffered water normally fluctuates between 6.5 and 9.0. Thus, water of Yashwant Lake with pH varying between 7.3 ± 0.05 to 8.3 ± 0.10 is well buffered with low alkalinity. Due to CO_2 and carbonic acid from high respiration, pH can reach dangerously low levels or due to rapid photosynthesis dangerously high levels (Wurtz and Durborow, 1992). None of these occurs at YSL.

8) Dissolved Oxygen:

Dissolved oxygen is an important limnological parameter indicating level of water quality and organic production in the water. Survival of aquatic organisms especially fishes depend upon levels of Dissolved Oxygen in the water. During present study, the dissolved oxygen of surface water varied from 12.9 ± 0.4 mg/L to 9.7 ± 0.3 mg/L at YLC in winter and summer respectively (Table 3.3, Fig. 3.11). The maximum dissolved oxygen in winter may be due to higher solubility of oxygen at relatively lower temperature while higher level in monsoon (11.6 ± 0.3 mg/L at YLC) may be attributed to circulation and mixing of water and atmospheric oxygen due to agitation of surface water. Vise a versa, the lower values of dissolved oxygen during summer may be attributed to the fact that the warm water holds less oxygen as well as increases the mineralization of non living matter which demands more oxygen (Kumar *et al.*, 2005) decreasing oxygen levels. Tape and Mutlu (2005) have linked the increase in dissolved oxygen in a reservoir in turkey to high run-off occurring during rainy season.

In Yashwant Lake positive correlation of dissolved oxygen is noted with NO_3^-, Transparency and Water Cover with non significant level at 0.05 level while negative correlation is established with pH, PO_4^{-3}, TDS, WT, Acidity, Alkalinity, Atmospheric temperature, Chloride and CO_2 at all the three stations (Table 3.5, 3.6 and 3.7). The level of oxygen concentration in aquatic ecosystem is dependent on temperature, photosynthetic activity, respiration of biotic communities and organic loading.

Further, with increasing altitude, there is a decrease in atmospheric pressure, implying that oxygen saturation will be lower. However, compensation occurs, because decreasing temperature due to high altitude enhances the solubility of oxygen. Hence, the observed dissolved oxygen level 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 annual mean dissolved oxygen differed non-significantly. Similar trends are observed for a series of Indonesian Lakes situated from 10 to 2125 m altitudes (Green *et al.*, 1996).

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). Water with dissolved oxygen concentration below 2 mg/L is not able to support the life. Low oxygen concentration will also affect the types of fish and invertebrates that inhabit the area (Anonymous, 2005a). It is important to note that low oxygen conditions are common in many lakes during summer when winds that promote mixing are absent and water at the bottom of the lake is slowly depleted of oxygen over the course of the summer (Anonymous, 2005b). Mixing of the water column, as full turnover occurs, typically restores oxygen throughout the Lake to healthy levels. Oxygen in the water is vital for the respiration of the organisms living at the bottom as well as near the surface. When the consumed oxygen is not replaced by new oxygen, insufficiency of oxygen caused is dangerous in terms of the survival of the living beings.

The highest dissolved oxygen recorded at YLC was a good pointer to the fact that the station is most productive with the high water quality parameters and will support diverse organisms.

9) Carbon-Dioxide:

Phytoplankton use CO_2 in photosynthesis, the pH of pond water increases as carbonic acid (*i.e.* CO_2) is removed. Phytoplankton and other plants can also combine with bicarbonates (HCO_3) to form CO_2 for photosynthesis and carbonates (CO_3^{-2}) are released.

$2HCO_3 + \text{(Phytoplankton)} \rightleftharpoons CO_2\text{(photosynthesis)} + CO_3^{-2} + H_2O$

$CO_3^{-2} + H_2O \rightleftharpoons HCO_3^- + OH^-\text{(Strong base)}$

High pH could also be viewed as a decrease in hydrogen ions (H^+).

$CO_3^{-2} + H^+ \rightleftharpoons HCO_3^-$ or

$HCO_3^- + H^+ \rightleftharpoons H_2O + CO_2$

(As expected inverse relationship between carbon dioxide and dissolved oxygen was noted in waters of Yashwant Lake (Table 3.5, 3.6 and 3.7).) When carbon dioxide content increases, oxygen content decreases (Mathew, 1978; Mahopatra, 1987; Shivkumar and Kuruppasomy, 2008). Carbondioxide, pH, alkalinity and temperature are directly related to each other since the pH depends upon the free carbon dioxide and bicarbonate-carbonate levels (Mathew, 1975; Michael, 1984). Kudari *et al.,* (2006) have correlated high pH of Hanamapur and Gudgur water bodies to the presence of algal blooms, which use free CO_2 for photosynthesis and increase the pH of the water body as is also suggested by Wurts and Durborow (1992). Organic decomposition, respiration, photosynthesis, diffusion and run-offs could also account for the variations seen in the CO_2 levels. Higher CO_2 in the dry season agrees with Renn's (1968) observation that CO_2 is released at high levels during low oxygen production.

Carbondioxide rarely cause direct toxicity to fish. However, its high concentrations with lower pond pH can limit the capacity of fish blood to carry O_2 by lowering blood pH at the gills. Hence, at a given DO concentration (e.g. 2 mg/L) fish may suffocate when CO_2 levels are high and appear unaffected when CO_2 is low (Wurts and Durborow, 1992). The mean range of CO_2 in YSL is within tolerable limit for fish production since it did not exceed the limit proposed by APHA, (1985) 10 mg/L.

10) Total Hardness (TH):

As per the guidelines for drinking water quality, there is evidence that death rates due to cardiovascular diseases are inversely correlated with the hardness of water, but there is insufficient proof for direct involvement of either calcium or magnesium. No recommendation on the restriction of municipal water softening or on the maintenance of minimum residual calcium or magnesium level is therefore warranted at present. In addition, there is no firm evidence for human beings that drinking water causes any adverse effects on health. The desirable limit of hardness in drinking water according to BIS standards is 300 mg/L.

According to Durfor *et al.*, (1964) 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. Considering this the water of Yashwant Lake having hardness between 49.3 mg $CaCO_3$/L. to 67.6 mg $CaCO_3$/L. changes from soft to moderately hard seasonally (Table 3.3, Fig. 3.13).

Total hardness is highest during summer at all the three stations, when water cover decreases (the water cover is inversely correlated with total hardness as discussed earlier) due to evaporation of water and concentration of calcium and magnesium salts (Bagde and Verma, 1985; Moundiotiya *et al.,* 2004; Lentz – Ciplani and Dunson, 2006). Further, Kaur *et al.,* (1996) have reported that high values of hardness results due to the regular addition of large quantities of sewage and detergents in the water body from the nearby residential localities. According to Spence (1964), waters with more than 60 ppm which may be equivalent to 60 mg $CaCO_3$/L hardness are classified as 'nutrient rich' waters. According to this classification the Yashwant Lake can be categorized as 'nutrient rich'.

Further, Khan *et al.,* (1986), Jindal and Kumar, (1993), Jhajhria, (2003) who studied the hardness of reservoirs in different parts of India showed that the hardness varies from reservoir to reservoir due to their geological setting. According to Khan *et al.* (1986) limestone and other calcareous rocks underlying the water course in the Deccan plateau are predominantly responsible for the hard water characteristic of many of the reservoirs of Bhopal. However, in Madhya Pradesh, the water is reported to be soft to medium soft with less mineral salts due to geo-chemical reasons *eg.* Mansarovar (Kulshreshtha *et al.,* 1992), Loni (Gupta, 1976), Bergi, Tawa, Barna, Sarni, Sukta, Sampna, Halali, Kolar Dahod (Unni, 1993), Undasa (Singh, 1986) and Nagar water bodies (Sharma and Diwan, 1989). Madhya Pradesh is big state hence, reserviors in different regions may show different hardness depending on geo-chemical reactions in the area.

The total hardness is significantly positively correlated with the Chloride (Table 3.5, 3.6 and 3.7). Chloride occurs mainly in the form of sodium chloride. The ecological significance of major cations or hardness of calcium and magnesium in the biotic dynamics of aquatic flora and fauna is a well established fact. 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.

11) Chloride:

The ecological significance of chloride lies in its potential to regulate salinity of water and exert consequent osmotic stress on biotic communities. Thrash *et al.* (1949) pointed out that high chloride concentrations are indicator of large amount of organic matter in the water and is suggestive of eutrophication. The maximum concentration of chlorides recorded in summer at all the three stations with 29.5 ± 1.4 mg/L at YLA, (Table 3.3, Fig. 3.14), can be attributed to the rise in temperature and evapotranspiration, low water level and water cover as is reported by Gonzalves and Joshi, (1946); Prasad *et al.* (1985); Moundiotiya *et al.* (2004); Kumar *et al.* (2006). In addition, numerous studies have confirmed that ground water inputs tend to increase the concentrations of chlorides (Allen *et al.*, 1999; Cengiz Koc, 2008). The draining of domestic organic waste of animal origin and industrial wastes without treatment and the agricultural fertilizers and pesticides used in agricultural land surrounding the lake also contribute to increase in chloride concentration. This is reflected by the second maxima of chloride concentration at YSL recorded in monsoon. The nearby human population and grazing animals might also be responsible for the higher load of organic matter entering in the lake during rainy season leading to rise in chloride content. The seasonal variations may be accounted for the additions from precipitations and evaporation and human activities (especially by washerman). The contribution of rains in increasing the chloride content in water has also been reported by Hutchinson (1957), Sehgal (1980) and Purohit and Saxena (1990). Further, the chloride values at YLA are nonsignificantly high (29.5 mg/L) as compared to YLB (27.8 mg/L) that reflects the anthropogenic activities such as washing, bathing, *etc.* at YLA. The present findings confirms the findings of Zafar (1964), Munawar (1970) and Singhai *et al.* (1990).)

In the present study chloride is negatively significantly correlated with water cover and DO at all the three stations whereas positively significantly correlated with CO_2, pH, PO_4^{-3}, TDS, TS, WT, AT, Acidity and Alkalinity at all the three stations (Table 3.5, 3.6 and 3.7).

Munawar (1970) has reported a direct correlation between chloride concentration and pollution level in freshwater ponds of Hyderabad. In present study the chloride values are comparatively low, ranging between 14 mg/L to 29.5 mg/L. It is far less than permissible limit of BIS (Bureau of Indian Standard) which is 250 mg/L indicating that system at YSL is able to recycle the sewage and organic matter load at present but in future if the load is increasing it may pollute the area.

12) Nitrite (NO_2^-):

Nitrites in water are either due to oxidation of ammonium compound or due to reduction of NO_3^- as an intermediate stage in nitrogen cycle. Nitrogen, a major constituent of proteins and nucleic acids occupies a predominant place in aquatic system. The highest nitrite concentrations found during monsoon at all the three stations could be because of release of nitrogen from sediments on the arrival of freshwater in monsoon (Table 3.4, Fig. 3.15). Whereas the minimum concentration noted during winter could be because of utilization of nitrogen by plants for growth during moderate winter of subtropical zone. According to Yang *et al.* (2001) absorption of nitrogen is maximum for the growth of plants thereby resulting into reduction of the total nitrite content in water. Though the photoperiod is short during winter, wetlands occurring in subtropical belt receive adequate sun light. Deshkar (2008) has also reported low NO_2^- in the wetlands of varied sizes in semiarid zone of Central Gujarat, India. (In present study, Nitrite is positively significantly correlated with AT, CO_2, pH, NO_3^-,

PO_4^{-3}, TS and TSS at all the three stations, while negatively significantly correlated with total hardness, water cover and transparency (Table 3.5, 3.6 and 3.7). The seasonal variations in nitrite are also influenced by nitrogen cycle which is active due to presence of microorganisms like nitrosomones and mesophilic bacteria (Subhamma and Sharma, 1992).

As said earlier, the presence of nitrites along with some toxic aromatic compounds are said to be imparting brown colour and offensive odour to water that becomes unfit for irrigation, fish and drinking by cattle and human beings. No such colour or odour were noted at YSL.

13) Nitrates (NO_3^-):

The major sources of nitrate in lakes and ponds are from catchment area by rainfall, sewage effluents, agro waste and suspended organic matter when algae and other suspended microorganisms die and settle down to the bottom. They carry their nitrogen and phosphorus with them during decomposition. The sediments form the largest pool of nitrogen in wetlands (Bowden, 1984; 1987) and from the sediments the nutrients leach out increasing the total concentration of nutrients of the wetland. As the nitrogen is released it becomes available for subsequent growth of aquatic biota (Singh and Mahajan, 1987). Nitrate (NO_3^-) is also formed from of agricultural fertilizers and mixing of human and animal wastes to the lake too (Harikrishnan and Azis, 1989; Murugavel and Pandian, 2000; Parashar *et al.*, 2006; Cengiz Koc, 2008; Sharma *et al.*, 2008). Since high amount of nitrate encourages the growth of plankton and aquatic plants, nitrate increases the productivity of water body that may be in the form of fish. Presence of nitrate in water indicates final stage of mineralization (Neema *et al.*, 1984).

(In the present study maximum nitrates recorded in monsoon followed by post monsoon (Table 3.4, Fig. 3.16) are in compliance to rainfall. This comes as drainage from catchment area that may contain organic matter, animal waste and agro waste.)

Positive significant correlation of nitrates have been established with phosphates, total suspended solids and nitrite at all the three stations and total solids at YLA and YLB, Oxygen and water cover at YLB, while negative significant correlation is established for total hardness and transparency at all the three stations (Table 3.5, 3.6 and 3.7).

Minimum nitrate level noted in summer may be attributed to the summer algal bloom and growth of aquatic plants which utilize the nitrate for their growth (Kannan, 1978). Nitrate nitrogen is one of the most important indicators of pollution of water. Nitrate represents the highest oxidized form of nitrogen. The WHO standard drinking water quality guidelines for nitrate is 45 mg/L. Thus, nitrate levels of Yashwant lake are within permissible limits.

14) Phosphate (PO_4^{-3}):

Phosphates are chiefly derived from decomposing organic matter, leaching of phosphorus rich bedrock and additionally from anthropogenic wastes (Girija *et al.,* 2007). Phosphate concentration in clean water ranges from 0.01 to 0.1 mg/L. Phosphorus present in the soil particles is reabsorbed in water (Khan and Ansari, 2005), thus the maximum phosphates at YSL during monsoon at all the stations studied may be correlated to the soil erosion when new water arrives. Harikrishnan and Azis (1989) and Murugavel and Pandian (2000) also recorded highest phosphate in Neyyar and Kodayar reservoir respectively in monsoon. Apparently rainwater contributes phosphorus to lake (Job and Kannan, 1980; Sahib and Azis, 1989; Wen, 1992).

The minimum phosphate during winter may be correlated to its locking by macrophytes and phytoplankton during their bloom decreasing their level in water (Kant and Raina, 1990) which is expected during post monsoon too.

In the present study phosphate is positively significantly correlated with acidity, alkalinity, AT, Cl^-, CO_2, NO_2^-, NO_3^-, pH, TDS, TS, TSS and WT while it is negatively significantly correlated with DO and Transparency at all the three stations (Table 3.5, 3.6 and 3.7). Negative correlation is also established with total hardness at YLB and water cover at YLA and YLC. The phosphate values crossed the permissible limit (0.1 mg/L), as is given by U.S. Public Health Standards (De, 2002) in the present study. These can be related to the geology of the region. The study area is located at higher altitude and the lithology at higher altitudes is often dominated by basaltic rocks, with associated fertile soil (Tadesse *et al.,* 2008).

The introduction of large quantities of nutrients, mainly nitrogen and phosphorus to Lake waters can cause eutrophication problems (Kouimtzis *et al.,* 1994; Fytianos *et al.,* 2002; Michelutti *et al.,* 2002). This can lead to low light penetration, reduction in oxygen concentration, clogging of water channels, lower the entertainment value as well as fish mortality (Tamot and Sharma, 2006). Normally phosphate acts as a limiting nutrient in the process of eutrophication and a lake can be aesthetically classified into good, fair, bad, very bad and awful status on the basis of percentage phosphate loading (Edmondson, 1960). On the basis of present study with reference to all the physico-chemical parameters evaluated over the two year study period across four seasons, the status of Yashwant Lake may be classified as "fair".