DISCUSSION

Temperature is the most important physical parameter that affects other physical properties of water, such as, density, viscosity, solubility of gases and dissolved solids. The degree and annual variation in temperature of a water body have a great bearing upon its productivity in general. All organisms, including fish, possess well defined limits of temperature tolerance with the optimum lying somewhere between. All metabolic and physiological activities, as well as life processes such as feeding, reproduction, movement and distribution of aquatic organisms, are greatly influenced by water temperature.

During the first and second year of study the lowest air temperature was recorded in the month of January at all the sites (Tables 1, 3, 5, 7, 9, 11 and 13). The air temperature was relatively low in Mirik due to its altitude. The air temperature showed positive and significant correlation with water temperature at all the sites (Tables 2, 4, 6, 8, 10, 12 and 14). Chakraborty *et al.* (1957), Kant and Anand (1978) and Rawat *et al.* (1995) also obtained strong positive and significant correlation between air and water temperatures. The air temperature showed significant difference among different sites at 5% significance level and it also had a significant difference among different seasons at 1% level of significance (Table 23).

Generally, the water temperature is influenced by air temperature and intensity of solar radiation. In the present study the lowest and highest water temperatures were recorded respectively in the winter and summer months (Table 15-21). The highest water temperature (25^0 C) recorded during the summer months might be due to higher air temperature and greater penetration of sunlight. The water temperature was low during winter and high during summer might be due to seasonal impacts at all the centers (Singh *et al.*, 1999b). The water temperature showed positive correlation with both biological oxygen demand (BOD) and chloride at all the sites and it is significant in case of BOD. It had a negative correlation with pH, total hardness and free CO_2 at all the sites and the correlation was significant in case of pH at all the sites (Tables 2, 4, 6, 10, 12 and 14) except Site 4 (Table 8). Welch (1952) and Munawar (1970) have observed that shallower the water body more quickly it reacts to the change in the temperature. The water temperature was significantly different among sites and seasons at 1% significance level (Table 24).

The hydrogen ion concentration (pH) is often considered as an index of water quality indicating potential productivity of water. The pH of Mirik Lake ranged from 6.3 to 8.1 (Tables 1, 3, 5, 7, 9, 11 and 13), the lowest value indicated marginally acidic nature of the lake. The acidic nature of Himalayan lakes has also been reported by Zutshi *et. al.* (1972) and Rawat *et.al.* (1993). The minimum and maximum lethal limits of water pH for fishes were set at 5.0 and 11.0 respectively, but normal fish growth was recorded between pH 6.5 to 8.0 (Swingle, 1967). The pH of Mirik Lake was always remained quite higher than the lethal limits but in case of Site 1 and Site 2, pH levels sometimes remained below the desirable limit which might be due to regular additions of slightly acidic (domestic and other) effluents from major and minor drains which joins to these sites. Similar results were reported in case of river Mayurakshi (Kumar, 1995). The pH values showed significant positive correlation with conductivity (Site 1, Site 2 and Site 4) (Tables 1, 3 and 7), dissolved oxygen (Site 1, Site 2, Site 6 and Site 7) (Tables 1, 3, 11 and 13), total alkalinity (all the sites) and total hardness (all the sites) (Tables 1, 3, 5, 7, 9, 11 and 13). It had a significant negative correlation with BOD (at Site 1, Site 2 and Site 5) (Tables 1, 3 and 9) and Chloride (at Site 3, Site 5 and Site 6) (Tables 5, 9 and 11). The pH variations among sites and seasons were significant at 1% significance level (Table 25). Rawat *et. al.* (1995) reported positive correlation of pH of water of Deoria Tal of Garwal Himalaya with total alkalinity and inverse correlation with water temperature.

Hutchinson *et al.* (1929) and Roy (1955) have shown that the higher pH is associated with the phytoplankton maxima. The minimum pH recorded in summer during first year may be due to low photosynthesis. Several workers have reported low pH during the low photosynthesis due to the formation of carbonic acid (Hannan and Yong, 1974; Cabecadas and Brogueira, 1987; Bais *et al.*, (1995). But Gautam (1990) reported highest pH in summer and lowest in rainy season. In the present study during the first year the maximum number of phytoplankton observed in monsoon and during the second year the maximum number of phytoplankton recorded in winter months (Table 38). The pH showed positive and significant correlation with phytoplankton at all the sampling sites. The pH values of Mirik Lake were always within the limits set for irrigation 5.5-9.0 and domestic use, 7.0-9.0 (ICMR, 1975) but not always within the limits set for protection of aquatic life, 6.5-9.0 (USEPA, 1975).

Conductivity is a measure of ability of a water sample to conduct an electric current proportional to the ionic strength of the water. This mostly depends upon the nature of various dissolved ionized substances, their relative concentrations and temperature.
During the first year of study, the highest conductivity (140.20μmhoscm^{-1})recorded in case of Site 2 in the month of May and lowest (54.81μmhoscm^{-1})was found from Site 3 in the month of August. During the second year of study, the conductivity values varied from 50.77 to 163.24μmhoscm^{-1}; the lowest being observed from Site 3 in the month of July and highest found from Site 2 in the month of April (Tables 5 and 3).

During both the year of study, the highest conductivities were recorded during summer followed by winter and lowest was recorded during monsoon (Table 15-21). This could be associated with the lower water volume in the lake during summer and winter coupled with the mixing of wastewater from a number of drains entering into the lake. During monsoon months the conductivity values were lower due to dilution as a result of rainfall. The conductivity showed highly significant positive correlation with total alkalinity and total hardness to all the sites. The conductivity varied significantly among sites and seasons at 1% significance level (Table 26). Imevbore (1978), Adebisi (1980) and Mishra (1999) stated the inverse relation of conductivity with water level which corroborates our findings. High positive correlation was observed between electrical conductivity, alkalinity and total hardness. Similar observations were also recorded by Mariappan and Vasudevan (2002). Highest specific conductivity during summer also reported by Bhawmik *et al.* (2003). Electrical conductivity which is the measure of ionic strength of water varies between 31.01 to 126.51 μmhoscm^{-1}. Conductivity was highest during summer presumably due to sewage input (Unni, 1996).

Dissolved oxygen is a measure of the amount of oxygen freely available in water. Dissolved oxygen (DO) is known to be a critical factor in natural waters (Hutchinson, 1975) indicating overall health of an ecosystem. During the first year of study the DO ranged between 4.20 to 10.00 mgL^{-1}. The highest being observed from Site 3 in the month of September and lowest from Site 4 in the month of February. During the second year of study, the minimum value of

DO was 4.6 mgL^{-1} found from Site 2 in the month of April while the maximum value (13.60 mgL^{-1}) recorded from Site 5 in the month of December (Tables 3 and 7).

The highest seasonal value of DO was recorded in the monsoon at all the sites (except Site 1 where it was highest in winter) during the first year of study while during second year study period the highest seasonal value of DO was found in winter at all the sites except Site 5 where it was highest in monsoon (Table 15-21). The minimum and maximum values for DO were 4.6 mgL^{-1} at Site 2 and 12.6 mgL^{-1} (September, 2007) at Site 4. The DO showed a positive correlation with pH and negative correlation with temperature and conductivity. The DO values of the lake showed significant difference among sites at 5% significance level and among seasons at 1% significance level (Table 27). The maximum DO found in winter may be due to low temperature. Similar observations were made by Moitra and Bhattacharya (1965). Hancock (1973) discussed about seasonal average and fluctuations in DO; he reported that it was maximum in winter and minimum in summer.

DO is the single most important gas for aquatic organisms; free O_2 or DO is needed for respiration. The decreased water temperature during winter season has a greater capacity to hold DO than warm water and probably led to a lower rate of respiration thereby allowing maximum DO in winter (Welch, 195). According to Swingle (1967), at DO between 1-5 mgL^{-1} the fish survive, but their reproduction are poor and growth are slow if the exposure continued and with DO less than 5 mgL^{-1} is not conducive for fish growth (Mondal and Barat, 2004). DO showed positive correlation with pH at all the sites, and was significant in case of Site 1, Site 2, Site 6 and Site 7 (Tables 2, 4, 12 and 14). It showed significant inverse correlation with free CO_2 and BOD at all the sites (Tables 2, 4, 6, 8, 10, 12 and 14). It had negative correlation with conductivity at all the sites and it was significant in case of Site 5, Site 6 and Site 7 (Table 10, 12 and 14). The DO showed significant difference among sites at 5% level and it had significant difference among seasons at 1% significance level (Table 27).

In the present study positive correlation between pH and DO was observed at all the sites and it was significant in case of Site 1, Site 2, Site 6 and Site 7 (Table 2, 4, 12 and 14). Similar observations were made by Atkins and Harris (1924), Verghese *et al.* (1992) and Shastri and observations were made by Atkins and Harris (1924), Verghese *et al.* (1992) and Shastri and Pendse (2001). Dissolved oxygen in water is essentital for aquatic life. Defficiency of dissolved oxygen gives bad odor to water due to anaerobic decomposition of organic wastes (Manivasakam, 1980).

During the first year of study the highest free CO_2 was recorded from Site 2 ($14 mgL^{-1}$) in the month of August. During the second year of study the free CO_2 varied from 3.80 mgL^{-1} to 16.0 mgL^{-1}. The highest value was observed in the month of March from Site 2 while the lowest was found from Site 7 in November (Tables 1 and 13). The seasonal value showed higher free CO_2 during winter at all the sites except Site 1 and Site 2 during the first year of study. The relatively lower CO_2 at Site 1 and Site 2 during winter might be associated with higher pH and DO values in these two sites (Tables 15 and 16). The highest free CO_2 values were observed from those sites where the pH values were relatively low (Tables 1, 3, 5, 7, 9, 11 and 13). The free CO_2 showed a significant negative correlation with DO at all the sites. The free CO_2 values varied significantly between the sites at 1% significance level and between seasons at 5% significance level.Rawat *et al.* (1993) also found negative correlation between free CO_2 and DO in case of Deoria Tal Lake.The highest free CO_2 found during winter at those sites where lowest DO values were recorded (Site 3, Site 4, Site 5, Site 6 and Site 7) and highest free CO_2 found at two sites (Site 1 and Site 2) during monsoon season when the DO and pH values were relatively low (Tables 1, 3, 5, 7, 9, 11 and 13).Higher concentration of free CO_2 during winter was also reported by Bhowmik *et al.* (2003).

The total alkalinity is a measure of acidic substance present in the water and cations balanced against them. Alkalinity plays an important role in aquatic production and is associated with free Co2 and pH. Alkalinity or acid combining capacity of water is generally caused by carbonate and bicarbonates of calcium and magnesium; calcium forms the major constituent. In the present study, only bicarbonate alkalinity was found in the water of the Mirik Lake, whereas carbonate alkalinity was absent. Bicarbonate is abundant in the water with a pH of 4.5-8.3 (Jhingran, 1991). The overall pH in the present study varied from 6.3 – 8.1 (Tables 1, 3, 5, 7, 9, 11 and 13). Hence, only bicarbonate alkalinity was obtained at all the sites. Alkalinity is a measure of the quantity of compounds that shifts the pH to the alkaline side of first year of study the highest alkalinity was recorded in the month of June (2006) from Site 7 (43.0 mgL^{-1}) and lowest 18.00 $mgL^{-1}$was observed during July (2006) from Site 1 (Tables 13 and 1). During the second year of study the highest alkalinity was found from Site 2 (60.00 mgL^{-1}) in the month of May (2007) (Table 3) and the lowest was observed as 20.00 mgL^{-1} from Site 1 (Table 1) in the month of July and September (2007) and in the Site 6 during September (2007) (Table 11). The total alkalinity found to be highest during summer followed by winter and the least values were recorded in monsoon season at all the sites during both the year of study (Table 15-21). Higher alkalinity in summer months may be due to lower water level. According to Bisop (1973) low alkalinity in the monsoon months were due to dilution effect. Similar observations were also reported by Dhanapakiam *et al.* (1999) and Shastri and Pendse (2001). High alkalinity during summer and sharp decline in monsoon was supported by Ray *et al.* (1966) Pehwa and Mehrotra (1966) and Srivastava and Kulshrestha (1990).

Adebisi (1980) showed inverse relationship between alkalinity and water level. Total alkalinity was significantly different among seasons (Table 29) and showed a significant positive correlation with total hardness (Tables 2, 4, 6, 8, 10, 12 and 14). Similar observations were reported by Barat and Jha (2002) and Thappa (2006). Total alkalinity showed a significant positive correlation with pH at all the sites (Tables 1, 3, 5, 7, 9, 11 and 13). Similar observation was found by Mondal and Barat (2004). The higher values of total alkalinity in summer may be due to low water level and presence of excess free CO_2 produced in the process of decomposition. Ruttener (1953), Munawar (1970) and Sunder (1988) observed the accumulation of bicarbonate in summer due to increased rate of decomposition. Hegde *et al.* (1985) also noticed the same phenomenon. The minimum values of bicarbonate alkalinity were observed during monsoon months may be due to the dilution effect and condition less favorable for the photosynthetic conversion to carbonates. Similar observations were also recorded by Rao (1971), Brajnandan *et al.* (1985) and Kumar (1995). They pointed out that the dilution plays a key role in lowering of the alkalinity. Adebisi (1980) also explained that the alkalinity is inversely proportional to the water level.

In principle, hardness is defined, as the total of soluble calcium and magnesium salts present in the water medium, which is expressed as its $CaCO_3$ equivalent. In most natural waters, usually HCO_3^- anions are associated with Ca_2^+, Mg_2^+, Na^+ and K^+ cations. Water contaminated with ocean salts or from dryland area containing sulphate and chloride ions are associated with Ca_2^+ and Mg_2^+ ions. Therefore, the total hardness of water includes sulphate and chloride besides carbonate and bicarbonate. Usually bicarbonates of Ca_2^+ and Mg_2^+ cause temporary hardness. Permanent hardness of water is due to soluble Ca_2^+ and Mg_2^+ carbonates and salts of inorganic acids ($CaSO_4$), (Rath, 1993). According to Swingle (1967), a total hardnessof 50 mgL^{-1} is the dividing line between soft and hard water. According to Kannan (1991) water with a hardness value 0-60 mgL^{-1} is considered as soft. In the present study, the hardness values varied from 8.00 mgL^{-1} - 30.00 mgL^{-1} during the first year of study while during the second year of study the highest hardness value was 38.0 mgL^{-1} and minimum was recorded as 9.00 mgL^{-1} (Tables 1, 3, 5, 7, 9, 11 and 13). For normal fish culture 20 mgL^{-1} hardness is needed (Boyd, 1982).

During the present study total hardness showed a peak during summer (Fig. 22, 32, 42, 52, 62,72 and 82). The peak during summer might be due to higher temperature and low water level in the lake as well as due to the addition of calcium and magnesium salts from detergents and soap used for bathing and cloth washing. Ajmal and Razi- Ud Din (1988) observed a higher hardness value in summer in the river Hindon and Kali Nadi. Munawar (1970), Moss (1973) and Patil (1982) and Bagde and Verma (1985). The lower values of total hardness during monsoon months might be due to dilution on account of rainfalls. The hardness of Mirik Lake showed a negative correlation with air and water temperature and a significant positive correlation with conductivity (Tables2, 4, 6, 8, 10, 12 and 14). The hardness varied significantly between sites at 5% and between seasons at 1% significance level (Table 30).

Chlorides are binary compounds of chlorine. A chloride is made of chlorine chemically combined with a metal. The presence of chloride, where it does not occur naturally, indicates possible water pollution. Maximum chloride content has been correlated with high degree of organic pollution and eutrophication (Goel *et al.* 1980). Contamination of water from domestic sewage can be monitored by chloride assays of the concerned water bodies. This is because human and animal excretions contain an average of 5 gmL^{-1} chloride (Paramasivam and Sreenivasan, 1981). The highest chloride was recorded as 31 mgL^{-1} from Site 4 during February and March (2006), while the lowest found from Site 1 in the month of July (2006) during the first year of study (Tables 1, 3, 5, 7, 9, 11 and 13). During the second year of study the highest chloride concentration was recorded from Site 2 (24.00 mgL^{-1}) in the month of October (2006). On the other hand the lowest chloride 10.00 mgL^{-1} was recorded from Site 2 during March (2007).

The maximum amount of chloride in winter and summer conferred by the influx of highly contaminated domestic sewage. Munawar (1970) suggested that higher concentration of chloride in water is an influx of pollution of animal origin and there is a direct correlation between chloride concentration and pollution level. Chloride concentration in water indicates the presence of organic wastes (Tresh *et al.*, 1949). The increase in chloride concentration in lake with the discharge of municipal and industrial waste was also reported by Ownbey and Key (1967). High levels of chlorides may be due to sewage dumping (Bhuvaneswaran *et.al.*, 1999). The chloride concentrations varied significantly among sites at 1% significance level (Table 31).

BOD is defined as the amount of oxygen required by microorganism to decompose biologically degradable organic matter in water under aerobic conditions. BOD is an essential parameter in water pollution measurement and in the evaluation of the self – putrificaction capacity of streams (Trivedy and Goel, 1986). It represents the biologically oxidisable organic loads present in water. The maximum BOD was recorded in summer than monsoon and winter (Table 15-21). The maximum BOD obtained in summer may be due to low volume of water and high content of organic matter and high temperature whereas minimum value of BOD obtained in winter may be due to low temperature which reduces the growth of microorganisms. Higher values of BOD were found in Site 1, Site 2 and Site 6. According to Hynes (1960) BOD values of 3.0 mgL^{-1} or more is of doubtful quality and that with more than 5.0 mgL^{-1} is bad. Accordingly the water of Mirik Lake is not satisfactory. Higher BOD values in Site 1 and Site 2 may be due to sewage contamination in these two sites. BOD values remain higher during monsoon due to inflow of sewage with runoff.

In the present study the highest seasonal values of BOD found in summer months except Site 1 where highest BOD observed during monsoon of the first year of study. It may be due to runoff during rainfall and sewage contamination at that site. BOD was lowest during winter in case of Site 1, Site 2 and Site 5 and the lowest value found during monsoon in case of Site 3, Site 4, Site 6 and Site 7. BOD test is found to be more sensitive test for organic pollution. According to the Royal Commission of Sewage Disposal water having BOD more than 5.0 mgL^{-1} is unsafe for domestic use (Her Majsty's Stationary Office, 1972). BOD showed a positive correlation with air and water temperature and free Co_2 and significant negative correlation with dissolved oxygen. BOD varied significantly among sites and seasons at 1% significance level (Table 32).

Plankton is the indicator of the trophic status of water bodies. The plankton production depends on various biotic and abiotic factors (Welch, 1952; Hutchinson, 1967; Wetzel, 1975). However, generalization of the community structure of plankton from the different lakes of the same as well as those of the different geographical areas is difficult (Pant *et al.*, 1985b). Further, a comparison between the species composition of the different lakes may not yield the correct information due to the differences in the methodology, number of samples and morphological features of the lake. However, species spectrum, richness, dominance, diversity and evenness of species give good information of the dynamic balance of a community (Pant *et al.*, 1985b). The Mirik Lake is dominated by Chlorophycean group, followed by Bacillariophyceae and least by Cyanophycean group. Similar pattern of phytoplankton was recorded in a sacred lake in Sikkim (Jain *et al.*, 2005).

In the first year, the maximum and minimum phytoplankton density were observed during summer and winter respectively might be related to water temperature and photoperiod. Ramkrishnaiah and Sarkar (1982) proposed the temperature as a vital factor responsible for the growth of algae. Wisharad and Mehrotra (1988) reported that higher proliferation of phytoplankton from winter to summer could be attributed to the progressively increasing water temperature and photoperiod. High density and diversity of phytoplankton were also observed during monsoon. It may be due to the high temperature (18.63-20.50^{0}C) during monsoon (Table 15-21).

Seasonal variations in the species diversity of phytoplankton in the Mirik Lake showed Cyanophyceae peak during summer, Chlorophyceae peak during monsoon, Bacillariophyceae peak during winter (Tables 43, 47, 51, 55, 34 and 39). Phillipose (1967) reported that the low acidity with pH range of 7.7 to 8.5 and bright sunshine were responsible for the development of Chlorococcales. Rao (1955) observed that higher concentration of oxidisable organic mater and longer period of sunshine appeared to be more responsible for the growth of blue green algae (Cyanophyceae) during summer. *Anacystis* sp., *Microcystis* sp., *Spirulina* sp., *Merismopedia* sp. are the dominant species among the Cyanophycean group.

In the second year the maximum number of phytoplankton was observed in summer. In winter the phytoplankton density was higher due to the presence of a large number of species of Bacillariophyceae group. Lund (1965) reported abundance of Bacillariophyceae population in colder months and opined that they grow under the condition of weak light and low temperature. Zafar (1967) also observed colder months to be more favourable for the multiplication of Bacillariophyceae in freshwater bodies. Similar observations have also been made by Venkateshwarlu (1969), Vass *et al.* (1977), Manikya (1984), Sarwar (1985), Sarwar *et al.* (1996), Gujarathi and Kanhere (1998) and Sedamkar and Angadi (2003). Rao (1955) and Sarwar and Zutshi (1988) reported that the cold water was more suitable for the growth of the diatoms.

Palmer (1969) listed 60 most pollution tolerant algal genera. A total of 33 genera of pollution tolerant algae were recorded in the present study from the various sampling sites of Mirik Lake (Table 60) According to Palmer (1969) an alga is called present when 50 or more individuals of it are present in one mL of water. For that reason only sixteen algal genera, eg., *Ankistrodesmus, Chlamydomonas, Chlorella, Closterium, Scenedesmus, Stigeoclonium, Cyclotella, Gomphonema, Melosira, Navicula, Synadra, Anacystis, Microcystis, Oscillatoria, Phormidium, and Euglena* were considered to prepare the pollution index. The numbers scored by each algal genera were totaled to get the value of algal genus index. A score of 20 or more for a sample was indication of organic pollution, a score of 15 to 19 was taken as probable evidence of high organic pollution and lower figures indicated that the organic pollution is not so high (Palmer, 1969).

During winter of the first year study period, the highest score was observed fourteen at Site 1 and Site 2 and the lowest score was recorded seven at Site 7. From the scores it can be concluded that during winter of the first year organic pollution was not so high. During summer of the first year study period, the highest score was observed nineteen at Site 1 and Site 6 followed by Site 2 (eighteen), Site 4 (sixteen) and Site 3 (fifteen) and the lowest score was recorded fourteen at Site 5 and Site 7. The total scores of all the seven sampling sites were shown in Fig. 86. In five sampling sites the total scores fall within the range of 15 to 19 which was taken as the probable evidence of high organic pollution.

During Monsoon higher scores were recorded eighteen from Site 1, Site 2 (sixteen) and Site 6 showed a score of fifteen. During winter of the second year of study the highest score was found fourteen at Site 1 and lowest was found three at Site 7. During summer the highest score was recorded nineteen at Site 1 and Site 3 and lowest was twelve from Site 5 and Site 7. During monsoon months the highest score was recorded from Site 1, Site 3, Site 4 and Site 6. The cause of pollution in case of Site 1 and Site 2 might be due to mixing of sewage coming from nearby hotels and households. The organic pollution at Site 6 was due to the inflow of wastes into the lake from Mirik bazaar area.

Zooplanktons play a significant role in determining the productivity of lake. Zooplanktons form food for many aquatic lives. Zooplanktons are good source of food for fishes which in turn are good sources of food for water birds. Presence or absences of a certain species of zooplankton in a water body are not only indicative of trophic status of water body but also acts as agent of energy transfer from one trophic level to other trophic level and provides information about the various linkages in the food chains and food web.

26 species of zooplankton representing 3 groups namely Rotifera, Cladocera and Copepoda were reported, out of which 17 species belongs to Rotifera, 6 Cladocera and 3 Copepoda group. During the first year of study the highest zooplankton diversity was observed during summer and monsoon. High quantities of organic matter favoured the summer peak of zooplankton in Indian freshwater lakes, namely, Sagar and Military engineering lakes at Sagar (Bais and Agarwal, 1995). Nair and Tranter (1971) found zooplankton peaks in winter and monsoon seasons.

During the first year of study, the rotifer population density and diversity was highest in summer followed by monsoon and winter. Higher population density and diversity of rotifer in summer was also reported by Jeelani *et al.* (2005) in case of Anchor Lake of Kashmir. The environmental parameters mainly the water temperature, exert significant impact on the relative abundance of rotifers (Jyoti and Sehgal, 1979). Rotifera forms the largest group among total zooplankton population. This group depicted higher qualitative diversity than other groups and it showed a number of peaks. The irregular periodicity in the abundance of rotifer population has already been indicated by several authors (Pennak, 1955; Krishnamoorty and Visweswara, 1966; Vasisht and Sharma, 1976; Mukhopadhyay *et al.*, 1981; Datta *et al.*, 1984). It may be mentioned that according to Reid and Wood (1976) rotifers never follow any predictable population pattern in fresh water impoundment. According to Singh (2000) rotifers have versatile capacity to survive in different environments; generally they are abundant in summer months indicating direct relationship with high temperature. Similar observations were found in the present study also. Rotifera and Cladocera were the most important components of the zooplankton community. The peak abundance of rotifers during warm (summer) season can be attributed to low population of diatoms in this period as reported by Jain *et al.* (2005). Zooplankton showed higher presence in summer season. Rotifers were largest contributor to total population in terms of number. Similar results were reported by Jain *et al.* (2004). Deshmukh (2001) reported 28 species of rotifera from Chhatri Lake of Amaravati with maxima in summer, and this observation corroborates with the present investigation. Devi (1997) also observed the maxima of rotifera in Ibrahimbagh during premonsoon and in Shathamraj reservoir of Hyderabad during monsoon period. Sharma and Diwan (1993) reported that the rotifers from Yeshwant sagar reservoir showed dominance during summer months. Similar results were also reported by George (1966). However, Ganapati (1943), Sakhare and Joshi (2006) recorded the dominance of Copepods and Le Fevre (1993) recorded the dominance of Cladocerans over other zooplanktons.

Cladocerans are important components of food web and an integral link in aquatic food chain in freshwaters (Battish and Kumari, 1986). Cladocera constitute an important group. The greater significance of Cladocera in the aquatic food chain as food for both young and adult fish was established much earlier (Pennak, 1978). Cladocerans constituted the second largest group of zooplankton in Mirik Lake. Cladocerans were found in higher number during winter and monsoon than summer. During summer the low density could be due to more dense growth of rotifers thus avoiding competition. This observation is a concurrence with the work of Sunkad (2005). *Daphnia* sp. among the cladocerans found to be more abundant during winter season since temperature adversely affected its presence (Pant *et al*, 1985b). Bell and Ward (1970) found that *Daphnia* sp. moved to cooler region of the lake when the temperature rose above 20^0C. Cladoceran species like *Daphnia* sp. and *Bosmina* sp. were recorded from the lake which are true representatives of shallow eutrophic habitat (Siraj *et al.*, 2007).

Free living Copepods are an essential link in food chain occupying the intermediate trophic level between bacteria, algae and protozoa on one hand and small and large plankton predators on the other. Though they are not as important as Cladocerans in the diet of fish, they are well known as important intermediate host for helminth parasites. During present investigation Copepods were represented by *Cyclops* sp., *Phyllodiaptomus* sp. and *Mesocyclops* sp. Copepoda constituted the third largest group of zooplankton. This group was recorded throughout the study period and found mostly in winter season which corrobotates the observation of Sunkad (2005). During the present investigation two species viz. *Brachionus bidentata, Mesocyclops* sp. were identified which were suggested as pollution indicator species by several workers (Pennak, 1968; Patalas, 1972; Pandit, 1980 and Sharma *et al.*, 2007a).

The herbivores comprised of all the zooplantonic groups except *Asplancha* sp.of rotifers group and *Cyclops* sp. and *Mesocyclops* sp. of Copepods and *Daphnia* sp. among Cladocerans in particular showed dominance during winter season where *Keratella* sp. showed affinity for filamentous or elongated cells. It appeared quite possible that producers were fed upon by *Keratella* and *Daphnia* species which in turn fed upon by *Asplancha* species.

It is evident that the Mirik Lake supports luxuriant growth of both phytoplankton and zooplankton depicting its high aquatic biodiversity. The lake is presently dominated by Chlorophyceae and Bacillariophyceae groups, however, the eutrophic indicator species, such as *Cryptomonas* sp., *Spirogyra* sp., *Anabaena* sp., *Oscillatoria* sp. and *Nostoc* sp. (Table 60) also invaded. The interaction of algae, herbivores and the predators with favoured climatic conditions has kept the lake within the resilience capacity however its longevity depends solely on the management of the surrounding watershed.

To assess the quality of water in terms of pathogenic and parasite organisms indicating a health risk for the human population, the use of an indicator system is considered to be indispensable, due to the vast variety of these organisms. The coliform bacteria, especially the thermo-tolerant types are considered to be a convenient indicator for the exposure of a water body to the faeces of warm blooded organisms, including man. Since human water- borne diseases are mainly transferred by exposure to fecal matter, the health risk can be associated by measuring the presence of these bacteria (De Zwart and Trivedy, 1994).

The occurrence of coliform group, total coliform, and fecal coliform has been used as principal ecological indicators of water pollution (Carpentor *et al.*; 1966, Holden, 1970; Rodrigue *et al.*, 1977; APHA, 2005). Generally the water samples showed a highest bacterial density during the rainy seasons as the bacteria are mainly derived from the soil and sewage that gain access to the lake through rain water or storm water. Coliform organisms, while relatively harmless themselves, are most invariably present in waters, they live longer than the disease producing organisms. Consequently, these organisms have been considered to be the prime indicators of water quality and potential health hazards (Millipore, 1986). For many years, the fecal coliform Eschericia coli have been used as an indicator of human enteric pathogens (Goldreich, 1966). However, it is now well established that *E. coli* is not limited to humans but also exists in the intestines of many other warm blooded animals (Orskov and Orskov, 1981).

During the first year of study the highest MPN value of fecal coliform was found from Site 2 (17000/100 mL) in the month of June (2006) and lowest was recorded from Site 7 (40/100 mL) in the month of September (2006) Table. The higher fecal coliform density observed during summer from Site 1, Site 2, Site 3, Site 4 and Site 7 and during monsoon from Site 5 and Site 6 (Table 80). During the second year of study the maximum fecal coliform was recorded from Site 1 (46000/100 mL) in the month of July (2007) and the lowest MPN value 40/100 mL observed from Site 3 in the month of January (2007) and Site 7 in the month of August (2007). The highest seasonal values suggest higher fecal coliform density during monsoon from Site 1, Site 2, Site 4 and Site 5 and during summer from Site 3, Site 6 and

Site 7. Crabill *et al.*, 1999 and Kistemann *et al.*, 2002 mentioned that a higher fecal coliform bacterium in water is associated with rainfall. Improper sanitary systems of households and hotels situated near the lake may also attribute to the higher fecal coliform density. According to Hutty, 1990 sewage pollution in tropical Asian regions is a severe health risk to people that live near rivers and waterways. Direct discharge of domestic waste, leaching from poorly maintained septic tanks and improper management of farm waste are suspected as the major sources of waterborne disease. The fecal coliform density of Site 1 and Site 2 were always higher than other sites. It may be due to the fecal contamination in these two sites. Drains from houses and hotels directly discharge waste water to the Mirik Lake especially at Site 1 and Site 2.

The coliforms bacteria are discharged from the human intestine and their presence indicates the possibility of the presence of pathogenic organisms. The coliform group comprises all of the facultative and aerobic gram-negetive, non-spore forming rod shaped bacteria. The coliform bacteria include the genera *Eschericia*, Citrobacter, Enterobacter and Klebsiella. The Eschericia coli are entirely of human origin but their exclusive estimation is difficult and hence the entire coliforms are used as indicator. (Trivedy and Goel, 1986).

The total coliforms were enumerable throughout the investigation period. During the first year of study period the highest total coliform density (92000 MPN/100 mL) was recorded from Site 2 in the month of June (2006). During the second year of study the MPN of total coliform varied from 70 to 110000 MPN/100 mL. The maximum total coliform density was recorded from Site 1 in the month of July (2007). The highest MPN value of total coliform bacteria was found in summer (54000/100 mL) from the Site 2 and the lowest value of MPN was recorded from Site 5 during winter (1003/100 mL) in the first year of study period. During the second year of study the MPN value was maximum at the Site 1 (98667/100 mL) during monsoon, while the lowest value was found from the Site 7 (725/100 mL) in the winter season. The seasonal variation in total coliform density revealed their higher presence during summer and monsoon and the lowest MPN value found in winter. The higher MPN of total coliform during summer may be due to the higher temperature which helped bacteria to grow in number. The peak coliforms numbers were observed during summer might also be due to lean discharge of water and higher concentration of drain effluents discharged into the lake. The maximum number of total coliforms was detected during monsoon season might be due to wash-out of fecal matter and over flowing of sewage drains by rain water. The highest total coliform density was recorded during monsoon may be attributed to the runoff during rainfall, which is a major factor in the loading of fecal materials mainly of bovine and human origin into the lake (Mondal *et. al.*, 2007). The lower MPN values of total coliform bacteria were found in winter may be due to the lower temperature in the winter which prevents the growth of total coliform bacteria.

According to the "Designated Best –Use water quality Criteria (CPCB, 2003)" the limit of number of total coliforms is 500/100 mL for "Class-B" type water. From the monitoring data it was observed that, most of the sites the total coliforms numbers were more than the required limit.

The HPC (heterotrophic bacterial count) values provide density of aerobic and facultative bacteria in water sample, which can grow at 37^0C. The HPC values are useful in warning about excessive microbial growth in any water and also in judging the efficiency of water and waste water treatment in removing microorganisms (Trivedy and Goel, 1986).

Heterotrophic bacterial load was found to be maximum in June (2006) from Site 2 (100,000HPC/ml) and the minimum was recorded in September (2006) from Site 7 (200 HPC/ml) during the first year of study. The highest HPC value was observed in the Site 1 (160000/mL) in the month of July (2007) and the lowest value recorded as 400/mL from the Site 7 during the second year of study. The seasonal heterotrophic bacterial density of surface water of Mirik lake varied from 1350/ml to 63500/ml. Heterotrophic bacterial load was found to be maximum in summer from Site 2 and the minimum was recorded in winter from Site 7 during the first year of study. The highest HPC value was observed in the Site 1 (116667/mL) in the monsoon season and the lowest seasonal value recorded in the winter (1265/mL) from the Site 7 during the second year of study. The HPC values often exceeded the drinking water standard limits (Bureau of Indian Standards) in Mirik Lake. The relatively higher density of heterotrophic bacteria at Site 1 and Site 2 may be due to the sewage input in these sites.