DISCUSSION

The temperature of air and water is an important factor indicating the quality of water. It influences aquatic life and concentration of dissolved gases such as CO₂, O₂, and chemical solutes. Changes in the temperature produce characteristic patterns of circulation and stratification. The water temperature, (at a depth of 1 feet) ranged between 15.2°C to 23°C in winter months and 23°C to 31.8°C during Summer months in the present study with a difference ranging from 1 to 8°C. However in rainy season from July to October the water temperature was found to get fluctuated only by a difference by 0.2°C to 2.8°C (Table 4.1). The water temperature during investigation period was always below the ambient temperature but followed the meteorological conditions. According to welch (1952) smaller water bodies react quickly
with the change is the atmospheric temperature. High summer temperature and bright sunshine acceleration the process of decay of organic matter resulting into the liberation of large quantities of CO₂ and nutrients. In the present investigation with increases in temperature during summer month, free CO₂ was recorded in the water samples. A direct relationship between the duration of bright sunshine and temperature has been observed in tropical countries (Zafar, 1986; Kadarker, 1994). The present results are in agreement with the above.

Free CO₂ dissolved in water is the source of carbon that can be assimilated and incorporated into the living matter of all the aquatic autotrophs (Hutchinson, 1957). The free CO₂ is directly proportional to bicarbonates and indirectly to carbonates. During present studies free CO₂ was rarely observed. It was recorded during late summer months (April, May and early rainy months (June and July). The absence of the free CO₂ may be due to its complete utilization in photosynthetic activity (Sreenivasan, 1971) or its inhibition by the presence of appreciable amount of carbonates in water (Sahai and Sinha, 1969). The present of free CO₂ during late summer and early rainy season may be due to depletion of DO and subsequent increase in the build up of free CO₂ by the process of anaerobic digestion of dead aquatic plants. In the present investigation high values of carbonate hardness were recorded throughout the year and hence the absence of fee CO₂ for most of the months may be due to utilization of carbon in carbonate formation.
The alkalinity in water is usually interpreted as the quantity and kinds of compounds such as bicarbonates, carbonates and hydroxides present which collectively shift the pH to the alkaline side of neutrality. The total alkalinity ranged between 196.28 mg/l to 382.5 mg/l in the present study.

A decline in the alkalinity was observed during the monsoon which may be due to dilution of water. High alkaline conditions, may be due to high photosynthetic activity of the phytoplankton, water temperature and industrial dumpings.

Hardness is governed by the contents of calcium and magnesium salts largely combined with bicarbonates and carbonates which make temporary hardness and with sulphates, chlorides and other anions of mineral acids causing permanent hardness. The upper permissible limits for hardness for irrigation and drinking water are 150 and 75 mg/l respectively and lakes above 64 mg/l are regarded has hardwater lakes (Ganapati 1973, 1980; Rao et al, 1989; Bini et al., 1999). The values of total hardness ranged between 15.2 mg/l and 344.62 mg/l, indicating very hardwater with maxima during winter months (Table: 4.1).

Calcium is essential for metabolic process in all living organisms. Lund (1965) suggested main effect of calcium on phytoplankton by buffering pH of water. The present study showed a range of 118.25 mg/l to 158.12 mg/l calcium carbonate hardness.
The maximum values of CaCO$_3$ hardness in the present studies may be due soluble nature of CaCO$_3$, however due to adsorption of other dissolved solids like silicates and sulphates, they might have settled down on the bottom soil and less CaCO$_3$ hardness of water was recorded during summer season. Boyd and Litchkopplar (1979) suggested that total alkalinity and total hardness values are normally similar in magnitudes and desirable levels of these parameters for fish culture generally fall within the range of 20 to 300 PPM.

The lake under investigation has water with high values of total hardness and total alkalinitities which are similar in magnitude but being very high the reservoir water may not be suitable for fish culture. From September to February total hardness was found to be more than 300 mg/l (Table 4.1). These months are the months of development of fingerlings of Rohu and Catla. Further magnesium hardness was also more. Magnesium could interfere in the fish metabolism and hence it is suggested that the lake is not suitable for intensive fish culture.

Chlorides occur naturally in all types of waters. High concentration of chlorides is considered to be the indicator of pollution due to high organic wastes of animal or industrial origin. The present study found a range of 21.65 mg/l to 77.11 mg/l of chloride and maxima in late rainy season. The lower values of chlorides in summer may be due to their deposition in the soil and evaporative loss. on the onset of rainy season the fresh water currents might have made the chlorides
soluble. In natural water 4 to 10 mg/l of chloride indicates its purity (Munawar, 1969; Srccenivasan, 1974). The present observations are in confirmation with that of George (1961); Khan and Siddiqui (1970) and Singh (1986).

The quantities of phosphate varied throughout the period of studies which might be due to the death and decomposition of algal and other aquatic vegetations present in the lake. The phytoplankton increased in number and the changes that occurred in its composition over the course of study, indicated that eutrophication of lake is preceding very rapidly. The trophic status of lakes and rivers is determined largely by the annual inputs of phosphorus (Kodarkar, 1994). The concentration of phosphates and phytoplankton density were found to be positively exponential in with each other present investigation, indicating the eutrophic status of the lake. The increased concentration of chloride and phosphate can be used as an index of eutrophication (Koldarkar et al., 1991).

A sudden increase in sulphates was observed from January reaching to maximum in April. Throughout the summer higher sulphate contents were noted. Similarly during rainy season also higher values of sulphate were recorded. The higher values of sulphates during summer can be attributed to the evaporation of water while the higher values from rainy season could be due to the entry of sulphates from catchment area of the lake due to run off. These explanations for the present observations are well in agreement with those of Kodarkar (1994) and
Sommaruga and Robarts (1997). Sulphates exhibited positive correlation with temperature conductivity and silicates and their presence in a particular concentration has favoured the growth of cladocerans (Table: 4.2). Similar types of observations have been reported by Hutchinson (1957).

Zooplanktons comprised of protozoons, rotifers, copepods, cladocerans and ostracods. The seasonal variation of these organisms is dependent on various biological and physicochemical parameters. Temperature, pH, free CO$_2$ and presence or absence of chlorides mainly affect their occurrence (APHA, 1998).

Rotifers dominated the zooplankton population of the lake (42.30 %), followed by Cladocerans (22.73 %), Copepods (17.22 %), protozoons (15.23 %) and ostracods (2.86 %). During the present study, 62 species were identified. They were abundant in summer months with a peak in May. But a sharp decrease in their number was noticed on the onset of rainy season. During late winter, again a slight increase in abundance of zooplankton was seen. During November protozoons dominated the lake. Temperature and pH favoured their growth. All the Zooplanktons showed a significant positive correlation with water temperature and the alkaline pH of the lake. This type of seasonal abundance is in confirmation with the findings of Zutshi et al. (1972; 1973) Seenay (1973); Sharma (1992), Ennola et al. (1998). Sarnelle (1999); The high temperature during summer favoured the growth of zooplankton.
as, at high water temperature, the multiplication, reproduction and metabolic activities of the zooplankton are increased. Jyoti and Sehgal (1979) reported that low temperature and high free CO₂ reduce the zooplankton population. Byars (1960) reported that zooplanktons prefer the alkaline nature of water. Chlorides and phosphates were also maximum during summer months which might have favoured the growth of zooplanktons.

The group rotifera was represented by 28 species. Higher temperature, less nutrients and low oxygen contents favoured them to flourish. This is in confirmation with the observations of Arora (1966a). Among observed rotifers the species Rotararia, Monostyla, Lepadella, Cephalodella, Brachionus falcatus were abundant and are pollution indicator species.

Cladocerans were represented by nine species. Phytoplankton particularly the members of chlorophyceae and myxophyceae were found to be favouring the abundance of the cladocerans. Accordingly, a high count of cladocerans was reported in March, April and May. This pattern of distribution may be due to the interaction of various physico-chemical and biotic factors. This is in confirmation with Nayar (1971) and Wetzel (1975). Water temperature, pH, silicates and sulphates favoured the growth of Cladocerans and total hardness showed significant -ve correlation with the cladoceran population (Table: 4.2). These correlation results are well in agreement with the results of Singh (1986) who studied fluctuations in the
composition of zooplankton population in relation to hydrobiological conditions of Rihadhad reservoir, U.P.

Copepods were represented by eight species and among them Cyclops, Paracyclops and Ecodiaptomus were recorded during 10 months of the year. Cyclops and Paracyclops dominated the lake. They exhibited a major peak in summer and minor peak in winter. This is in confirmation with the findings of Bini et al. (1997) and Maier et al. (1998). The summer peak may be due to the abundance of diatoms and blue green algae. Minor peak in winter may be attributed to the abundance of phytoplankton (Chlorophyceae, Bacillariophyceae and Euglenineae) in the present investigation. A decrease in rainy season may be because of predation of planktonivorous shrimps, prawns and fishes (Baruah, et al, 1998).

Production Biology of copepods and cladocerans in three south east Shri Lankan low land reservoirs and its comparison to the tropical freshwater bodies was carried out by Bandu Amarasinghe et al. (1997). Mean zooplankton production biomass and annual zooplankton production were found to be positively related to mean phytoplankton biomass and it proved to be a good predictor of mean zooplankton biomass and a moderate annual zooplankton biomass. The present results are similar to those of Bandu-Amarsighe (1997). The copepod population was significantly correlated with protogoon, rotifer, cladoceran and ostracod population (Table 4.2).
Ostracods were represented by five species and they showed summer maxima (Table 4.7) and significant correlation with water temperature, pH and free CO$_2$, and also with protozoon rotifer, cladoceran and copepod population. They were 5th in the order of population. They contributed only 2.86% of the total zooplankton population. Their abundance also coincide with ample phytoplankton in summer (Table 4.11 to 4.14). The results with respect of seasonal distribution of ostracods are similar to those of Chandrasekhar and Kodarkar (1994) and Ade (2001).

Productivity of a lake is the most important biological phenomenon which involves trapping of radiant energy of the sun and its transformation into high biological energy by the process of photosynthesis using inorganic materials of low potential energy. The primary productivity relates to the amount of organic matter synthesised in a certain space per unit turn. The morphological and geological characters and physico-chemical properties of water show a direct relation with primary production (Adoni, 1985). Gross primary productivity (GPP) refers to the observed changes in the biomass plus all the predatory and non predatory losses during an unit time. While, net primary productivity (NPP) is the rate of accumulation of new organic mater per unit time i.e. gross primary productivity minus all losses.

The average gross primary production (GPP) and average
net primary production (NPP) were found to be 0.0417 mg/c/l/6hrs and 0.0263 mg/c/l/6hrs respectively during the present investigation. The values of both GPP and NPP were found maximum in October and the minimum values were recorded during August month. GPP showed a distinct bimodal pattern with another peak in March (0.0632 mg/c/l/6hrs).

Plankton biomass has shown low values during rainy season and high values during October and March (Table 4.16). G/R ratio was maximum during October (4.52) and minimum during February (1.10).

Singh et al. (1980) reported high production in early summer and low values in winter, late summer and rainy season. However, in the present investigation productivity (both GPP and NPP) was found to be maximum both during winter and summer. This could be because of abundance of phytoplankton, less turbidity and nutrient rich water of the Chhatri lake. The decreased productivity in August is probably due to high turbidity and hence minimum transparency. The productivity was found to be increased during September (post rainy season) when the turbidity was found to be decreased slightly.

Singh et al. (1980) reported the net productivity of Rihand reservoir raining between 130.84 to 636.62 mg/l/day; while Salter and Wright (1974) obtained 571.92 to 1318.66 mg/l/day productivity of Bighorn lake which was described as moderately productive by them.
Thosar and Das (1984) have reported the productive nature of different lakes of Nagpur. They reported gross productivity ranging between 87.47 to 137.47 mg C/m²/h and net productivity ranging between 62.47 to 75 mg C/m²/h respectively by Krishnamurthy and Abdulappa (1972). From this data it can be inferred that the lake Chhatri is Oligotrophic.

In the present investigation statistical analysis was carried out to find possible relationship of productivity with physico-chemical variables. Singh (1986) reported a highly significant positive relationship of primary productivity and temperature. Pillai et al., (1975) stated that water temperature did not show any significant impact on the productivity of ecosystem. Qasim et al., (1972) have also reported that water temperature has no direct impact an GPP and NPP. Nair et al., (1983, 1984) clearly mentioned that the correlation coefficient did not reveal any significant relationship between primary production and water temperature. In the present investigation we have also noticed an insignificant positive correlation between productivity (GPP and NPP) and water temperature (Table 4.2). The winter values of GPP and NPP were also higher (Table) when the water temperature was low and hence it can be inferred that the productivity is independent of temperature fluctuations in water.

Light is an important factor for the photosynthetic activity of phytoplankton, penetration of light is checked by the presence of suspended particles at the surface affecting the photosynthesis in
sub-surface water (Singh et al., 1980). They have reported that turbidity acts as limiting factor for plankton abundance Shreenivasam, (1965) Pathak, (1979) Saha et al. (1985), Singh (1991) and Sommaruga et al. (1999) reported a significant positive correlation between primary productivity and transparency. In the present study a significant negative correlation between GPP as well as NPP is observed. Further NPP is found to be positively correlated with water temperature. A number of workers have reported direct correlation between alkalinity and productivity (Kaul and Vass, 1970; Mathew, 1975; Saran, 1980; Takamura et al., 1989; Singh, 1991; Sommaruga et al., 1999).

In the present investigation when the whole lake is considered as an integrated unit, then gross primary productivity was found to be positively exponential with biomass.

The macrophytes derive nutrients from the bottom sediment nutrient poor affecting the productivity of the lake (Trisal, 1981; Pandit, 1984). However, the consumption of nutrients helps in maintaining the algal bloom under control, otherwise the growth of algal blooms usually decrease the dissolved oxygen content. The macrophytes might be responsible for the luxuriant growth of planktons, by maintaining the ecological balance, Singh and Sharma (1990) suggested that macrophytes help to fight pollution. The submerged species of macrophytes found at the margins also act as green manure which might have favoured the abundance of zooplankton in the Chhatri. Besides
food, the marginal and submerged macrophytes also provided suitable breeding and sheltering places for the macroinvertebrates and fishes. Singh and Sharma (1990) recorded leaves and stems of submerged and marginal plants, as the breeding places for many macroinvertebrates including the insects.

Macrophytes, especially the submerged species, Ipomoea observed in the lake Chhatri found to give support to large quantities of epiphytic algae and also periphyton which might have formed the favourable environment for fishes and hence a large number of fishes were seen during the period of investigation. The macrophytes growing in the lake also constitute the principle source of food in the food chains of fishes.

Insects are very important organisms in the aquatic environment and occupy almost all conceivable habitats, having wide range of habits. The aquatic insects are important component of food web in an ecosystem. Their interaction with other biotic communities and with abiotic factors within their microhabitat make them interesting and valuable indicators of water quality. The aquatic insects constitute exclusive stable diet of high animals. Insect fauna of any limnetic habitat exert not only potential, but a profound influence on the economics of the fresh water resource (Tonapi, 1980).

In Chhatri lake, the insects are represented by six orders
viz. Coleoptera, Diptera, Ephemeroptera, Hemiptera, Odonata and Trichoptera. A total of 28 species observed includes 5 of Coleoptera, 5 of Diptera, 4 of Ephemeroptera, 7 of Hemiptera, 5 of Odonata, and 2 of Trichoptera.

Rao et al. (1987) observed comparative aquatic insect population fluctuations in the three water bodies of Ujjain. They recorded a total of 61 species out of which 26 species in lentic water, 20 in lotic water and 15 in both waters.

In the present studies, insect groups were more prominent in the littoral zone where abundance of vegetation is available. David and Ray (1966) supported this pattern of abundance. Ray et al. (1966) also observed that in comparison to river Ganga, Jamuna possess a rich aquatic vegetation and fauna associated with the vegetation. The flora have both direct and indirect relationship with the fauna in serving as food for various species and providing suitable breeding grounds for various insects and molluscs (Moore, 1915 and Berg, 1950).

The majority of insect species found in average eutrophic body of water can tolerate a broad range of physico-chemical conditions of water which render them useless and some of them adapt and become indicators of the water quality (Roback, 1962). David and Ray (1966) observed that May flies and Damselfly nymphs and Hemipteran bugs were found inhabiting in the comparatively well oxygenated zone.
Crosswell (1949) observed that Ephemeroptan nymphs and larvae, Odonates, Diptera. Beetles and water bugs require low oxygen, while some others like Caddis flies and May fly larvae require higher oxygen contents.

Nebeker (1971) reported that increased temperature accelerate the emergence of aquatic insects. Macrophytic vegetation also play a major role in their emergence. At all sampling stations on the banks of surface water was covered by macrovegetation ( Potemogetion, Lemna etc. ) which provide a macrohabitat for Coleopterans. According to Vierssen and Verhoeven (1983) macrophytic abundance is major factor in the occurrence of Coleopteran species and vegetation coverage must be of decisive importance with respect to the numbers of aquatic Coleoptera species.

Vinikour (1980) found that macroinvertebrate community was dominated by Chironomus larvae and insect other than chironomids which were minor components of the fauna. According to Tonapil (1980) the chironomids form a significant portion of the macroinvertebrate fauna in most fresh water habitat. They are important link in the food chain like algae, macroinvertebrate, the larger macroinvertebrates and the fish.

Gauffin and Tarzwell (1952,1956); Paine and Gauffin (1956) and Curry (1965) have reported that Chironomus larvae are able to live in water with low dissolved oxygen concentration. The results show that
Chironomus larvae were frequently found at all sampling stations. Generally the Chironomus larvae are considered as a common inhabitants of mud (Hynes, 1960) which are rich in organic matter. They can tolerate fairly high concentration of \( \text{H}_2\text{S} \) and ammonia gases also. Adoni (1985) suggested that the presence of chironomids in high densities indicate highly eutrophic condition.

Some organisms namely *Psychoda* and *Chironomus* are found helpful in determining the septic conditions in a water body. These are generally used in defining the extent of bad to moderate organic pollution (Ellis, 1937). Extensive studies of Hynes (1960) and Lloyed (1944) indicate that where the concentration of organic matter is high enough to produce total deoxygenating, no normal aquatic animals survive, but they may be replaced by the larvae of the *Psychoda* sp. and *Eristalis* sp. Both these larvae are air breathers whose normal habitats are rich in organic matter. They overcome the problems by breathing through air tubes which open at the tips of their tails. Thus they need only to keep their tails at the surface.

Ephemeropterans constitute an integral part of aquatic environment in their larval as well as nymphal stages. These nymphs are of immense utility as bio-indicator of pollution besides their use as fish food. Hubbard and William (1978) observed that the May fillies larvae (Ephemeroptera) are one of the most important groups of aquatic insects that spend the major part of their lives as nymphs in the water,
leaving it only to mate and lay eggs. They often tolerate only an extremely narrow range in their immediate environment. The absence or presence of a particular species in a water body can often yield much information about the quality and environmental characteristics of that water.

The mayfly nymphs are generally considered as pollution sensitive, but some species have been found to be tolerant to specific kind of pollution (Michael and Peters, 1978). David and Waterhouse (1983) reported that Ephemeroptera was less pollution tolerant. Roback and Richardson (1969) found Stenonema to be very sensitive to organic and chemical pollution. Ephemeropterans were found to be colonised on the aquatic macrophytes. They were more abundant on Potamogeton indicus and Hydriella verticillata.

Some species of Hemiptera such as Gerris inhabit free floating vegetation. Corixa and Ranatra were found to colonise on submerged macrophyte and some species like Diploynchus and Adebus prefer the roots of vegetation which form the shelter. Maximum number of this group may be due to the presence of abundant higher aquatic vegetation.

The odonata nymphs include those of dragon flies Boyeria, Hagnius and damsel flies, Coenagrion which are found in all fresh water habitats where there is abundant of oxygen and unpolluted water (Tonapi, 1980).
According to Roback (1962) the odonata is not a sensitive group, they cannot tolerate high changes in pH and BOD. According to David and Ray (1966) being air breather, most of Odonates can survive even in highly deoxygenated environment. The respiration also occurs through the body surface in Damsel flies nymphs.

Odonatans are associated with *Potamogeton* and *Nelumbo nucifera*. Schramn *et al.* (1987) also recorded moderate abundance of Odonata on *Potamogeton* and *Eichhornia*.

Hynes (1970) pointed that the Trichopterans are delicate tool in assessment of pollution. The order, Trichoptera is an important and abundant component of the benthic macro-invertebrates community. It is in great conformity with the present study. Roback (1965) was of the opinion that some Caddisfly larvae appeared tolerant to moderate pollution. Schumacher and Schremmer (1970) observed *Hydropsyche instabilis* in moderately polluted water, which was in confirmation with the present findings.

Thus, the overall impact of physico-chemical parameters of lake water on growth of zooplankton and phytoplankton has indicated that the lake is on the verge of becoming eutrophic. The excessive growth of macrophytes and insects supports the eutrophication process of the lake.