DISCUSSION
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A. Physico-chemical parameters:

Our country India is in having large number of lotic and lentic environment with rich flora and fauna. These water bodies are indispensable as they satisfy our domestic and other needs. Such aquatic bodies as per Cole (1979) not only provide transportation, hydro-electric power but also a means for sewage and waste disposal, fish for food and sport and other recreation, including aesthetic appreciation.

A large number of limnological factors with organic and inorganic compounds dissolved in water have created a stressed condition and polluted environment to the floral and faunal species in habiting in it. It is true that when the contamination level crossed beyond the self regulatory mechanism the pollution is found increased in the water body. These are basic reasons to have a change in natural physico-chemical and biological spectrum in any fresh water system.

As per Natrajan and Pathak (1985) every water body receives more energy in comparison to land, so is a large reservoir of energy and organic matter. It contains an intricate web of life in enormous verity, which is sustained as an organic production system, by energy radiated from the sun. All the various organisms in habitting in a water body are generally liked to gather in food chain in accordance to their mode of obtaining energy. It is known as trophic structure. The limnological information are the essential tools in determining the nature and status of water body.

Colour and Odour

Colour and Odour of water are the parameters which normally either remained unattained or neglected by different workers. The only work available is of Das and Pandey (1978) who made studies on some of the physico-chemical and biological indicator of pollution in Nanital lake and observed

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brownish-green to yellow shish-green colour of water and fishy and with light to strong smell methane during their study period i.e. from January to June. The only other work available is the work of Garg et al. (2007) on Bharatpur area, they made simple comments in all water samples, there was no colour and no odour. In the current investigation also there was no odour in any of the water sample. But brownish colour was seen due to muddy water in rainy season which got disappeared gradually and ultimately the light brown colour turned down to colourless clear water.

**Temperature**

Temperature plays a pivotal role in determining life in biosphere as well as hydrosphere, directly or indirectly. Sonar river, is a fresh water body located in the tropical region. Since tropical regions are known for the seasonal changes, during the current study period too remarkable seasonal variations in the water temperature were recorded. The water temperature ranged from 19°C to 34°C (for surface) and 18°C to 34°C (for depth). Generally, water temperature depends on the atmospheric conditions, i.e. humidity, wind velocity, intensity of light radiation, length of photoperiod etc.


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The seasonal variations in here observed, recorded minimum water temperature during winter season, and maximum in summer season. The minimum water temperature during winter season could be due to low intensity of solar radiation and the maximum in summer season can be explained with the help of Table no. 4a, 4b and 4c, which indicated that during March, April, May and June the temperature was comparatively higher than the other months. This can be attributed to high rate of evaporation and back radiation in the same season. A similar fluctuation pattern of the water temperature was also reported by Parvateesam et al. (1991) on the Anasagar lake, Tanti and Saha (1992) on the thermal spring of Rajgir, Ghosh (1997) on the Kosi river, Kumar and Gajaria (1997) on the Matar village fish pond, Mishra and Tripathi (2003) on the Ganga river, Kumar et al. (2004) on the river Kosi, Gupta and Sharma (2004) on the Ban-Ganga stream, Saxena and Chouhan (2004) on the Jamuna river, Saxena et al. (2005) on the Sengar river, Duran and Suicmez (2007) on the Cekerek stream of Turkey and in the same year, Pandarkar and Mane on Visapur Dam of Ahmedanagar (Maharashta), Clear thermal stratification was never observed in Sonar river water. Holomixis of water due to wave action, created by wind velocity as well as bioturbation could be due to lack of thermal stratification.

Generally, the water temperature of any water body affected by physical factors, but it governs the other physico-chemical factors of water, as well as sediment and regulates the productivity and diversity of flora and fauna in an aquatic ecosystem. Hence temperature is an indispensable factor in limnological studies. It had a positive correlation with Turbidity, Free CO₂, BOD and Acidity, while it was negatively correlated with DO, Total hardness, Magnesium, Calcium, Sodium, Potassium and Sulphate.

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**Conductivity**

Conductivity is a numerical expression of the ability of an aqueous solution to carry an electric current. This ability of conductivity depends on the presence of ions, their total concentration mobility, valence and relative concentration and on the temperature of measurement (APHA, 1985). All kinds of water in nature contain inorganic and organic compounds in dissolved form. These dissolved compounds in water are turned in to total dissolved solids. The conductivity of natural water varies with respect to concentration of total dissolved solids. Hence both are inter dependent factors.

In the present study, the conductivity of river water fluctuates between 0.08 to 0.94 \( \mu \)mho and 0.06 to 0.88 \( \mu \)mho for surface and depth water respectively. It was lowest in the month of August and highest during the month June. Seasonally, the minimum value of conductivity was recorded in rainy season and maximum in winter season.

The minimum conductivity in rainy season may be due to:-
1. Dilution effect of rains and sedimentation of dissolved solids at low temperature.
2. Minimum dissociation of ions in rainy season.
3. Generally, maxima concentration of minerals in the same season. Similar phenomenon was also observed by Thomas and Ratlifte (1973) in a man made lake of Ghana, Khan and Ejik (1983) on the lake of Jos plateau (Nageria) and Kala and Sharma (2002) on the Alaknanda river at Grahwal Himalya.

Low evaporation of water at low temperature in winter season was the main factor responsible for the high value of conductivity. However, the findings of some workers showed dissimilarity with current observation of conductivity. Parvateesam *et al.* (1991) observed the maximum and minimum conductivity during rainy and winter seasons respectively. Ghosh (1997) reported the highest and lowest value of conductivity in rainy and summer seasons. Joshi and Sharma
(2003), and Kumar et al. (2004) recorded its maxima range in rainy season and minimum in winter season. Whereas, in 2007 Duran and Suicmeze found the maximum and minimum concentration of conductivity during rainy and summer season respectively.

Conductivity of the river water was considerably low because, all the selected stations were located in tropical region. Jhingran (1985) has also emphasized the importance of location, geological history of basin, rainfall, bottom deposit and presence and absence of inflowing waters, in the regulation of conductivity.

In the present investigation, correlation coefficients of conductivity show that the factors responsible for ionic exchange, i.e. sodium, potassium, calcium, bicarbonate, sulphate etc. are positively correlated. (Table no. 67).

**Secchi transparency**

Secchi transparency has been used as first spol checks of eutrophication (Edmondson, 1972, Carlson, 1980). According to Lind (1936) Secchi transparency of any water body is controlled by at least three variables - (A) Absorption and scattering of light by algae (B) Scattering of light by non-algal particles (C) Non-particles light absorption. In the Sonar river if has been observed that last two variables were responsible for determining the Secchi transparency. Secchi transparency varied between 14 cm. to 88 cm. The findings of Bhatt and Pathak (1990) were also similar in Kosi river.

In the Sonar river, the maximum transparency was recorded in the month of November at Kesli (A3) station. Settling of seston, reduction in planktonic biomass, presence of fairly good amount of water and less bioturbation might have been the reasons for the maximum transparency in winter season specially in November04. Almost similar variations in transparency were also recorded by some other workers like
Vijayaraghavan (1973) who worked on three fresh water ponds at Madurai. In the same way Sharma and Pattanayak (1985) worked on fresh water ponds in and around Bhubneshwar, Joshi et al. (1996) studied the Ganga canal at Jwalapur, Sharma and Shrestha (2001) investigated Tinau river at West Nepal and Saxsena et al. (2005) investigated Sengar river and all have supported the present results by reporting maximum transparency in winter season either in the month of January and February. As per these workers they documented the minimum in rainy season but here the minimum value was recorded in August only at Garhakota otherwise mostly in summer season.

The minimum Secchi transparency in summer (April) might have been due to decreasing of water level but in August could be attributed to the turbidity caused by run off water from the catchment areas, water current and cloudy weather, which may have affected the light penetration in the water body. It was observed that after a few months of heavy rains, the value of Secchi transparency increased. It may be due to sedimentation of silt and increased water level. Saha (1987) and Sharma et al. (1990) had suggested that light penetration could be affected as a result of high turbidity caused by inflow of water. Joshi and Sharma (2003) worked on annual variations in the physico-chemical parameter of Yamuna river. In the same year Kour and Joshi concentrated on Ganga river and Thailaga (2004) worked on the lake at Ooty and all have reported minimum transparency in rainy season. The low value of Secchi transparency during summer season might be due to the low water level, abundance of planktons, high wind velocity and extensive fishing in the same season. Chaurasia and Adoni (1985) worked on Sagar lake, in the same year Adoni and Vaishya studied the phytoplankton productivity in relation to seasonal diel and vertical productivity in Central Indian
reservoir and Kumar made his studies on fresh water beel of West Bengal. All of them have reported the minimum transparency in summer and maximum in winter season.

Secchi transparency has an inverse correlation with number of physico-chemical parameters (Welch, 1935 and Hussainy, 1967). According to them, increase in concentration of Calcium, Magnesium, Sulphate and turbidity checks the penetration of light in the water body. A negative correlation of Secchi transparency with Total hardness, Magnesium hardness, Calcium hardness and Turbidity provides support to above the conclusion. (Table no. 67).

**Turbidity**

Turbidity in the running water is either due to suspended inorganic substance (such as silt and clay) or due to planktonic organisms. It mainly restricts sunlight and effects on photosynthesis or primary productivity. As a natural phenomenon maximum Turbidity is recorded in the Indian river during monsoon period where sweeping from the catchments area run in to the river. The Turbidity of any water body mainly depends upon its geography, turbulence and ecology of the catchments area. During the present investigation the Turbidity ranged from below 100 NTU (16 to 90 NTU). Singh and Bhomick (1985) has recorded the maximum (110 NTU) Turbidity from the Ganga river, Chopra and Hashim (1990) have reported the range of Turbidity between 3 to 7.85 NTU from the three sampling stations of Ganga river, Sharma et al. (1990) have noticed the Turbidity ranged from 10 to 350 NTU from the altitude river Bhilangana. The minimum and maximum Turbidity have been noted during the month of January and July respectively by Sharma and Shreshtha (2001) from the Tinau river of western Nepal. While Mishra and Joshi (2003) had been observed its maximum value in the month of July and minimum value during the month of February from the Ganga river at Haridwar.
Seasonal fluctuations in turbidity were also estimated and noticed that the lowest turbidity was recorded in winter season, which might be due to the poor quantities of settleable suspended solids and non-living materials in the water body. These findings lend support of the earlier studies. Bhowmick and Singh (1985) reported the high turbid water in September and minimum turbid in July in Ganga at Patna, while Khanna et al. in 1997 reported highest turbidity in August and nil in the month of January, February and March in the same river at Hardwar. However Joshi and Sharma (2003) on Yamuna river and Gaikwad et al. on Tapi river and reported maximum turbidity in rainy season and minimum in summer season.

The great magnitude of turbidity has been found during rainy season. This rise in turbidity may be due to rainfall which added silt, detritus, sand, clay, phytoplankton, microscopic organisms and other non-living materials to the river water. The similar research reports have been noticed by Sharma (1985) on the Bhagirathi river, Joshi et al. (1996) on the Ganga canal at Jwalapur, Kala and Sharma (2002) on the Alaknanda river and Kour and Joshi (2003) on the Ganga river. A drastic rise of Turbidity and consequent fall of transparency was recorded during the whole study period. It restricts mainly the sunlight which affects the photosynthesis and primary productivity. The correlation coefficients of turbidity with the other factors has been cited in the Table no.67.

**Hydrogen ion Concentration (pH)**

pH is defined as the negative log of the hydrogen ion concentration (Golderman and Horne, 1983). The pH value is usually influenced by changes in carbon di-oxide, carbonates and bicarbonates. Natural water are mostly alkaline in nature. The value of pH in any water body would be indices of its productivity. During the present investigation too, the water body remained always towards the alkaline side. The range of pH varied from 6.1 to 7.9 pH. The range of pH varies
considerable from water body to body. Sharma (1985) while studying the seasonal abundance of phytoplankton in the Bhagirathi river reported the range of variation between 7.2 to 9.25 with minimum in January and maximum in June. In the same year Bhomick and Singh recorded the minimum and maximum range of pH in Ganga river at Patna during the month of July and January respectively. Prasad et al. (1985) the lowest pH has been found in June and highest in July during the study of pond water. Saha (1987) documented the range of pH between 7.2 (in summer-April and May) to 8.1 (in rainy-August) in a pond at Bhagalpur. The different range of pH has been observed by several workers in different water bodies but it invariably remained towards alkaline side Parvateesam et al. 1991, Mazhar and Kapoor 1992, Bais et al. 1993 reported (7.78 to 10.06 units) of pH in Sagar lake, Kumar and Gajaria 1997. Slathia et al. (2001) recorded the pH with a narrow annual variation between 6.03-6.78 and attributed it to respiration process of organisms.

In the present study, the maximum pH value (7.9 pH) was recorded at Garhakota (A) station in the month of October. Seasonally it was maximum in winter season and minimum during summer season. Kour and Joshi (2003) also reported the highest value of pH during winter season for Ganga river. pH is one of the most important attribute of any aquatic system, since all the bio-chemical activities depend on the pH of surrounding water. The pH of natural water is affected by geo-chemical and biological process. High value during winter season may be due to increase in photosynthetic activity and low dilution capacity. Low value of pH was recorded during summer season, may be due to the presence of free carbon dioxide. Joshi et al. (1996) studied the Ganga canal, Vijayakumar and Ramesha (2002) worked on a pond of Gulbarga (Karnataka), Kala and Sharma (2002) at Alaknanda river, Joshi and Sharma

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(2003) on the Yamuna river though reported maximum values in winter season but they observed the minimum values of pH in rainy season and Kumar et al. (2004) recorded the higher and lower values of pH during winter and summer seasons. While, recently Pandarkar and Mane (2007) reported the minimum pH in winter and maximum in summer seasons which is just opposite to the present observation.

The fluctuation in the pH values in Sonar river water was only due to its own physico-chemical and biological activities. A positive correlation of pH with carbonate alkalinity can be explained by photosynthetic activities (Table no. 67). Due to maximum consumption of carbon dioxide during photosynthesis by autotrops, the bicarbonates convert in to carbonates, resulting an increase in the pH level of water. Golterman and Meyer (1985) had also observed a similar relationship between pH and carbonates. Correlation coefficients of pH with other physico-chemical properties have been also recorded in the Table no. 67.

**Alkalinity**

Alkalinity of water is its acid neutralizing capacity and is primarily a function of Carbonate, Bicarbonate and hydroxide contents. The measurement of alkalinity is taken as an indication of the concentration of these constituents (APHA, 1985). Alkalinity shows the productive nature of water body. Generally, due to wide range of fluctuation in carbonate alkalinity, it is considered as one of the important parameter indicating the trophic status and production pattern of an aquatic ecosystem. According to Hutchinson (1957) and Golterman (1975), when excessive utilization of carbon dioxide and bicarbonates takes place by Phytoplanktons and macrophytes, carbonates and hydroxyl ions increase in the system, resulting the increase of pH and carbonate. The above findings were also found true in the present investigation. It
was noted that the value of carbonate alkalinity were comparatively higher in July, September, December and April. A slight increase in the value of pH and carbonates were also recorded in the above months. Higher carbonate alkalinity during the month of July, September, December and April might be due to the maximum utilization of carbon dioxide. At the same time it could be possible that the bicarbonate have been used as an alternative source of CO₂ and may have resulted in carbonates as by product. Consequently, slight decrees in the value of bicarbonate alkalinity was also noticed during the February-May and July-September. Thus it can be inferred that carbonate alkalinity increased with decreased bicarbonate alkalinity and can be used as its indicator.

Seasonal variations in carbonate and bicarbonate alkalinity were remarkable. The minimum value of carbonate alkalinity did not follow any definite pattern because of nil recording on the several occasions (Table 49a). Its maximum value was recorded in rainy season, can be attributed to lower the photosynthesis during same season. Similar results were also recorded by Kumar and Gajaria (1997). The minimum and maximum seasonal values of bicarbonate alkalinity were recorded during summer and rainy season respectively. The minimum value of bicarbonate in summer season might be due to the maximum utilization of bicarbonate by plankton specially phytoplanktons. The maximum concentration during rainy season might be due to increased water level and concentration of associated factors. Carbonate and bicarbonate alkalinity showed inverse relation during all three seasons in present investigations as well as the result of Chourasia and Adoni (1985) might have been increased. The similar phenomenon was also observed by Chourasia and Adoni (1985) in a eutrophic lake of Sagar.

Since the total alkalinity is the sum of the carbonate and bicarbonate alkalinity, therefore its concentration and
fluctuation also based on these two compounds. The total alkalinity was minimum in summer season while it was maximum in rainy season. Similar findings were also reported by Verma and Sahu (1985) in a lake water during 1982-83. Das and Pandey (1978), Saha (1987), Rauthan et al. (1992), Kumar and Gajaria (1997), Pandey et al. (1998) have made little bit different results by reporting maximum alkalinity in summer but minimum in different seasons like summer itself (June) winter and rainy season. While Kumar and Gajaria (1997) and Vijayakumar and Ramesha (2002) reported maximum in rainy season and minimum in winters, however Joshi (1996) minimum alkalinity in rainy and maximum in winters in a river of Western Himalayas, Kala and Sharma (2002) also made some type of results for Alaknanda river at Garhwal. But Parashar et al. (2003) find maximum (in November) and minimum (in December) values of alkalinity in Ganga Canal at Hardwar during Kumbh period. Mishra and Tripathi (2003) in Ganga river and Pandarkar and Mane (2007) in Visapur Dam (Maharashtra) observed the maximum in summer and minimum in rains.

Only few workers have reported carbonate and bicarbonate separately. Kant and Raina (1990) reported maximum in summer (June) and minimum in winter (November and December) values for carbonate and maximum for bicarbonate in January and nil value in summers. However Ghosh (1997) recorded nil value of carbonate through out the study period and maximum of bicarbonate in summer and minimum in rainy season.

An inverse correlation between carbonate alkalinity and free CO₂ was observed. A positive correlation of carbonate alkalinity with pH, provide support to conversion of bicarbonate during dense population of phytoplankton. Bicarbonate alkalinity was positively correlated with calcium hardness and total hardness. A very strong positive correlation of total alkalinity with bicarbonate alkalinity in comparison carbonate alkalinity reveals that the values of total alkalinity depend on bicarbonate alkalinity rather than carbonate alkalinity. The
coefficient of correlation of carbonate, bicarbonate and total alkalinity is given in the Table no. 67.

**Acidity**

Acidity of the water is its capacity to neutralize a strong base and is mostly due to the presence of strong mineral acids, weak acids (like carbonic, acetic acids) and the salts of strong acids and weak bases (like ferrous sulphate, aluminum sulphate). These salts on hydrolysis produce a strong acid and metal hydroxides which are sparingly soluble thus producing the acidity. Addition of waste waters having acidity producing substances also increase the acidity of the water. However, in natural water most of the acidity is present due to the dissolution of CO$_2$ which forms carbonic acid. (Trivedi and Goel, 1986)

In the current investigation, the acidity content in Sonar river water varied from 10 mg/L to 586.6 mg/L. It was minimum at Garhakota (A$_6$) station in the month April05 while, its maximum concentration was noted at Kesi (A$_2$) station in the month of July04. Babu Rao (1981) has reported the nil concentration of acidity from the four sampling sites of Hussain Sagar lake in Hyderabad. Bhatt and Pathak (1990) had been noted the range of acidity between nil to 0.08 mg./L from the seven sampling stations of Kosi river. While, Chopra and Hashim (1990) recorded the acidity concentration between 4.16 mg/L to 5.97 mg/L from twelve sampling Ghats of Ganga river. According to him WHO and ISI have not recommended any range of acidity for the suitability of bathing. Acidity depends upon the presence of decomposition vegetable matter and free CO$_2$. A positive correlation of acidity with free CO$_2$ provides the support to above conclusion. Arasu et al. (2006) recorded the minimum and maximum content of acidity during the months of October and February respectively.

In the present study, the seasonal fluctuations in acidity were also estimated. The minimum acidity was found during winter season. Mishra and Tripathi (2003) reported the lowest
value of acidity during winter season. The maximum concentration was noted during rainy season. Presence of uncombined CO$_2$, organic acids, tannic acid, humic acid and mineral acid might be responsible for the higher value of acidity during (the month of July) the rainy season. Maximum acidity was recorded during summer season by Mishra and Tripathi (2003).

The values of coefficient correlation of acidity with others physico-chemical parameters is recorded in the Table no. 67. The acidity of Sonar river water positively correlated with alkalinity, turbidity, free CO$_2$ and COD while it was negatively correlated with hardness, pH, conductivity and sulphate.

**Free Carbon dioxide (CO$_2$)**

Carbon dioxide in neutral waters is derived from various sources viz. 1. The atmosphere 2. Respiration of animals and plants. 3. Bacterial decomposition of organic matter. 4. Inflowing ground water in position of top soil. 5. Finally from within the water itself. The CO$_2$ content of air is about 0.03% by volume due to rapid industrialization in recent time (Jhingran, 1985). The concentration of free CO$_2$ recorded in the river water ranged between nil (0) to 81.4 mg/L. Generally the presence of free CO$_2$ was recorded at most of the stations during the whole investigation period, while it was observed rare (BDL) at Gourjhamar (A$_3$) station in the month of February for both the levels. Bhowmick and Singh (1985) while studying the physico-chemical factors of Ganga river found that the free CO$_2$ content was absent in the month of October, December, January and maximum was reported in the month of June. While in the same year Adoni and Yadav noted that except November and December the free CO$_2$ content was completely absent during the whole study period in a eutrophic lake. Chouhan et al. (1990) reported the nil concentration of free CO$_2$ up to the depth of 3 meters in Narmada river but 5.4 mg/L of CO$_2$ was recorded at the depth of 5 meters. Kant and Raina in the same year, also reported nil CO$_2$ during the months of March and April (summers) and highest
concentration was observed in the month of June in two ponds of Jammu unlike present observations.

Joshi (1996) while working on river Sutlej and Saha (1997) at perennial pond of Bhagalpur recorded the maximum concentration of free CO$_2$ in rainy season and minimum in winters. However results of Joshi et al. (1996) were different for Ganga Canal at Jwalapur (Hardwar). They also reported maximum in rainy season (August) but minimum in summers (March). However, Ghosh (1997) worked on Kosi river and observed its highest value in winter season and lowest in summer, while Slathia et al. in 2001 made their reports on Rehtari spring with a comment that highest of CO$_2$ was observed in rainy season along with the month of May and lowest in winters (October). Further in 2004 Kumar et al. reported highest value in summer and lowest in rains in Jamuna river. In the same year Gupta and Sharma worked on Ban-Ganga stream and in 2005 Saxena et al. on Sengar river and reported its maximum concentration during summers and minimum in winter season. The results of present investigations getting support of these two reports by reporting the same results (maximum in summer and minimum in winter). The highest free CO$_2$ level during summer season may be due to the increase in population density of aquatic fauna which produce carbon dioxide by respiration. The minimum concentration of free CO$_2$ during winter season might be due to the decaying of organic matter carried in to the water body during the rainy season and its utilization in photosynthesis. But moderate values of photosynthesis and dilution effect of water were the factors which kept the concentration of CO$_2$ at a moderate level during rainy season. Kant and Raina (1990) reported the similar findings during their investigations.

A negative correlation between free CO$_2$ and carbonate alkalinity was found in current investigations. Qadri and Saha
(1984) and Kant and Raina (1990) have also found a similar relationship between carbonate alkalinity and free CO₂. Whereas, its positive correlation was found with transparency, water temperature, turbidity and acidity. The correlation of free CO₂ with other physico-chemical are given in the Table no. 67.

**Dissolved oxygen (DO)**

Oxygen is one of the most important constituent of water which is needed for the metabolic processes of plants and animals communities and is an indicator of water condition. The atmospheric air contains 20.9% oxygen and 79.1% nitrogen. The air dissolved in water consists of 65.9% nitrogen and 34.91% oxygen. It shows that oxygen is comparatively more soluble in water then nitrogen, and remains in dissolved form. The level of DO in natural water depends on the physical, chemical and biological activities (APHA, 1985).

In the current investigation, the DO contents in Sonar river varied from 2 mg/L to 10 mg/L. DO was never observed below 2.4 mg/L except once (2 mg/L) at Rehli (for depth) in the month of May 05. Anoxic conditions at the bottom were noted by Sreenivasan (1970) in Krishnagiri, Amaravati and Bhavanisagar reservoir. However in the present study anoxic condition was never observed. The solubility of oxygen is greater in cold water than warm water. Temperature and altitudinal changes in atmospheric pressure affect the solubility of oxygen (Hutchinson, 1957). The current observations indicate inspite of poor temperature the maximum DO content was recorded in winter and minimum in rainy season along with the month of June when the rains starts from the middle of the month. Kant and Raina (1990) reported the importance of photosynthesis in the solubility and saturation of oxygen content in water.

Seasonal fluctuation in DO was remarkable during the current investigations. The results go along with these results showing the maximum magnitude during winter seasons and minimum in rains, could be attributed to solubility of oxygen at

The DO was poor during rainy season which might be due to:

1. Comparatively higher temperature in rainy season which may have reduced the solubility of oxygen.
2. Low population of Phytoplanktons.
3. Putrefactions of organic matter which was added to the river though run off water.
4. Presence of free carbon dioxide in the same season.

The flood conditions also reduced the DO concentration in rainy season. The results of present study and observations got support from parallel studies conducted by Joshi (1996), Joshi et al. (1996) Ghosh (1997), Slathia et al. (2001), Kala and Sharma (2002) and Kumar et al. (2004).

A negative correlation of water temperature with DO provides support to the poor solubility of oxygen, observed at higher temperature during rainy season. Inverse relationship of temperature and DO has also been observed by Rao (1955) and Singh (1960). The other values of correlation coefficient of DO is given in the Table no. 67.

**Biological Oxygen Demand (BOD)**

BOD test measure oxygen required for the biodegradation of the organic matter. It also measures the oxygen used to oxidize reduced forms of nitrogen unless their oxidation is prevented by
inhibitor (APHA, 1985). On an average basis, BOD approximates the amount of oxidizable organic matter present in the solution and BOD value can also be used as measure of waste strength (Trivedi and Goel 1986). Microorganisms, pH and nitrification process are the important factors influencing the BOD.

Monthly values of BOD ranged from 0.83 mg/L to 8.9 mg/L in the Sonar river water. Bhatt and Pathak (1990) reported 3.4 mg/L maximum and 0.6 mg/L minimum BOD from Kosi river, Chopra and Hashim (1990) noted 5.12 mg/L BOD from Ganga river, Joshi et al. (1996) recorded 3.9 mg/L BOD from Ganga Canal at Jwalapur. Khanna et al. (1997) investigated BOD values from 1.85 to 3.15 mg/L in Ganga river at Hardwar, Pandey et al. (1998) reported BOD range from 2 to 6.5 mg/L in a tropical fresh water Kund, Mishra and Joshi (2003) noted BOD values from 0.1 to 2.1 mg/L in Ganga river. The above observations are parallel to the values of BOD observed in the current study period.

Seasonal mean values of BOD in Sonar river water were observed minimum and maximum during rainy and winter season respectively. The dilution of water might be the main factor for reducing the BOD in the same season. The present data gathered for biological oxygen demand agrees with the findings of Young (1974), Jenson (1979), Kumar et al. (2004) from Jamuna river and Gaikwad et al. (2004, minimum-rainy and maximum-winter). Kumar et al. (2004) reported little different result in Kosi river. They observed minimum value of BOD in summer and winter as other workers have noted but for maximum, he differs with them by reporting in rainy season. The maximum BOD was observed during winter season. It might be due to the reason of lower water level in winter in comparison to the rainy season because of evaporation. Nitrogenous components are also very high during the same season. The might be caused the high BOD. Similar findings (higher in winter) have been also reported by Ambasht (1988), Panday et al. (1998) from a fresh water Kund and Kumar et al. (2004) from the Kosi river.

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The correlation of BOD with other physico-chemical parameters have been listed in the Table no. 67.

**Chemical Oxygen Demand (COD)**

COD determination is a measure of oxygen equivalent of the organic matter content at a sample that is susceptible to oxidation by a strong chemical oxidant (APHA 1985). COD is mainly due to the presence of carbonaceous and nitrogenous compound. The COD test does not give any indication of the biodegradability of the wastes (Trivedi and Goel, 1986).

COD values varied between 2 to 17 mg/L during the course of investigation period. Singh and Wadhwani (1989) reported the rang of COD between 6.6 to 14 mg/L from four water bodies of Trans Gomti Area, Lacknow, Parashar et al. (2003) also observed the low rang of variation of COD from 2.20 to 3.51 mg/L from two Ghats of Ganga Canal at Hardwar. The present investigation of the COD derives support from the above research reports.

The lowest and highest seasonal mean values of COD were recorded during summer and winter seasons respectively. The lower concentration of COD was recorded during the summer season might be attributed to the declined decomposition of organic matter. While it was maximum during winter season. This may be due to the presence of high amount of reducing agents in the water body, which increased the Chemical Oxygen Demand (COD). The similar reports were made by Arora et al. (1973), Pandey et al. (1998) and Kumar et al. (2004) in different water bodies. The biodegradable and chemodegradable organic matter were higher in the Sonar river water. This is proved by the positive correlation of COD with BOD.

The correlation of COD with other physico-chemical factors have been tabulated in the Table no. 67.

**Hardness**

The hardness of water is mainly due to the presence of calcium and magnesium salts present in the water, as
carbonates, bicarbonates, sulphates, chlorides etc. Birge and Judy (1911) classified the natural water on the basis of total hardness as:

(i) **Soft water**:- Which contains small amounts of calcium and magnesium in solution and in which the average bound CO₂ dose not exceed 5 mg/L. (ii) **Medium water**:- Which contains bound CO₂ between 5 to 22 mg/L. (ii) **Hard water**:- Which contains more than 22 mg/L of bound CO₂, which may even exceed 50 mg/L. Ohle (1934) classified water on the basis of the presence of calcium content as: (i) **Poor**: Less than 10 mg/L. (ii) **Medium**: Between 10 to 25 mg/L. (iii) **Rich**: More than 25 mg/L. of calcium.

In the present investigations, the seasonal variations show that the minimum of calcium and magnesium hardness along with the total hardness in rainy season when the water level in the river was high. Thus poor concentration in the rainy season might be accounted to the dilution brought about by rain water. However the total hardness as well as the calcium and magnesium hardness was highest during winter season. For the total hardness these findings lead support with the results of Bhowmick and Singh (1985) who worked on Ganga river at Patna, Vijayakumar and Ramesha (2002) who worked on a pond of Karnataka, Pandey and Pandey (2003) who worked on Saryu river. Pandarkar and Mane (2007) who worked on Visapur Dam of Maharashtra. But Olsen and Summerfield (1977), Parvateesam *et al.* (1991) and Duron and Suicmez (2007) registered a different view by recording minimum of total hardness in winter which is just opposite to current findings and maximum of total hardness in summer season.

Singh and Dutta Munshi (1992) and Slathia *et al.* (2001), they agree with the current findings with maximum total hardness in winter season but they reported minimum in summer not in rainy season. While Kumar and Gajaria (1997) and Pandey *et al.* also worked on total hardness but they have
recorded minimum in summer and maximum in rainy season. Just inverse results to this investigation were reported by Mishra and Tripathi (2003) i.e. minimum in winter and maximum in rainy season. However the findings of Sharma and Shrestha (2001) who made investigations on Tinau river in Nepal, were totally different as observed the minimum as well as maximum both levels in summers. In 2004 Gaikwad et al. and Kumar et al. made comments on total hardness respectively in Tapi and Kosi river but they reported minimum of it in rains and maximum in summer season.

Only few of the above mentioned workers have made comments separately on magnesium and calcium concentration. Joshi (1996) worked on Sutlej river and reported maximum of calcium in winter and minimum in rainy season. The present investigations are getting support with his result as well as Bhowmick and Singh (1985). A winter rise of calcium and total hardness could be attributed to thin water volume and low temperature in the same season. However Kant and Raina (1990), Sen et al. (1992) and Slathia et al. (2001) reported maximum calcium concentration in rainy season and minimum in summers. However Bais (1993) reported the nil calcium and magnesium harness in Sagar lake.

Magnesium is main constituent of autotrops. It is required universally by chlorophyllous plants as the magnesium prophyrin component of chlorophyll molecules, and as co-factor for various enzymatic transformation in the cell (Wetzel, 1975). During the course of investigation it was observed that the magnesium content of water started decreasing with the increasing in phytoplankton population. Thus, the maximum value of magnesium content during winter season can be attributed to the less phytoplankton population and consequently fall in the utilization of magnesium content. The minimum values of magnesium hardness were recorded during rainy season. It
might be due to dilution affect of rains water in the same season. Bhowmick and Singh (1985), Kant and Pandey (1985), Joshi (1996) and Slathia et al. (2001) have been also reported the similar findings. While, Kant and Raina (1990) has reported the maximum concentration of magnesium in winter (as found in current observations) and minimum during summer season. Sen et al. (1992) has found the highest magnesium content in the month of August and September and lowest during the months of February and March. However Sharma (2004) have been recorded the maximum concentration of magnesium in summer and winter season than in spring and monsoon.

Table no. 67 shows the coefficients of correlation of calcium, magnesium and total hardness with each other and also with other physico-chemical parameters. Since the total hardness showed a positive correlation with calcium hardness and magnesium hardness, it may be concluded that the total hardness depended mainly on calcium and magnesium salts. The positive correlation of carbonate and bicarbonate with total hardness denote that both types of salts were responsible for total hardness. On the basis of calcium and total hardness concentration, Sonar river can be categorized as medium productive water body.

**Sulphate**

Sulphate is widely distributed and occurs in all kinds of natural waters. Biological oxidation sulphate also increase its concentration. In natural waters, the concentration of sulphate ranges from a few to several thousand milligrams per litre (APHA, 1985). Discharge of domestic sewage, geology of drainage and industrial wastes tends to increase its concentration in water. In the Sonar river, the sources of sulphate were very limited because there is no domestic drainage (sewage), industrial wastes etc. in its surrounding area. Therefore, quantity of Sulphate detected during the study period ranged from nil to 9.9 mg/L.
Studies in the field of limnology conducted so far reveal that the concentration of sulphate differs from water body to water body, due to its location and source of sulphate. Bhatt and Pathak (1990) recorded the range of Sulphate from 0.80 to 3.5 ppm. in Kosi river, Chouhan et. el. (1990) reported the various range of sulphate at the various depth of Narmada river. Kumar and Gajaria (1997) found a range of 28.1 to 57.3 ppm. in the Kunjrao fish pond. The fluctuation of sulphate between 2.33 mg/L to 13.33 mg/L was noted by Nandan and Aher (2002). The observations of Bhatt and Pathak (1990) are parallel to the values of sulphate observed in the present investigations.

The seasonal variations in sulphate content recorded variations. The maximum concentration of sulphate was noted during winter season. It may be due to the decomposition of sulphur compound and biological oxidation of sulphur bacteria. The present finding also drive support from the study conducted by Adoni and Yadav (1985) in a eutrophic Lake of Sagar and Pandarkar and Mane (2007) in Visapur Dam of Maharashtra. The minimum concentration of sulphate was recorded in rainy season. The possible reason for low concentration could be the dilution factor because of increased water level in the season. Kant and Raina (1990) made observations on two ponds of Jammu and reported minimum concentration of sulphate in rainy season and maximum in summers, but Kumar and Gajaria (1997) recorded minimum concentration in winter and maximum in rainy season in the fish pond of Matar village at Hardwar, in 2002 Bhattacharya et al. supported the result of Kant and Raina when they worked on the upper stretch of Gangatic West Bengal.

Sulphate content was negatively correlated with Secchi transparency, which reveals that the colour produced due to sulphate and its concentration, checks the penetration of light inside the water body. A positive correlation of Sulphate with total phytoplankton suggests its importance for the growth of
plankton population. Other values of coefficients of correlation have been cited in Table no. 68.

**Chloride**

Chloride occurs naturally in all types of water due to its high solubility, and is one of the major inorganic anion in water. Its concentration in fresh water is generally taken as an indicator of sewage pollution (Wetzel 1966, Trivedi and Goel 1986).

Nandan and Aher (2002) reported that in case of chloride content showed fluctuations between 11.36 mg/L to 49.5 mg/L on the Mausam river in Maharashtra. In the present investigation, the concentration of chloride recorded varied between (18.9 to 59.6 mg/L). Bhowmick and Singh (1985) reported the chloride range from 14.18 mg/L in July to 28.4 mg/L in April from the Ganga river. Saha (1987) investigated the physico-chemical parameters of a perennial pond at Bhagalpur and reported 3.4 mg/L (October) to 8.5 mg/L (May) chloride. Chouhan et al. (1990) recorded a very narrow range (7.10 mg/L to 9.30 mg/L) of chloride on Narmada river. While a wide range (32.66 mg/L in Monsoon to 854.8 mg/L in summer) of chloride has been reported by Parvateesam et al. (1991) in Anasagar lake at Ajmer. The range of chloride content in the present study appears to be more are less similar to the range reported by Nandan and Aher (2002).

The accumulation of chloride in water bodies received attention of many Indian ecologist. Sreenivasan (1968), Venkateswarlue (1981) etc. reported an increase in chloride content in Indian water bodies. In the current investigation, minimum concentration of chloride content was noted in summer season while, it was maximum in rainy season. Maximum human and animal interferences and increased autochthonous matter during rainy season may be responsible for the greater magnitude of chloride. The observations are in agreement with those obtained by Kant and Raina (1990), Tinti and Saha (1992), Slathia et al. (2001). But unlike these reports
and current investigations Parvateesam *et al.* (1991) and Kumar *et al.* (2004) reported minimum chloride content in Monsoon and maximum in summers. Recently, Pandarkar and Mane (2007) recorded the minimum range of chloride in winter and maximum in summer season.

Chloride content of the river water showed a positive correlation with a number of parameters (Table no.67), which indicates its affinity with almost all the parameters. Chloride has a tremendous power to combine with metallic cations to forms a stable compound. It is due to its lone pair of electron (-) valiancy.

Thus it can be inferred that the average fluctuation and concentration of chloride in Sonar river is a sign of moderate healthy water body, far away from organic pollution.

**Sodium and Potassium**

Sodium and Potassium present in all kinds of water. Potassium is found in smaller amount in comparison to sodium (Goldman and Horne 1983, APHA 1985). Potassium plays a vital role in the metabolism of fresh water. But sodium plays a minor role in aquatic system and its importance to all organisms had been not yet fully understood, except in the case of exchange and transport of ions. Sodium as well as potassium are utilized by Blue-green algae and macrophytes in larger quantities (Wetzel 1966, Brownell 1979). Potassium is required by cells as an enzyme activator and is present in large quantities inside the cells of aquatic biota than in the surrounding medium.

Sodium ranged from 7 to 14 mg/L and potassium varied between 1 to 2.3 mg/L in the water of Sonar river. Verma and Sahu (1985) noticed the range of sodium between 9.50 to 19.76 mg/L and potassium 2.1 to 8 mg/L during their investigations of Sagar Lake. Saha and Pandit (1985) observed the concentration of Sodium between 9 to 26.4 mg/L while, the content of Potassium varied from 0.42 to 1.4 mg/L in a reverine ecosystem. 25 mg/L Sodium and 0.20 mg/L. Potassium have been noticed by

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Kumar (1990) from the high altitude lake of Dashauhar. Bhatt and Pathak (1990) also reported the value of sodium from 2.5 to 9.7 mg/L from the seven sampling stations of Kosi river. The findings of Saha and Pandit (1985) and Batt and Pathak (1990) are parallel with the values of potassium and sodium observed in present investigations.

The minimum seasonal values of sodium and potassium were recorded in summer season. The possible reason for their low concentration in summer season could be the nutrients viz. sodium and potassium might have utilized in large quantity by the organisms, because in the current investigation the planktonic population (phyto and zooplankton) were also found with great magnitude in same season. Gupta and Sharma (2004) and Sivagurunathan and Dhinakaran (2006) observed similar types of diel fluctuations during different seasons of the year.

Sodium and potassium were also reported with great magnitude during winter and rainy seasons respectively. The similar observation have been also observed by Adoni and Yadava (1985) during the investigations of eutrophic lake of Sagar. Higher concentration of potassium during rainy season might be due to the inflow of rain water which carried the potassium contents from agricultural fields and other wastes. Productivity were also comparatively low during rainy season in comparison to the summer. Blue-green algae might not have utilized potassium in large quantity. Ghosh (1997) noticed minimum potassium in winter and maximum in monsoon period in the river Kosi.

Rodhe (1949) suggested a general rule for all fresh water as $\text{Ca}^{++} > \text{Mg}^{++} > \text{Na}^+ > \text{K}^+$ for cations and $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^-$ for anions. Deviation from the pattern is being considered as an indication of pollution. But Rao (1971) found that general rule given by Rodhe (1949) can deviate from the order. The water of Sonar river follows the general rule in case of cations, but as for
as the anions are concerned the order was as $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$ despite the fact it was a non polluted water body. Both these elements indicated a positive correlation with conductivity, bicarbonate alkalinity and total hardness. While sodium was negatively correlated with $\text{CO}_2$, DO, BOD etc. and potassium was negatively correlated with carbonate alkalinity, water temperature and turbidity. The results of correlation coefficient of sodium and potassium with other variables have been given in the Table no.67.
B. Planktons:

Phytoplankton observed in the present investigation, belongs to groups *Chlorophyceae, Bacillariophyceae, Cyanophyceae* and *Euglenophyceae*. Quality and quantity of phytoplankton population, depends upon several environmental factors. In the current study, it was observed that the density of phytoplankton touched peak level in two occasions. The first peak level which was comparatively higher was recorded in the month of April05 and coincided with the rise in temperature and decrease in water level. The second peak was found during the month of March05 and coincided with accumulation of nutrients. Bhowmick and Singh (1985) in Ganaga river at Patna and Sharma and Sahai (1995) on Jari reservoir of Allahabad also noticed the similar findings. Finally, it was calculated that the rich population of phytoplankton was observed during the summers and it was poor in rainy season. Food, rain fall, velocity of current, high turbidity and overcast sky may be independently or collectively be responsible for such a fall in phytoplankton density during rainy season. During the whole investigation period, Blue-green algae (*Cyanophyceae*) were dominant over the rest of the phytoplankton community.

*Cyanophyceae*:

Blue-green algae thrive virtually in all aquatic ecosystems because they have an extraordinary functional and structural heterogenecity (Carr and Whitton, 1973). Blue-green algae benefit not only from their photosynthetic ability but from their chemotropic and heterotrophic capabilities too.

Blue-green algae were dominant over all the phytoplanktonic communities and were seen throughout the investigation period. In the present investigation they were seen minimum (9 org/L) in the month of November04 and maximum (176 org/L) during the month of February05. Patnaik (1973) has reported the minimum and maximum of Cyanophyceae during the month of August and March respectively. While, Rana et al.
observed heavy bloom of blue-green algae in summer (May-June) and late rainy season (September-October).

Chroococcus was the most dominant member of blue-green algae. Inspite of the presence of Chroococcus, Oscillatoria appeared as the second dominant species of Chlorophyceae during the whole study period. Generally, Chroococcus and Oscillatoria were found to be distributed in the entire water body but number of Blue-green algae was observed lower at Garhakota (A6) station in comparison to the other stations. Das and Pandey (1978), Bhowick and Singh (1985), Sharma (1985) Mazhar and Kapoor (1992) and Nayak and Khare (1993) reported the dominance of Blue-green algae with hot summer months and minimum number in rainy or winter season.

Rao (1955) recorded the importance of sunshine for the development of Cyanophyceae while, Munawar (1974) reported the temperature range of 28-30°C to be the most suitable for Blue-green algae. Rao (1955) pointed out that in comparison to temperature the bright sunshine was found more responsible for the growth of Blue-green algae. Munawar (1970) and Hosmani and Bharti (1980) reported that higher concentration of dissolve oxygen, carbonate and total alkalinity favored to the growth of Blue-green algae. Nandan and Patel (1985), Patil and Nandan (1994) and Nandan and Jain (2002) have reported the importance of DO for development and growth of Cyanophyceae.

In the present investigations, the abundance of Cyanophyceae was noted during summers while, it was poor in winter season. The moderate value of Cyanophyceae was noted in rainy season. The above findings lend support of the reports of Joshi et al. (1996) on the Ganga canal, Joshi (1996) on Sutlej river and Kumar and Gajaria (1997) on the fish pond of Matar village. In 1998, Pandey et al. recorded the peaks of Blue-green algae during the summer months. Gaikwad et al. (2004) also estimated the maximum and minimum number of Cyanophyceae during summer and winter season respectively. In the current

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study, the summer peak of Cyanophyceae could be explained to the scorching sun, favorable water temperature and availability of necessary nutrients for development and growth. The positive correlation between Cyanophyceae population and water temperature also provides the support to above conclusion.

The population of Cyanophyceae was inversely correlated with Secchi transparency. Similar relationship of Blue-green algae with Secchi transparency was also recorded by Smith (1986) and Canfield et al. (1989). A positive correlation of Blue-green algae with conductivity and sodium content of water, established the fact that the rich cation water was favorable for the development and growth of Cyanophyceae. Provasoli (1969) also reported positive correlative between Blue-green algae and sodium content of water.

Blue-green algae (Cyanophyceae) was also able to use carbonate more efficiently in comparison to other species of algae, thereby enabling them to photosynthesize at lower carbon dioxide concentration and resulting in more carbonates during their abundance. Due to this fact, a positive correlation was found between population of Blue-green algae and carbonate alkalinity.

Although, Blue-green algae are often found in eutrophic or hyper eutrophic water bodies, but they also known to contribute significantly to the population in mesotrophic and oligotrophic water body. During the study period, it was observed that though Sonar river was moderately productive, the contribution of Blue-green algae was maximum in phytoplankton population.

**Chlorophyceae:**

Group Chlorophyceae varied from 5 org/L to 135 org/L during the period of current study. Chlorophyceae abundant during April05 and lesser in the month of August04. Contribution of Chlorophyceae to total phytoplankton ranged from 13.33% to 45.07%.
Temperature has been considered as an important factor for regulating the growth and distribution of Chlorophyceae. Bhoomnck and Singh (1985) at Ganga river, Sharma et al. (1990) on Bhilangana river, Pandey et al. (1998) on tropical fresh water Kund and Kala and Sharma (2002) on Alakananda river also reported the maximum growth of Chlorophyceae in the warmer months of the year. Gaikawad et al. (2004) recorded that the first maxima of Chlorophyceae occurred during summer season and second during winter season, when the temperature fluctuated between 19°C to 41°C. Sharma and Sahai (1995) has been also noted the maximum value of Chlorophyceae during summer season. Kant and Anand (1978) and Nayak and Khare (1993) described a gradual rise in temperature from February onward, as optimal condition for the growth and reproduction of Chlorophyceae. In present investigation there was a gradual rise in the population of Chlorophyceae from February onward and touched a peak level in April. Observation of the present study is in the agreement with findings of Kant and Kachroo (1977) and Pandey et al. (1998). It has been observed that the favorable temperature for the growth and development of Chlorophyceae ranged between 22°C to 25°C. Though, temperature affected the growth and periodicity of Chlorophyceae so, in the present investigation period, Chlorophyceae yield was maximum during summer season. The summer maxima can be attributed to:

1. Low water level
2. Maximum mineralization
3. Sufficient light and favorable temperature.

Kant and Anand (1975) observed that Chlorophyceae multiplied rapidly in Mar. and poorly represented in rainy season. In the present investigation, the poor concentration of Chlorophyceae was observed during rainy season. High turbidity and dilution effect were observed to be responsible for reducing the Chlorophyceae population. The above recordings lend supports of the report of Sharma (1985) on Bhagirathi river, Sharma and Sahai (1995), Khanna et al.
(1997) on the Ganga river, Kumar and Gajaria (1997) on a fish pond, Pandey et al. (1998) on a tropical fresh water Kund, Kala and Sharma (2002) on Alaknanda river and Gaikwad et al. (2004) on Tapi river. Here it was observed that the maximum number of Chlorophyceae was found in the Umaria (A1) station in comparison to the other stations.

According to Gonzalves and Joshi (1946) and Zafar (1967) high pH was favorable for the development of Chlorophyceae. Volecha (1983) in lower lake of Bhopal, recorded the maximum development of Chlorophyceae when the pH values ranged between 7.8 to 9.5 pH. In the present study, the above report supports the positive correlation between pH and Chlorophyceae.

A positive correlation was found between Chlorophyceae and carbonate alkalinity, while an inverse correlation was estimated with bicarbonate alkalinity. Mostly, the members of Chlorophyceae were responsible for carbon assimilation. During the abundance of Chlorophyceae, free CO₂ might be completely utilized and created a deficit of carbon-dioxide. At the same time bicarbonates present in the water might have been converted in to carbonate and released CO₂ to compensate the deficit. Due to the above conversion the carbonate alkalinity increased with the increase in the density of Chlorophyceae, resulting in a positive correlation. Correlation coefficient of Chlorophyceae with other physico-chemical parameter with zooplankton community are given in the Table no. 68.

**Bacillariophyceae:**

During the investigation period of Sonar river, members of Bacillariophyceae group ranged between 2 to 98 org/L. It was minimum in the month of September04 and maximum during the month April05. Vyas (1968) reported two peaks of diatoms in October and May in the Pichola lake at Udaipur. Patnaik (1973) also reported to peaks of diatoms in April and June in the Chilka lake of Orissa. Kant and Anand (1978) noted the maximum number of Bacillariophyceae during rainy season.
While, Sharma and Gupta (1981) showed the maximum abundance of Bacillariophyceae in early morning hours but there poor quantity at the evening and night hours during the study of diurnal variation of a shallow pond of Aligarh. In the present study period, the great magnitude of Bacillariophyceae was found in summer season while they were observed lesser during rainy season. According to Rao (1977) the seasonal fluctuation of diatoms dose not follow any definite pattern, because certain form of diatoms multiply in summer season and others during winter season. Sharma (1985) noted the winter peak in Bhagirathi river, Ab Hussein and Mason (1988) recorded the peak of diatoms during winter and early summer and associated it with relatively high level of soluble reactive phosphorus and nitrate. Chouhan et al. (1990) reported the abundance of Bacillariophyceae at different levels of depth from the Narmada river. Mazhar and Kapoor (1992) noted the maximum percentage of diatoms in the month of January from Dorania river. Nayak and Khare (1993) exhibited dominance of diatoms in summers. While Joshi in the Sutlej river and Joshi et al. (1996) in Ganga Canal estimated the peak level of Bacillariophyceae during the winter season which, subsequently declined rapidly to a minimum level in August and June respectively. Kala and Sharma (2002) have reported the maximum and minimum concentration of Bacillariophyceae during the summer and rainy season respectively from the Alaknanda river at Garhwal Himalaya. In the current investigations the peak of Bacillariophyceae was observed in summers and least number in rains. These results are in accordance with results of Nayak and Khare (1993 for two lakes of Panna), Pandey et al. (1998 on tropical fresh water Kund). In 2002 Kala and Sharma have also reported the maximum concentration of Bacillariophyceae during summers and minimum in rainy season from Alaknanda river at Garhwal. It was also observed that the percentage composition of diatoms was higher in winter season and lower in

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summer season. A positive correlation has been found between the population of Bacillariophyceae and water temperature during the study period. The average annual values of Bacillariophyceae population indicate that they were maximum at Umaria (A1) station and minimum at Garhakota (A5) station (Table no. 41a to 45b).

A direct relation of water temperature with diatoms population was reported by Sharma and Pant (1979), Khan and Ejike (1984). However, several ecologists recorded an inverse relationship between water temperature and diatoms population (Rao 1955, Datta et al. 1959, Mathew 1972). Zafar (1964) observed that phosphate and sulphate nutrients were responsible for diatoms population. According to him phosphate and sulphate was more important for the growth and periodicity of diatoms. In the present study, the positive correlation between sulphate and Bacillariophyceae provides support, above conclusion. The result of correlation coefficient of Bacillariophyceae with other physico-chemical parameters have been given in the Table no. 68.

**Euglenophyceae:**

During the investigation period, Euglenoids were present in lowest number among the phytoplankton community. Irregular distribution and poor concentration of Euglenophyceae in Sonar river water was an indication of healthy water body. Rao (1955) and Hutchinson (1967) reported abundance of Euglenophyceae in rich organic matter, high temperature and elevated concentration of CO₂. In the current study, the value of Euglenoids ranged between nil to 14 org/L. It was found that they were totally absent at Garhakota (A5) station throughout the year. Euglena, the most dominant member of Euglenophyceae was noticed at Umaria (A1) station. While maximum number of Euglenophyceae was found during the month October at Gourjhamar (A3) station. Bais et al. (1993) found the range of Euglenoids between 11 to 678 org/L in the Sagar lake. Kumar and Gajaria (1997) noted the range of

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Euglenoids from 2.1 to 14.8 org/L form the fish pond of Kunjrao (Gujrat). Nandan and Aher (2002) have reported the range of Euglenophyceae between 10 to 45 org/L during the period from 1998 to 1999 and between 5 to 50 org/L in 1992 to 2000 from the Mausam river in Maharashtra. In the same year Nandan and Jain recorded the minimum and maximum magnitude of Euglenoids from 143 to 178 org/L respectively from Sonvad dam of Maharashtra.

In the current study, the greater numbers of Euglenoids were observed during summer months. It could be attributed to high temperature, low water spread area, high pH and higher concentration of oxidizable organic matter during the same months. Nayak and Khare (1993) from two lakes of Panna, Kumar and Gajaria (1997) from a fish pond of Matar village (Gujrat), Pandey et al. (1998) from a tropical fresh water Kund, Gaikwad et al. (2004) from Tapi river and Negi et al. (2004) from a Wetland of Himachal Pradesh also estimated the abundance of Euglenophyceae during the summer season. It was also observed that they were poor during winter season. The similar results were also recorded by Nayak and Khare (1993) and Kumar and Gajaria (1997).

A strong positive correlation of Euglenophyceae with hydrogen ion concentration indicates that the population of Euglenophyceae preferred high alkaline environment of water for their development and growth. The correlation coefficient of Euglenophyceae with other physico-chemical factors have listed in the Table no. 68.

Zooplankton :-

Due to relatively long life span presence through out the year, and their role as grazer of algae and bacteria, zooplanktons particularly crustacean species, act as integrator of a variety of physico-chemical and biological conditions in water body and abundance should be a measure of productivity of water body (Chapman et al. 1985). Community of zooplankton in Sonar river
consist of *Rotifera*, *Copepoda*, *Cladocerance*, *Protozoan* and *Ostracods* in order of dominance. Conspicuous seasonal variation of zooplankton was observed during the investigation period. The population of zooplankton ranged from 40 org/L to 328 org/L. The maximum number of zooplankton was recorded in the month of June05 and minimum during the month of November04. In case of station wise variation, they were observed minimum and maximum respectively at Rehli (A4) and Garhakota (A3) stations. Seasonal peak was recorded during summer season while, they were poor in number in rainy season. The summer peak of zooplankton might be due to these suspected reasons. (1) The temperature of summer season was higher which stimulated the reproduction, development and growth of zooplanktons. (2) Alkalinity, higher pH, hardness and some other important nutrients during same season may also have favored the growth and development of zooplankton directly or indirectly. (3) Low concentration of water during summer season might be another reason for their summer peak. (4) Zooplanktons are the primary consumers but Flora (phytoplankton) is known as primary producer. Since phytoplankton serve as food of zooplankton, their abundance during same season might have enhanced the population of zooplankton in the water body.

George (1961) reported the maximum population of zooplankton in winter season. However, Robinson and Robinson (1971), Rao *et al.* (1981) reported the maximum abundance of zooplankton in summer months. Ramakrishnaiah and Sarkar (1982) reported the peak of zooplankton during April-June. While Sharma and Sahai (1995) estimated the peak level of zooplankton community in warmer months. Current results go along with the results of Ramakrishnaiah and Sarkar (1982) and Sharma and Sahai (1995).
Rotifera:

The population of Rotifera never exceeded more than 195 org/L in Sonar river, during the course of study period. They were poor (10 mg/L) in the month of July 04 at Kesli (A2) Station while their maxima (195 org/L) was noted during the month of June 05 at the same station. Robinson and Robinson (1971) reported the maximum density of Rotifera during the month of May-June and August-September from the Chad lake. Patnaik (1973) had been noticed the peak level of Rotifera during the months of November, February and March from the various sampling stations of Chilka lake.

Mazhar and Kapoor (1992) calculated the minimum percentage of Rotifera in April and maximum during the month of October. While Slathia et al. (2001) reported the minimum and maximum number of Rotifera during the months of January and April respectively.

Among the different Seasons, the peak level of Rotifera was recorded during summers. Vashisht (1968) reported maxima of Rotifera in summers in tropical water. Bhati and Rana (1987) recorded the peak of Rotifers in winter and summer Seasons. Chouhan et al. (1990) noticed the Rotifera as dominating group at various depth of Narmada river. Mazhar and Kapoor (1992) in the Dourania river and Sharma and Sahai (1995) in Jari reservoir reported the maximum number of Rotifera in summers.

Apart from this, some workers like Slathia et al. (2001), Negi et al. (2004) and Indra and Ramanibai (2006) have also recorded the maximum density of Rotifera during summer season. But, Nayak and Khare (1993) and Joshi et al. (1996) found the peak level of Rotifera during winter season. However maximum and minimum number of Rotifera was reported during the rainy and summer seasons in Tapi river by Gaikwad et al. (2004).

In the present study, the minimum number of Rotifera was reported during the rainy season. Similar findings have been
established by Slathia et al. (2001), Negi et al. (2004) and Indra and Ramanibai (2006).

However Pennak (1949, 1955) did not report any seasonal variation in Rotifera and Wesenberg-lund (1910) recorded slight fluctuation in the number of Rotifera with the change of season. Clear seasonal variation in Rotifera was reported by several workers like Awatramani (1980), Gupta (1984), Singhai (1986) and Howkins (1988).

Byars (1960) reported that the temperature is an important factor responsible for the productivity and growth of Rotifera. However Pejler (1957) mentioned that not only temperature, but also a set of other physico-chemical factors too influenced the population of Rotifera. According to him some Rotifera preferred winter season while others were abundantly found during summer season. In the current study, although the maximum number of Rotifera where related with summer months. Strong positive correlation of Rotifera with temperature provides the support of the reports of Byars (1960). A positive correlation has been also obtained between Rotifera and conductivity. Conductivity of water depended on the concentration of dissolved solids in the water. Hence both can be considered as inter-related factors. The positive correlation of Rotifera with conductivity can be explained as the dependent nature of conductivity on the presence of organic and inorganic anions like Carbonate, Chlorides, Sulphate, Phosphate etc. in combination with metallic cations such as Ca$^{++}$, Mg$^{++}$, Na$^{+}$, K$^{+}$ etc. Hence the higher values of conductivity indicates that the above mentioned organic and inorganic ions were present in appreciable amount and served as essential nutrients for the development and growth of aquatic biota (Rotifera).

A positive correlation of Rotifera with bicarbonate and total alkalinity were also established. Some limnologist considered that the Rotifera prefers the alkaline medium of water. They also reported that the presence of Brachionus as an

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indicator of high alkalinity and is also known to be a characteristic of hard water. Rotifera have been assumed as indicator of water quality for the first time by Kolkwitz and Marrson (1902, 1909). Later on Kolkwitz (1935) listed two species of Rotifera as polysaprobic, six taxa as alphamesosaprobic, seven as betamesosaprobic and three as oligosaprobic according to their occurrence in different types of water body.

Positive correlation of Rotifera population with chloride, total hardness, sodium, potassium and negative correlation with turbidity and acidity have been also found (Table no. 69).

_Copepoda_:  

Copepods registered their presence through out the year but it was minimum (6 org/L) in the month of January at Kesli (A2) station and maximum (172 org/L) during the month of June at Garhakota (A2) station in the whole study period. _Cyclops_ and _Neodiaptomus_ were the members, which constitute the major part of Copepods population. However, _Nauplius_ and _Diaptomus_ were also present in the group of Copepoda. The _Cyclopoids_ remained dominant through out the year except on a few occasions (Table no.61a to 65b) Swar and Fernando (1980) and Sharma and Saksena (1983) also reported the dominance of _Cyclopoids_ throughout the year while, Mazhar and Kapoor (1992) have reported abundance of _Cyclops_ sp. as well as _Diaptomus_ sp. from Dorania river (Bareilly U.P.). They found the maximum percentage of _Cyclops_ in April and minimum during the month of May.

In the current findings, the presence of maximum number of Copepods in the month of June, can be attributed to the low water level. A review of concerned literatures showed that the monthly peaks of Copepods did not follow any definite pattern (Chapman 1972, Vashisht and Jindal 1980). Govind (1963) observed the three peaks of Copepods during the month of February, June and October in 1961. Joshi (1996) and Negi _et al_.

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(2004) noted the peak of Copepods in the month of April. While, Poulouse and Maheshwari (2006) have been reported the abundance of Copepods during the months of October and November in Ramgarh lake of Jaipur.

During the current investigation, it was also observed that the peak of Copepods was detected in summer season. It might be due to low concentration of water and sufficient temperature and food for their growth and development. While, they were poor during winter season. It may be due to low water temperature which affected directly or indirectly to their food supply. Awatramani (1980), Unni (1984) observed the dominancy of Copepods during summer months. Patil and Gouder (1985) reported irregular pattern in the periodicity of Copepods during summer season. Nayak and Khare (1993) noted the highest and lowest values of Copepods during the winters and monsoon. While, Gaikwad et al. (2004) found the maximum number of Copepods during summer and totally absent in winter season.

The finding of Awatramani (1980), Unni (1984) and Gaikwad et at. (2004) lend support to the findings of present investigations. A persual of Table no.68 reveals the importance of environmental factors in relation to the population of Copepod during the study period.

Cladocera:

The population of Cladocera was varied from 4 to 57 org/L during the whole investigation period. They were minimum in the months of September at Kesli (A2), December at Gourjhamar (A3) and January at Rehli (A4) and Garhakota (A5) stations. While their peak level was seen in the month of April at Umaria (A1) station. Patnaik (1973) had observed the peak level of Cladocera in August-November during the whole study period. Sarma and Pattanaik (1985) noted the minimum and maximum percentage of Cladocera from 2.13% to 25.05% during the month of December and March respectively. While the maximum percentage of Cladocera in the month of December and
minimum percentage during the month of May were reported by Mazhar and Kapoor (1992) in Dorania river.

Seasonally the highest population of Cladocera was recorded during the summer months. Das and Shirvastava (1956) observed the peak of Cladocera in December and January while Awatramani (1980) found Cladocera virtually absent during winter season in Sagar lake. Wishard and Mehrotra (1988) also recorded a sparse distribution of Cladocera in Gularia reservoir during winter season. Joshi (1996) reported the summer peak (February-April) of Cladocera in Sutlej river.

In the present study, the highest population of Cladocerans was found in the month of April. The abundance of Cladocerans during summers (April) might be due to the presence of sufficient food, low concentration of water and favorable water temperature. Gaikwad et al. (2004) in Tapi river and Negi et al. (2004) in the Pong Wetland (Himachal Pradesh) also reported the similar findings.

The present findings are contrary to the finding of Patil and Gouder (1985) who reported the abundance of Cladocera at low temperature. The poor density of Cladocerans was recorded during rainy season. Poor number during rainy season might be due to the water current and dilution factors. Sharma (1983) reported that after July the density of Cladocerans declined sharply. Nayak and Khare (1993) also recorded the poor concentration of Cladocera during rainy season. However, the minimum and maximum density of Cladocera was calculated in winter season by Gaikwad et al. (2004) in Tapi river and maximum density was reported by Poulouse and Maheshwari (2006) from Ramgarh lake during same season.

In the current investigations, several physico-chemical parameters were found positively correlated with Cladocerans populations which were also directly or indirectly related with food supply (Table no. 68).
Protozoa:-

Protozoans ranged from 0 to 72 org/L during the course of current study. The maximum density of Protozoans with maximum percentage (42.35) was recorded in the month of July04 at Garhakota (A3) station. The maximum percentage composition of Protozoans in July04 could be explained in term of accumulation of allochthonous matter in the water body from catchments area through run off water during the first showers of the rain. Cairns (1965) and Patnaik (1973) also studied the density of Protozoans increase with organic matter present in the water body. As far as seasonal flucutation is concerned, the maximum density of protozoa was reported in summer season. It might be favorable condition and low concentration of water in same season. Sharma (1983) observed the maximum population of Protozoa in the month of March, Ganpati (1964) in Almati reservoir and Awatramani (1980) in Sagar lake recorded the maximum population of Protozoa in the month of February. Barbieri and Orlandi (1989) observed that the peak of Protozoa during summer season when dissolve oxygen concentration become low. Nayak and Khare (1993) also reported the maximum density of Protozoa in the summer months. Slathia et al. (2001) have also found that the maximum concentration of protozoa in warmer months of summer season. Recently, Paulose and Maheshwari (2006) reported the highest concentration (38.3%) of Protozoa during the month of Feb. when the total zooplankton population was at the lowest level.

In the present study, the moderate values of Protozoa was observed during rainy season while, they were poor in winter season. It might be low water temperature and poor ability of food particles in the same season as compared to other seasons. Several physico-chemical factors were found to be responsible for the growth and development of Protozoa population which are amply supported by the results of coefficients of correlation of Protozoa with physico-chemical factors (Table no. 69).
Ostracoda:-

Cypris and Stenocypris were the representatives of Ostracoda and their contribution was relatively minimum to the zooplankton community. Indra and Ramanibai (2006) observed three species of Ostracoda with much reduced abundance, from Chennai Coast (Tamil Nadu). Poulse and Maheshwari (2006) also found three species of Ostracoda with their very poor percentage to zooplankton population. While, Thirumala et.al. (2006) noted only one species of Ostracoda from Ayyanakere lake of Karnataka.

Their numerical abundance never exceeded beyond 42 org/L. Besides, they could not be traced during several months. The maximum population of Ostracoda was found in the month of June at Kesli (A2) station. Joshi (1996) reported the abundance of Ostracoda during February-April in Sutlej river.

Seasonal fluctuation of Ostracoda population was also recorded. The minimum and maximum density of Ostracoda was found during the rainy and summer season respectively. Low population of Ostracoda in rainy season may be due to dilution factors. While, low concentration of water level and suitable water temperature might be responsible for the summer maxima. Only few workers have made reports the presence and the seasonal variations of Ostracoda. Young (1974) recorded the irregular fluctuation of Ostracoda during his study period. While, Joshi (1996) noted the peak level of Ostracoda in summer months. The coefficient of correlation of Ostracoda with physico-chemical parameters and, other plankton groups have been listed in Table no. 69 and 70.
C. Inter-relationship among planktonic population

A qualitative and quantitative study of phyto and zooplanktons provides the relationship between them. Phytoplanktons are known as primary producer and zooplanktons as primary consumer of any aquatic ecosystem. The variation in the population of primary producers is regulated by several environmental factors like light intensity, water temperature, alkalinity, hardness, availability of nutrients, rate of reproduction, rate of removal due to death or consumption by zooplankton and other aquatic organisms. Generally, the relationship between phytoplankton and zooplankton has been accepted but whether it is positively related or inversely related has been a controversial matter for a long time.

Inverse correlation between phytoplankton and zooplankton had been recorded by Wright (1954, 1958), Das and Shrivastava (1956 a), Moitra and Mukharji (1972) and Awatramani (1980) in different water bodies. But Goldman et al. (1968) reported the positive correlation between these two communities. In the current investigation also positive correlation has been observed between the two communities. (Table no. 70). Generally, zooplanktons are herbivorous in nature and depend on phytoplankton for their nutrition. Whenever, there is abundance of phytoplankton in the water body, the zooplankton populations also increase. This is because whenever food is sufficient and temperature is suitable, the reproduction and development of zooplankton is enhanced. During the present study, the maximum number of phytoplankton and zooplankton population was observed in the months of April and June. In April, the population of phytoplankton was maximum but there after a decline was noticed due to the pressure of zooplankton population. According to this theory, the zooplankton and phytoplankton show an inverse correlation (Anderson et al.)
1955). But it has been reported by several ecologists that the zooplankton consume only a certain portion of phytoplankton, which are smaller in size (Porter 1973, 1977 and Gliwicz 1977). Kajak (1980) also reported in his findings that zooplankton are unable to control the blooms of algae. Hence, a positive correlation between phytoplankton and zooplankton observed during the current investigations provides the supports to the above findings.

Michael (1968 a) recorded that the total abundance of micro-crustaceans showed direct relationship with phytoplankton community. Similar findings have been reported in the present investigations (Table no. 70). Though, all the groups of phytoplankton showed positive relationship with total phytoplankton, but the correlation between Cyanophyceae and total phytoplankton was found strongest (r=0.831). Thus it can be concluded that Cyanophyceae formed a major part of the total phytoplanktonic community.
CONCLUSION

We have been using the inland water resources for numerous purpose for many years. Our country is rich in large number of lentic and lotic water resources with a rich flora and fauna. These resources are indispensable, as they satisfy our domestic and industrial needs. Such aquatic water bodies not only provide transportation, hydroelectric power but also a means for sewage and waste disposal, fish for food and sport, and other recreations, including aesthetic appreciation (Cole, 1979).

The fast urbanization and industrialization have adversely effected by pollution to our valuable water resources. A large number of limnological factors with organic and inorganic compounds dissolved in water have created a stressed condition and polluted environment to the plant and animal species inhabiting in it. The biochemical parameters exist in a fixed space and having dynamic ecological balance, the stress of pollution gets altered. It is also true pollution is increased when the contamination level crosses beyond the self regulatory mechanism. Therefore, these are the basic reasons to have a change in natural physico-chemical and biological spectrum in fresh water system.

Since fishes have rich nutritive value and can solve the food problem up to a certain extent, it is very essential to manage the water resources related with fish culture scientifically. Though, several limnological studies have been conducted in ponds, lakes, reservoirs and rivers but, limnologists have not yet paid much attention towards the study of physico-chemical and biological factors with a view to enhance the fish production, rivers cover a major portion of fresh water in our country which could be utilized for fish culture as well as other purpose. The various organisms inhabiting a water body are generally linked together in food chains in accordance to their mode of obtaining energy. It is known as trophic structure. Therefore, the water and its flora and fauna play a key role in deciding the production potential of an aquatic system.
Therefore, the limnological information is the essential tool in enhancing the productivity of available water resources.

During the recent few years pond fishery has become popular not only in our country but all over the world. The inland water areas of our country have immense potential for increased food production, especially the ponds. However a large number of natural water bodies and man made lakes have not been exploited in our country through proper culture based fishery. As a matter of fact the fish farming is the practical application of limnology and aquaculture biology, through which we can fulfill the protein requirement of our society.

India represents the tropical region which has specific range of annual variability of sunlight, temperature and ecological conditions. The annual changes of climatic conditions, physico-chemical and biotic parameters in tropical water differ greatly with temperate waters. Therefore, the efficiency and variability of trophic structure must also differ greatly between these regions. The multidimensional uses and management of such valuable water resources may be possible only by knowing their present limnological and ecological characteristics.

It is a matter of fact that a big number of fresh water resources of our country especially ponds, reservoir, rivers and even natural lakes are being eutrophied and degraded because of regular lauding of nutrients. Most of the polluted water bodies have a huge number of vegetation and algal blooms covering the open area of water. The nutrients containing phosphorus and nitrogen generally increase the productivity of water body. It is thus obvious that the species composition of plankton inhabiting in such deteriorating water conditions may be highly useful in predicting water conditions and its potential of productivity.

Thus present observation were undertaken to note the relevant data of fresh water Sonar river of Sagar district. After knowing the physico-chemical and biological conditions of that water body, it would be possible to suggest some appropriate steps in order to further conservation and management.

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