CHAPTER 3

INDIAN LIMNOLOGY, A REVIEW
The publication of Prasad 1916 is the pioneer work in the field of Limnology in India. After this several publications are made by various workers in this field. To highlight a few are those of Iyengar (1940) on the algal flora of some muddy rain water pools; Gonzalves and Joshi (1946), Suxena (1955), Ganapati (1955-1956), Singh (1959) on the ecology of phytoplankton. Increased eutrophication of ponds, lakes and reservoirs attracted many workers. In recent years a number of publications have appeared. To mention a few are those of Zafar (1953-1967), on limnology of ponds and lakes; Khan and Quayyam (1966), on ionic composition of inland waters, Munawar (1970-1974) and Rao (1971-1975) on the ecology of freshwater ponds; Kant and Kachroo (1973) on the limnology of Kashmir lakes; Hosmani and Bharati (1975-1980), on the limnological studies of Dharwad.

During 1980, two review articles based on the Indian limnology have been published. Prasad and Singh (1980), reviewed both lotic and lentic water limnology based on 94, papers published in various journals of India as well as abroad by various workers. This review contains physical factors such as temperature, chemical factors, such as pH, alkalinites, silica, chlorides, iron, phosphates, nitrogen factors, dissolved oxygen, organic matter and biological factors include algal periodicity, water bloom, diurnal variations and pollution biology. They are of the opinion that the pollution ecology of inland waters of India is in infancy and attempts should be made to study the algal community in relation to pollution on long-term basis, structural changes in the community complex should be studied as it is believed that, individual taxa, because of the complexity of factors involved, can't serve as useful indicators of water quality.

Gulati and Wartz Schulz (1980) reviewed Indian works and in the status of limnology in India based on the publications in "Hydrobiologia" on various
aspects, such as ecology of ponds, water chemistry, plankton, algal diurnal variations, productivity and zooplankton. They are of the opinion that limnologists should concentrate more on problems related to utilization of water resources for food production, pollution control, public health water supplies, and interdisciplinary education programs.

After 1980 several limnological studies on inland fresh waters of India have been made. However, no review has been made after 1980. Therefore, an attempt is made to review the progress of Indian limnology after 1980. Thus, the review in this chapter comprises results of several papers published in various journals by Indian Limnologists. In all 162 number of available papers have been consulted. For convenience all the papers referred in this Thesis have been arranged alphabetically in the reference section and are being serially numbered. In this review chapter, the concerned papers have been referred with corresponding numbers. In the discussion part the papers are referred with authors names and year of publication.

WATER TEMPERATURE:

The temperature fluctuations and thermal patterns of few Indian lakes, reservoirs, tanks and ponds have been described by many workers. Very wide range between air temperature and water temperature is noticed in small pools where there is less water. The direct relation between air temperature and water temperature has been recorded by many workers. This has been attributed to the shallow nature of the habitats, may be for this reason thermal stratification is not common in Indian waters as there would be sudden mixing up of water. However, a gradual rise in water temperature from winter onwards has been observed in the pond resulting in thermal stratification and thermocline formation during summer.
(January-June) which declines steadily due to wind action, decreased day length, and heavy rainfall. The bimodel peak of water temperature, one during summer due to the solar influx on the surface phenomena and another during monsoon has been observed, as the lake portrayed a state of non-stratification because of the rapid circulation of the absorbed atmospheric heat by the overlying effect of wind.

The E.C and pH are controlled by temperature. Direct relation of water temperature with DO has been observed. It may be due to the enhanced photosynthesis by phytoplankton. Contradictory to the above observation, the inverse relation between water temperature and DO has also been noticed may be due to the enhanced rate of decomposition due to rise in water temperature which leads to the depletion of DO.

There are several opinions about temperature relation with plankton production. This is due to the nature of the habitat. A rise in temperature leading to the increase in phytoplankton mass is observed in two fish ponds where there was high pH and DO content. Contrast to this, in rock pools, there was a decline in productivity due to rise in temperature. Thus, the water temperature is found to play an insignificant role on the seasonal changes of plankton as is the typical observation of tropical ponds.

pH:

There is a diverse opinion regarding the seasonality of pH in Indian waters. During summer the decrease in pH is found to be due to the increased rate of decomposition of the organic matter in bottom soil. Summer high temperature accelerate this process, which would accumulate more free CO₂ and subsequently decrease the pH. On the contrary, the monsoon decrease in pH has been found to be due to inflow of rain water, resulting in the dilution of
alkaline substances on one hand and also due to dissolution of atmospheric CO₂ during monsoon there would be a continuous liberation of free CO₂ through respiration and decomposition of biota, consisting mainly macrophytes, resulting in anoxic conditions at the bottom and decrease pH level. Similarly the winter minimum of pH is attributed to the low rate of photosynthesis because of prevailing low temperature and accumulation of more CO₂. However, the highest values of pH in this season has also been observed. This has been reasoned out to more oxygen holding capacity of water due to low temperature and comparatively less rate of decomposition. On the contrary, the high pH during summer is due to high photosynthetic rate and CO₂ is extracted from HCO₃ leading to increase in CO₃ content and the pH. In few cases monsoon maxima of pH has also been noticed and is attributed to inflow of allochthonous materials from the catchment areas.

Higher the pH indicates the high degree of photosynthetic activity resulting in high primary production and plankton bloom and also is an indication of DO supersaturation. The pH and DO are dependent on photosynthetic process which utilizes the CO₂ and increases the levels of DO and pH. Thus pH exhibits an inverse relation with CO₂ and a direct relationship with DO, CO₃ and Dissolved solids. The low pH tends to dissolve the calcium which has been precipitated at higher pH during the high photosynthetic periods of summer. Some nutrients particularly the phosphorous is also co-precipitated with calcium and are released into the water.

The study on pH in Indian lentic waters thus indicates that it would not follow a definite seasonal pattern. The decrease in pH during summer is attributed to increase in CO₂ due to the decomposition of organic matter at higher temperature and winter decrease would be due to low rate of photosynthesis resulting in
more accumulation of \( \text{CO}_2 \). However, many workers have noticed winter maxima due to increased \( \text{DO} \) content because of low rate of decomposition at low temperature. Similarly summer maxima is noticed whenever there is high photosynthetic rate utilizing \( \text{CO}_2 \). Thus \( \text{pH} \), \( \text{DO} \) and \( \text{CO}_3 \) increase with decrease in \( \text{CO}_2 \) during summer. Low \( \text{pH} \) has been found to release more \( \text{Ca} \) which has been precipitated during high photosynthetic period.

**TURBIDITY:**

Not much information on turbidity of Indian water is available. Generally tropical reservoirs have higher turbidity as compared to their temperate counterparts. In lakes the turbidity is due to the eroded soil particles, colloidal suspension and pigments caused by decomposition of organic matter.

The high turbidity values during monsoon is reported by many workers. It is generally due to the inflow and addition of large amount of suspended organic matter and soil particles. Higher density count of phytoplankton and the concentration of total solids also leads to the high turbidity, which indicates the eutrophication. Turbidity retards the photosynthetic rate and minimises the growth of phytoplankton showing an inverse relation. The significant negative correlation between turbidity and methyle orange alkalinity is also seen.

**ELECTRIC CONDUCTIVITY (E.C):**

The E.C is the indicator of concentration of electrolytes in an ecosystem, which indicates the rate of metabolic activity. Low E.C. in the major and medium reservoirs is due to large quantity of water in them and high E.C. in the minor reservoirs is due to the lesser in quantity of water. Thus it shows an inverse relation with the size of the pond.
Higher E.C. values during summer\textsuperscript{25,92,231,239} is found to be due to lower water renewal capacity and more evaporation rate resulting in the retention of more salts. The monsoon higher E.C.\textsuperscript{355} may be due to the surface run off, mainly the inflowing sewage, which adds minerals the water.\textsuperscript{156,355} The post-monsoon maxima of E.C. would be due to the increased concentration of salts if there is a retarded precipitation coupled with the faster evaporation decreasing the water volume considerably.\textsuperscript{60} However, the minimum values during monsoon would be mainly due to dilution.\textsuperscript{25,60} The richness of waterbody, in other words the high nutrients, is related to the increase in E.C.\textsuperscript{312} showing the higher degree of nutrients\textsuperscript{355,385} thus indicating the high trophic status.\textsuperscript{385}

Since E.C. is mainly dependent upon the concentration of salts it shows positive correlation with salinity\textsuperscript{239}, and its components such as Na, Ca, Mg, CO\textsubscript{3}, HCO\textsubscript{3}, SO\textsubscript{4},\textsuperscript{350} and Chloride\textsuperscript{243,350}. pH,\textsuperscript{231,230,239} atmospheric temperature\textsuperscript{239} and negative correlation (inverse relation) with DO.\textsuperscript{92}

In conclusion the E.C. of smaller waters such as ponds remains always more than the bigger habitats such as reservoirs. Normally the summer increase is due to evaporation and consequent decrease in water volume resulting in increase of salt concentration. On the contrary the monsoon decrease takes place as a result of precipitation diluting the water. But this depends on the quality of inflowing water as sewage contamination in the catchment area would rather increase the E.C. in either monsoon or post monsoon seasons. Since E.C. is directly related to the salinity and its components it is considered as a good indicator of trophic level.

**DISSOLVED ORGANIC MATTER (DOM):**

Dissolved Organic Matter, is mainly dependent upon water temperature and
DO. Tropical waters have higher values of organic matter that reach their peak during summer. In winter, the values of DOM may decrease due to its utilization by macrophytes. On the contrary the higher value of DOM during pre and post monsoon seasons, appeared to be due to partially decomposed aquatic submerged vegetation and the water logged conditions. During winter the high amount of organic matter is due to low rate of photosynthesis coupled with high decomposition rate. The monsoon maxima of organic matter is also reported which is attributed to the inflow of water with sewage from surroundings. The increase in organic matter results in high BOD and COD decreasing the DO. This reduces the pH.

High degree of organic pollution favours algal growth resulting in blooming of algae. Higher inflow of organic matter leads to eutrophication through higher production.

Thus it is concluded that, there is not much information available on the organic matter in Indian waters after 1980. Many have stressed that its concentration increases during summer. However, during monsoon also it may increase if the inflowing water gets mixed with sewage. The concentration goes down during winter due to its utilization.

CHLORIDE:

The inflow of sewage and drains rich in animal refuse are the main source of chloride content in ponds. Chloride shows a well marked seasonal variation. The summer increase is due to loss of water by evaporation because of high temperature. The same during rainy season may be ascribed to influx of rain water and bathing activity in certain places. However, the decrease during winter may be due to the dilution of...
water resulting from the rains of the previous season. High chloride may account for organic effluents indicating the organic pollution. Thus chloride can be an indicator of possible eutrophication tendency.

High chloride concentrations are indicators of large amount of organic matter as it is largely dependent on domestic pollution such as sewage. Hence, reservoirs situated in urban areas show chloride content several times more than those situated in rural areas. Addition to this, non-biodegradable and biodegradable industrial chemicals and hydrocarbon compounds from factory effluents also add the chloride content to the ponds. The chloride content of pond water is directly and linearly associated with the plankton population in all the seasons. Positive correlation between zooplankton production and chloride content has been observed.

Thus from the study it can be concluded that the main source of chloride in the water is through sewage and animal refuse indicating its organic pollution. Usually, it is high during summer due to more evaporation. In some cases influx of waste water may bring about its higher value during monsoon.

**DISSOLVED OXYGEN (DO):**

The variation in DO depends upon various factors such as temperature, both atmospheric and water temperature, E.C., DOM., pH and CO₂. It is said to be controlled by temperature showing an inverse relationship with water temperature. The DO depletion in water is mainly due to the sewage inflow which causes the decomposition of organic matter in which DO is invariably utilized resulting in low photosynthesis. To some extent less solubility of gases due to high temperature of summer also leads to the depletion of oxygen. However, in monsoon the less DO content in water is
mainly due to high turbidity, due to inflow of water from catchment areas and low illumination, resulting in low photosynthetic activity. Winter depletion of oxygen is also noticed, mainly due to the respiratory demand of the algal blooms which exceed the photosynthetic activity. On the contrary, the high values of DO during winter is due to the low water temperature resulting in high oxygen holding capacity, and also the circulation of water by cooling and draw down of DO in water. The monsoon maxima of DO is also reported because of the inflow of well oxygenated rain water into the pond and the agitation of water by wind and rain resulting in subsequent diffusion of DO into the water. Higher values of DO coincide with phytoplankton maxima. Generally it is low during monsoon and then a gradual increase in temperature accelerates photosynthetic DO production, which in turn increases the DO content in water in winter.

Although in general DO values increase during monsoon and winter, the occasional higher values of DO during summer, which is contrary to the general pattern, has also been observed and is attributed to the photosynthetic activity of both macrophytes and microphytes. Deficiency of oxygen indicates the eutrophication of the waterbody, and reflects the nature and extent of pollution of the waterbody. DO shows an inverse relationship with free CO₂ and direct relationship with pH.

To conclude, oxygen production is temperature dependent and its fluctuation is mainly controlled by photosynthetic activity of phytoplankton. During cold months the dissolution of atmospheric oxygen during circulation and also photosynthesis increases the DO content in cold water. Influx of oxygen rich rain water also increases the DO content. Normally it depletes in warm months, being utilized for decomposition, but sometimes high rate of photosynthesis of both macrophytes and phytoplankton would add more oxygen to water.
CARBON-DI-OXIDE (CO₂):

The photosynthesis and respiration are the two major factors that influence the amount of CO₂ in water. Besides this, the introduction of allochthonous organic materials mainly sewage and industrial effluents add more CO₂ to water.

In the observations made by many workers, the CO₂ system was absent throughout the study period. This is attributed to more photosynthetic activity. Further, it may also indicate slow decomposition rate and less metabolic activities, and the high pH which brings conversion of CO₂ into CO₃ and HCO₃⁻. Thus its absence leads to high demand of this gas and the presence of this gas in water is attributed to the lack of adequate phytoplankton, thus the regular and constant occurrence of free CO₂ may be due to the decomposition of organic matter.

Presence of free CO₂ during rainy season indicates its influx primarily through rain water which brings about the formation of carbonic acid by natural CO₂ and its absence during rest of the year is because of its rapid uptake during photosynthesis. The monsoon increase of CO₂ mainly due to the decay of winter and spring macrophytes is also reported. An increase in free CO₂ during summer is attributed to the accelerated biochemical activities because of more organic matter. Decrease in DO mainly because of more decomposition, results in increased CO₂, which in turn decreases the pH, thus showing the negative relation of CO₂ and DO, and CO₂ and pH. Although CO₂ is the single most important factor affecting the aquative organisms like phytoplankton, showing an inverse relation with them, possibly due to the increased rate of decomposition, no significant relation between the two is also reported. This shows that the phytoplankton are able to utilize other sources of carbon. Thus it is not a limiting factor for phytoplankton production.
Thus CO₂ may remain absent because of more photosynthesis, less decomposition and metabolic activities. Conversion of CO₂ into CO₃ brings about increase in pH value. It also shows wide range of seasonality. The increased value during monsoon is attributed to influx of rain water and during summer to the accelerated biochemical activities. Its lower value is attributed to utilization by phytoplankton.

**TOTAL ALKALINITY:**

Alkalinity of waters refers to the quantity and kinds of compounds present which collectively shift the pH to the alkaline side. The alkalinity is usually imparted by the presence of bicarbonates, carbonates and hydroxides. Studies on Central Indian reservoirs indicate that calcium and carbonate are the most dominant ions. The minor reservoirs have higher concentration of bicarbonates as compared to the major reservoirs the presence of carbonates and bicarbonates shows the higher degree of human interference, such as bathing and use of detergents for washing.

The total alkalinity would be high during winter, may be due to the more utilization of CO₂ by growing phytoplankton which ultimately increases the alkalinity. The summer higher values may be attributed to the maximum growth of phytoplankton and high rate of evaporation. The lower values of alkalinity have also been recorded during monsoon may be due to the dilution by water from catchment areas. Higher bicarbonates during monsoon may be due to the addition of salts from surroundings. In summer higher values have been attributed the rate of evaporation, bathing and washing activities. Further, the lower values of this factor during summer has also been reported. It may be because of higher phytoplankton growth. Contrary to this, lower winter values have also been reported. The CO₃ values would be high during monsoon and in early summer and low during winter.
Carbonates and bicarbonates show inverse relationship. This is due to the photosynthetic activity of phytoplankton resulting in the removal of half bound CO₂ from HCO₃⁻ leaving certain amount of CO₃⁻ in the water which rises the CO₃⁻ value. The total alkalinity also show negative correlation with free CO₂ and pH. However, the positive relation between pH and DO with alkalinity is also reported at low temperature.

The phytoplankton can utilize other sources of carbon in absence of CO₂ thus showing an inverse relation with HCO₃⁻, positive correlation with CO₃⁻ and total alkalinity. In contrast to this is the opinion that CO₃⁻ behaves independently to the production rate.

In general, alkalinity is high in minor reservoirs as compared to major reservoirs. The main source of CO₃⁻ and HCO₃⁻ are bathing and the use of detergents for washing. It also shows wide range of seasonality. In absence of CO₂ the CO₂¹ and HCO₃⁻ are the main source of carbon for photosynthesis.

**NITRATE:**

Nitrate is detected only in traces in major reservoirs of India may be because of its utilization by growing phytoplankton. The agricultural runoff from the fields, animal dung and domestic activities, and the sewage input are the main sources of nitrogen in the ponds. Thus the polluted waters contain more nitrogen than unpolluted waters. Which indicate the oligotrophic nature of a pond.

A rise in nitrate concentration is often accompanied by fall in free ammonia and a fall in nitrate coincides either with rise in nitrite or free ammonia, indicating the interdependence of NO₃⁻-N, NO₂⁻-N and NH₃⁻-N. Further, the dominance of
NH₃-N over nitrates and nitrites in less alkaline waters is due to the anoxic conditions that facilitates the denitrification and ammonification and the faster rate of decomposition. The higher rate of NH₃-N during summer is due to the decaying of organic matter and low during rains is due to its utilization by phytoplankton. It has been reported that ammonia is preferred over by phytoplankton than any other forms. This is attributed to the increased availability of ammonia which intensifies the process of glycolysis with the formation of more pyruvic acid. This enhances the rate of photosynthesis.

The nitrates increase during monsoon mainly due to the addition of different nitrogenous compounds through rain washing. The summer higher values are due to the decaying of organic matter. The lowest value recorded during summer and winter is attributed to the increased autotrophic assimilation.

Higher concentration of nitrogen (NH₃-N, NO₂-N and NO₃-N) suggests its higher potential for organic production. Summer increase in temperature results in more decomposition of organic matter and thus, evolves more CO₂ which reduces pH and increases NO₃. The nitrate nitrogen decreases with increase in primary productivity, which may be due to the more utilization of nitrate by growing plankton. A direct relation of nitrate with oxygen has been reported.

Animal dung and sewage input are the main sources of nitrogen. Of the three nitrogenous compounds NH₃-N is more preferred by phytoplankton. In general NO₃-N would increase during monsoon as compared to summer and winter due to surface runoff.

PHOSPHATE:

Phosphate is transported through soil particles, from agricultural lands, animal
excreta, sewage effluent and by domestic waste such as washing and bathing. Thus the water free of contamination shows lower concentration of PO₄. The PO₄ was detected only in traces in major reservoirs, but the quantity was more in minor reservoirs due to the domestic and sewage input. ⁶⁷, ³⁸₁.

The seasonal variation in phosphate content appears to be dependent upon rain and drainage from surface runoff. Thus, it shows higher concentration during monsoon. ³³, ³⁴, ⁵⁶, ¹⁷⁰, ³⁵₂, ³⁷² Contrary to this higher values of PO₄ during summer has also been noticed which is attributed to the depletion of water level by evaporation ³⁵⁴ and the PO₄ release after decomposition of organic matter. ⁵⁰, ²⁹⁶ The winter increase of PO₄ is also reported ²⁵, ⁵¹ which is due to the domestic sewage input. The lower values of PO₄ during summer ²⁵ and in winter ³³, ³⁴ are due to the rapid utilization of PO₄ by growing phytoplankton and thus it often acts as a limiting nutrient. ³³, ⁷⁸.

The increase in PO₄ due to sewage contamination has been reported by many workers. ⁵¹, ⁷⁸, ³⁵⁷, ³⁸₁. Addition of this nutrient brings about the higher potentiality to the organic production ³⁵⁵, leading to the eutrophication. ⁷⁸, ³⁷², ²²⁷, ²⁴³. It increases the bacterial content resulting in increasing oxygen demand. ⁷⁸, ²⁴³. The blooming of phytoplankton coinciding with the high content of PO₄ and thus showing the positive relationship is also reported. ¹⁸, ¹⁴², ¹⁷⁰. Contrary to this, inverse relationship of PO₄ with phytoplankton ³⁴⁵, ³⁵⁸ and aquatic flora ³⁵⁸, ⁴⁰⁵ is possibly due to its rapid consumption for the growth of the latter.

The main sources of PO₄ in the ponds is through surface inflow, animal excreta sewage and demostic waste from bathing and washing. Generally it is high during monsoon due to surface inflow. Summer increase do occur due to evaporation of water. Addition of PO₄ leads to organic pollution indicating eutrophication.
HARDNESS, CALCIUM AND MAGNESIUM:

The term hardness is frequently used as an assessment of the quality of water supplies. The hardness of the water is governed by the content of calcium and magnesium salts largely combined with carbonates and bicarbonates (Temporary hardness) and with sulphates, chlorides, and other anions (permanent hardness). The main source of Ca and Mg in the ecosystems are the pond basins, catchment runoff from agricultural fields which are loaded with fertilizers like lime, superphosphates etc. The human disturbance like washing of cloths with detergents and soaps and the sewage input also adds the Ca and Mg to the water bodies.

The total hardness would be high during monsoon may be due to the addition of salts. The summer high values are also reported by some workers who have attributed to the surface water evaporation. The lower values recorded during winter and in summer are found more due to biotic activities such as more utilization of salts and their ions by vigorously growing algae. Hardness shows direct relation with total alkalinity and hence pH.

Calcium shows more variation probably due to the fact that it is more reactive and can exhibit a marked seasonal dynamics as compared to Mg. It may also be due to the fact that CO₂ reacts more rapidly with Ca salts converting large quantity of calcium into soluble bicarbonates.

Calcium increases during winter and in rains which may be due to the surface runoff. Higher values of Ca at higher temperature has also been reported, which is due to the production of more CO₂ and thus bicarbonate making calcium more solublable. The lower values during summer...
may be due to its utilization by algae \(^{155,227,354}\) and in monsoon \(^{277,383}\) due to dilution. Calcium shows inverse relationship with water temperature \(^{155}\) and with the rate of production. \(^{345}\) Magnesium is relatively stable atom reacting slowly, high during rainy season and winter season \(^{227}\), compared to summer and show inverse relation with phytoplankton. \(^{155}\).

Calcium and magnesium are the main contents of hardness. Surface inflow from surrounding fields, human disturbances like washing are the main sources. Generally it is high during monsoon due to addition of salts from surrounding. The summer higher values are attributed to evaporation and production of more \(\text{CO}_2\). Lower values are mainly due to their utilization by algae.

**IRON (Fe):**

Higher concentration of iron may be attributed to the natural contamination through run-off from iron rich soils \(^{374}\). Other sources of iron in the ponds are waste materials, storage tanks, water pipes and corrosion of taps. \(^{348}\) Decrease in water level, agricultural activities in catchment areas and increased diffusion of ferrous iron from the sediments at lower oxygen concentration near the sediment surface also leads to the increase concentration of iron in the waterbodies \(^{412}\). It is high during summer may be due to more evaporation and less oxygen content. Its decrease during monsoon is mostly due to the dilution of water.

**SILICA:**

In the waterbodies silica may arise from both autochthonous and allochthonous means. \(^{186,208}\) It occurs either in solution or as silicate polymers derived from catchment soils or from biogenic origin. \(^{208}\) The highest silica value is recorded during monsoon \(^{315,354}\), which is due to the input of silica polymers through surface run-off containing turbid silica-rich rain water. Their depletion during winter \(^{266}\).
and summer \(^{354}\), may be due to sedimentation \(^{302,303}\) is due to the more consumption by growing plankton, especially diatoms. \(^{208}\). Particulate silica is known to impart coloration and turbidity to the water. \(^{142}\). It does not show any relation with other physico-chemical factors. \(^{155}\).

**SODIUM AND POTASSIUM:**

Both sodium and potassium are the major cations present in waterbodies. However, their occurrence in abundance, as highly solvable cations of numerous salts that alter the natural water, is not common. \(^{401}\). The higher consumption of Na and K in the lakes, may be due to the better growth of phytoplankton in them. \(^{357}\). reported its lowest value because of its utilization by growing phytoplankton. The Na is more dominant than K, whereas K is said to have wholesome effect on the quality of irrigation water \(^{350}\), as K show positive relation with SAR (Sodium Adsorption Ratio). \(^{350}\).

**PHYTOPLANKTON PRODUCTIVITY:**

For the development of reservoirs, fisheries on scientific lines, the biological productivity by estimating planktonic population is of vital importance. \(^{358}\) Tropical waters are considered to be more productive. \(^{185}\) The productivity of the reservoirs is mainly dependent on light \(^{139}\) amount, duration and frequent shading by macrophytes may cause depletion of phytoplankton during summer. \(^{52}\) .

Phytoplankton productivity did not show any seasonal pattern which goes with the generally accepted view that in tropical waters production is moderate with little seasonal oscillations in productivity whereas, in temperate waters there are drastic seasonal changes \(^{385}\).

The productivity is not affected by a single factor, but is the result of cumulative
effect of a number of factors interacting together. Some important factors are transparency, water temperature, pH, CO₂, DO, NO₂ and PO₄. Increase in water temperature enhances the growth and hence the total production. The growing plankton release the DO by photosynthesis reduce the CO₂. The primary productivity is dependent on the phytoplankton composition and relative proposition of the different groups of algae rather than the total phytoplankton number.

Phytoplankton productivity will be maximum during summer because of long duration of light, high temperature and nutrient reserve. However, some times there would be monsoon maxima this leads to the addition of nutrients from catchment areas. Similarly, winter maxima is also reported may be due to low pH and low water temperature. The lower values during monsoon would be mostly due to dilution of water. The increase in primary productivity increases the pH because of the utilization of CO₂ which releases the DO. The lower values of transparency reduces the primary productivity by checking the light penetration. Nitrogen and phosphates enhance the phytoplankton growth and population. This is further supported by the observation that the N/P ratio shows positive correlation with phytoplankton production. However, this phenomenon does not hold good always. The NO₂ and PO₄ can increase the phytoplankton growth rate only when the factors are added to a medium deficient of them. If these nutrients are in surplus in the medium will not have any effect on productivity.

SPECIES DIVERSITY:

The species diversity is an expression to use the relation between the number of species and the number of individuals in an ecosystem. It is the best single means to assess the biological integrity in the freshwater system. In clean water it is
high, while in eutrophic water it is low\textsuperscript{372}, due to the formation of blooms. Thus the reduction in the species diversity of algal forms substantiates the polluted nature of the water body\textsuperscript{32,224}, thus it decreases with the extent of pollution\textsuperscript{81,126}.

Species Diversity index may be used as good index for the determination of degree of pollution as diversity index is inversely correlated with pollution\textsuperscript{207}. The more the diverse flora, the better is the quality of water.\textsuperscript{307} Thus the Index not only provides the trophic scores of the waterbodies but also the trends of its trophic development.\textsuperscript{281}.

In general in oligotrophic lake the species diversity increases with the commencement of summer,\textsuperscript{81,299,301} because of rise in the temperature which leads to a spurt in the growth of serval species. With the onset of rains, the dominance of many suppressed species increases due to the dilution of overall pollution level.\textsuperscript{81} The change in the nutrient availability also facilitate the enhancement of many other species. Thus it results in the increasing the diversity\textsuperscript{81,310}. On the contrary, dilution of eutrophic water during rains may lead to monsoon maximum.\textsuperscript{240} The winter minimum values\textsuperscript{299} are due to low water temperature, light penetration, HCO\textsubscript{3} and total alkalinity. The summer lesser values are also reported\textsuperscript{207,310} may be due to the dominance of only bloom forming algae. Addition of domestic sewage might be one of the causes for depleting the diversity.\textsuperscript{385} The major reservoirs have low species diversity, due to poor nutrients.\textsuperscript{381} The species diversity of the stable pond is higher than the pond subjected to greater biotic disturbances.\textsuperscript{301}

**ALGAE AS INDICATORS OF WATER QUALITY:**

The wastes in the water medium serve as the nutrients which stimulate the growth and reproduction of algae. Several algal forms have been looked upon by the biologists as the indicator organisms.\textsuperscript{301}
ALGAL SPECIES INDICATORS:

The species like, *Oscillatoria rubescens*, *Tabellaria fenestrata*, and the genera like *Anabaena*, *Ankistrodesmus*, *Ceratium*, *Chlorella*, *Fragilaria*, *Lyngbya*, *Microcystis*, *Gomphonema*, *Pediastrum*, *Phormidium*, *Scenedesmus*, *Synebra*, *Tabellaria*, and *Oscillatoria* have been designated as the indicators of pollution and their presence proves that the water is eutrophic. The organically polluted waters are characterized by the presence of *Euglena*. The sewage indicators include the species like, *Chlorella vulgaris*, *Crucigermata tetrapedia*, *Cyclotella menaghminiana*, *Euglena acus*, *Cr. polymorpha*, *Nitzschia palea*, *Oocystis pusilla*, *Stephendiscus astrea* and the genera like *Aphanizomenon* and *Oscillatoria*. However, the oligotrophic species which are characterised by their presence in low NO₃ and PO₄ medium are *Melosira granulata*, *Cosmarium variokatum* and *V. rotundatum* is also considered as the oligotrophic species and *Ceratium hirundinella* as mesotrophic specie.

The sewage invaders include the species like *Ankistrodesmus falcatus*, *Merismopedia minima*, *Navicula radiosa*, *Nitzschia palea*, *Phormidium angustissima*, and *P. molle*. The temperature tolerant species are *Mastigocladus laminatus*, *Microcystis* sp., *Oscillatoria terbriformis*, *Cyclotella* sp., *Navicula* sp., *Phacus* sp., *Euglena gracilis*, which prefer low temperature. The hard water indicators are *Cosmarium variokatum*, *V. rotundatum*, *Pinnularia* sp., *Volvox* sp., and *Microcystis* sp. The Otil tolerant species are *Kirchneriella contorta*, *Pediastrum duplex*, *Scenedesmus acuminatus*, *S. quadricauda*, *Euglena* and the sensitive species is *Synedra* sp. The species like *Anabaena cylindrica*, *E.polymorpha*, *Francia ovalis*, *Glenodenium* sp. *Gymnodenium* sp., *Microcystis aeruginosa*, *Peridinium*.
cinctum, Spirulina nordstii, Phormidium sp. Volvox sp. prefer to
grow in rich PO₄ containing water showing their affinity towards PO₄ rich waters.
High pH is favourable for the growth of Peridium cinctum, Spirulina nordstii, Pandorina sp. Phormidium sp. Chlorogonium sp. Euglena acus. E. gracilis. However, the species Chlymedomonas and Carteria sp. can prefer the pH around neutrality. The Arthrospira platensis and Microcystis aeruginosa, Spirulina nordstedtii, Pediastrum simplex, Glenodenum gymnodenium, Pandorina sp. Phormidium sp. Spirogyra. Chlorogonium sp. prefer well oxygenated water for their growth. In presence of high BOD, COD and chloride the euglenoid member such as Euglena acus, E.gracilis, Phacus sp. grow and multiply. The chloride also favours the growth of Euglena polymorpha and Microcystis aeruginosa. The nitrate is also one of the essential nutrient for the growth of Glenodenum gymnodenium, Microcystis aeruginosa, Peridinium cinctum, Spirulina nordstedtii, Pandorina sp. Phormidium sp. Chlorogonium sp. The presence of DOM is the best indicator of organic pollution and favours the growth of Chlamydomonas, Carteria sp. and Euglena polymorpha. However, the DOM invaders are Pandorina and Chlorogonium sp. The alkalinity favours the growth of M.aeruginosa. Chlorogonium, Volvox and Pandorina.

The E.polymorpha need high Fe and NH₄ for its growth. The biological pollution, due to the plants and animal activities, indicators are Microcystis aeruginosa and M. flosaque. Phormidium tenue is the industrial pollution indicator and the Oscillaoria species is also considered as pollution tolerant species.

CHLOROCOCCALE:

Chlorococcales is an extremely large and morphologically diverse group. with almost totally freshwater in distribution. The planktonic chlorococcales are
ubiquitous in distribution among waters of different salinity. They constitute one of the important components of the microflora of the warm tropical waters. Apart from being abundant they are with diversified nature too. It has been found that temperature plays an important role in the periodicity of chlorococcales. They occur in high density during summer where there is a slight increase in temperature. They also show their abundance during monsoon may be due to the fact that soon after the first spell of rains there is slight increase in water temperature. Their decrease in number during winter and fall end of rainy season is therefore, possibly due to low temperature and dilution of water. The increase in chlorococcales coinciding with the total phytoplankton peak is reported. Their opinion that the development of chlorococcales under wide ranges of temperature indicates their periodicity based not only on temperature but also on the interspecific competition with other algae such as cyanophyceae.

Apart from water temperature other factors favouring chlorococcales are high pH and thus the alkalinity and DO. This confirms that, chlorococcales need well oxygenated and less polluted freshwaters for their growth. This is supported by the inverse relation of this group with PO₄ and DOM. In contrast to this high amount of NO₃ and PO₄ and also DOM promoting chlorococcales growth is also noticed. A positive correlation with organic nitrogen is reported.

DESMIDIALES:

Desmids are of unique importance in classifying the lakes. Oligotrophic lakes are characterised by the chlorophycean flora with conspicuous desmids. These are almost exclusively fresh water algae confined to natural waters with low salinity.
In the periodicity of desmids, water temperature, light, pH, DO and NH₃-N have major role to play. Whereas nitrates, phosphates and chlorides have little significance. They show their abundance during early summer and winter, as they prefer moderate temperature and less turbidity. Their number decreases during monsoon because of more rains which causes turbidity. High pH favours the growth of desmids, which may be due to the utilization of CO₂ for photosynthesis during their predominance. On the contrary the high pH 8.38 may not favour the growth of Desmids always. High concentration of oxidisable organic matter inhibits the active multiplication of Desmids. Presence of high dissolved O₂ even in the presence of high DOM is due to the photosynthetic release by desmid bloom. The high organic matter during desmid bloom may be due to release of certain metabolic substances and also due to some cells being added to the medium. High consumption of DO favouring the growth of desmids is also observed. Generally, low NO₃, PO₄²⁻ favour the growth of desmids, but there is a positive relation of NO₃ with desmid growth, might be due to recycling, the decomposition of nitrogen favoured as DO levels are increased. In general calcium rich waters do not favour the desmid growth. Similarly magnesium shows negative relation with the desmid growth may be due to its utilization in chlorophyll synthesis. Desmids occur more in less alkaline waters. The NH₃-N shows inverse relation with desmid population.

The occurrence of desmids plays an important role in the evaluation of nutrient status. Dominance of desmids indicates the oligotrophic nature of the waterbody. The poor growth of desmids indicates the eutrophic nature of the waterbody and also high degree of pollution.

**BACILLARIOPHYCEAE:**

Diatoms tend themselves very well to the ecological studies as the associations
they form are the result of their environment and thus the best indicators of physical and chemical conditions of the environment. 97

Diatoms grow and colonise during the warmer periods 55, 170, 348, 356, showing that water temperature directly influences the diatom growth. Contradictory statement is that the low temperature and the decreased level of nutrients increase the diatom population during winter. 249, 277, 310, 348, 357, 366, 385 The monsoon maxima of diatoms is also reported 170, 203, 362, 383, is mainly due to increase in water temperature and decrease in nutrients due to dilution. The lean population in winter and monsoon 55, may be due to deficiency of nutrients. During May 383 the decrease in diatoms count is due to high nutrient load and very high temperature. The increase in water temperature leads to spurt of diatoms 55, 384, showing their direct relationship. Thus these studies indicate that diatoms in Indian waters tolerate a wide range of temperature.

Other factors related to diatoms growth are organic matter, DO, pH and other physical factors. 159. The increase in water temperature leads to spurt of Diatoms 55, 384, showing their direct relationship. Contradictory to this is the retarded growth of diatoms due to increase in temperature 310, showing inverse relation. On the contrary, there may not be any relation between water temperature and diatom population.

Although diatoms flourish well when nitrates and phosphates are in lower quantity and the peaks of some diatom species coincide with the decrease in nitrates and phosphates 385. Diatoms prefer to grow in nitrate and PO₄ rich water 170. Similarly, the ammoniacal nitrogen and organic nitrogen are also found to favour the growth of diatoms 327. Some species of diatoms are adopted to increased ammonia-nitrogen and chlorides 326. There is a negative correlation between silica and diatoms bloom 291, may be due to more utilization during their growth. The dominance of diatoms
may be regarded as a sign of eutrophic nature, diatoms are supposed to avoid polluted waters.  

CYANOPHYCEAE:

Cyanophyceae members determine the plankton of ponds and lakes in the tropical areas. South Indian lakes are dominated by the members of cyanophyceae and the dominance of these cyanophyceae over the other groups of algae leading to the formation of bloom may be due to their shorter multiplying time.  

Temperature is considered to be the prime factor which influences the plankton periodicity with their peak during summer, when there is high temperature and more nutrient load. Their growth continues to monsoon when there is a high water temperature and the nutrient loading through surface runoff. The winter and post monsoon maxima of cyanophyceae is due to high nutrient load through surface inflow of monsoon which forms the nutrient rich condition of the pond. But their population may decline at fall end of monsoon due to dilution of water and consequently their growth may decrease to a larger extent during colder months.

Usually cyanophyceae prefer hard waters to soft waters and the major factors that influence their growth are light, temperature, high pH, organic matter, nitrates and PO₄, DO and CO₂ alkalinity, organic nitrogen, Ca and Mg. High temperature with long hours of sunshine is very much suitable for the cyanophycean growth showing their positive correlation. High temperature with low O₂ favours more growth of cyanophyceae. Although the abundance of cyanophyceae is dependent upon organic matter, high DOM and low calcium hinders the growth of cyanophyceae. The positive relation of
cyanophyceae with calcium\textsuperscript{11,206}, supports the above said view. Phosphates\textsuperscript{170,206}, nitrates\textsuperscript{125,170,357}, and organic nitrogen\textsuperscript{206}, also show their positive correlation with the cyanophyceae growth confirming the view that they are the essential nutrients for the growth of cyanophyceae. Moderate temperature (25\degree C - 30\degree C) and alkaline water coupled with higher consumption of CO\textsubscript{3} and Mg, favour the blue green algal growth.\textsuperscript{11} High pH with more chemical oxygen demand also favours the blue greens.\textsuperscript{159}

Dominance of cyanophyceae indicates the eutrophic nature of the waterbodies when the water is said to be organically polluted.\textsuperscript{159,240} Nitrogen inhibits the growth of heterocystous forms\textsuperscript{206} and the presence of only a few heterocystous forms among the cyanophyceae members indicates the eutrophication.\textsuperscript{232} The higher amount of DO in eutrophic waterbodies is due to the photosynthetic activity of blue greens.

**EUGLENOPHYCEAE:**

The euglenoid group either individually or collectively multiply vigorously to colour the medium in which they occur forming blooms, during which their species diversity is low. Thus the development of euglenophyceae is sporadic with precise periodicity in their development.\textsuperscript{10}

The periodicity of eugleoids show that they were more in winter\textsuperscript{159, 234, 348} and in summer.\textsuperscript{234,348} The summer maxima is attributed to high water temperature with the more amount of DO and good amount of nutrients. They are also recorded in rainy season\textsuperscript{356,362}, when there is lot of nutrients added to the pond. The temporary waterbodies with highly polluted environment rich in organic matter\textsuperscript{234}, chlorides, PO\textsubscript{4} and Fe but with low consumption of DO\textsuperscript{234}, are congenial for euglaid population\textsuperscript{390,393} High amount of DOM suited for euglenoid growth is reported
by 207,234, and the low DOM inhibiting the euglenoid growth 185. The poor representation of euglenoids is also observed 185—an indicative of poor organic matter for the growth and development of Euglenophyceae. The sudden increase of euglenoid species with decrease in the organic nitrogen indicates their inverse relation 130, with Euglenophyceae.

History of Limnology in Dharwad:

The credit of starting limnological studies in Dharwad goes to Gandhi 1959 who began the study in 1949 on Mugad tank and while recording 58 diatom species classified them on the basis of Halobion spectra. This was followed by Jayanagoudar 1964 who worked on the ecology of Nuggikeri lake during 1957-58 and discussed the periodicity of algae. Limnology in Dharwad gained momentum after this work and many aspects have been studied. In the foregoing discussion the important findings have been given.

The phytoplankton in Dharwad waters is constituted by volvocales, chlorococcales and desmids of Chlorophyta, Euglenophyta, Cyanophyta, Bacillariophyta, Chrysophyta and rarely Pyrrophyta. Abundance of blue-green algae is seen in the ponds but lakes have more diversity. 128,129 High concentration of calcium, organic matter, nitrogen and phosphate possibly favour this group in the pond. 111 They also dominate in fish tanks. 107 The enrichment culture of lake sediment showed greater percentage of cyanophyceae in the surface sediments. 113

Little information is available about most sensitive desmid groups. The ponds are poor while the lakes are rich in desmids. Interestingly increase in pH and oxygen but low levels of nitrate, phosphate, calcium, magnesium and bicarbonate are favourable to this group. 111,128. Ecology of chlorococcales is not clearly understood. Although their abundance is high in ponds they remain subdominant.
to blue-greens. Dicloster acuatus has been recorded for the first time from India. The alga appeared to prefer low pH, alkalinity, hardness and chloride.

Distribution of euglenoids is similar to blue greens. They are dominant in ponds as compared to lakes. However, they are sporadic in fish tanks. Similar to desmids the diatoms are more in lakes than ponds and are favoured by nitrate, phosphate and silica. Further, higher calcium, oxygen and low organic nitrogen and organic matter also help diatom growth.

Dharwad has many temple tanks located at various places. Ecology of temple tanks is rather scanty. The ponds are in general eutrophicated mainly due to biotic disturbance and interestingly chlorococcales dominate over other groups of algae. Factors like calcium and nitrate favour their growth. High organic matter and organic nitrogen are also found to be beneficial for their growth. Quick succession of algae is another unique feature of temple tanks. Blooming of algae following festival disturbance is also common in these tanks.

Several methods have been employed to evaluate the trophic status of Dharwad tanks, which include Composite Trophy Index values, Species Diversity Indices and Nygaard's Phytoplankton Quotients etc. In general it can be concluded that the ponds are eutrophic and lakes are oligotrophic. The eutrophication is mainly due to sewage disposal. However, some of the village ponds become eutrophic during summer mainly due to reduction in water level and biotic disturbances like washing of clothes, cattle bathing etc. Some of the moderate sized tanks also become eutrophicated in summer mainly due to reduction in water.