CHAPTER VIII

GENERAL DISCUSSION
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Lakes are extremely complex ecosystems with specific characters of its own due to the various interactions occurring between the physico-chemical and biological attributes within the system. The intimate association with the catchment area further adds to their complexity depending upon the size, extent and type of the surroundings and the level of human interference. Higher biological interaction results in the acceleration of the natural process of eutrophication, leading to the death of the system, if not properly managed.

The concept of eutrophication can be traced back to the earlier decades of this century, when Naumann (1917, 1919) first applied the terms eutrophic, mesotrophic and oligotrophic to classify the water bodies on the basis of nutrient enrichment. Prior to this, the terms were used to describe the nutrient status of German bogs from nutrient rich to nutrient poor (Weber, 1907). With the onset of the applied usage of scientific studies the concept of eutrophication is not restricted to the application of 'eutrophication sensu stricto' but also encompasses "the effects of eutrophication". Hence the causes, consequences and correctives together constitute a complete study of any particular system.

To assess the trophic status in terms of oligo-meso- and
eutrophic conditions, the plankton have received great attention. Both phytoplankton and zooplankton have long been used as indicators of water quality (Hutchinson, 1967; Das and Pandey, 1978; Khan, 1984; Krishnamoorti, 1984; Michael, 1984). The plankton, in turn, are dependent on the physico-chemical characteristics of water (Balkhi et al., 1984). The physico-chemical factors interact and modify the environment making it congenial for a group of organisms and at the same time eliminating the other organisms from the same environment. Thus a study of any one factor for a complete assessment of the trophic status of any water body remains futile to this date. Edmondson (1946) very aptly stated that "the action of any one environmental factor is modified by the variation in another, making it useless to seek any one factor as being the most important."

Among the various physical factors the influence of water temperature and availability of light energy are, of course, overriding. Temperature will control rates of the anabolic and catabolic fluxes, of the nutrient influx, and of many physiological processes. Temperature also occupies a central position in physical limnology as the main density determining factor exerting a fundamental influence on motion and stratification.

During the present studies no marked thermal stratification could be observed in any of the water bodies. The widest fluctuation between surface and bottom temperatures was noticed during the summer season, when the atmospheric temperature was
highest. The highest difference in temperature was noticed at Bila reservoir (4.5°C during March), which is deepest among the three water bodies. Forsyth and Mackenzie (1981) during their studies on acid lakes found that thermal stratification is rare in shallow lakes. The water temperature during the study period was mostly homothermal with less than 2.0°C difference between surface and bottom. All the water bodies under investigation can be categorised as warm, polymictic type following Hutchinson's classification (1957).

The water temperature closely followed the fluctuations in air temperature and was maximum during summer and minimum during winter, with a slight increase during post-monsoon period. Welch (1952) stated that smaller the body of water, more quickly it reacts to the changes in atmospheric temperature. The water bodies under consideration are comparatively smaller, hence water and air temperatures go hand in hand, as also observed by Prasad et al. (1985).

Primary productivity measurements are among the most useful biological determinations. As primary production is light dependent, the availability and penetration of the natural sunlight in the aquatic systems are of great importance. As biological productivity can cause changes in the colour and turbidity of the water, measurements to determine the amount of natural light penetrating the upper layers of a lake have been used classically to describe changes in the trophic level.
Minder (1943) showed that the average Secchi disc reading in Lake Zurich decreased from 3.1 m before 1905 to 2.1 m during 1905-1910, and to 1.4 m between 1914-1928. The Secchi disc readings observed at Sagar lake ranged between 11.4 to 85.6 cm in the summer of 1970 (Adoni, 1975) and between 12.0 to 17.5 cm in the severe summer of 1982 (preliminary study). The observations clearly indicate the rate of deterioration of the water body from 1970 to 1982.

The transparency values were lower in Sagar lake which is most productive, and higher in Bila reservoir which is less productive. The highest transparency was noticed at Chittora reservoir. The transparency was controlled by both production and incoming turbid rain water. Light and temperature were found to have a marked effect on physico-chemical variables and primary production within the seasons; but the effect was marked to some extent during the change of season due to physical entrance or exit of nutrients and silt.

During the present studies, the variations in the majority of the ions were associated with the fluctuation in the water level. With the consequence the variation in the biological properties too was noticed. Similar observations are those by Carter (1950), Adoni (1975) and Belsare (1982). In all the three systems the water level fell to a great extent during summers due to increased evapotranspiration. This susceptibility
to the fluctuations in weather conditions especially rain and temperature, when the water body is shallow, has been well documented in the studies of Qadri and Shah (1984). The rain water entering the system affected it differently depending on the catchment area. The increase in phosphate and nitrate during monsoon at Bila and Chittora reservoirs, can be directly attributed to the entry of these elements from the catchment through rain water. The higher phosphate content at Sagar during monsoon is the total effect of enhanced summer and also through its entrance via rain water. Both nitrate and phosphate were higher at Sagar lake (Max. $\text{PO}_4 - 484$ ug $l^{-1}$, $\text{NO}_3 - 1090$ ug $l^{-1}$) than at Bila reservoir ($\text{PO}_4 - 111$ ug $l^{-1}$ and $\text{NO}_3 - 210$ ug $l^{-1}$). These two important nutrients as far as eutrophication and primary production are concerned clearly mark higher trophic status of Sagar lake as compared to Bila reservoir. The primary production values indirectly reflected the trend in the nutrients, with higher production at Sagar lake in comparison to Bila reservoir. The minimum G.P.P. of 1.13 g C m$^{-3}$ d$^{-1}$ observed at Sagar lake was their maximum value observed at Bila reservoir during the present study period. Though the nutrient level at Chittora too was quite high (Max. $\text{PO}_4 - 102.8$ ug $l^{-1}$ and $\text{NO}_3 - 200$ ug $l^{-1}$), the production values were still lower than what observed at Bila reservoir.

Davis (1955) considered pH of the water as a good indicator of pond or lake productivity. During present studies pH of the water was found to be directly related to the production, and
fluctuated accordingly. The higher values of pH at Sagar lake (maximum 10.5) correspond to higher production and trophic status of the lake. The higher pH in summer at Sagar lake and higher pH in monsoon at Bila and Chittora reservoirs were coupled with high G.P.P.; and low pH in winters with low primary production. The direct relation of pH with productivity is clearly evident. Moyle (1945) stated that if the seasonal fluctuations are not marked, then pH may not prove to be useful as an index of productivity.

The carbonate-bicarbonate system in the aquatic bodies has been given great emphasis due to its bearing on productivity. The high production was directly related with carbonates and inversely with bicarbonates at Sagar lake and Bila reservoir. Similar relation has also been noticed by Singhal (1980) and Saran (1980). The higher values of bicarbonate were noticed at Sagar lake in comparison to Bila reservoir. Ruttner (1963) found that with decrease in the CO$_2$ concentrations more bicarbonates are used till finally the tension of CO$_2$ may decline to effect the productivity. Free CO$_2$, during present studies, was never encountered in the surface waters, but was occasionally present in bottom waters, where tropholytic activity is greater than trophogenic activity. In general, a stratification in alkalinity was noticed with lower carbonate content in deeper waters except during the period when the overlying water column is not significant as was mostly observed at Station I of Sagar lake. The carbonates had a negative
correlation with bicarbonates, which controlled the total CO₂ content. Moyle (1949) found inverse relation between free carbon dioxide and pH, which was evident during the present studies where the bottom pH was lower than the surface waters.

According to Ganapatil (1970) carbon dioxide can be a limiting factor for primary production in tropical lakes, where permanent bloom of blue-green algae such as *Microcystis* is present and the pH is as high as 9 to 10 units. During the study period, the bicarbonates were always present in fairly large amounts, hence the absence of free carbon dioxide was never a limiting factor, yet the production in Chittora reservoir was less though the alkalinity was highest at this reservoir, as is observed for other ionic composition. This suggests that some other factor is playing an upper hand in limiting its production.

The hardness values were highest in Chittora, followed by Sagar lake and Bila reservoir. As per Sawyer and McCarty's classification (1967), the water at Chittora reservoir remains hard for most part of the year (values ranging between 150-300 mg l⁻¹) while the other two water bodies have moderately hard water (75-150 mg l⁻¹). The water of Bila reservoir tends to become soft at some part of the year.

The calcium values too were quite higher at Chittora, which supports a good growth of large bivalves and gastropods, whereas the values of Bila reservoir were lower than Sagar lake
except in summer. Bila reservoir, too, supports the growth of bivalves.

Moss (1973) associated the increase in hardness with increased eutrophication. Prasad et al. (1985) reported higher values of hardness from more polluted ponds than those of less polluted ponds, suggesting the parameter as an indicator of water quality. Higher alkalinity has also been found to be associated with eutrophic and polluted waters (Philipose, 1960; Munawar, 1970; Moss, 1973). The above observations seem true when the waters of Bila reservoir and Sagar lake are compared, but the highest values of both alkalinity and hardness are observed at Chittora reservoir, which is least polluted and shows no sign of eutrophication as far as the effects of increase in nutrients are concerned.

Chloride is also an important parameter which gives an indication to the amount of pollution due to animal waste. The chloride concentration was higher in the polluted Sagar lake, and the maxima observed during present study was 107 mg l⁻¹ as compared to the maxima of 71 mg l⁻¹ observed during 1978-79 (Saran, 1980), which indicates to the increased human and animal interference at this site. Not much variation in chloride content was observed, except for evaporative concentration during summers at Sagar lake and Chittora reservoir and entrance from catchment through rain water and sub-surface run-off at Bila reservoir.

The dissolved oxygen was present in significantly substantial
amounts at the three reservoirs, with supersaturated condition occasionally observed at surface waters of Sagar lake except for a few months of summer season. The water of Bila and Chittora reservoirs was supersaturated during the monsoon months. The oxygen showed clear stratification with much lower values in the bottom waters. The fluctuation between the oxygen content of surface and bottom waters was more at Sagar lake and Bila reservoirs as compared to Chittora reservoir; the fluctuation got more pronounced during summer when the tropholytic activities on the bottom and trophogenic activity at the surface increased. The hypolimnetic oxygen deficit has been used as an index of eutrophication. As no marked thermal stratification occurred to interfere with the mixing of water, the oxygen was never observed to be depleted in the bottom waters.

The organic matter input in a lake body plays an important role both through the nutrient brought along with it and also by shallowing the lake by addition to the sediments. The carbohydrate content of water finds its source through extracellular release by the primary producers and through decomposition of organic matter and can be indicative of organic matter input. The carbohydrate was maximum at Sagar lake, with lower values at Chittora and Bila reservoirs. The high primary production of phytoplankton, and also the macrophytic production at Sagar lake makes it rich in organic matter content which is autochthonous in nature. The higher carbohydrate content of summers, in comparison to winter values suggests to its
increase by decomposition processes and extracellular release. The higher monsoon values at Bila and Chittora reservoirs are indicative of allochthonous source of carbohydrate.

The microbial biomass production and also its fluctuation (0.8 to 9.6 mg l\(^{-1}\) d\(^{-1}\)) was greater at Sagar lake in comparison to Chittora reservoir (0.32 to 1.92 mg l\(^{-1}\) d\(^{-1}\)) and Bila reservoir (0.32 to 1.12 mg l\(^{-1}\) d\(^{-1}\)). The higher values at Sagar indicate towards its high organic input and hence higher trophic status. In other two reservoirs, the organic input is low. The minimum values during winter suggest towards low metabolic rates at lower temperature, whereas an increase during summer to higher rate of metabolic processes being favoured by higher temperature.

The higher organic matter production at Sagar lake is due to the primary production by the macrophytes in addition to the high planktonic production. The rich macrophytic flora supported by Sagar lake further strengthens the view that is most eutrophic of the three water bodies. The Sagar lake harbours a large number of macrophytes which include Potamogeton pectinatus, P. crispus, Hydrilla verticillata, Nelumbo nucifera, Nymphaoides indica, Vallisneria spiralis, Zizhonia cressipes, Hygroryza aristata, Trapa bispinosa etc. The presence of P. pectinatus as a dominant form throughout the year confirms the eutrophic and polluted nature of the lake, as this plant species is well known for its tolerance to sewage contamination. Ho
(1979b) found *P. pectinatus* growing as close as 10 m from the sewage inflow in Forfar. Earlier Sculthorpe (1967) commented on the plants ability to penetrate further upstream than other plants and reach the most heavily polluted zone.

The popular view that the macrophytes provide protection and breeding sites for fauna is well founded, but their dynamic roles are of greater significance. In shallow systems, the role of macrophytes in nutrient cycling plays an important role in the overall metabolic status of the water body affecting the rate of eutrophication. The decompositional studies conducted on *P. pectinatus*, *H. verticillata* and *P. crispus* reveals that more than 50% of the dry matter is lost just within 40 days of the commencement of decomposition, with the maximum release of nutrients just within 10 days. Vyas (1986) stated that the release of nutrient was more rapid upto a period of 30 days. The decomposition process was greatly affected by the structural variability of the plants, with high rate of decomposition in the leafy species, *P. crispus*. *H. verticillata* shows great structural variability during its growth phase and hence the rate, though higher in comparison to *P. pectinatus*, shows great fluctuations during different seasons. Wetzel (1975) noted that the difference in the amount of fibre and nitrogen content results in different degree of decomposition in different plants. The resistant structural parts of plants, such as those in *P. pectinatus*, adds substantially to the growth of the sediment and shallowing of
the lake, and enhances eutrophication.

Misra (1938) and Gopal (1971) during investigations on rooted macrophytic species concluded that the edaphic factors are equally important for their growth as for any other terrestrial species. According to Hutchinson (1975) the aquatic macrophytes take up inorganic nutrients both from surrounding water and the sediments. It is a matter of controversy whether it is the substrate or the surrounding water that provides the bulk of mineral requirements to the plant. The studies using radioactive tracer techniques (Frank and Hodgson, 1964; Bristow and Whitecombe, 1971; De Marte and Hartman, 1974) indicate that both the substrate and the water medium provide nutrients to the plant; but the relative importance of substrate and surrounding water depends on a number of factors, the nature of plant species under consideration being one.

During present studies, the rooted submerged plants were found to have more release of nutrients which can be attributed to the capacity of these plants to exploit the nutrients of the sediments in addition to the nutrient present in the surrounding water. Subsequent translocation from the sites of absorption as well as further release into the water after root uptake has been shown by Gentner (1977). Therefore, the macrophytes may act as nutrient pumps between sediment and water. Though, extracellular release of nutrients occur, majority of the nutrients are retained during growing season. Hence, much of the release of nutrients occur during decomposition.
with the release of phosphates and nitrates just within a few
days of decomposition. (Nichols and Keeney, 1973). The release
of phosphates and nitrates were observed to be more than 60% just within 24 hours of incubation. Barko and Smart (1980)
found that the phosphorus release is dependent primarily on
tissue decay rather than on excretory processes. The phosphorus
release during the present study was invariably found to be
greater than the amount of nitrate released.

The lack of well developed roots has led some investigators
to consider them to be of secondary importance to shoots in
nutrient uptake (cf. Schulthorpe, 1968), but the nutrient
uptake by roots is more likely to be dependent upon root surface
area, internal anatomy and physiological transport mechanisms
rather than on root biomass. Later investigations on phosphorus
uptake by shoots versus roots of submerged plants (Bristow,
1975; Bole and Allen, 1978) have indicated the predominance
of roots in phosphorus absorption. Working on *Myriophyllum
spicatum*, Bole and Allen (1978) demonstrated almost exclusive
phosphorus uptake from sediments by roots when shoots were
simultaneously exposed to concentration of $\text{PO}_4-\text{P}$ upto 0.5 mg l$^{-1}$ in the water. Barko and Smart (1980) studied the mobilization
of sediment phosphorus by three submerged freshwater species
on five different sediments and found that *Hydrilla verticillata*,
*Myriophyllum spicatum* and *Egeria densa*, which had minor root
systems (on biomass basis), were fully capable of deriving
their phosphorus nutrition from the sediments.
The studies on the submerged species infer that P. pectinatus, H. verticillata and P. crispus, which form a great percentage of total macrophytes, play an important role in nutrient mobilization. Vyas (1986), too, has reported H. verticillata as having maximum mineral removing potentiality and quite rich in nutrient status apart from being the most efficient trapper of solar energy. These plants are extracting nutrients and rendering them available, which otherwise would have been lost to the sediments. The resulting enrichment of the water in this way is greatly accelerating the process of eutrophication in the already eutrophicated Sagar lake.

The decomposition studies point out that less nutrient is released by the free floating species which rather underestimates the ability of water hyacinths, the major free floating form at Sagar lake. Eichhornia crassipes has spongy lacunate tissue in all the organs which provide buoyancy to the plants and facilitate its easy movement along the wind or water currents; and hence, the plant is not restricted to the shallow littoral zone but infests the deep limnetic zone too. This unique plant, not only grows both in vertical as well as horizontal directions, but is equally efficient in exploitation of nutrients from the sediments during drier periods. This feature of large phenotypic variability of the plant with water level and soil moisture regimes, adds to the total contribution of this free floating plant towards enrichment and deterioration of the water body.
Moreover, the hydrological role of the macrophytes too play an important role. Evapotranspiration by the floating plants may significantly affect the water balances of lakes and reservoirs and, in turn, may have several undesirable repercussions. A preliminary study on evapotranspiration rates from cover of hyacinth, Salvinia and duckweeds has shown 5-10 times more amount of water loss through the cover of these plants than that from the free surface area (Gopal, 1973).

It is evident that macrophytes, be it rooted or submerged or free floating, are adding tremendously to the eutrophication problem, yet it is the free floating forms which have the advantage of easy removal from the water bodies. Hence the ability of these plants to remove nutrients, along with their relative easy removal suggests that periodic harvesting of E. crassipes should be employed to counter eutrophication of Sagar lake. The macrophytic flora can also be used as biofertilizers. Vyas (1986) got encouraging results for the use of various macrophytes as fertilizers.

The higher organic matter production at Sagar lake, leads to a large amount of detritus production and the sediments are rich in organic matter. This site supports a rich benthic fauna in comparison to Bila and Chittor reservoirs. Of all the benthic habitats, leaves and leaf detritus have the largest populations (Mackay and Kalff, 1968); and Egglishaw (1960) demonstrated that the abundance of many species was positively
correlated with the amount of vegetable detritus. Boyne and Ingram (1975) during their investigations on benthos of Howard Creek observed that the site with high leaf accumulations supported large number of animals.

The presence of large number of Chironomid larvae and _Tubifex tubifex_ at Sagar lake, confirms its eutrophic nature as they have been shown to be indicators of water quality (Commachan, 1981). The benthic population at Bila and Chittora reservoirs consist of large number of bivalves, _Lamellidens_, which is completely absent from Sagar lake, and hence these organisms seem to be less suited for polluted environments. The molluscan fauna of Sagar lake was represented only by the gastropods, among which _Viviparus bengalensis_ and _Lymnaea acuminata_ were dominant.

Many workers have reported molluscs to be dominant in the littoral fauna (George, 1966; Michael, 1968; Commachan, 1981). During present studies, though the molluscs remained restricted to the littoral zone and were completely absent from deeper zones, they did not dominate the benthic fauna in the sediments being periphytonic in nature.

The chironomids were dominant throughout the lake. Unlike earlier reports of chironomids being more at littoral and oligochaetes at limnetic zone, the chironomids were found to be present in more numbers at deeper zone. This can be attributed to the loose sediments rich in organic matter at deeper zones.
The littoral was exposed to air during the drier period, and hence had compact sediment and was less congenial for the organism.

The seasonal pattern of the total benthos reflected the cycles of the dominant chironomids. The maximum density was observed during the summers. Different workers have reported different peaks ranging from winter to summer season (Shrivastava, 1956; Krishnamoorti, 1966, Michael, 1968; Gommachen, 1981). Hynes (1972) and Boyne and Ingram (1975) observed its abundance during two periods, late summer and late winter fall. Boyne and Ingram (1975) attributed the observations to be the result of two late season emergences of chironomidae. Coffmann (1973) observed major emergences of midges in late summer and early fall in a stream in Pennsylvania.

A large number of dead Chironomid larvae were encountered in the benthic samples during the study period. The ratio of the living organisms to the dead ones was more than two on a few occasions. The rich benthic fauna, along with the large number of dead organisms, encountered at the Sagar lakes is indicative of the rich food going waste in the system, which could otherwise be economically utilised by harvesting fish.

Detritus is a significant food source for many species of benthos, including the chironomidae; it has been shown to be important for the younger larvae of species that shift diets
as they mature (Cummins, 1973; Coffmann, 1973). The high
detritus production at Sagar lake, through the decomposition
of the macrophytes is a good source of food for the benthos.

The studies reveal high production potentialities for
secondary and tertiary production at Sagar lake, which is
unexplored and unexploited. The stocking of benthic feeders
and detritivorous fishes at Sagar lake, will not only prevent
further damage of this water body but will also help in reversal
of the deterioration under way to some extent.