# Characterization Of Abiotic Status Of Lake Mansar At Surinsar- Mansar Ramsar Site In The NW Himalayas

S.M. Zubair, A.H. Ahrar

**Abstract:** Lake Mansar is a cherished tourist destination due to which many business outlets have been established along its bank. A greater portion of its catchment area has been converted into agricultural and residential purposes due to which silt and soil eroded form the catchment area is washed into the lake. Consequently the lake has been reduced to a mere sink for domestic as well municipal sewage, detergents, soaps, faecal matter, cow dung, agricultural run-off from the fields in the catchment area and nutrients from the cremation ground and deer park located along the bank of the lake. To further aggravate the problem of the lake, Department of Public Health and Hygiene is abstracting 3 lac gallons of water a day from the water body to supply potable water to 20 thousand people. Subsequently the present study revealed that lake water remains hard all throughout the year with BOD values fluctuating from clean to fairly clean category and hardness values varying from moderately hard to hard water body, total phosphates varying its trophic status from mesoeutrophic to hypereutrophic and values of Nitrate Nitrogen placing it in eutrophic category.

**Keywords:** Total Alkalinity, Biochemical Oxygen Demand, Total Hardness, Sulphates, Total Phosphates, Silicates, Nitrates, Ammonia, Lake Mansar.

————————————————◆————————————————

## Introduction

Since various resources like energy, water and materials needed for growth are variously scarce on the planet earth, hence competitive ecological battles are quite common and as a consequence, the organisms have developed interacting systems of eating and being eaten, which collectively have shaken down to use these resources efficiently and therefore have given a superficial appearance of an "ordered ecosystem" or "homeostatic ecosystem". This order remains unshaken as long as the system remains undisturbed. However, this system is always extremely vulnerable to externally imposed changes, which may eventually destroy it and allow its replacement by something different (Moss, 1999). Though lakes enjoy a complete life cycle yet the process of senescence is accelerated by human intervention. The natural process of lake succession from its creation to destruction is a gradual process for all but a few small lakes. Some lakes get quickly filled up with the sediments, while some others are eventually destroyed by the same catastrophic processes which were once the root of their creation. Once a lake is created, a biotic community starts establishing in it. The lake then progresses to some trophic equilibrium wherein a certain productivity status is achieved (Goldmand & Horne, 1983).

—————————————————————

- **S.M. ZUBAIR,** Division of Aquatic Sciences, The Himalayan Ecological and Conservation Research Foundation, 51/5, Lane No 25, Swarn Vihar PO Muthi-181 205, Jammu, J&K, India
  Ph./Fax: 01933260204
  Email at: zubairhuma@gmail.com
- **A.H. AHRAR,** Consultant Environmentalist, The Himalayan Ecological and Conservation Research Foundation, 51/5, Lane No 25, Swarn Vihar PO Muthi-181 205, Jammu, J&K, India

The ever increasing human intervention into the natural processes has resulted in cultural eutrophication, which is the most potent factor in accelerating the natural ageing process of a lake. In fact people are the causative agents of cultural eutrophication which ensures severe enrichment of natural waters by municipal sewage along with agricultural drainage. This discharge of sewage and excesses of fertilizers has imposed an accelerated rate of succession upon many inland waters of the world thereby resulting in their senescence. Lake Mansar in the suburbs of Jammu is a famous tourist spot which is receiving more than 5 lakh tourists every year. Besides the growing human settlement in the catchment area which is being used for agricultural purposes as well, the lake waters are qualitatively deteriorating. The sewage, waste, animal dung, human faecal matter, pesticides, fertilizers, soil erosion due to massive deforestation, idol immersion, washing and bathing along the shores of lake have further added to the nutrient content of lake waters. In this context, present study has been initiated to determine the abiotic health of Lake Mansar.

## Materials and Methods

Lake Mansar, revered for being the seat of Sheshnag, is a sub-tropical, beautiful, rural lake located between $75^0 5' 11.5''$ to $75^0 5' 12.5''$ E longitude and $32^0 40' 58.25''$ to $32^0 40' 59.25''$ N latitude at an elevation of 665 meters in the east of Jammu city. The lake is a sub-oval shaped, closed lacustrine system with no surface channels flowing into it. The lake receives freshwater from the sub-terranean springs and surface run-off. The lake is surrounded by 700-800m tall hills forming an evergreen canopy of diverse plant species. The reserve forest on the western bank of the lake is dominated by *Pinus roxburghii, Ficus religiosa, Mangifera indica* and other sub-tropical plants. Though the lake basin is thinly populated yet the impact of tourism and habitation in the catchment area on the ecology of lake are becoming more severe due to the influx of domestic sewage, animal excreta, fertilizers, pesticides, silt, detergents etc. Mansar, a sub-tropical, countryside, charming lake, about fifteen thousand years old (Krishnan & Prasad, 1970) is geologically said to have

50

originated by the damming of a river which once flowed along the strikes of the lower Shiwalik range (Zutshi, 1985). Of the two lakes in the Surinsar-Mansar Ramsar site, Lake Mansar is the biggest one catering to the demands of portable water for 20,000 individuals living within the diameter of 18Kms for which the Department of Public Health Engineering is withdrawing about 3lakh gallons of water per day. In order to assess the ecology and henceforth the health of the lake, four study stations at a distance of 500-750 meters from each other along the bank were carved. Station I is located near Mansar Bazaar on the northern side of the lake which is bordered by macrophytes, Station II is located on the eastern side of the lake near Sheshnag temple where pollution from detergents, wheat/rice flour, third pollution and religious activities like Mundan and Idol immersion is a common scene, Station III is located on the southern aspect of the lake near deer park and cremation ground and Station IV is located near JKTDC cafeteria and Tourist bungalows on the western aspect of the lake where evergreen canopy shelters the lake water. The abiotic parameters like total alkalinity, total carbon dioxide, Biochemical oxygen demand and total hardness were estimated by following APHA (1985) and Adoni (1985).

## Results

Abiotic status of an aquatic ecosystem largely reflects its health and productivity status. Since abiotic features depends on a multitude of physical, chemical and biological interactions hence assessing water chemistry is of vital concern as it is directly linked with human welfare. So the results of the present study are presented hereunder.

**A) Total Alkalinity:** In a natural aquatic ecosystem, alkalinity referred to as the total quantity of base that can be determined by titration with strong acid (Hutchinson, 1957), is due to the hydrolysis of salts formed by weak acid and strong base. Though alkalinity is usually caused by the presence of hydroxides, carbonates and bicarbonates of the cations viz., Ca, Mg, Na, K, $NH_4$ & Fe in combined state yet it is also caused though less frequently by borates, silicates & phosphates (Wurts and Durborow, 1992). According to Swingle (1967) total alkalinity is due to phenolpthalein alkalinity and methyl orange alkalinity. Total alkalinity of high range is encountered in water having pH value of 8.4 to 10.5 (Jhingran, 1978). At pH value of 4.5 to 8.3 range carbonate alkalinity is very less and is dominated by the presence of free carbon dioxide and bicarbonate alkalinity (Jhingran, 1978). So alkalinity is a measure of acid that water can absorb before a designated pH is achieved (Wurts and Durborow, 1992). During the course of present investigation, total alkalinity values on an average were found to vary from 163.36 mg/l to 288.62 mg/l. In the first year of study (Oct., 2003 to Sept. 2004), average total alkalinity values varied from 179.70±18.09 mg/l (October) to 276.80±20.21 mg/l (August). While during second year (Oct. 2004 to Sept. 2005), on an average total alkalinity values varied from 163.36±15.53 mg/l (October) to 288.62±16.66 mg/l (August). Perusal of table 1 reveals that total alkalinity values recorded a bimodal peak, one during winter and the other during monsoons. Subsequently, total alkalinity recorded an increase in concentration from April to August followed by a decrease in post monsoons and

spring. Increase in total alkalinity during summer may be attributed to stagnation of water (Blum, 1957); accelerated rate of photosynthesis leading to greater utilization of carbon dioxide and utilization of bicarbonates as source of inorganic carbon by phytoplanktons for the process of photosynthesis so as to release carbonates which can cause pH to climb dramatically (Wurts and Durborow, 1992). And increase in alkalinity during winter may be due to decay and decomposition of organic matter; prevalence of bicarbonate system (Freiser and Fernando, 1966) and low water level. Higher alkalinity values during monsoons may be due to greater agitation of water leading to a decrease in $CO_2$ content and leaching of carbonates & bicarbonates from catchment area. Fall in alkalinity values during post monsoon period may be due to : i) increased turbidity leading to decreased rate of photosynthesis & ii) leaching of sewage and faecal matter from catchment area into the domain of lake and consequent increase in organic matter content. Fall in alkalinity during spring may be due to increased photosynthetic utilization of inorganic carbon and overturning of lake waters leading to mixing & uniform distribution of carbonates & bicarbonates. Besides total alkalinity was found to record a positive but significant correlation with water temperature (r = 0.455, P =0.05), bicarbonates (r = 0.949, P =0.01), total carbon dioxide (r = 0.966, P = 0.01), BOD (r = 0.446, P =0.05), chlorides (r = 0.408, P = 0.05), conductivity (r = 0.484, P = 0.05), TDS (r = 0.484, P = 0.05), sulphates (r = 0.684, P = 0.01), silicates (r = 0.553, P = 0.01), nitrates (r = 0.631, P = 0.01), iron (r= 0.713, P = 0.01) and hydrogen sulphide (r = 0.747, P = 0.01) but negative and significant correlation with calcium (r= -0.570, P =0.01), magnesium (r = -0.502, P = 0.05) and total hardness (r = -0.553, P = 0.01). Philipose (1959) classified water medium in India into three broad categories on the basis of alkalinity values viz., alkalinity value from 4-50 mg/l as low; alkalinity value from 50-100 mg/l as moderate and alkalinity value from 100-600 mg/l as high. Accordingly the presently investigated lacustrine system with alkalinity values varying from 163.36 mg/l to 288.62 mg/l may be placed in highly alkaline category. But Barret (1953) and Vass *et al.* (1977) have suggested that the total alkalinity value of 60 mg/l or more indicates hard water. In this context, it can be said that Mansar waters remain hard throughout the year.

**B) Biochemical Oxygen Demand:** Biochemical Oxygen Demand, a measure of the quantity of oxygen consumed by micro-organisms during the decomposition of organic matter (Voznaya, 1981) is the most commonly used parameter for determining the oxygen demand of microbes for degrading organic substances. Since BOD is linked directly with the decomposition of dead organic matter, hence higher values of BOD can be directly related with the pollution status of lake (WQM, 1999). Moreover, BOD has been considered as an important pollutant causing low dissolved oxygen concentrations (USEPA, 2006). Besides, BOD could also be used as a measure of the efficiency of treatment processes and is an indirect account of biodegradable organic compounds in water. During the course of present investigations, BOD values (Table 2a) on an average varied from 1.125±0.3269 mg/l (March) to 2.000±0.5099 mg/l (August) in the first year of the study (Oct.2003 to Sept.2004) and from 0.775±0.2487 mg/l

51

(March) to 2.900±0.6708 mg/l (July) in the second year of the study (Oct. 2004 to Sept.2005). According to a popular classification (Table-2b) used in Great Britain (Maitland, 1978), Mansar waters with BOD values ranging from 0.075 to 2.900 mg/l, fluctuates from very clean to fairly clean category.

**Table 2b: Pollution Classification cited from Maitland (1978)**

| S. No. | BOD (mg/l) | Classification |
|--------|-----------|----------------|
| 1. | 0.0 – 1.0 | Very Clean |
| 2. | 1.0 – 2.5 | Clean |
| 3. | 2.5 – 4.0 | Fairly Clean |
| 4. | 4.0 – 6.0 | Doubtful |
| 5. | 6.0 – 10.0 | Poor |
| 6. | 10.0 – 15.0 | Bad |
| 7. | 15.0 – 20.0 | Very Bad |
| 8. | 20.0 + | Extremely Bad |

Perusal of table 2a reveals that BOD recorded bimodal maxima, one during winter and the other during monsoons. While spring and autumn recorded a decrease, summer recorded an increase in BOD values. Winter maxima of BOD concentration may be due to reduction in water level; increased load of bird guano as the lake is a preferred abode for many migratory aquatic birds during winter; reduction in phytoplankton population leading to a decrease in DO content of the lake waters and increased decomposition. The present winter maxima is in total contrast to the observations of Hosetti and Patil (1987) who recorded a decrease in BOD values during winter. Monsoon maxima of BOD values may be due to influx of solid organic wastes which in turn increases the activity of bacteria that feeds on organic matter and steps up competition for oxygen with natural indwelling fauna (Nudds, 2002); decrease in DO values due to the influx of carbon dioxide rich rain water; influx of sewage (untreated), faecal matter, nutrients, silt, wastes etc. from the catchment area along with the surface run-off and inflow of agricultural overland-flow containing fertilizers, manure, litter etc. Nanda and Tiwari (2002) also recorded an increase in BOD values during monsoons. Increase in BOD values during summer may be attributed to organic enrichment of lake through floral offerings (at Sheshnag temple), idol immersion and decomposition of decaying aquatic weeds; increase in bacterial population due to high water temperature; increase in organic load and suspended solids; influx of sewage and third pollution arising out of tourist influx and increased concentration of fish faecal matter containing carbohydrates that are not digestible to fishes (Nudds, 2002). Similarly spring minima may be due to increase in the phytoplankton population leading to an increase in DO content and strong wind action which induces mixing. Likewise the decline in BOD values during autumn may be due to the outcome of wind action, increased water level following monsoon rains and dilution effect left by rain water. Moreover it has been found that BOD shares an inverse relationship with DO content. Similar relationship between BOD and DO concentration has been recorded by Coscun *et al.* (1987) and Dixit *et al.* (2005). Moreover BOD recorded positive but significant correlation with

bicarbonates ($r = 0.496$, $P = 0.05$), total alkalinity ($r = 0.446$, $P = 0.05$), total carbon dioxide ($r = 0.503$, $P = 0.05$), sulphates ($r = 0.434$, $P = 0.05$), total phosphates ($r = 0.493$, $P = 0.05$), fluoride ($r = 0.423$, $P = 0.05$), iron ($r = 0.615$, $P = 0.01$), cadmium ($r = 0.544$, $P = 0.01$) and hydrogen sulphide ($r = 0.833$, $P = 0.01$) but negative and significant correlation with pH ($r = -0.522$, $P = 0.01$) and DO ($r = -0.899$, $P = 0.01$). Perusal of table 2a furthermore reveals that the BOD recorded well marked seasonal variations at each of the four study sites and that the BOD value was recorded higher at station III followed by station II, I and IV thereby indicating the fact that the stations are exposed to varying degrees of pollution and anthropogenic influences.

**C) Total Hardness:** Total Hardness, a measure of the quality of water supplies, is governed by the content of calcium and magnesium salts largely combined with bicarbonate and carbonate (temporary hardness) and with sulphates, chlorides and other anions of mineral acids (permanent hardness). However, total hardness is used to classify water as soft and hard. Swingle (1967) has suggested that the total hardness of 50 mg/l of $CaCO_3$ is equivalent to the dividing line between soft and hard water and the water having hardness ≥ 15 mg/l is suitable for the growth of fishes. Jhingran (1978) suggested that water with <5 mg/l $CaCO_3$ is not at all suitable for fish growth. In the present study, hardness of water varies from 94.42 mg/l to 227.68 mg/l in Lake Mansar which implies that the lake water is suitable for fish growth. During the present study, average total hardness values varied from 94.42±16.84 mg/l (August) to 223.03±19.94 mg/l (December) in first year of study (Oct. 2003 to Sept. 2004). During the second year of study (Oct.2004 to Sept. 2005), total hardness varied from 135.29±19.05 mg/l (September) to 227.68 ± 18.52 mg/l (February). Perusal of table 3 reveals that total hardness recorded maxima during winter and a decline during summer and monsoon seasons while in the post monsoon period total hardness recorded an increase in its concentration. Winter maxima of total hardness may be due to the cumulative effect of reduction in the autotrophic uptake of Ca and Mg due to reduced algal and macrophytic population at low temperature; stagnation of water due to weak nature of wind; reduction or decrease in water level; decomposition of dead organic matter; sewage contamination of lake water which is a common scene at Lake Mansar and washing of clothes and bathing of cattle (Naik and Purohit, 1996). Summer decline in total hardness values may be due to increased utilization of Ca and Mg carbonates and bicarbonates by photosynthetically active plants; increase in algal and photosynthetically active macrophytes; high DO content due to increased utilization of free carbon dioxide in photosynthesis which in turn results in the precipitation of calcium as $CaCO_3$ or marls and active stirring and aeration of surface waters of lake leading to an increase in DO content and reduction in carbon dioxide concentration. This observation is in agreement with Sehgal's (1980) findings but is contrary to the observation of Jana (1973) who recorded rise in the values of total hardness during summer. Similarly, fall in total hardness during monsoons may be due to the dilution effect of rain water. This observation gets reinforcement from the findings of Sehgal (1980) and Gochhait (1991). Increase in total hardness during post monsoon season

may be attributed to decline in pH values due to the presence of free carbon dioxide which leads to the conversion of insoluble carbonates (marls) to soluble bicarbonates; aggregation of nutrients washed away from the catchment area into the lake by rains; decrease in the rate of photosynthetic utilization of free carbon dioxide due to increased turbidity and decreased utilization of calcium and magnesium and its conversion into biomass. Furthermore, perusal of table 3 reveals that total hardness of Lake Mansar is extremely high at all the four stations wherein well marked seasonal variations were observed. Besides total hardness recorded positive but significant correlation with calcium (r = 0.988, P =0.01) and magnesium (r = 0.954, P =0.01) but negative and significant correlation with atmospheric temperature (r = -0.566, P = 0.01), water temperature (r = -0.621, P = 0.01), bicarbonates (r = -0.500, P = 0.01), total alkalinity (r = -0.553, P = 0.01), total carbon dioxide (r = -0.515, P = 0.05), sulphates (r = -0.756, P = 0.01), silicates (r = 0.634, P = 0.01), nitrates (r = -0.865, P = 0.01), iron (r = -0.537, P = 0.01)and hydrogen sulphide (r = -0.407, P = 0.05). But Sawyer (1960) has classified water into three broad categories on the basis of range of total hardness values viz., <75 mg/l – Soft; 76-150 mg/l – Moderately Hard and 151-300 mg/l – Hard. With reference to this classification, Lake Mansar may be addressed as moderately hard to hard water body. Perusal of table 3 reveals that there is an increase in the values of total hardness from one year to another which implies that the pollution load on the lake is growing with every passing year. Of all the stations, station III recorded highest values of total hardness which indicates that the said station is upholding greater quantum of varied pollutants viz., soaps, detergents, nutrients, faecal matter, domestic sewage, agricultural fields overland flow etc. and hence is highly polluted of all the stations.

## D) SULPHATES

Sulphate, the predominant form of sulphur in an aquatic ecosystem, is of immense importance as it affects ecosystem productivity, abundance and distribution of biota (Fish, 1956) etc. Nearly all assimilation of sulphur takes place as sulphates but during decomposition of organic matter, sulphur is reduced to hydrogen sulphide which is oxidized rapidly (Hutchinson, 1957; Hem, 1960b). Being an essential component of amino acid in the form of elemental sulphur, sulphates constitute an important constituent of proteins. In natural waters, sulphates are reduced to sulphydral (-SH) groups by autotrophs and are incorporated into proteins. Though aquatic ecosystem is enriched with sulphates by solubilization from rocks (Nriagu and Hem, 1978), atmospheric precipitation augmented greatly by combustion products (Fisher *et al.*, 1968: Hemond, 1994), fertilizers, dry deposition (Jensen and Nakai, 1961; Steele and Buttle, 1994), decomposition of organic matter containing proteinaceous sulphur and its anaerobic reduction (Jensen and Nakia, 1961) etc yet a major pool (90%) of it exists in the mineral soils (Houle and Carignan, 1995). The retention of sulphur in soils of the drainage basin and their release to natural waters varies with regional lithology and agricultural application of sulphate containing fertilizers (Wetzel, 2001). In an aquatic environment, sulphates do not limit the growth and distribution of biota (Lehman and Branstrator, 1994) but it

affects the cycling of other nutrients, productivity etc (Wetzel, 2001). Sulphates in the form of sodium and magnesium sulphates exert cathartic actions in aquatic medium (APHA, 1985) and its concentration above 250 mg/l in potable water is objectionable (NEERI, 1986). But the values of sulphates recorded during the present study reveals that the sulphate values were well below the proposed objectionable range. During the present investigations, average sulphate values varied from 3.050±0.760 mg/l (March) to 20.070±3.384 mg/l (July) in the first year of study (Oct 2003 to Sept.2004). But during second year (Oct. 2004 to Sept.2005), sulphate concentration on an average varied from 4.875±0.441 mg/l (March) to 21.950± 2.571 mg/l (August). Perusal of table 4 reveals that sulphate recorded a unimodal peak during monsoons followed by a decline from post monsoon to winter season. But from spring onwards, sulphates recorded an increase upto summer. Monsoon maxima may be attributed to: i) Rise in water level due to incessant rains (Cole, 1975); ii) Inflow of sewage, faecal matter and minerals from catchment area and leaching of nutrients from cremation ground along with surface run-off; iii) Bottom soil-water interactions; iv) Weathering and solubilization of rocks and v) Decrease in dissolved oxygen content due to the inflow of nutrients and acidic rain water which ultimately reduces the oxidation of hydrogen sulphide. Similar rise in sulphate content during monsoons has also been observed by Fisher *et al.* (1968) and Hemond (1994). Decline in sulphate content from post monsoons to winter season may be due to: i) Dilution effect induced by local rains; ii) Reduced decomposition of organic matter at low temperature; iii) Overturning of lake leading to mixing of sulphate–poor hypolimnetic waters with the eplimnetic layer; iv) Low temperature and v) Reduction of sulphates into sulphides which is subsequently oxidized rapidly. Similar observation has been made by Sehgal (1980) and Tripathi and Pandey (1990). But Gochhait (1991) recorded an increased concentration of sulphates during winter. Increase in sulphate content during spring and summer may be due to: i) Decreased water level; ii) Accelerated rate of decomposition due to high temperature; iii) Greater release of sulphate from decomposition processes than is actually consumed by aquatic plants and iv) Inflow of detergents, soaps, sewage and human faecal matter. Similar findings were placed on record by Sehgal (1980) and Tripathi and Pandey (1990). But the present observation is contrary to the findings of Gochhait (1991) who recorded a decline in the concentration of sulphates during summer season. Meanwhile sulphates recorded positive but significant correlation with atmospheric temperature (r = 0.681, P = 0.01), water temperature (r = 0.791, P = 0.01), bicarbonates (r = 0.620, P = 0.01), total alkalinity (r = 0.684, P = 0.01), total carbon dioxide (r = 0.632, P = 0.01), BOD (r = 0.434, P =0.05), silicates (r = 0.759, P = 0.01), nitrates (r = 0.852, P = 0.01), iron (r = 0.470, P = 0.05) and hydrogen sulphide (r = 0.605, P = 0.01) but negative and significant correlation with calcium (r = -0.736, P = 0.01), magnesium (r = -0.807, P = 0.01) and total hardness (r = -0.756, P = 0.01). Perusal of table 4 also reveals that the sulphate values recorded wide seasonal variations. But the values recorded at station III are comparatively greater than the rest three stations I, II and IV which implies that the station III is highly polluted.

## TOTAL PHOSPHATES

Phosphates constitute an important nutrient essential for the growth of organisms (Wiebe, 1931b). Being indispensable constituent of cellular components like nucleic acids (DNA, RNA, Phosphoproteins), enzymes, vitamins, nucleotide phosphates (ADP, ATP) etc phosphates play an incredible role in the biochemical pathways of respiration and carbon dioxide assimilation (Wetzel, 2001). Though relatively small amounts of phosphates are available in the hydrosphere yet it is of considerable significance in limiting the biological productivity (Laxmaiah et al., 1994; Wetzel, 2001) and any increase in its concentration not only affects the aquatic biota (Upadhyay, 1998) but also leads to pollution (Vollenweider et al., 1974). Although atmospheric precipitation (Chapin and Uttormark, 1973; Cole et al., 1990; Newman, 1995), geochemical conditions (Vollenweider, 1968) and ground water are important sources of phosphorus yet the major contribution to aquatic phosphate content is from agricultural and watershed run-off (Biggar and Corey, 1969; Lewis, 1986 and Lal, 1998), fertilizers (Skaggs et al., 1994, Jordan and Weller, 1996), detergents (Moss et al., 1980) and domestic sewage (Gassmann and Schorn, 1993; Glindemann et al., 1996). Hence phosphate concentration in upland or mountainous fresh waters are generally low while an increased concentration of phosphate in lowland waters is imminent due to leaching from sedimentary rock deposits. Moreover, phosphates have been observed to share an inverse relationship with pH (Otsuki and Wetzel, 1972). During the present investigations extending from October 2003 to September 2005, total phosphate values varied form 0.028 mg/l to 0.245 mg/l. Wetzel (1975) classified lakes on the basis of total phosphate content into following categories:

1. Oligotrophic      <0.005 mg/l
2. Mesotrophic      0.005 to 0.01 mg/l
3. Mesoeutrophic      0.01 to 0.03 mg/l
4. Eutrophic      0.03 to 0.1 mg/l
5. Hypereutrophic      >0.1 mg/l

The trophic status of the Mansar Lake as per the classification of Wetzel (1975) varies from mesoeutrophic to hypereutrophic in different seasons. Increased phosphate concentration beyond 0.2 mg/l increases the growth of phytoplanktons (Iqbal and Kataria, 1995). In fact Lake Mansar recorded an increase in phytoplankton population in summer and monsoon seasons during which the lacustrine system recorded maximum values of phosphates. During the first year of study (Oct. 2003 to Sept 2004), average phosphate concentration varied form 0.049±0.010 mg/l (April) to 0.165±0.037mg/l (September). While during the second year of the study (Oct. 2004 to Sept. 2005), phosphates on an average varied from 0.059±0.010mg/l (April) to 0.181±0.040 mg/l (September). Perusal of table 5 reveals that phosphate concentration increased from April to September i.e. from summer until it reached its maxima during monsoons. Thereafter phosphate values declined during winter until it reached its minima during spring. Increase in phosphate concentration during summer may be due to: Higher temperature (Pasternak and Kasza, 1979); Increased decomposition rate and greater release of nutrients there from; Contamination of lake water with faecal matter and sewage effluents (Bolas and Lund, 1974); Increased lake productivity (Vollenweider, 1968); Microbial biochemical mobilization of phosphates from particulate stores to dissolved phosphates (Bostrom et al., 1982; Stumm and Morgan, 1995); Increased growth of rooted macrophytes which withdraw greater quantum of phosphates from the sediments (Denny, 1972; Barko and Smart, 1981; Brock et al., 1983a, b) and release the same into water after death and decay and excretion by vertebrates especially birds and fishes. The present observation is in complete conformity with the findings of Ray and David (1966), Goel et al. (1981), Shukla et al. (1989) and Gochhait (1991) who recorded a rise in phosphate content during summer. But Sehgal (1980) recorded absence or decrease in phosphate concentration during summer. Monsoon maxima in phosphate values may be attributed to: Leaching of phosphorus containing fertilizers from the agricultural fields (Skaggs et al., 1994); Influx of sewage, eroded soil/silt, faecal matter, detergents and soaps along with run-off.; Weathering of phosphate bearing rocks by the monsoon rains; Washing of utensils and bathing of cattle and Washing of lake side lawns fertilized with phosphorus containing fertilizers by the rain water. Similar observation was made by Kadlec (1960); Armstrong and Schindler (1971); Rao (1972), Hannen et al. (1972); McColl and Forsyth (1973); Toetz (1973); Stewart and Markello (1974); Jhingran (1975); Mitchell (1975); Saad and Samir (1979); Sehgal (1980); Boralkar (1981); Jansson et al. (1986); Gochhait (1991) and Jordan and Weller (1996). Contrary to the present observation, Otsuki and Wetzel (1972) recorded low phosphate concentration during rainy season. Decline in phosphate concentration during winter and spring may be due to its co-precipitation with carbonates at high pH (Otsuki and Wetzel, 1972) and its utilization by algal planktons during photosynthesis (Gonzalves and Joshi, 1946; Saad and Samir, 1979). Gochhait (1991) recorded a decline in phosphates values during winter. Anyhow total phosphates recorded positive but significant correlation with BOD (r= 0.493, P = 0.05), conductivity (r = 0.443, P = 0.05), TDS (r = 0.440, P = 0.05), silicates (r = 0.572, P = 0.01), nitrates (r = 0.434, P = 0.05), sodium (r = 0.525, P =0.01), potassium (r = 0.675, P = 0.01), fluorides (r = 0.777, P = 0.01) and iron (r = 0.474, P = 0.05) but negative and significant correlation with DO (r = -0.485, P = 0.05). Perusal of table 5 furthermore reveals well marked seasonal variations in the total phosphate content of Lake Mansar at all the study sites. Of all the stations, station III is having greater amounts of phosphates thereby indicating its polluted nature. An increase in phosphate content observed during second year of study can be attributed to greater precipitation in that year in comparison to first year of study which leaches greater amounts of fertilizers from the catchment area of the lake, a greater portion of which has been converted into agricultural fields.

## SILICATES

In natural waters, silica commonly occurs in the form of soluble undissociated orthosilicates derived from the siliceous rocks in the catchment area (Maitland, 1978). Silicon constitutes about 12 % of the lithosphere wherein it exists in the form of granites, pegmatites, schists, gneisses, quartzites and sand stone (Clarke, 1934). Silica enters the

54

aquatic medium via monsoon rains while washing rocky substratum containing quartz, sewage from the catchment area and decomposition of diatoms. Although silica is relatively unreactive and moderately abundant in fresh waters yet it is of major significance to diatomaceous algae, chrysophytes and some higher aquatic plants and sponges (Wetzel, 2001). During the course of present investigations, silicates on an average varied from 4.1875 mg/l to 7.1625 mg/l and this high range of silicates may be attributed to sandy nature of bottom soil and inflow of ground waters (Wetzel, 2001). A careful study of table 6 reveals that during first year of study (Oct. 2003 to Sept. 2004), silicate concentration on an average varied from 4.1875±0.6280 mg/l (March) to 7.0500±0.2263 mg/l (September). While during second year of study (Oct. 2004 to Sept. 2005) on an average silicate content of Lake Mansar varied from 4.350±0.2474 mg/l (February) to 7.1625±0.2011 mg/l (September). Besides, silicates were observed to record a unimodal peak during monsoons followed by a decline during winter and spring and an increase during summer. Similar trend in the seasonal cycle of silicates was observed by Mason and Bushwell (1950). Maxima in silicate concentration during monsoons may be attributed to: i) inflow of rains washing quartz containing rocky substratum (Wetzel, 2001) and ii) sewage from the catchment area into the domain of lake. This observation is in agreement with the findings of Sundarraj and Krishnamurthy (1981) who recorded an increase in silicate concentration during monsoons. Decline in silicate content in Lake Mansar during winter and spring may be due to the individual or cumulative effects of:

i)    Assimilation of silicates by diatoms which sediment with their incorporated silica from the trophogenic zone more rapidly than the silica replaced by inputs to the aquatic environment from the surface and ground waters (Schelske and Stoermer, 1971; Conley et al., 1993).
ii)   Increase in soil pH, as adsorption of silicates on to the soil particles increase within the pH range of 4-9 (McKeague and Cline, 1963 a, b).
iii)  Adsorption of silica to dead diatoms and cells.
iv)   Abstraction or outflow of water (Tessenow, 1966).
v)    Enhanced production of diatoms due to low temperature (Lee, 1962; Munawar, 1970, Bailey-Watts, 1976).

This observation is in line with the findings of Gochhait (1991) but is contrary to the observations of Pehwa and Mehrotra (1966) and Ray et al. (1966) who recorded an increase in silicate content during winter. Similarly, summer increase in silicate content may be attributed to: Higher temperature (McKeague and Cline, 1963a, b; Tessenow, 1966); Increase in the rate of release of sediment silica at higher temperature (Rippey, 1983); Decrease in diatom growth (Ruttner, 1963; Munawar, 1970) and Enhanced rate of decomposition leading to the release of silica from diatoms. The present observation is in complete conformity with the findings of Gochhait (1991) who recorded a similar rise in silicate concentration during summer. However silicates recorded positive but significant correlation with atmospheric temperature (r= 0.600, P = 0.01), water temperature (r = 0.631, P = 0.01), carbonates (r = 0.633, P

= 0.01), total alkalinity (r = 0.553, P = 0.01), total carbon dioxide (r = 0.438, P = 0.05), conductivity (r = 0.521, P = 0.01), TDS (r = 0.520, P = 0.01), sulphates (r = 0.759, P = 0.01), total phosphates (r = 0.572, P = 0.01), nitrates (r = 0.836, P = 0.01), fluoride (r = 0.488, P = 0.05) and iron (r = 0.438, P = 0.05) but negative and significant correlation with calcium (r = -0.644, P = 0.01), magnesium (r = -0.634, P = 0.01) and total hardness (r = -0.634, P = 0.01).

## NITRATE NITROGEN

Nitrate, an important factor which controls the occurrence and abundance of phytoplankton, is a common form of inorganic nitrogen entering the fresh waters from the drainage basin, ground waters and precipitation (Wetzel, 2001). Being responsible for the formation of chlorophyll (Rodhe, 1948), nitrate is one of the most important limiting factors in the development of phytoplanktons (Welch, 1952). In natural aerobic waters, most nitrogen occurs as nitrates (Maitland, 1978) in varying amounts depending upon the nature of water shade, seasons, degree of pollution and the abundance of planktons (Sommer, 1989). Moreover, nitrates are considered to supply nitrogen in more available forms than nitrites and ammonia (Welch, 1952). During the course of present investigation, average values of nitrate-nitrogen varied from 0.3312±0.678 mg/l (January) to 0.5107 ± 0.0595 mg/l (August) in the first year of study (Oct. 2003 to Sept. 2004). While during the second year of the study (Oct. 2004 to Sept. 2005), nitrate values on an average varied from 0.2762±0.0701 mg/l (February) to 0.5075±0.0957 mg/l (August). Perusal of Table 7 reveals that nitrate-nitrogen concentration varied from 0.2762 mg/l to 0.5107 mg/l in Lake Mansar. Ganapati (1960) pointed out that the concentration of nitrate-nitrogen beyond 0.15 mg/l is an indicative of eutrophication. And the same criteria places Lake Mansar in eutrophic category. Table 7 further reveals that nitrate-nitrogen recorded a peak during monsoons followed by a decline during winter and an increase during summer season. Monsoon maxima in nitrate concentration may be attributed to:

i)    Influx of decaying organic matter and faecal matter (Asuquo, 1989), nitrogenous fertilizers from agricultural fields (Boralkar, 1981) and nutrients from cremation ground.
ii)   Increased rate of nitrification and bacterial decomposition.
iii)  Contamination of lake water with sewage washed away by run-off into the domain of the lake.
iv)   Influx of nitrate from catchment area along with rain water (Shukla et al., 1989).

The present observation is in complete conformity with the findings of Matsudaria and Kato (1943), Sahai and Sinha (1969), Das et al. (1992), Saxena (1998) and Upadhyay (1998). Decline in nitrate content during winter may be due to the cumulative or individual effects of:

i)    Active uptake and utilization of nitrates by macrophytes (Lee et al., 1975).
ii)   Increased nitrification at low temperature (Maulood and Hinton, 1980).
iii)  Reduced rate of decomposition at low temperature.

55

Similar observation was made by Gonzalves and Joshi (1946), Singh (1965), Sahai and Sinha (1969), Sehgal (1980) and Gochhait (1991). Increase in the concentration of nitrates during summer may be due to:

i)    Increase in the mineral nitrogen level in the medium at high temperature (Pasternak and Kasza, 1979) due to evapo-transpiration.
ii)   Inputs of nitrogen from guano of water bird (Manny *et al.*, 1975, 1994).
iii)  Leachate from direct leaf fall (Wetzel, 2001).
iv)   Formation of algal mats on the surface (Sunderraj and Krishnamurthy, 1981).
v)    Increased rate of decomposition of organic matter.
vi)   Discharge of sewage into the aquatic medium (Goel *et al.*, 1981)
vii)  Decaying macrophytes.

This observation is in agreement with the findings of Sehgal (1980), Tripathi and Pandey (1990) and Gochhait (1991). Nevertheless nitrates recorded positive but significant correlation with atmospheric temperature (r = 0.749, P = 0.01), water temperature (r = 0.756, P = 0.01), carbonates (r = 0.420, P = 0.05), bicarbonates (r = 0.537, P = 0.01), total alkalinity (r = 0.631, P = 0.01), total carbon dioxide (r = 0.559, P = 0.01), sulphates (r = 0.852, P = 0.01), total phosphates (r = 0.434, P = 0.05), silicates (r = 0.836, P = 0.01), iron (r = 0.501, P = 0.05) and hydrogen sulphide (r = 0.469, P = 0.05) but negative and significant correlation with calcium (r = -0.850, P = 0.01), magnesium (r = -0.884, P = 0.01) and total hardness (r = -0.865, P = 0.01). Perusal of table 7 reveals that due to greater precipitation nitrate values increased greatly in Lake Mansar during second year of the study. Of all the stations, station III recorded higher values of nitrate nitrogen thereby indicating the eutrophic nature of the said station. Kudesia (1980) opined that nitrate values within 0.48 mg/l limit are permissible but the concentration of nitrates beyond this limit indicates organic pollution. As per this criterion, most of the stations experienced organic pollution during monsoons while for rest of the year, water contained permissible level of nitrates. This differential concentration of nitrates at different stations during different seasons may be due to peculiar geochemistry of the lake catchment area.

## AMMONIA

Ammonia, generated by biological dissimilation of nitrate and decomposition of organic matter by heterotrophic bacteria from deamination of proteins, amino acid, urea and other nitrogenous organic compound (Adoni, 1985; Wetzel, 2001), is an important source of nitrogen for some plants (Welch, 1952). Moreover, ammonia is an energy efficient source of nitrogen for plants, as the energy required to assimilate nitrogen is lowest for ammonical nitrogen in comparison to nitrate-nitrogen (Wehr *et al.*, 1987; Wetzel, 2001). In unmodified natural waters, ammonia primarily exists as $NH_4^+$ and $NH_4OH$, the latter being highly toxic to many organisms especially fish (Trussel, 1972). Though the amount of ammonia and ammonium compounds in aquatic resources is very small averaging less than 0.1 ppm but the amounts exceeding 2.5 ppm are generally detrimental and the quantities of more than 1.0 ppm usually indicate organic pollution (Ellis *et al.*, 1946). During the present

investigation, ammonia concentration on an average varied from 0.130±0.0014 mg/l (June) to 0.1542±0.0094 mg/l (August) in the first year of study (Oct. 2003 to Sept. 2004). While during second year of the present study (Oct. 2004 to Sept. 2005), average values of ammonia in Lake Mansar varied from 0.1200±0.0245 mg/l (May) to 0.1535±0.0086 mg/l (August). Perusal of table 8a reveals that ammonia concentration in the Lake Mansar recorded a bimodal peak, one during winter and the other during monsoons while during spring and summer, ammonia recorded a sharp decline. Winter maxima of ammonia concentration may be due to:

i)    Decomposition of organic matter (Golterman, 1975a, b).
ii)   Decrease in algal population leading to a decrease in the assimilation of ammonia.
iii)  Inflow of sewage.
iv)   Influx of bird droppings into the lake as it is visited by many aquatic birds during winter.

The present observation is in line with the findings of Stadelmann (1971). But contrary to this observation, Kulkarni *et al.*(1988), Edmondson (1992) and Kumar *et al.*(2002) recorded minima of ammonia during winter. Maxima of ammonia concentration during monsoons may be attributed to:

i)    Influx of overland flow especially from agricultural fields.
ii)   Influx of organic matter, sewage, faecal matter etc along with surface run-off.
iii)  Precipitation of atmospheric nitrogen in the form of ammonia (Maitland, 1978).
iv)   Washing of nutrients from the cremation ground into the lake.

Similar observations have also been made by Naik and Purohit (1996) and Kumar *et al.* (2002). Decline in the concentration of ammonia during spring and summer may be due to:

i)    Increase in algal population and rapid assimilation of ammonical nitrogen by algae (Liao and Lean, 1978; Wehr *et al.*, 1987).
ii)   Adsorption of ammonia to sediment particles (Kamiyama *et al.*, 1977).
iii)  Mineralization of ammonia followed by its sedimentation (Gambrell and Patrick, 1978).

Contrary to the present observation Golterman (1975a, b) and Kumar *et al.* (2002) recorded maxima of ammonia content during summer in the water bodies studied by them. As a matter of fact ammonia recorded positive but significant correlation with conductivity (r = 0.563, P = 0.01), TDS (r = 0.562, P = 0.01), sodium (r = 0.734, P = 0.01), potassium (r = 0.734, P = 0.01) and iron (r = 0.437, P = 0.05) but negative and significant correlation with atmospheric temperature (r= -0.472, P = 0.05). Perusal of table 8 also reveals that the ammonia content of Lake Mansar recorded well marked seasonal variations at each of the four stations. A careful study of table 8 reveals that of all the stations, station III contains greater ammonia

concentration thereby indicating that the said station is under the acute stress of anthropogenic influences like sewage, faecal matter, agricultural run-off etc.

## Acknowledgements

## References:

[1]. **Adoni, A.D. (1985):** Workbook on Limnology. Pratibha Publishers, C-10 Gour Nagar, Sagar – 470 003, India. 216 pp. APHA (1985)

[2]. **Armstrong, F.A.J. and Schindler, D.W. (1971):** Preliminary chemical characterization of waters in the experimental lakes area, North-western Ontario. *J. Fish Res. Board Can.,* 28: 171-187.

[3]. **Asuquo, F.E. (1989):** Water quality of the Calabar River, Nigeria. *Trop. Ecol.*, 30(1): 31-40.

[4]. **Bailey-Watts, A.E. (1976):** Diatom silica relations in the plankton of Loch Laven, Kinross. *Freshwater Biol.*, 6: 69-80.

[5]. **Barko, J.W. and Smart, R.M. (1981):** Comparative influences of light and temperature on the growth and metabolism of selected submersed freshwater macrophytes. *Ecol. Monogr.*, 51: 219-235.

[6]. **Barret, P.H. (1953):** Relationship between alkalinity and absorption and regeneration of added phosphorus in fertilized trout lakes. *Am. Fish. Soc.*, 82: 78-90.

[7]. **Biggar, J.W. and Corey, R.B. (1969):** Agricultural drainage eutrophication. In: Eutrophication: Causes, Consequences, Correctives. National Academy of Sciences, Washington D.C. pp. 404-445.

[8]. **Blum, J.L. (1957):** An ecological study of the algae of the saline river, Michigan. *Hydrobiol.*, 9: 361-408.

[9]. **Bolas, P.M. and Lund, J.W.G. (1974):** Some factors affecting the growth of *Cladophora glomerata* in the Kentisch Stour*. Treat. Exam.,* 23: 25-51.

[10]. **Boralkar, D.B. (1981):** Studies of the Krishna River ecosystem between Karod and Sangli (Maharashtra). A report of the project carried out by Science Colllege Karod, during July-December, 1980. pp. 1-18.

[11]. **Bostrom, B., Jansson, M. and Forsberg, C. (1982):** Phosphorus release from lake sediments. *Arch. Hydrobiol. Beih. Ergebn. Limnol.*, 18: 5-59.

[12]. **Brock, T.C.M., Arts, G.H.P., Goossen, L.L.M. and Rutenfrans, A.H.M. (1983a):** Structure and annual biomass production by *Nymphoides peltata* (Gmel.) O. Kuntze (Menyanthaceae). *Aquat. Bot.*, 17: 167-188.

[13]. **Chapin, J.D. and Uttormark, P.D. (1973):** Atmospheric Contributions of Nitrogen and Phosphorus. *Tech. Rep. Wat. Resources Ctr. Univ. Wisc.* 73-2. 35pp.

[14]. **Clarke, G.L. (1934):** Factors affecting the vertical distribution of copepods. *Ecol. Monogr.*, 4: 530–540.

[15]. **Cole, C.A. (1975):** A Textbook of Limnology. 2$^{nd}$ Edn. New York. The C.V. Mosby Co., St. Louis, London. 726pp.

[16]. **Cole, J.J., Caraco, N.F. and Likens, G.E. (1990):** Short range atmospheric transport: A significant source of phosphorus to an oligotrophic lake. *Limnol. Oceanogr.*, 35: 1230-1237.

[17]. **Conley, D.J., Schelske, C.L. and Stoermer, E.F. (1993):** Modification of the biogeochemical cycle of silica with autrophication. *Mar. Ecol. Prog.* Ser. 101: 179-192.

[18]. **Coscun, I., Yurteri, S., Mirat, T. and Gurol, D. (1987):** Removal of dissolved organic contaminants by ozonation. *Environmental Progress*, 6(40): 240-244.

[19]. **Das, H.B., Kalita, H., Saikia, L.B., Borah, K. and Kannur, S.B. (1992):** Physico-chemical characteristics of Brahmanputra water at Tezpur. *Poll. Res.* 11(3): 169-172.

[20]. **Denny, P. (1972):** Lakes of South-western Uganda. I. Physical and chemical studies on Lake Bunyonyi. *Freshwater Biol.*, 2: 143-158.

[21]. **Dixit, S., Verma, N., Tiwari, S. and Bajpai, A. (2005):** The effects of aeration units on water quality in Upper Lake, Bhopal, India. *Electronic Green Journal*, Issue 22: 1-5

[22]. **Edmondson, W.T. (1992):** Nutrients and phytoplankton in lake Washington. In: Nutrients and eutrophication. The limiting nutrient controversy (Likens, G.E. ed.). *Spec. Symposium Limnol. and Oceanogr.*, 1: 172-193.

[23]. **Ellis, M.M., Westfall, B.A. and Ellis, M.D. (1946):** Determination of Water Quality. Fish and Wildlife Service, U.S. Dept. Interior, *Res. Rept.* 9: 122pp.

[24]. **Fish, G.R. (1956):** Chemical factors limiting growth of phytoplankton in Lake Victoria. *East African Agricult. J.*, 21: 152-158.

[25]. **Fisher, D.N., Gambell, A.W., Likens, G.E. and Bormann, F.H. (1968):** Atmospheric contributions to water quality of streams in the Hubbard Brook

Experimental Forest, New Hampshire. *Water Resources Res.*, 4: 1115-1126.

[26]. **Freiser, H. and Fernando, Q. (1966):** Ionic equilibria in Analytical Chemistry. Wiley and Sons, New York.

[27]. **Gambrell, R.P. and Patrick, W.H.Jr. (1978):** Chemical and microbiological properties of anaerobic soils and sediments. In: Plant life in aerobic environments (Hook, D.D. and Crawfors, R.M.M. eds.). Ann. Arbor. Aci. Inc. Ann. Arbor. Mich. pp. 375-425.

[28]. **Ganapati, S.V. (1960):** Ecology of Tropical waters. *Proc. Symp. Algalogy*, ICAR New Delhi. 204 – 218.

[29]. **Gassmann, G. and Schorn, F. (1993):** Phosphine from harbor surface sediments. *Naturwissenschaften*, 80: 78-80.

[30]. **Glindemann, D., Stottmeister, U. and Bergmann, A. (1996):** Free phosphine from the anaerobic biosphere. *Environ. Sci. Pollut. Res.*, 3: 17-19.

[31]. **Gochhait, B.C. (1991):** Studies on limnological factors of river Buddhabalanga at Baripada (Orissa). Ph. D. thesis, Utkal University.

[32]. **Goel, P.K., Trivedy, R.K. and Gopal, B. (1981):** Role of limnological studies in monitoring sewage pollution. Proc. of Silver Jubilee Symp. on Trop. Ecol. Bhopal, India. Sec. 68-77.

[33]. **Goldman, C.R and Horne, A.J. (1983):** Limnology. Mc Graw- Hill international Book Company. pp. 464.

[34]. **Golterman, H.L. (1975a):** Physiological Limnology. Elsevier Scientific Publishing Co. New York. 489pp.

[35]. **Golterman, H.L. (1975b):** "Chemistry of Running Waters", pp. 39-80. In: River Ecology (Whitton, B.A. ed.). Blackwell, Oxford.

[36]. **Gonzalves, E.A. and Joshi, D.B. (1946):** Fresh water algae near Bombay. *J. Bombay Nat. Hist. Soc.*, **46**(1): 154-176.

[37]. **Hannen, H.H., Young, W.C. and Joe, J.M. (1972):** Nitrogen and phosphorus dynamics in three Central Texas impoundments. *Hydrobiol.*, 40(1): 121-129.

[38]. **Hem, J.D. (1960a):** Complexes of ferrous iron with tannic acid. In: Chemistry of Iron in Natural Water. *U.S. Geol. Surv. Water-Supply Pap.* 1459-D: 75-94.

[39]. **Hem, J.D. (1960b):** Some chemical relationships among sulfur species and dissolved ferrous iron. In: Chemistry of Iron in Natural Water. *U.S. Geol. Surv. Water-Supply Pap.* 1459-C: 57-73.

[40]. **Hemond, H.F. (1994):** Role of organic acids in acidification of freshwaters. In: Acidification of Freshwater Ecosystems: Implications for the future (Steinberg, C.E.W. and Wright, R.F. eds.). John Wiley & Sons, Chichester. pp. 103-115.

[41]. **Hosetti, B.B. and Patil, H.S. (1987):** Performance of stabilization ponds at different depths (Mitchell, R. ed.). John Wiley and Sons, N.Y. Vol. 2, 1-30.

[42]. **Houle, D. and Carignan, R. (1995):** Role of $SO_2$ adsorption and desorption in the long term S budget of a coniferous catchment on the Canadian Shield. *Biogeochemistry*, 28: 161-182.

[43]. **Hutchinson, G.E. (1957):** Treatise on Limnology, Vol. I. John Wiley and Sons, New York, London.

[44]. **Iqbal, S.K. and Kataria, H.C. (1995):** Physico-chemical analysis and water quality assessment of Upper Lake of Bhopal. *Indian Journal of Environmental Protection*, 15(7): 504 – 509.

[45]. **Jansson, M., Persson, G. and Broberg, O. (1986):** Phosphorus in acidified lakes: The example of Lake Gardsjon, Sweden. *Hydrobiol.,* 139: 81-96.

[46]. **Jensen, M.L. and Nakai, N. (1961):** Sources and isotopic composition of atmospheric sulfur. *Science*, 134: 2102-2104.

[47]. **Jhingran, V.G. (1975):** Fish and Fisheries of India. First Edition. Hindustan Publishing Corporation (India), Delhi. 954pp.

[48]. **Jhingran, V.G. (1978):** Fish and Fisheries of India. Hindustan Publishing Corporation (India), Delhi. pp.954.

[49]. **Jordan, T.E. and Weller, D.E. (1996):** Human contributions to terrestrial nitrogen flux. *Bioscience*, 46: 655-664.

[50]. **Kadlec, J. (1960):** The effect of a draw down on the ecology of a water fowl impoundments. Rep. 2276, Game Dep. Mich. Dep. Conserv., Lansing: 181pp.

[51]. **Kamiyama, K., Okuda, S. and Kawai, A. (1977):** Studies on the release of ammonium nitrogen from the bottom sediments in freshwater regions. II. Ammonium nitrogen in dissolved and absorbed form in the sediments. *Jpn. J. Limnol.*, 38: 100-106.

[52]. **Krishnan, P.V. and Prasad, R. (1970):** Tectonic framework of a tertiary belt of the Sub-Himalayas of Jammu. Publication Centre Advance studies Geology, Chandigarh, No. 7-19.

58

[53]. **Kudesia, V.P. (1980):** Water Pollution. (Principles of disinfection of drinking water and its analysis Ist Edn. K.K. Mittal, Pragati Prakashan. Meerut, India.

[54]. **Kulkarni, A.Y., Khatavkar, S.D. and Goel, P.K. (1988):** Studies on physico-chemical characteristics of the water bodies at Aundh in South Western Maharashtra with reference to the stress of human activities. *Indian J. Environmental Protection*, 8(2): 109-114.

[55]. **Kumar, A., Bohra, C. and Singh, A.K. (2002):** Ecotechnology for limnological profile of Kawar Lake with special reference to Biogechemical cycles. In: Ecology and Ethology of Aquatic biota (Kumar, A. ed.). Daya Publishing House, Delhi, India, vol. II, pp. 149-200.

[56]. **Lal, R. (1998):** Soil erosion impact on agronomic productivity and environment quality. *Crit. Rev. Pl. Sci.*, 17: 319-464.

[57]. **Laxmaiah, C.H., Mehmood, S.K. and Rao, V.N. (1994):** Nutrient status and biological characteristics of Nacharam Lake. *Poll. Res.*, 13(3): 253-258.

[58]. **Lee, G.F. (1962):** Studies on the Iron, Manganese, Sulphate and Silica balance and distributions for Lake Mendota Madison, Wisconsion. *Trans. Wisc. Acad. Sci. Art. Litt.*, 51: 145-155.

[59]. **Lee, G.F., Bentley, E. and Amundson, R. (1975):** Efffects of Marshes on water quality. In: Coupling of land and water systems (Hasler, A.D. Ed.). Springer-Verlag, Berlin, Beiddberg, New York. pp. 105-126

[60]. **Lehman, J.T. and Branstrator, D.K. (1994):** Nutrient dynamics and turnover rates of phosphate and sulfate in Lake Victoria, East Africa. *Limnol. Oceanogr.* 39: 227-233.

[61]. **Lewis, W.M.Jr. (1986):** Nitrogen and phosphorus runoff losses from a nutrient-poor tropical moist forest. *Ecology,* 67: 1275-1282.

[62]. **Liao, C.F.H. and Lean, D.R.S. (1978):** Nitrogen transformations within the trophogenic zone of lakes. *J. Fish. Res. Board Can.*, 35: 1102-1108.

[63]. **Maitland, P.S. (1978):** Biology of Fresh waters, Ist ed. Blackie and Son Limited, Bishopbriggs Glasgow. G642NZ.

[64]. **Manny, B.A., Johnson, W.C., and Wetzel, R.G. (1994):** Nutrient additions by waterfowl to lakes and reservoirs: Predicting their effects on productivity and water quality. *Hydrobiol.*, 279/280: 121-132.

[65]. **Manny, B.A., Wetzel, R.G., and Johnson, W.C. (1975):** Annual contribution of carbon, nitrogen and phosphorus to a hard water lake by migrant Canada geese. *Verh. Internat. Verein. Limnol.*, 19: 949-961.

[66]. **Mason, W.P. and Bushwell, A.M. (1950):** Examination of Water. John Wiley and Sons Inc., New York. pp.652.

[67]. **Matsudaria, Y. and Kato, T. (1943):** The quantities and qualities of the impurities contained in the rain water falling in the cities of Osaka and Kobe. *Japan Univ. to Sora*, 23: 71-86.

[68]. **Maulood, B.K. and Hinton, G.C.F. (1980):** A study of the pollution ecology of Kaliasan River (Iraq) with particular reference to Sulaimaniyah Sugar factory. *Zanco Ser. A pure Appl. Sci.*, 6: 97-124.

[69]. **McColl, R.H.S. and Forsyth, D.J. (1973):** The limnology of a thermal lake: Lake Rotowhero, New Zealand.1.General description and water chemistry. *Hydrobiol.*, 43(3): 313-332.

[70]. **McKeague, J.A. and Cline, M.G. (1963a):** Silica in soil solutions. I. The form and concentration of dissolved silica in aqueous extracts of some soils. *Can. J. Soil Sci.*, 43: 70-82.

[71]. **McKeague, J.A. and Cline, M.G. (1963b):** Silica in soil solutions. II. The adsorption of monosilicic acid by soil and other substances. *Can. J. Soil Sci.*, 43: 83-96.

[72]. **Mitchell, S.F. (1975):** Phosphate, nitrate and chloride in a eutrophic coastal lake in New Zealand. *N. Z. J. Marine Freshwat. Res.*, 9(2): 183-198.Moss *et al.* (1980)

[73]. **Munawar, M. (1970):** Limnological studies in fresh water ponds of Hyderabad, India. I. The biotope, *Hydrobiol.*, **25**(1):127-162.

[74]. **Naik, S. and Purohit, K.M. (1996):** Physico-chemical analysis of some community ponds of Rourkela. *I.J.E.P.*, 16(19): 679-684.

[75]. **Nanda, S.N. and Tiwari, T.N. (2002):** Quality of water in the Hirakud reservoir. In : Management of Aquatic Habitats (Mishra, S.R. Ed.). Daya Publishing House, New Delhi, pp. 62-72.

[76]. **NEERI (1986):** Manual on Water and Waste Water Analysis. National Environmental Engineering Research Institute, Nagpur.

[77]. **Newman, E.I. (1995):** Phosphorus inputs to terrestrial ecosystems. *J. Ecol.,* 83: 713-126.

[78]. **Nriagu, J.O. and Hem, J.D. (1978):** Chemistry of pollutant sulfur in natural waters. In: Sulfur in the environment. II. Ecological Impacts (Nriagu, J.O. ed.). John Wiley & Sons, New York. pp. 211-270.

[79]. **Nudds, K. (2002):** Cole notes: BOD is bad. *Aquatalk*, VI(2): 3

[80]. **Otsuki, A. and Wetzel, R.G. (1972):** Coprecipitation of phosphate with carbonates in a marl lake. *Limnol. Oceanogr.,* 17: 763-767.

[81]. **Pasternak, K. and Kasza, H. (1979):** Chemical reaction and Primary production of the phytoplankton in the warmed water of the Rybrik reservoir. *Acta Hydrobiol.*, 20(4): 305-322.

[82]. **Pehwa, D.V. and Mehrotra, S.N. (1966):** Observations of fluctuation in the abundance of plankton in relation to certain hydrobiological condition of River Ganga. *Proc. Nat. Acad. Sci.*, 36B(2): 157-189.

[83]. **Philipose, M.T. (1959):** Freshwater phytoplankton of inland fisheries. Proc. Symp. Algology, I.C.A.R., New Delhi, pp. 272-291.

[84]. **Rao, V.S. (1972):** An ecological study of three freshwater ponds of Hyderabad India I. *The Environ. Hydrobio.*, 39: 351-372

[85]. **Ray, P. and David, A. (1966):** Effect of industrial wastes and sewage upon the chemical and biological composition and fisheries of the River Ganga at Kanpur (U.P.). *J. Environ. Hlth.*, 8: 307-339.

[86]. **Ray, P., S.B. Singh and K.L. Sehgal (1966):** A study of some aspects of ecology of the river Ganga and Yamuna at Allahabad (U.P.) in 1958-59. *Proc. Nat. Acad. Sci.* India, 36B(3): 235-272.

[87]. **Rippey, B. (1983):** A laboratory study of the silicon release process from a lake sediment (Lough Neagh, Northern Ireland). *Arch. Hydrobiol.*, 96: 417-433.

[88]. **Rodhe, W. (1948):** Environmental requirements of freshwater plankton algae. *Symbolae Botanicae Upsalienses*, 10: 1-149.

[89]. **Ruttner, F. (1963):** Fundamentals of Limnology, 3rd Edition (Translated by D.G. Frey and F.E.J. Fry). University of Toronto Press, Cananda.

[90]. **Saad, M.A.H. and Samir, E.A. (1979):** Limnological studies on the river Tigris. Iraq. II. Seasonal variations of nutrients. *Int. Rev. Gesamten. Hydrobiol.*, 63(5): 705-720.

[91]. **Sahai, R. and Sinha, A.B. (1969):** Investigation on bio-ecology of inland waters of Gorakhpur (U.P.) India. I. Limnology of Ramgarh lake. *Hydrobiol.* 34: 433-447.

[92]. **Sawyer, C.H. (1960):** Chemistry for sanitary Engineers. McGraw Hill Book Co., New York.

[93]. **Saxena, A. (1998):** Primary productivity studies in a sewage polluted lake with special reference to phytoplankton. Ph.D. Thesis, Barkatullah University, Bhopal.

[94]. **Schelske, C.L. and Stoermer, E.F. (1971):** Eutrophication, silica depletion and predicted changes in algal quality in Lake Michigan. *Science*, 173: 423-424.

[95]. **Sehgal, H.S. (1980):** Limnology of Lake Surinsar, Jammu with reference to zooplankton and fishery prospects. Ph.D. thesis, University of Jammu.

[96]. Shukla, S.C., Kant, R. and Tripathy, B.D. (1989): **Ecological investigations on physico-chemical characteristics and phytoplankton productivity of river Ganga at Varanasi. Geobios,** 16**(1): 20-27.**

[97]. **Singh, M. (1965):** Phytoplankton periodicity in a small lake near Delhi. I. Seasonal fluctuations of the physico-chemical characteristics of the water. *Phykos*, 4: 61-68.

[98]. **Skaggs, R.W., Breve, M.A. and Gilliam, J.W. (1994):** Hydrologic and water quality impacts of agricultural drainage. *Crit. Rev. Environ. Sci. Technol.,* 24: 1-32.

[99]. **Sommer, V. (1989):** Nutrient status and nutrient competition of phytoplankton in a shallow hyper-eutrophic lake. *Limnol. Oceanogr.*, 34: 1162-1173.

[100]. **Stadelmann, P. (1971):** Strickstoffkreislauf und Primarproduktion im mesotrophen Vierwaldstattersee (Horwer Bucht) und im eutrophen Rotsee, mit besonderer Berucksichtigung des Nitrts als limitierenden Faktors. *Schweiz. Z. Hydrol.*, 33: 1-65.

[101]. **Steele, D.W. and Buttle, J.M. (1994):** Sulphate dynamics in a northern wetland catchment during snowmelt. *Biogeochemistry*, 27: 187-211.

[102]. Stewart, K.M. and Markello, S.J. (1974): **Seasonal variations in concentrations of nitrate and total phosphorus and calculated nutrient loading for six lakes in Western New York. Hydrobiol.,** 44**(1): 61-89.**

[103]. **Stumm, W. and Morgan, J.L. (1995):** Aquatic chemistry: Chemical equilibria and rates in natural waters. 3rd Edition. John Wiley & Sons, New York. 1040pp.

[104]. **Sundarraj, U. and Krishnamurthy, K. (1981):** Environmental features of an interior mangrove region in Pitchvaram. Proc. of Silver Jubilee Symp. of Trop. Ecol. Bhopal. pp.257-275.

[105]. **Swingle, H.S. (1967):** Standarization of chemical analysis for water and pond muds. *FAO Fish Rep.*, 44 (4): 397-421.

[106]. **Tessenow, U. (1966):** Untersuchungen uber den Kieselsaurehaushalt der Binnengewasser. *Arch. Hydrobiol.* (Suppl), 32: 1-136.

[107]. **Toetz, D.W. (1973a):** The limnology of nitrogen in an Oklahoma reservoir: Nitrogenase activity and related limnological factors. *Am. Midland Nat.*, 89: 369-380.

[108]. **Toetz, D.W. (1973b):** The Kinetics of $NH_4$ uptake by Ceratophyllum. *Hydrobiologia,* 41: 275-290.

[109]. **Tripathi, A.K. and Pandey, S.N. (1990):** Water Pollution. Ashish Publishing House, Punjabi Bagh, New Delhi-110 026.

[110]. **Trussel, R.P. (1972):** The percent un-ionized ammonia in aqueous ammonia solutions at different pH levels and temperatures. *J. Fish. Res. Board Can.*, 29: 1505-1507.

[111]. **Upadhyay, N. (1998):** Physico-chemical analysis of Kaliasote dam water to evaluate its versatile potentiality including irrigation use. Ph.D. Thesis, Barkatullah University, Bhopal.

[112]. **USEPA (2006):** Total maximum daily load (TMDL) for dissolved oxygen and biochemical oxygen demand in St. John River above Sawgrass Lake (WBID 2893X) middle St. Johns River basin, Florida. USEPA region 461 Forsyth Street SW Atlanta, Georgia 30303.

[113]. **Vass, K.K., Raina, H.S., Zutshi, D.P. and Khan, M.A. (1977):** Hydrobiological studies on River Jhelum. *Geobios*, 4: 228-242.

[114]. **Vollenweider, R.A. (1968):** Water Management Research: Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorous as factors in eutrophication. Technical Report, O.E.C.D. Paris. pp.143.

[115]. **Vollenweider, R.A., Munnawar, M. and Stadelmann, P. (1974):** A comparative review of phytoplankton and primary production in the Laurentian Great Lakes. *J. Fish. Res. Bd. Canada*, 31: 739-752.

[116]. **Voznaya, N.F. (1981):** Chemistry of water and microbiology. Translated from the Russian by Alexander Rosinkin. Ist Edition. Mir Publishers, Moscow.

[117]. **Wehr, J.D., Brown, L.M. and O'Grady, K. (1987):** Highly specialized nitrogen metabolism in a freshwater phytoplankter, *Chrysochromulina breviturrita. Can. J. Fish. Aquat. Sci.*, 44: 736-742.

[118]. **Welch, P.S. (1952):** Limnology. Second Edition. Mc Graw Hill, Book Co. New York and London.

[119]. **Wetzel, R.G. (1975):** Limnology. W.B. Sanunders Co. Philadelphia, pp. 743.

[120]. **Wetzel, R.G. (2001):** Limnology: Lake and River Ecosystems. 3rd Edition. Academic Press: A Harcourt Science and Technology Company, 525B Street, Suite 1900, San Diego, California. pp.1000.

[121]. **Wiebe, A.H. (1931a):** Notes on the exposure of several species of fish to sudden changes in the hydrogen ion concentration in the water and to an atmosphere of pure oxygen. *Trans. Am. Fish. Soc.*: 216-224.

[122]. **Wiebe, A.H. (1931b):** Dissolved phosphorus and inorganic nitrogen in the water of the Mississippi river. *Science*, 73: 652.

[123]. **Wiebe, A.H. (1931c):** Notes on the exposure of several species of pond fishes to sudden changes in pH. *Trans. Am. Fish. Soc.*, 50: 380-393.

[124]. **WQM Report (1999):** Annual report on water quality monitoring of upper and lower lakes of Bhopal. Vol. I and II.

[125]. **Wurts, W.A. and Durborow, R.M. (1992):** Interactions of pH, carbon dioxide, alkalinity and hardness in fish ponds. Southern Regional Aquaculture Center, Publication No. 464.

[126]. **Zutshi, D.P. (1985):** The Himalayan lake ecosystem. In: Environmental Regeneration in Himalayas: Concept and Strategies (Singh, J.S. Ed.). The Central Himalayan Environmental Association and Gyanodaya Prakashan, Nainital, pp. 325-342.

### TABLE 1: MONTHLY VARIATION IN TOTAL ALKALINITY (mg/l) ALONG THE FOUR STATIONS AT LAKE MANSAR

| Year | | 2003 – 2004 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 195.20 | 189.00 | 204.40 | 186.40 | 213.50 | 201.50 | 201.60 | 213.75 | 213.50 | 237.90 | 286.60 | 194.90 |
| | II | 176.90 | 201.20 | 201.60 | 198.20 | 207.40 | 195.50 | 171.00 | 213.50 | 216.80 | 222.90 | 277.80 | 182.80 |
| | III | 195.50 | 220.70 | 228.80 | 216.80 | 219.60 | 216.90 | 207.50 | 227.90 | 222.90 | 244.95 | 298.60 | 215.95 |
| | IV | 151.20 | 179.10 | 207.10 | 186.40 | 190.63 | 179.80 | 170.60 | 197.95 | 209.60 | 219.60 | 244.20 | 182.80 |
| Mean | | 179.70 | 197.50 | 210.47 | 196.95 | 207.78 | 198.42 | 187.67 | 213.27 | 215.70 | 231.33 | 276.80 | 194.11 |
| Standard Deviation | | 18.09 | 15.51 | 10.57 | 12.43 | 10.80 | 13.28 | 17.00 | 10.59 | 4.87 | 10.45 | 20.21 | 13.54 |
| Year | | 2004 – 2005 | | | | | | | | | | | |
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 170.80 | 195.20 | 194.90 | 186.40 | 203.20 | 191.80 | 189.00 | 206.80 | 216.80 | 255.50 | 295.20 | 225.20 |
| | II | 152.50 | 182.40 | 182.70 | 170.80 | 195.50 | 188.70 | 164.80 | 206.80 | 203.20 | 244.95 | 284.00 | 224.80 |
| | III | 184.90 | 210.10 | 205.20 | 201.80 | 216.80 | 213.40 | 183.00 | 222.50 | 222.90 | 286.60 | 310.50 | 234.40 |
| | IV | 145.25 | 161.50 | 167.50 | 152.50 | 187.58 | 176.60 | 170.80 | 194.70 | 195.50 | 220.80 | 264.80 | 225.20 |
| Mean | | 163.36 | 187.30 | 187.57 | 177.87 | 200.77 | 192.62 | 176.90 | 207.70 | 209.60 | 251.96 | 288.62 | 227.40 |
| Standard Deviation | | 15.53 | 17.83 | 14.06 | 18.29 | 10.77 | 13.27 | 9.58 | 9.86 | 10.82 | 23.62 | 16.66 | 4.04 |

### TABLE 2: MONTHLY VARIATION IN BIOCHEMICAL OXYGEN DEMAND (mg/l) ALONG THE FOUR STATIONS AT LAKE MANSAR

| Year | | 2003 – 2004 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 1.80 | 1.50 | 1.50 | 1.60 | 1.80 | 1.20 | 1.00 | 1.20 | 2.60 | 1.60 | 2.00 | 1.80 |
| | II | 1.60 | 1.50 | 1.40 | 2.00 | 1.20 | 1.00 | 1.20 | 1.00 | 0.80 | 1.80 | 2.20 | 2.00 |
| | III | 1.80 | 2.00 | 1.50 | 2.60 | 2.20 | 1.60 | 1.90 | 1.20 | 2.80 | 2.00 | 2.60 | 2.20 |
| | IV | 1.40 | 1.20 | 1.00 | 1.40 | 1.20 | 0.70 | 1.00 | 0.80 | 1.60 | 1.00 | 1.20 | 1.40 |
| Mean | | 1.650 | 1.550 | 1.350 | 1.900 | 1.600 | 1.125 | 1.275 | 1.050 | 1.950 | 1.600 | 2.000 | 1.850 |
| Standard Deviation | | 0.165 | 0.287 | 0.206 | 0.458 | 0.424 | 0.326 | 0.369 | 0.165 | 0.804 | 0.374 | 0.509 | 0.296 |
| Year | | 2004 – 2005 | | | | | | | | | | | |
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 1.80 | 1.60 | 1.20 | 1.50 | 2.90 | 0.60 | 0.90 | 2.00 | 1.80 | 2.60 | 3.00 | 2.20 |
| | II | 2.20 | 1.60 | 2.00 | 2.20 | 3.20 | 0.70 | 1.00 | 2.00 | 1.90 | 3.20 | 2.40 | 2.20 |
| | III | 2.60 | 2.00 | 2.80 | 2.40 | 3.60 | 1.20 | 1.40 | 2.60 | 2.90 | 3.80 | 2.20 | 2.60 |
| | IV | 1.20 | 1.00 | 0.90 | 0.80 | 1.80 | 0.60 | 0.80 | 1.20 | 1.60 | 2.00 | 1.80 | 1.90 |
| Mean | | 1.950 | 1.550 | 1.725 | 1.725 | 2.875 | 0.775 | 1.025 | 1.950 | 2.050 | 2.900 | 2.350 | 2.225 |
| Standard Deviation | | 0.517 | 0.357 | 0.739 | 0.629 | 0.668 | 0.248 | 0.227 | 0.497 | 0.502 | 0.670 | 0.433 | 0.248 |

*TABLE 3: MONTHLY VARIATION IN TOTAL HARDNESS (mg/l) ALONG THE FOUR STATIONS AT LAKE MANSAR*

| Year | | 2003 – 2004 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 158.30 | 192.85 | 213.02 | 200.05 | 200.05 | 166.74 | 132.57 | 142.78 | 143.22 | 105.01 | 109.07 | 150.57 |
| | II | 195.78 | 211.72 | 229.76 | 218.83 | 205.72 | 189.55 | 182.55 | 167.47 | 164.29 | 115.48 | 71.70 | 103.10 |
| | III | 191.95 | 214.65 | 247.50 | 206.19 | 181.87 | 168.14 | 163.12 | 153.06 | 137.74 | 132.33 | 105.05 | 157.23 |
| | IV | 175.27 | 199.58 | 201.85 | 157.94 | 144.69 | 142.90 | 120.88 | 122.94 | 95.13 | 70.81 | 91.85 | 97.33 |
| Mean | | 180.33 | 204.70 | 223.03 | 195.75 | 183.08 | 166.83 | 149.78 | 146.56 | 135.10 | 105.91 | 94.42 | 127.06 |
| Standard Deviation | | 17.17 | 10.25 | 19.94 | 26.39 | 27.54 | 19.07 | 28.19 | 18.72 | 29.00 | 25.96 | 16.84 | 31.20 |
| Year | | 2004 – 2005 | | | | | | | | | | | |
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 161.51 | 177.69 | 189.55 | 207.05 | 215.86 | 202.30 | 154.37 | 143.82 | 155.30 | 133.71 | 96.80 | 119.39 |
| | II | 159.67 | 173.39 | 190.16 | 213.22 | 228.80 | 226.88 | 203.16 | 174.24 | 176.25 | 174.04 | 147.77 | 143.81 |
| | III | 177.61 | 206.93 | 226.88 | 232.81 | 253.41 | 242.69 | 227.16 | 204.83 | 214.65 | 207.45 | 190.25 | 158.16 |
| | IV | 139.76 | 183.48 | 193.45 | 202.85 | 212.65 | 200.85 | 169.16 | 151.48 | 147.92 | 117.67 | 125.19 | 119.79 |
| Mean | | 159.64 | 185.37 | 200.01 | 213.98 | 227.68 | 218.18 | 188.46 | 188.59 | 173.53 | 158.22 | 140.00 | 135.29 |
| Standard Deviation | | 15.51 | 14.95 | 18.00 | 13.25 | 18.52 | 20.24 | 32.91 | 27.40 | 29.92 | 40.49 | 49.46 | 19.05 |

**TABLE 4: MONTHLY VARIATION IN SULPHATES (mg/l) ALONG THE FOUR STATIONS AT LAKE MANSAR**

| Year | | 2003 – 2004 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 4.25 | 3.80 | 3.65 | 3.45 | 3.35 | 3.10 | 9.20 | 12.35 | 16.20 | 19.20 | 15.10 | 11.30 |
| | II | 4.60 | 4.10 | 3.80 | 3.55 | 3.20 | 3.15 | 11.50 | 14.20 | 15.80 | 22.20 | 17.58 | 13.95 |
| | III | 4.80 | 4.55 | 4.32 | 4.15 | 4.05 | 3.90 | 13.68 | 15.75 | 17.95 | 23.20 | 20.10 | 16.85 |
| | IV | 3.20 | 3.15 | 3.10 | 2.70 | 2.20 | 2.05 | 7.60 | 11.20 | 12.80 | 15.68 | 13.20 | 10.50 |
| Mean | | 4.212 | 3.900 | 3.718 | 3.463 | 3.200 | 3.050 | 10.495 | 13.375 | 15.688 | 20.070 | 16.495 | 13.150 |
| Standard Deviation | | 0.712 | 0.587 | 0.502 | 0.595 | 0.763 | 0.760 | 2.659 | 2.009 | 2.139 | 3.384 | 2.999 | 2.874 |
| Year | | 2004 – 2005 | | | | | | | | | | | |
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 7.20 | 5.80 | 5.25 | 5.20 | 5.00 | 4.65 | 11.20 | 13.50 | 17.60 | 20.10 | 22.45 | 14.50 |
| | II | 11.97 | 7.60 | 5.25 | 5.10 | 5.05 | 4.40 | 8.20 | 12.65 | 17.55 | 19.20 | 21.35 | 17.65 |
| | III | 14.20 | 11.15 | 7.85 | 6.30 | 5.95 | 5.40 | 10.20 | 14.50 | 19.35 | 21.30 | 25.10 | 16.50 |
| | IV | 9.60 | 7.35 | 6.80 | 5.40 | 5.20 | 5.05 | 8.20 | 12.60 | 14.10 | 16.65 | 18.90 | 14.50 |
| Mean | | 10.743 | 7.975 | 6.288 | 5.500 | 5.300 | 4.875 | 9.450 | 13.313 | 17.150 | 19.313 | 21.950 | 15.788 |
| Standard Deviation | | 3.017 | 2.261 | 1.272 | 0.548 | 0.442 | 0.441 | 1.500 | 0.893 | 2.199 | 1.972 | 2.571 | 1.559 |

63

### TABLE 5: MONTHLY VARIATION IN TOTAL PHOSPHATES (mg/l) ALONG THE FOUR STATIONS AT LAKE MANSAR

| Year | | 2003 – 2004 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 0.145 | 0.108 | 0.138 | 0.135 | 0.100 | 0.085 | 0.050 | 0.070 | 0.088 | 0.105 | 0.145 | 0.152 |
| | II | 0.168 | 0.195 | 0.130 | 0.142 | 0.090 | 0.068 | 0.060 | 0.045 | 0.095 | 0.120 | 0.150 | 0.174 |
| | III | 0.200 | 0.182 | 0.165 | 0.170 | 0.105 | 0.090 | 0.055 | 0.060 | 0.090 | 0.125 | 0.168 | 0.220 |
| | IV | 0.105 | 0.076 | 0.065 | 0.050 | 0.062 | 0.040 | 0.032 | 0.028 | 0.050 | 0.075 | 0.096 | 0.115 |
| Mean | | 0.154 | 0.140 | 0.124 | 0.124 | 0.089 | 0.070 | 0.049 | 0.050 | 0.080 | 0.106 | 0.139 | 0.165 |
| Standard Deviation | | 0.034 | 0.049 | 0.036 | 0.044 | 0.016 | 0.019 | 0.010 | 0.015 | 0.017 | 0.019 | 0.026 | 0.037 |
| Year | | 2004 – 2005 | | | | | | | | | | | |
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 0.135 | 0.112 | 0.095 | 0.085 | 0.092 | 0.076 | 0.065 | 0.080 | 0.110 | 0.125 | 0.155 | 0.162 |
| | II | 0.142 | 0.122 | 0.135 | 0.096 | 0.080 | 0.065 | 0.070 | 0.095 | 0.120 | 0.145 | 0.145 | 0.185 |
| | III | 0.212 | 0.190 | 0.152 | 0.120 | 0.090 | 0.100 | 0.060 | 0.105 | 0.148 | 0.174 | 0.210 | 0.245 |
| | IV | 0.100 | 0.085 | 0.060 | 0.070 | 0.050 | 0.035 | 0.042 | 0.062 | 0.085 | 0.100 | 0.100 | 0.135 |
| Mean | | 0.147 | 0.127 | 0.110 | 0.092 | 0.078 | 0.069 | 0.059 | 0.085 | 0.115 | 0.136 | 0.158 | 0.181 |
| Standard Deviation | | 0.040 | 0.038 | 0.035 | 0.018 | 0.016 | 0.023 | 0.010 | 0.016 | 0.022 | 0.027 | 0.036 | 0.040 |

### TABLE 6: MONTHLY VARIATION IN SILICATES (mg/l) ALONG THE FOUR STATIONS AT LAKE MANSAR

| Year | | 2003 – 2004 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 4.95 | 5.15 | 4.36 | 4.15 | 3.90 | 3.65 | 4.20 | 5.35 | 5.20 | 6.25 | 6.80 | 6.80 |
| | II | 5.68 | 5.40 | 5.15 | 4.85 | 4.85 | 4.20 | 6.00 | 6.00 | 5.75 | 6.10 | 6.60 | 7.30 |
| | III | 4.75 | 4.35 | 4.10 | 3.95 | 4.00 | 3.70 | 4.10 | 4.55 | 4.80 | 4.95 | 5.20 | 6.85 |
| | IV | 6.95 | 6.40 | 5.90 | 5.40 | 5.95 | 5.20 | 5.95 | 6.10 | 5.65 | 6.20 | 6.95 | 7.25 |
| Mean | | 5.5825 | 5.3250 | 4.8775 | 4.5875 | 4.6750 | 4.1875 | 5.0625 | 5.500 | 5.3500 | 5.8750 | 6.3875 | 7.0500 |
| Standard Deviation | | 0.8620 | 0.7318 | 0.7057 | 0.5759 | 0.8234 | 0.6228 | 0.9133 | 0.9962 | 0.3791 | 0.5367 | 0.6967 | 0.2263 |
| Year | | 2004 – 2005 | | | | | | | | | | | |
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 4.10 | 3.90 | 5.20 | 4.60 | 4.20 | 4.15 | 4.50 | 5.50 | 5.00 | 6.80 | 6.95 | 7.00 |
| | II | 5.20 | 4.85 | 5.35 | 5.95 | 4.70 | 5.20 | 6.20 | 6.20 | 6.10 | 6.45 | 6.35 | 7.25 |
| | III | 5.00 | 4.20 | 5.55 | 4.20 | 4.05 | 4.45 | 5.00 | 6.00 | 5.85 | 6.10 | 6.15 | 6.95 |
| | IV | 6.10 | 5.20 | 5.90 | 5.25 | 5.45 | 5.10 | 6.15 | 6.15 | 5.80 | 6.95 | 7.20 | 7.45 |
| Mean | | 5.100 | 4.7125 | 5.500 | 4.7500 | 4.350 | 4.875 | 5.7125 | 5.9625 | 5.6875 | 6.575 | 6.6625 | 7.1625 |
| Standard Deviation | | 0.7106 | 0.7667 | 0.2622 | 0.3921 | 0.2474 | 0.2968 | 0.5319 | 0.2769 | 0.4128 | 0.3288 | 0.4277 | 0.2016 |

64

### TABLE 7: MONTHLY VARIATION IN NITRATE - NITROGEN (mg/l) ALONG THE FOUR STATIONS AT LAKE MANSAR

| Year | | 2003 – 2004 | | | | | | | | | | | |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 0.415 | 0.295 | 0.280 | 0.250 | 0.310 | 0.380 | 0.425 | 0.420 | 0.450 | 0.475 | 0.503 | 0.420 |
| | II | 0.420 | 0.335 | 0.320 | 0.300 | 0.325 | 0.375 | 0.440 | 0.410 | 0.460 | 0.480 | 0.495 | 0.460 |
| | III | 0.520 | 0.455 | 0.460 | 0.435 | 0.480 | 0.440 | 0.460 | 0.480 | 0.530 | 0.580 | 0.605 | 0.590 |
| | IV | 0.400 | 0.365 | 0.300 | 0.340 | 0.220 | 0.305 | 0.315 | 0.365 | 0.380 | 0.420 | 0.440 | 0.418 |
| Mean | | 0.4387 | 0.3625 | 0.340 | 0.3312 | 0.3337 | 0.3512 | 0.4100 | 0.4187 | 0.4550 | 0.4887 | 0.5107 | 0.472 |
| Standard Deviation | | 0.0474 | 0.0588 | 0.0707 | 0.0678 | 0.0939 | 0.0939 | 0.0562 | 0.0409 | 0.0531 | 0.0577 | 0.0595 | 0.0701 |
| Year | | 2004 – 2005 | | | | | | | | | | | |
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 0.340 | 0.255 | 0.285 | 0.245 | 0.230 | 0.320 | 0.340 | 0.440 | 0.425 | 0.495 | 0.520 | 0.472 |
| | II | 0.385 | 0.265 | 0.290 | 0.285 | 0.260 | 0.330 | 0.412 | 0.398 | 0.420 | 0.480 | 0.500 | 0.465 |
| | III | 0.565 | 0.425 | 0.475 | 0.410 | 0.395 | 0.430 | 0.560 | 0.535 | 0.580 | 0.610 | 0.640 | 0.565 |
| | IV | 0.370 | 0.320 | 0.215 | 0.215 | 0.220 | 0.210 | 0.250 | 0.280 | 0.335 | 0.350 | 0.370 | 0.450 |
| Mean | | 0.4150 | 0.3162 | 0.3162 | 0.2887 | 0.2762 | 0.3225 | 0.3905 | 0.4132 | 0.4400 | 0.4837 | 0.5075 | 0.4880 |
| Standard Deviation | | 0.0881 | 0.0674 | 0.0963 | 0.0742 | 0.0701 | 0.0779 | 0.1134 | 0.0915 | 0.0883 | 0.0921 | 0.0957 | 0.0451 |

### TABLE 8: MONTHLY VARIATION IN AMMONIA (mg/l) ALONG THE FOUR STATIONS AT LAKE MANSAR

| Year | | 2003 – 2004 | | | | | | | | | | | |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 0.140 | 0.148 | 0.150 | 0.152 | 0.155 | 0.145 | 0.142 | 0.134 | 0.128 | 0.154 | 0.158 | 0.150 |
| | II | 0.152 | 0.144 | 0.153 | 0.155 | 0.158 | 0.142 | 0.136 | 0.130 | 0.130 | 0.150 | 0.159 | 0.148 |
| | III | 0.155 | 0.156 | 0.158 | 0.150 | 0.160 | 0.150 | 0.141 | 0.139 | 0.132 | 0.165 | 0.162 | 0.157 |
| | IV | 0.135 | 0.125 | 0.128 | 0.126 | 0.142 | 0.140 | 0.132 | 0.128 | 0.130 | 0.136 | 0.138 | 0.144 |
| Mean | | 0.1455 | 0.1432 | 0.1472 | 0.1457 | 0.1537 | 0.1442 | 0.1377 | 0.1327 | 0.1300 | 0.1512 | 0.1542 | 0.1497 |
| Standard Deviation | | 0.0082 | 0.0113 | 0.0114 | 0.0115 | 0.0070 | 0.0037 | 0.0040 | 0.0042 | 0.0014 | 0.0103 | 0.0094 | 0.0047 |
| Year | | 2004 – 2005 | | | | | | | | | | | |
| | Months | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. |
| Stations | I | 0.142 | 0.145 | 0.146 | 0.155 | 0.159 | 0.142 | 0.138 | 0.120 | 0.110 | 0.148 | 0.156 | 0.162 |
| | II | 0.144 | 0.148 | 0.150 | 0.157 | 0.162 | 0.160 | 0.140 | 0.138 | 0.095 | 0.136 | 0.148 | 0.160 |
| | III | 0.148 | 0.142 | 0.156 | 0.159 | 0.147 | 0.150 | 0.148 | 0.142 | 0.138 | 0.156 | 0.165 | 0.152 |
| | IV | 0.136 | 0.128 | 0.132 | 0.138 | 0.120 | 0.118 | 0.105 | 0.080 | 0.070 | 0.080 | 0.120 | 0.140 |
| Mean | | 0.1425 | 0.1407 | 0.1460 | 0.1522 | 0.1470 | 0.1425 | 0.1327 | 0.1200 | 0.1032 | 0.1300 | 0.1472 | 0.1535 |
| Standard Deviation | | 0.0043 | 0.0076 | 0.0088 | 0.0083 | 0.0165 | 0.0155 | 0.0164 | 0.0245 | 0.0246 | 0.0297 | 0.0168 | 0.0086 |