CHAPTER-V

Discussion

Algae are the primary producers, source of protein, biopurifier and bioindicators in aquatic ecosystems (Patralekh and Patralekh, 2004; Ariyadej *et al.*, 2004). Growth of algae is regulated by physicochemical properties of water (Dahl and Wilson, 2000). It was also reported that different species of algae can tolerate different magnitude of water quality parameters (Kotut *et al.*, 1998). The ranges of tolerance on the other hand, determine the diversity, distribution and seasonality of algal species (Akbay *et al.*, 1999). In this present investigation physicochemical properties of water *viz.* surface water temperature, pH, conductivity, turbidly, TDS, TSS, DO, free CO_2, biological BOD, COD, alkalinity, hardness, calcium, magnesium, chloride, sodium, potassium, nitrate, phosphate, total oil content were studied to understand the water quality of the selected study sites and tried to establish their relationship with diversity, distribution and seasonality of algal species in the ponds of Tinsukia District.

Surface water temperature

Surface water temperature is an important water quality parameter that directly affects the algal community in any water body (Hutchinson, 1957; Brett, 1969; Shastree *et al.*, 1991). In the present investigation, the surface water temperature varied from 14.99 ^{0}C during the winter to 33.44^{0}C during the monsoon season. Both the lowest and highest values were recorded in the study pond S1. Except in the study site S5, the maximum water temperatures were recorded during monsoon season and in all the study sites it was minimum during winter season. In the site S5, water temperature was maximum during premonsoon season (Fig.2). The trend of higher temperature in monsoon and lower in winter months was in corroboration with findings of Dey and Lahon (1979), Singhal *et al.* (1985, 1986), Day and Kar (1987), Hazaika (1997) and Kakati (2011) in some freshwater bodies in Assam.

The water temperature was found to regulate several studied water quality variables in the studied aquatic bodies which were in conformity with the findings of Brett (1969) and Shastree *et al.*, (1991). Surface water temperature showed significant positive correlation with turbidity in study site S1, S2 and S3; with TDS and TSS in S2, with BOD in S1 and S3, with COD in S1, with alkalinity in S5, with magnesium in S1 and with gross primary productivity in the study site S1and S2 (Table-18 to Table-22). However, increasing temperature was found to responsible for deceasing dissolved oxygen in S1, S3, S4 and S5. Surface water temperature was also negatively correlated with conductivity in S3; with BOD and COD in S5; with hardness and magnesium in S4; with sodium in S1, S2 and S3; with potassium in S3 and with chloride in S5. The TOC in all the ponds except S1 significantly decreased as the water temperature increased. Water temperature also showed significant positive correlation with algal density in the study site S 5 (Table-22).

pH

pH is one of the most important ecological factor in any aquatic systems (Senthikumar and Sivakumar, 2008). In this study, pH showed fluctuation within the range of 4.13 in S1 to 8.74 in S3 (Fig.2). In all the study sites, pH values were recorded both in acidic to alkaline range in different sampling seasons. The average values of pH ranged from 4.13 to 7.54 in S1; 6.31 to 7.98 in S2; 5.52 to 8.74 in S3; 5.52 to 8.74 in S4; 5.41 to 8.07 in S5 (Fig.2). There was no any definite trend in fluctuation of pH was observed in this study. Similar observation was also reported by Kakati (2011) in her study on ecology of eight historical ponds of Kamrup district, Assam.

pH showed significant positive correlation with chloride in study site S3 and with nitrate and GPP in site S5. On the other hand, increase in pH was found to associate with decrease in conductivity in study sites S1, S2 and S5. pH was in significant inverse correlation with BOD in S2; with alkalinity and hardness in S1; with potassium in S5; with nitrate in S3; with phosphate in S4 and S5, with productivity in S2 and S3. Algal density showed significant negative correlation with pH in the study pond S2 (Table-18 to Table-22). Sheeja (2005) also observed significant influence of pH on environmental factors like conductivity, chloride, alkalinity, hardness, nitrate and phosphate in the line of our work.

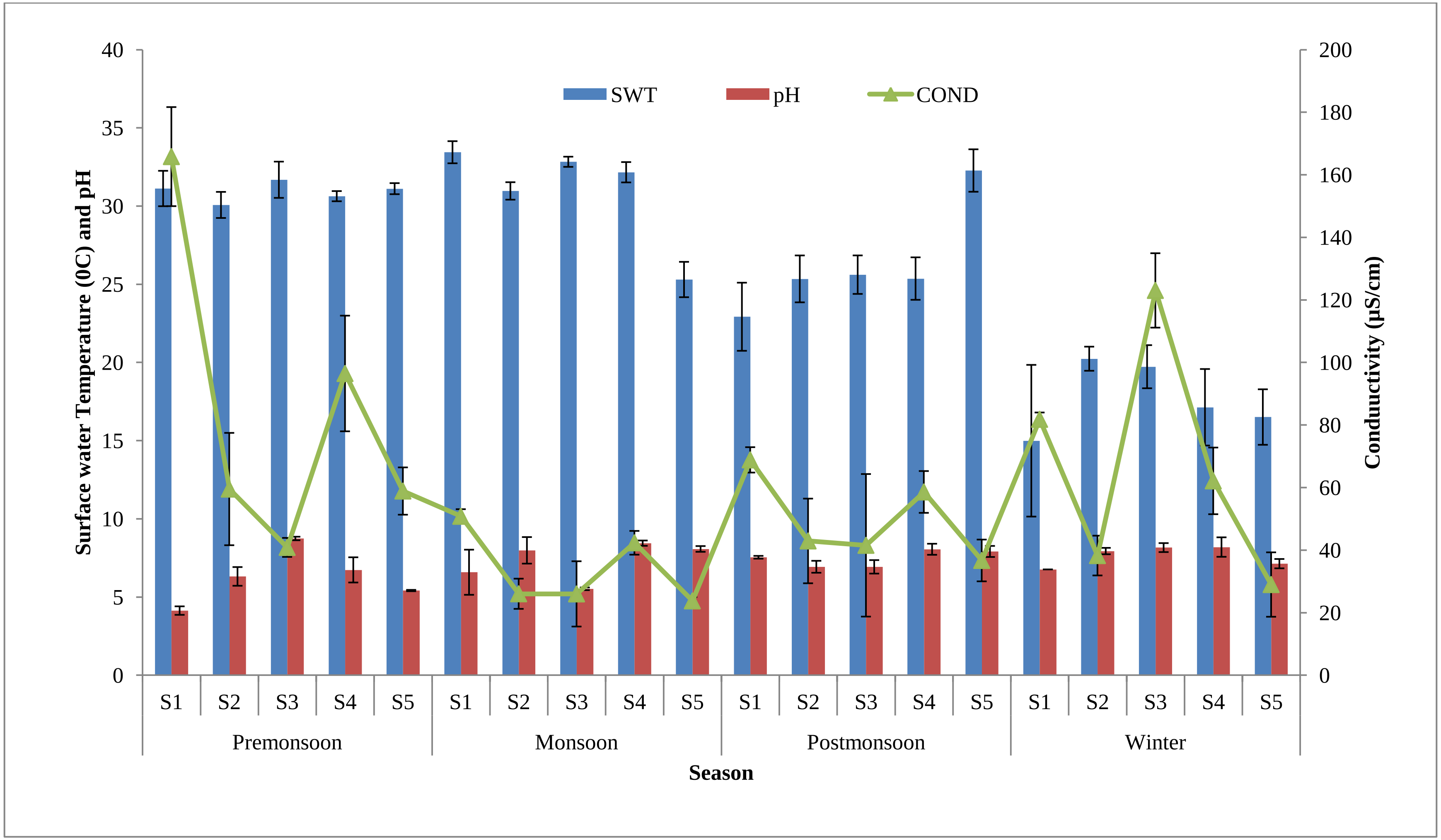


Fig.2: Seasonal variation of surface water temperature, pH and conductivity in the study sites.

Conductivity

Conductivity in water depends on the nature and concentration of electrolytes dissolved in water (Elayaraj and Selvaraju, 2014). Conductivity in the present study ranged between 23.75 µS/cm recorded during monsoon in S5 to 165.8 µS/cm recorded during premonsoon in S1. A typical trend of seasonal change in conductivity was observed in each study sites. It was within the range of 50.8 to 165.8 µS/cm in S1, 26.02 to 59.8 µS/cm in S2, 25.98 to 123.01 in S3, 42.91 to 96 µS/cm in S4 and 23.75 to 58.87 in S5 (Fig.2). In all the ponds conductivity was minimum in the monsoon season. Except in the pond S3, in all other ponds, highest value of conductivity was recorded during premonsoon season. In S3, conductivity was maximum in winter season. The higher values of conductivity in premonsson and winter season was due to increase in ionic concentration in water which in conformity with the observation of Narayana *et al.* (2005) in a fresh water tank at Sagar taluk of Shimoga district, Maharastra.

Conductivity showed significant positive correlation with TSS in the pond S5; with DO in site S3; with BOD in S2; with alkalinity in S1, S3 and S5; with hardness in S1, with sodium and TOC in S3; with potassium in S3 and S4; with phosphate in S5. Inversely, conductivity had significant negative correlation with temperature and turbidity in S3; with pH in S1, S2 and S5 and with TDS in S1 (Table-18 to Table-22).

Turbidity

Turbidity depends on the various dissolved and suspended matters and also on the plankton population present therein (Chondar *et al.*, 1988). In the present study, of all the study sites, turbidity was recorded highest in the pond S1 (246.4 NTU) during monsoon and lowest in the pond S5 (29.38 NTU) during post monsoon season. Turbidity showed distinct variation along the season in all the study sites. In the study sites S1 and S2, turbidity was higher in winter and lower in monsoon season. It was recorded maximum of 246.4 NTU and minimum of 83.8 NTU in S1 and that of maximum 159.07 NTU and minimum 34.46 NTU in S2. In the pond S3, turbidity was minimum of 58.53 NTU during winter and maximum of 166 NTU in premonsoon season. In the site S4, lowest turbidity of 34.41 NTU was noted during postmonsoon and highest of 44 NTU was noted in premonsoon season. Turbidity was recorded highest of 48.56 NTU during winter and lowest of 29.38 NTU during postmonsoon in the site S5 (Fig.3). From the study it was observed that turbidity values were comparatively higher in the ponds S1, S2 and S3 than the other two ponds. It may be due to higher dissolved and suspended solids in water which is in conformity with the findings of Kadam *et al.* (2007) and Saha and Pandit (2012).

Turbidity showed significant positive correlation with temperature in ponds S1, S2 and S3; with TDS, TSS and GPP in S2; with free CO_2 and COD in S1 and with BOD in S3. On the contrary, it had significant inverse correlation with conductivity in S3; with DO in S1 and S2; with magnesium in S2; with TOC in S2 and S3 and with GPP and algal density in S5 (Table-18 to Table-22).

Total dissolved solid (TDS) and Total suspended solid (TSS)

TDS and TSS composed mainly of carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates (Mishra and Saksena, 1991). They control the light penetration in aquatic bodies and hence affect the growth of aquatic organisms including algae (Swarnalatha and Narsigharao, 1998). Rising concentrations of TDS and TSS increase the nutrient status of water body which was leading into eutrophication of aquatic ecosystems (Singh and Mathur, 2005).

TDS was found highest of 334.74 mg/l in the pond S1 during monsoon and lowest of 135.04 mg/l in the pond S2 during winter season. In all the ponds except S5, highest values of TDS were recorded during monsoon season. In S5 it was highest of 217.83 mg/l during post monsoon season. TDS was recorded within the range of 229.64 to 334.74 mg/l in S1; 135.04 to 170.58 mg/l in S2; 199.4 to 254.42 mg/l in S3; 137.17 to 165.71 mg/l in S4 and 173.81 to 217.83 mg/l in S5 (Fig.3). TDS showed strong positive correlation with temperature, turbidity and nitrate S2 and with TSS in S1, S2 and S4. However, it had significant negative correlation with conductivity in S1 and with DO and sodium in S2 (Table-18 to Table-22).

Of the study sites, TSS was recorded highest of 179.33 mg/l in the pond S1 and lowest of 52.23 mg/l in the pond S2. In all the ponds TSS was noted higher during

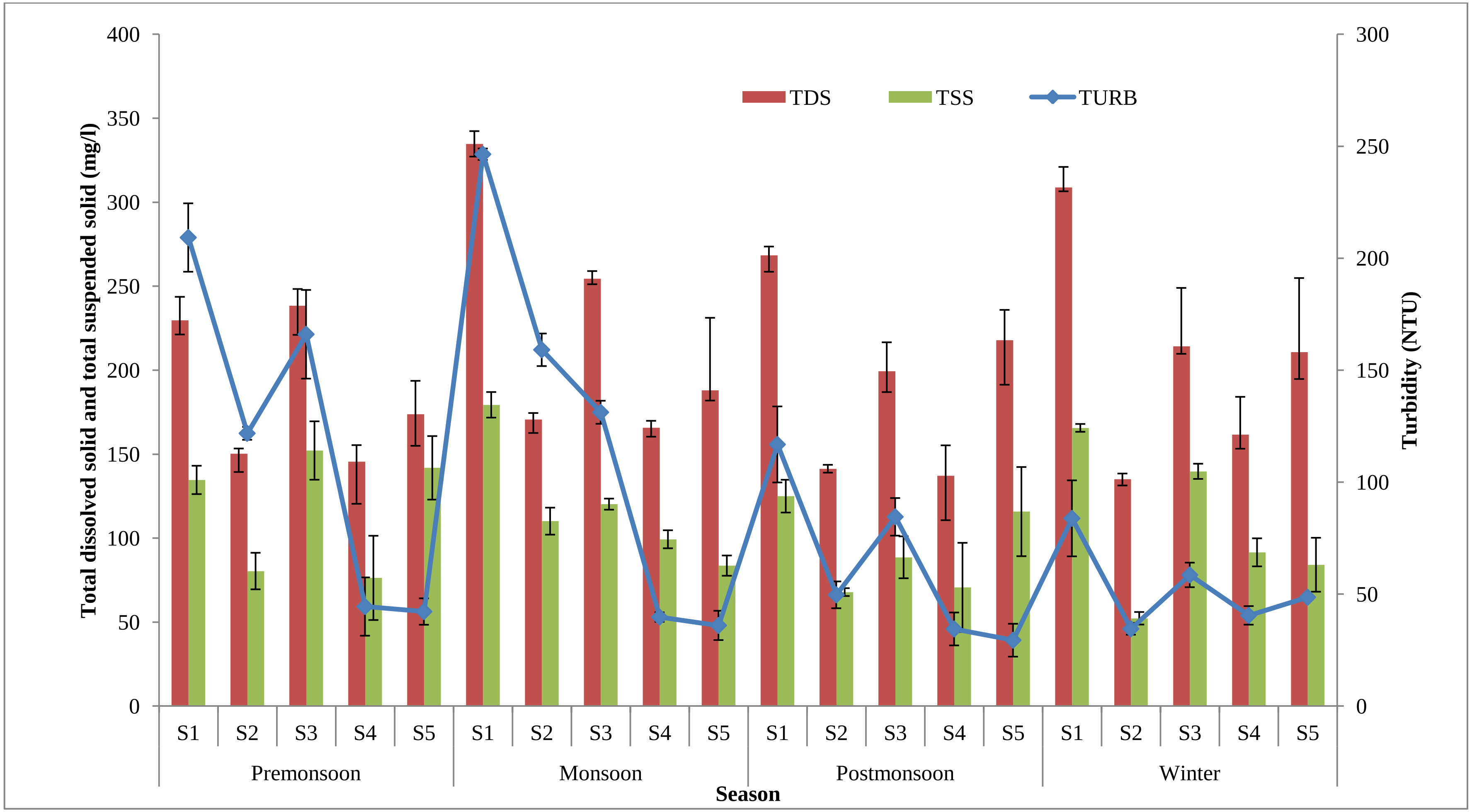


Fig.3: Seasonal variation of TDS, TSS and turbidity in the study sites.

monsoon except in S5, where it was highest during premonsoon season. The lower value of TSS was recorded during postmonsoon season in all the ponds except S2, where it was minimum during winter season. The values of TSS recorded within the range of 124.94 to 179.33 mg/l in S1; 52.23 to 110.06 mg/l in S2; 88.54 to 152.12 mg/l in S3; 70.61 to 99.27 mg/l in S4 and 83.58 to 141.80 mg/l in S5 (Fig.3). The higher TDS and TSS in monsoon season were due to the surface runoff of rain water from the adjacent localities into the water. It was in conformity with the observations of Senthikumar and Sivakumar (2008) and Raveen *et al*. (2008). TSS exhibited significant positive correlation with water temperature, turbidity, nitrate and GPP in S2; with conductivity, alkalinity and phosphate in S5; with TDS in S1, S2 and S4; with COD, magnesium and chloride in S3 (Table-18 to Table-22).

Dissolved Oxygen (DO)

Dissolved oxygen is a very important water quality parameter of aquatic ecosystems required for many physical and biological processes prevailing in water. Dissolved oxygen affects the solubility and availability of many nutrients and therefore productivity of aquatic ecosystem (Wetzel, 1983).During the present study DO concentration was within the range of 1.28-11.45 mg/l. The highest value (11.45 mg/l) was recorded in the pond S4 during winter and lowest value (1.28 mg/l) in the pond S1 during premonsoon season. DO was recorded within the range 1.28 to 7.57mg/l in S1; 3.26-11 mg/l in S2; 5.25-8.35 mg/l in S3; 7.73-11.45 mg/l in S4 and 7.27-8.27 mg/l (Fig.4). In this present study, DO showed highest peak value during winter season in all the study sites which may be attributed due to overall low temperature of water during winter in the ponds which was in conformity with Wetzel (1983), Hazarika (1997), Kakati (2011) and Elayaraj and Selvaraju (2014). According to Reid (1961) lowering of temperature increases solubility of oxygen in water. On the contrary, increasing temperature in summer also increases microbial decomposition rate causing depletion of oxygen level in water (Bedge and Verma, 1985).

DO showed significant positive correlation with conductivity in S1; with BOD in S5; with sodium and potassium in S1 and S3; with chloride in S5 and with TOC in S2, S3, S4 and S5. On the other hand, DO showed significant negative correlation with surface water temperature in S1, S3, S4 and S5; with TDS in S1 and S2; with free CO_2

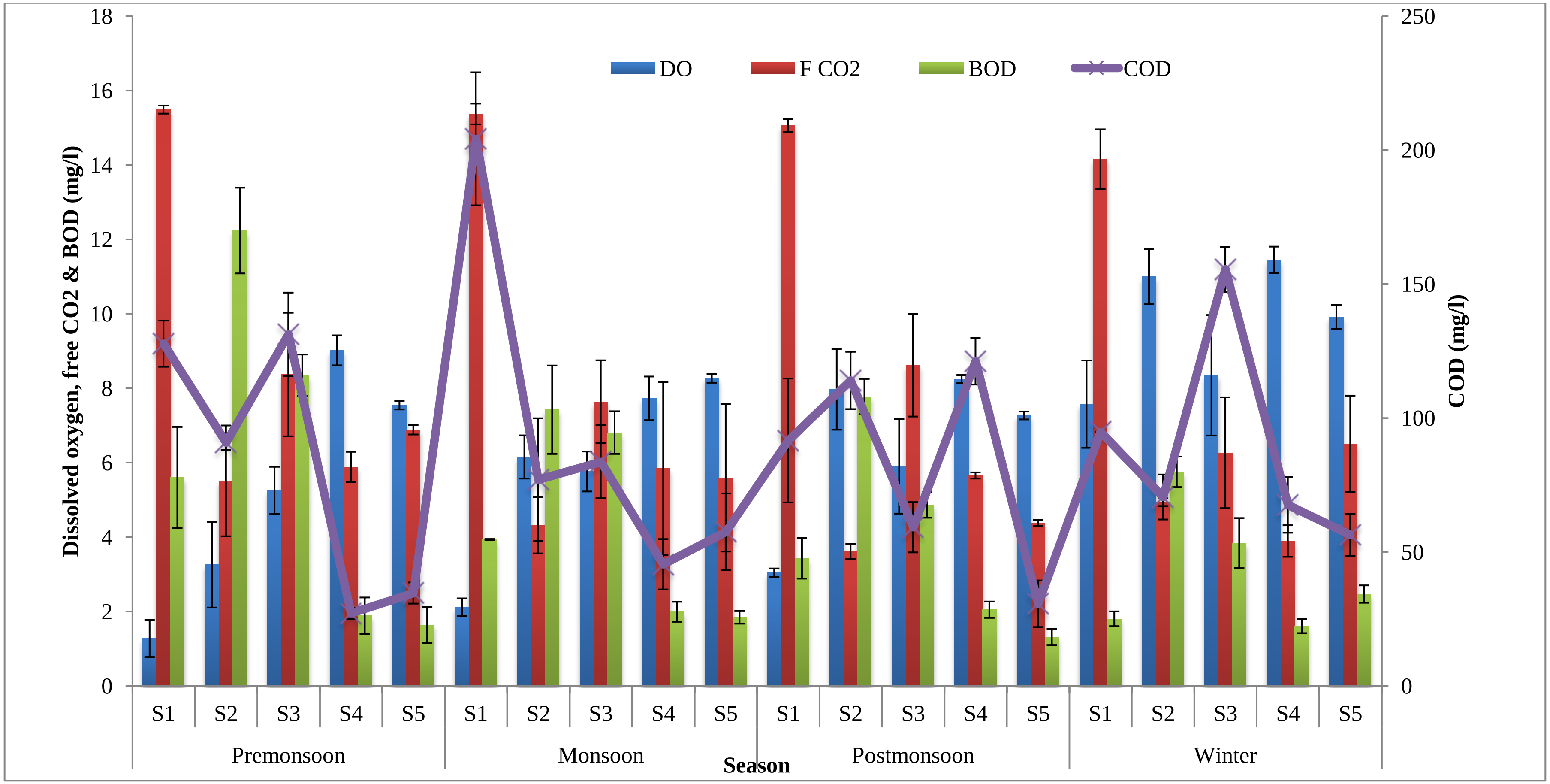


Fig.4: Seasonal variation of DO, free CO_2, BOD and COD in the study sites.

in S1, S3 and S4; with BOD in S1 and S2, with alkalinity in S5, with hardness, magnesium and GPP in S2 and with phosphate in S1 (Table-18 to Table-22).

Free carbon-di-oxide (FCO_2)

Free carbon-di-oxide (FCO_2) in water is due to the respiratory action of the living biota and also due to release of CO_2 during the microbial decomposition of organic matters (Singh, 1999). Algae can absorb free CO_2 from water bodies (Shivalingaiah *et al*., 2009). FCO_2 in this study varied from 3.61 to 15.49 mg/l. The lowest value (3.61 mg/l) was recorded in postmonsoon season in the pond S2 and the highest value (15.49 mg/l) was found during premonsoon season in the pond S1. FCO_2 fluctuated within the range of 14.15-15.49 mg/l in S1; 3.61-5.51 mg/l in S2; 6.26-8.61 mg/l in S3; 3.89-5.88 mg/l in S4 and 4.38 to 6.88 mg/l in S5 (Fig.4). In this investigation, FCO_2 was found maximum during the premonsoon season in all the study ponds except S3. Higher value of FCO_2 in premonsoon may be due to decay and decomposition of organic matters which were brought to the ponds by premonsoon showers. It was in conformity with the observation of Joshi *et al*. (1995).

FCO_2 showed significant positive correlation with turbidity, BOD, sodium and potassium in the pond S1. Inversely, it had negative correlation with DO in site S1, S3 and S4 and with phosphate in the pond S1 (Table-18 to Table-22).

Biological Oxygen Demand (BOD)

Biological oxygen demand is the volume dissolved oxygen required by microorganism for aerobic decomposition of organic matter present in water (Raveen *et al.*, 2008). It is one of the most important parameter of water to access status of pollution (Mittal and Sengar, 1991). The BOD of unpolluted water is less than 1 mg/l, moderately polluted water 2 - 9 mg/l and in heavily polluted water more than 10 mg/l (Shivalingarah *et al.*, 2009). The observations of present study showed highest value of BOD 12.24 mg/l in the pond S2 during premonsoon season and lowest value of 1.32 mg/l in S5 during postmonsoon season. BOD values fluctuated in between 1.8-5.6 mg/l in S1; 5.77-12.24 mg/l in S2; 3.84-8.35 mg/l in S3; 1.61-2.05 mg/l in S4 and 1.32-1.84 mg/l in S5. In the ponds S1 to S3, BOD was highest during premonsoon and lowest during winter season. In the pond S4, BOD was highest during postmonsoon and lowest during winter season and in S5 BOD was highest during monsoon and lowest during postmonsoon season (Fig.4). Similar observation was also made by Shivalingaiah *et al*. (2009) in some temple ponds of Karnataka. Higher value BOD in S1to S3 indicated moderate to heavy pollution in those respective ponds.

BOD exhibited significant positive correlation with temperature in S1 and S3; with pH, conductivity, hardness, calcium and magnesium in S2, with turbidity in S3 and with DO and chloride in S5. On the other hand, BOD showed significant inverse correlation with pH, DO, free CO_2, sodium and potassium in S1 and with DO in S2 (Table-18 to Table-22).

Chemical oxygen demand (COD)

Chemical oxygen demand is the measure of oxygen required for chemical oxidation of organic matters (Saksena *et al.* 2008) and thus indirectly estimates the amount of organic compounds in water. In the present study, COD was found in the range of 27.06 mg/l recorded in the pond S4 during premonsoon to 204.16 mg/l recorded in S1 during monsoon season (Fig.4). It was recorded as 91.56-204.00 mg/l in S1; 70.47-113.97 mg/l in S2; 59.17-155.46 mg/l in S3; 27.06-121.16 mg/l in S4 and 30.62-57.5 mg/l in S5. COD values did not show any distinct trend of seasonal change among the study sites (Fig.4). However, it was observed that the COD values were higher than the BOD values among the study sites. The high COD values indicate that some degree of non biodegradable oxygen demanding pollutants were present in the water (Dhanalakshmi *et al.,* 2013).

COD in this study showed significant positive correlation with water temperature and turbidity in S1; with chloride and phosphate in S2 and with TSS, alkalinity, sodium, potassium and phosphate in S3 (Table-18 to Table-22).

Hardness

Hardness of water is principally due to Ca and Mg salts mainly the carbonates and sulphates (Wadia, 1961). Of the study sites, minimum hardness of 4.18 mg/l was recorded in the pond S2 during winter and maximum of 49.86 was recorded in S4 winter. In this investigation hardness recorded in the range of 7.65 to 14.43 mg/l in S1; 4.18 to

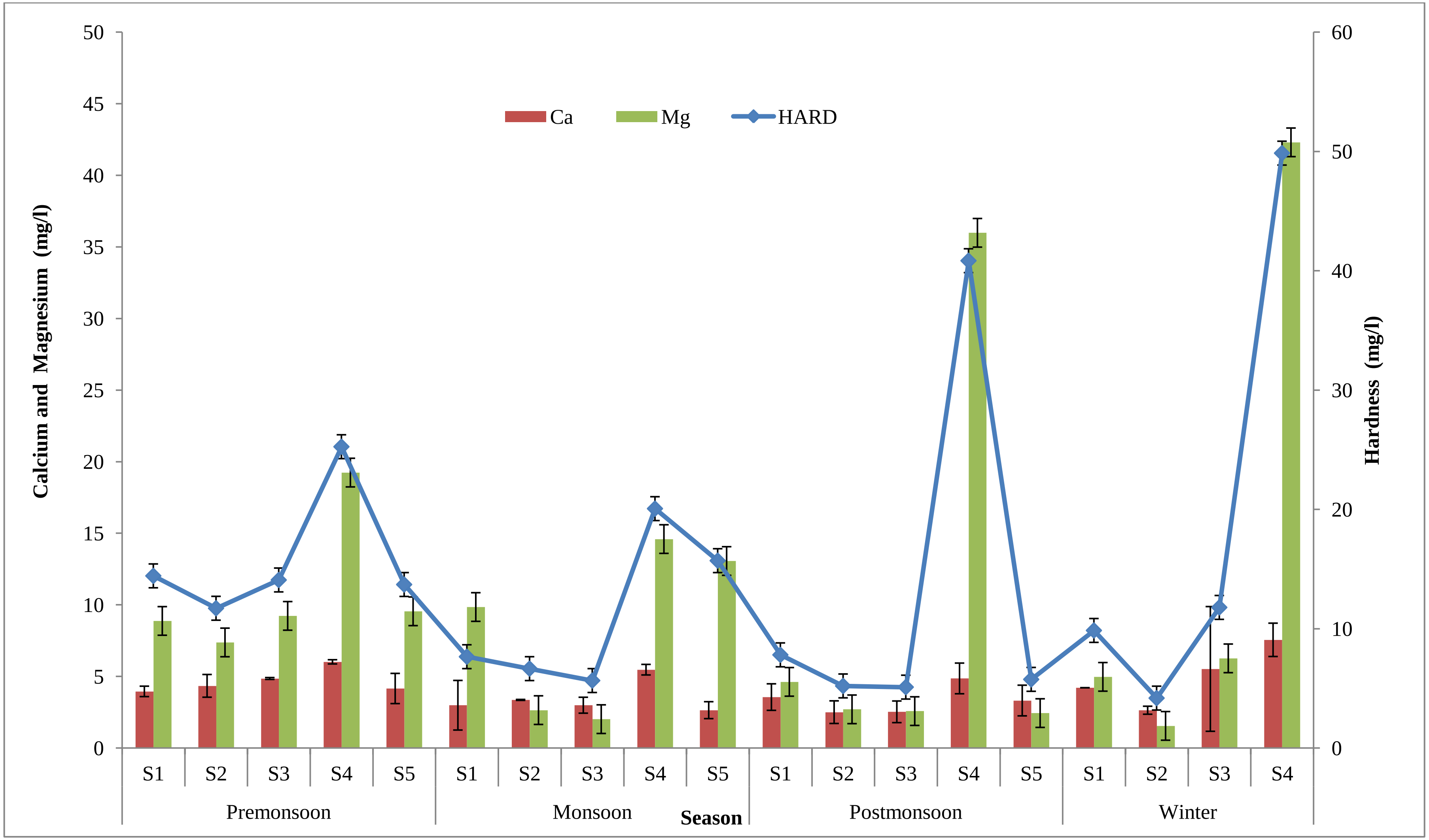


Fig.5: Seasonal variation of surface calcium, magnesium and hardness in the study sites.

11.71mg/l in S2; 5.10 to 14.08 mg/l in S3; 20.06 to 49.86 mg/l in S4 and 5.75 to 23.28 mg/l in S5 (Fig.5). Hardness values did not show uniform trend in seasonal change among the study sites. However, in study sites S1, S2 and S3, the hardness values were maximum in premonsoon season. Kataria *et al*., (1996) also recorded maximum value of total hardness in premonsoon season at Kolar reservoir in Bhopal, Madhya Pradesh. Higher temperature which increase the concentrations of salts by excessive evaporation may raise the hardness in water in this season which is in conformity with Harney *et al.*(2013).

Hardness showed significant positive correlation with conductivity in S1; with BOD in S2; with alkalinity in S1 and S3; with calcium and magnesium in S2 and S3 and with TOC in S4. Inversely, it had significant negative correlation with water temperature and alkalinity in S4, with pH in S1; with DO in S2 and with GPP in S3 (Table-18 to Table-21).

Calcium

Calcium is one of the most abundant element in aquatic ecosystems essential and important as cell wall constituent and regulatory factor for physiological functions of aquatic organisms (Chourasia and Adoni 1985; Ansari and Prakash, 2000). In this present study, maximum concentration of calcium recorded as 7.55 mg/l in the pond S4 during winter season and minimum as 2.5 mg/l in the site S2 during postmonsoon season. Calcium values were found within the range of 2.99-4.21 mg/l in S1; 2.5-4.34 mg/l in S2; 2.53-5.52 mg/l in S3; 4.86-7.55 mg/l in S4 and 2.44-19.72 mg/l in S5 (Fig.5). Except in the pond S2, calcium concentration was observed higher during winter season in all other study ponds. Munawar (1970) and Yadav *et al.* (2013) also noted higher value of calcium during winter season.

In this investigation calcium showed significant positive correlation with BOD in S2; with alkalinity in S3; with hardness in S2 and S3; with magnesium in S2, S3 and S4 and with TOC in S4. On the other hand it had significant negative correlation with alkalinity in S4 and with GPP in S3 (Table-19 to Table-21).

Magnesium

Magnesium is one of the main constituents in natural water and is one of the vital components of chlorophyll (Harney *et al.* 2013). Magnesium is one of the constituents that create water hardness. In this endeavour, maximum concentration of magnesium 42.3 mg/l was recorded in the site S4 and minimum of 1.54 mg/l was recorded in S2 during winter season. Concentration of magnesium was varied within the range of 4.62-9.85 mg/l in S1; 1.54-7.37 mg/l in S2; 2.01-9.23 mg/l in S3; 14.59-42.3 mg/l in S4 and 2.44-19.72 mg/l in S5. It did not show any distinct trend of seasonal change in concentrations (Fig.5).

Magnesium showed significant positive correlation with surface water temperature in S1; with TSS in S3; with BOD in S2; with hardness in S2, S3, S4 and S5; with calcium in S2 and S3 and with TOC in S4. On the contrary, magnesium had significant inverse correlation with surface water temperature in S4; with DO in S2; with alkalinity in S4 and with GPP in S3 (Table-18 to Table-22).

Alkalinity:

Alkalinity is a measure of acid nutrilizing capacity of water (Krishnaram *et al*. 2008). It is generally imparted by the salts of carbonates, bicarbonates, phosphate, nitrates, borax, silicates etc., together with the hydroxyl ions in a free states (Jain and Seethatathi, 1996). In the present investigation alkalinity ranged from 8.90 mg/l in S1 during monsoon to 68.76 mg/l in S3 during winter season. Concentration of alkalinity varied within the range of 8.9-15.45 mg/l in S1; 19.25-22.45 mg/l in S2; 32.97-68.76 mg/l in S3; 34.34-49.02 mg/l in S4 and 9.38-22.16 mg/l in S5. Alkalinity did not exhibit distinct trend of seasonal change (Fig.6).

Alkalinity in this study exhibited significant positive correlation with surface water temperature in S5; with conductivity in S1, S3 and S5; with TSS in S5; with hardness in S1 and S3; with COD, calcium, sodium, potassium and TOC in S3. Inversely, it had negative correlation with pH in S1; with GPP in S3; with hardness, calcium and magnesium in S4; with DO and chloride in S5 (Table-18 to Table-22).

Sodium (Na)

In natural waters, the concentration of sodium is generally low and the major sources of sodium are weathering of various rocks. However, domestic sewage, industrial effluent, agricultural runoff containing high concentration of sodium increases its concentration in fresh water after contamination (APHA, 2012). In this investigation

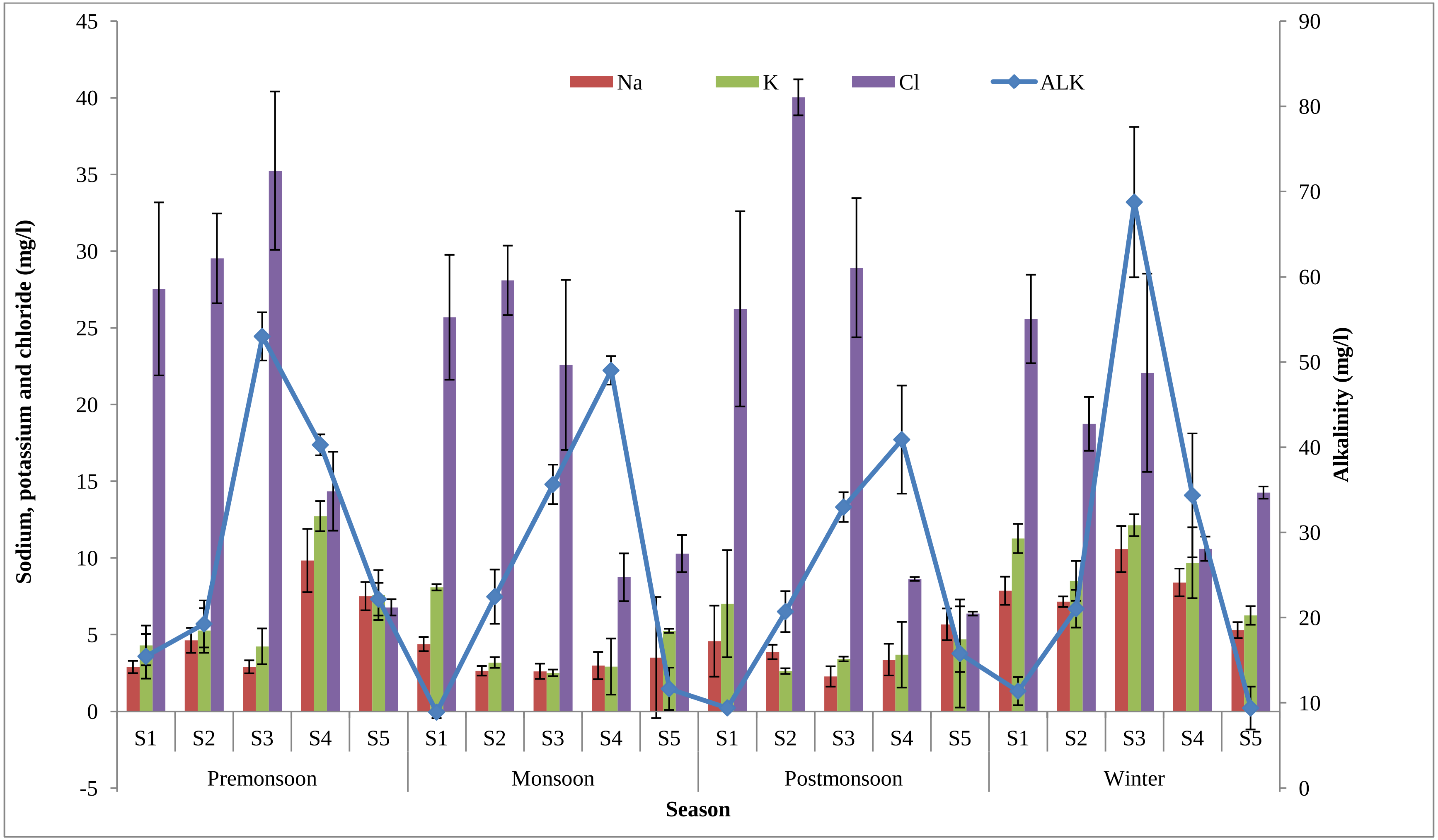


Fig.6: Seasonal variation of sodium, potassium, chloride and alkalinity in the study sites.

sodium concentration fluctuated in between 10.58 mg/l during winter and to 2.27 mg/l during postmonsoon in the pond S3. In other study ponds sodium concentration showed variation within the range of 2.89-7.86 mg/l in S1; 2.64-7.15 mg/l in S2, 2.98-9.83 mg/l in S4 and 3.5-7.51 mg/l in S5 (Fig.6). The variations were observed significant over the seasons and across the study sites. Higher concentration of sodium indicated industrial, domestic and agricultural contamination in the study ponds which was supported by the findings of Trivedy and Goel (1984).

Sodium showed significant positive correlation with conductivity, COD, alkalinity in pond S3; with DO in S1 and S3; with potassium in S1, S2 S3, and S4; with phosphate in S4 and with TOC in S2 and S3. On the contrary, sodium had inverse correlation with surface water temperature in S1, S2 and S3; with turbidity, TDS and TSS in S2; with free CO_2 and BOD in S1; with GPP in S1, S2 and S4 and with NPP in S4 (Table-18 to Table-21).

Potassium (K)

Potassium is an essential element in both plant and human nutrition, and occurs in natural fresh waters as a result of mineral dissolution, but the quantities increase in polluted waters from waste waters, decomposing plant material, and from agricultural runoff (APHA, 2012). In this study, highest value of potassium was noted as 12.72 mg/l in study site S4 during premonsoon season and lowest value was noted as 2.51 mg/l in the study S3 during monsoon season (Fig.6). The values of potassium ranged between 4.3-11.27 mg/l in S1; 2.62-8.5 mg/l in S2; 2.51-12.13 mg/l in S3; 2.92-12.72 mg/l in S4 and 4.7-7.58 mg/l in S5. The fluctuations were found significant over the different seasons and across the different study sites (Fig.6).

Potassium showed significant positive correlation with conductivity in S3 and S4; DO in S1 and S3; with COD and alkalinity in S3; with sodium in S1, S2, S3 and S4; with chloride in S4 and with TOC in S2 and S3. On the other hand, potassium in this study exhibited negative correlation with surface water temperature in S3; with pH in S5; with BOD in S1; with chloride in S2; with nitrate and phosphate in S5; with GPP in S1, S2, S4 and S5 and with NPP in S4 (Table-18 to Table-22).

Chloride (Cl)

Chloride is one of the most important water quality indicator (Bhattacharya *et al.* 2002). In this investigation concentration of chloride was recorded highest of 40.03 mg/l in S2 and lowest of 6.37 mg/l in S5 during postmonsoon season (Fig.6). Chloride concentrations ranged between 25.58-27.54 mg/l in S1; 18.74-40.03 mg/l in S2; 22.07-35.25 mg/l in S3; 8.63-14.35 mg/l in S4 and 6.37-14.26 mg/l in S5 (Fig-6). The higher values of chloride in the oil contaminated ponds S1 to S3 may be associated with frequently runoff loaded with contaminated water from surrounding (June and Fred, 1987; Sunder, 1988).

In this investigation chloride exhibited significant positive correlation with pH and TSS in S3; with conductivity and potassium in S4; with DO, BOD and TOC in S5 and with COD and algal density in S2. Inversely, chloride had negative correlation with surface water temperature, TSS and alkalinity in S5; with potassium in S2 and with GPP in S1and S4 (Table-18 to Table-22).

Nitrate (NO_3)

Nitrate is an important parameter of water to determine organic pollution and it represents the highest oxidized form of nitrogen (Elayaraj and Selvaraju, 2014). Nitrates are contributed to fresh water through discharge of sewage, industrial wastes and runoff from agricultural fields (Yadav *et al.*, 2013). The nitrates are an important source of nitrogen for algae in water (Harney *et al.*, 2013). In this present study, the values of nitrate were recorded very low. Nitrate content recorded highest of 0.95 mg/l in the pond S4 during monsoon and lowest of 0.19 mg/l in the pond S3 during premonsoon season (Fig.7). The values of nitrate ranged between 0.24-0.31 mg/l in S1; 0.23-0.37 mg/l in S2; 0.19-0.55 mg/l in S3; 0.68-0.95 mg/l in S4 and 0.61 to 0.88 mg/l in S5. In Assam, low values of nitrate in different aquatic system were recorded by Goswami (1985), Baruah (1995), Hazarika (1997) and Hazarika (2007). Except in the site S1, highest nitrate concentrations were recorded during monsoon season in all the other study ponds (Fig.7). It may be due to influx of nitrogen rich runoff water that bring large amount of contaminants which is in conformity with Anderson *et al.* (1998).

Nitrate showed significant positive correlation with pH, GPP and NPP in pond S5; with TDS and TSS in S2 and with NPP in S1 and S5. On the contrary, nitrate had inverse correlation with pH in site S3 and with potassium and phosphate in S5 (Table-18 to Table-22).

Phosphate (PO_4)

Phosphate is an important nutrient for the maintenance of the fertility of water body. Phosphate enters surface water from human-generated wastes, industrial effluent and land run off. Phosphate is the key nutrient causing eutrophication leading to extensive algal growth (Yadav *et al.*, 2013). Phosphate in large concentration in water is an indication of pollution through sewage and industrial waste. In this present investigation highest phosphate concentration was recorded as 1.06 mg/l during premonsoon and lowest as 0.52 mg/l during postmonsoon in the site S4 (Fig.7). In rest of the sites it ranged between 0.57-0.73 mg/l in S1; 0.56-0.74 in S2; 0.57-0.73 in S3 and 0.64-1.01 in S5 (Fig.7).

Phosphate showed significant positive correlation with conductivity, TDS and potassium in the site S5; with free CO_2 in S1; with sodium in S4 and with COD in S2 and S3. Inversely, it had significant negative correlation with pH in S4 and S5; with DO in S1, with COD in S4; with GPP in S3 and with nitrate and NPP in S5 (Table-18 to Table-22).

Total oil content (TOC)

Total oil contains hydrocarbons, sulphur, metals, aliphatics, aromatics, PAHs, PCBs and the effects of these compounds on aquatic components depend on grades and types, and the duration it has been in the water (Taş *et al.* 2010). Oil spill creates surface film on water that prevents gaseous exchange and adversely affects the growth of living organisms including algae (Schramm, 1972). Crude oil contamination generally found to be inhibitor of photosynthesis and growth in algae (Gaur, 1981; González *et al.* 2009). In present investigation, highest concentration of TOC was recorded as 29.14 mg/l in S3 during winter and lowest as 0.69 mg/l in S4 during monsoon season. TOC showed variations within the study sites as 11.15-18.32 mg/l in S1; 2.8-12.46 mg/l in S2; 4.17-29.14 mg/l in S3; 0.69-1.91 mg/l in S4 and 1.02-3.31 mg/l in S5 (Fig.7). Higher concentrations of TOC were recorded in the ponds S1 to S3 which located near oil exploration and production sites (Fig.7). Due to recession of water in dry winter, concentrations of TOC were subsequently increased in the studied ponds.

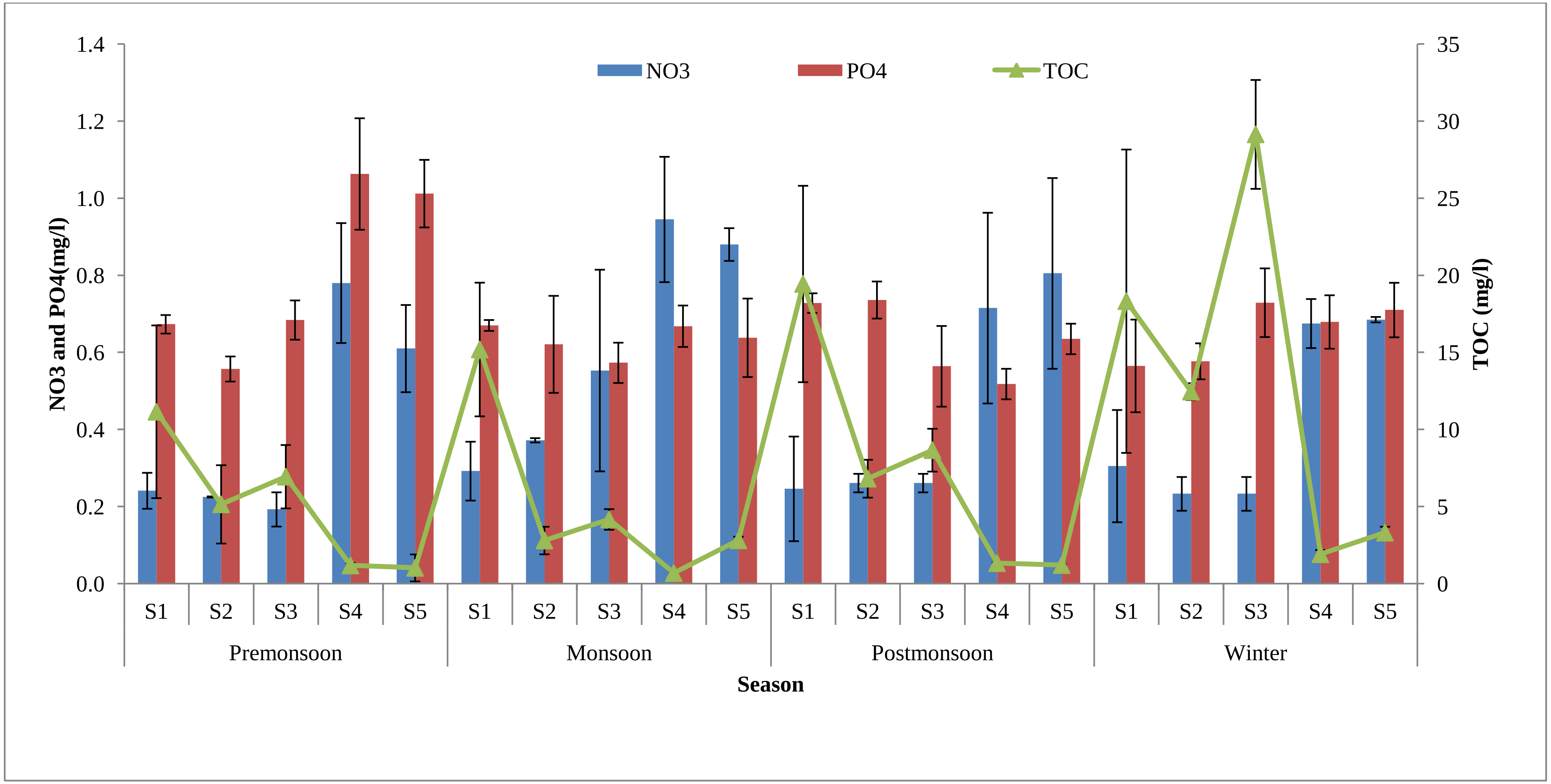


Fig.7: Seasonal variation of nitrate, phosphate and TOC in the study sites.

TOC showed significant positive correlation with conductivity and alkalinity in the pond S3; with DO in S2, S3, S4 and S5; with COD and chloride in S5; with hardness and magnesium in S4; with sodium and potassium in S2 and S3. On the other hand, TOC had strong inverse correlation with surface water temperature in S2, S3, S4 and S5; with turbidity in S2 and S3; with TDS and GPP in S2; with TSS in S2 and S5 and with alkalinity in S5 (Table-18 to Table-22).

Primary Productivity

Primary productivity is the measure of the rate of conversion of radiant energy to chemical energy through the process of photosynthesis (Verma, 2002). Various forms of algae play the major role in aquatic productivity. Gross primary productivity (GPP) is the total rate of photosynthesis including the organic matter used up in respiration during the measuring period on the other hand; net primary productivity (NPP) is the rate of storage of organic matter in plant tissues in excess after being utilized in respiration by plants during the incubation period. Primary productivity is studied to understand the effect of pollution on the efficiency of aquatic systems. Pollution affects the production/respiration ratio in an aquatic system, a proper level of which is very essential for the healthy condition of the system. In natural unpolluted water, production usually exceeds respiration but in organically polluted systems, respiration exceeds production and no oxygen is left available for the normal aerobic bioactivity of the system leading to the destruction of the system (Kumar, 2002).

In the present study GPP was recorded highest of 6.13 mg/l in the site S4 during monsoon season and lowest of 1.54 mg/l in S1 during winter season. The values of GPP ranged between 1.54-2.41 mg/l in S1; 1.06-3.55 mg/l in S2; 2.26-3.79 mg/l in S3; 4.19-6.13 in S4 and 2.36-5.1 mg/l in S5 (Fig.8). In study sites S1, S3 and S5, the higher values were observed during postmonsoon season. Whereas, higher values were observed during monsoon season in pond S2 and S4. Except in S4, GPP was noted overall lower during winter in the other ponds. In S4, GPP was lowest during premonsoon season (Fig.8). GPP showed significant positive correlation with surface water temperature in S1 and S2; with turbidity, TDS and TSS in S2. However, it had negative correlation with conductivity, COD, alkalinity, hardness, calcium, magnesium and phosphate in S3; with sodium and potassium in S1 and S2 and with TOC in S2 (Table-18 to Table-22).

NPP in this investigation was found highest of 4.14 mg/l in the site S4 during postmonsoon season and lowest of 0.53 mg/l in S3 during premonsoon season. It was fluctuated between 1.31-1.77 mg/l in S1; 0.54-1.75 mg/l in S2; 0.53-1.84 mg/l in S3; 2.11-

4.14mg/l in S4 and 1.19-3.51 mg/l in S5. The values of NPP did not show any definite seasonal trend of fluctuations (Fig.8). NPP showed significant positive correlation with COD in S4; with nitrate in S1 and with phosphate and GPP in S5. Inversely, it had negative correlation with pH in S2; with TDS and COD in S3 and with sodium, potassium and phosphate in S4 (Table-18 to Table-22).

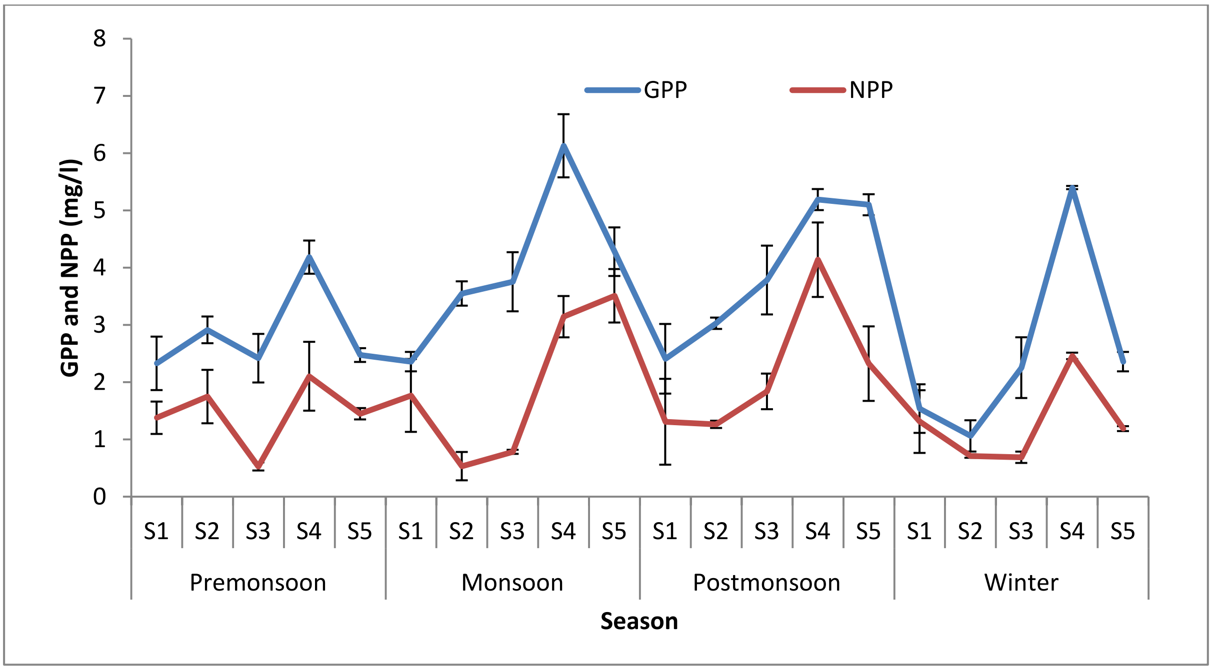


Fig.8: Seasonal variation of GPP and NPP in the study sites.

Algal Enumeration

The present investigation was undertaken to develop a fresh water algal database of Tinsukia district (Assam) with special reference to oil field contamination. It revealed that a good numbers of algal species inhabited in the studied aquatic bodies.

A total of 317algal species belonging to 108 genera representing 15 orders and 29 families were recorded under seven taxonomic classes namely Cyanophyceae, Chlorophyceae, Xanthophyceae, Chrysophyceae, Dinophyceae, Euglenophyceae and Bacillariophyceae (Table-7). Among these classes Chlorophyceae was the dominant group consisting of 53 genus, 171 species, followed by Cyanophyceae (23 genus, 69 species), Bacillariophyceae (17 genus, 49 species), Euglenophyceae (6 genus, 16 species), Xanthophyceae (5 genus,7 species), Chrysophyceae (4 genus,5 species) and Dinophyceae (1species). The average ratios of Chlorophyceae, Cyanophyceae, Bacillariophyceae, Euglenophyceae, Xanthophyceae, Chrysophyceae and Dinophyceae observed during the study period were 34.2 : 13.8 : 9.8 : 3.2 : 1.4 : 1 : 0.02 in community composition. Chlorophyceae had highest 54% contribution which was followed by Cyanophyceae with 22%, Bacillariophyceae with 15%, Euglenophyceae with 5%. Both Xanthophyceae and Chrysophyceae with 2 % each while Dinophyceae had a negligible portion of 0.32% (Fig.9). Singh and Gaur (1988), Joseph and Joseph (2002), Baruah *et al.*, (2009), Bordoloi and Baruah (2015 a), Bordoloi and Baruah (2015 b) also found Chlrophyceae as the dominant group in crude oil contaminated aquatic systems studied by them.

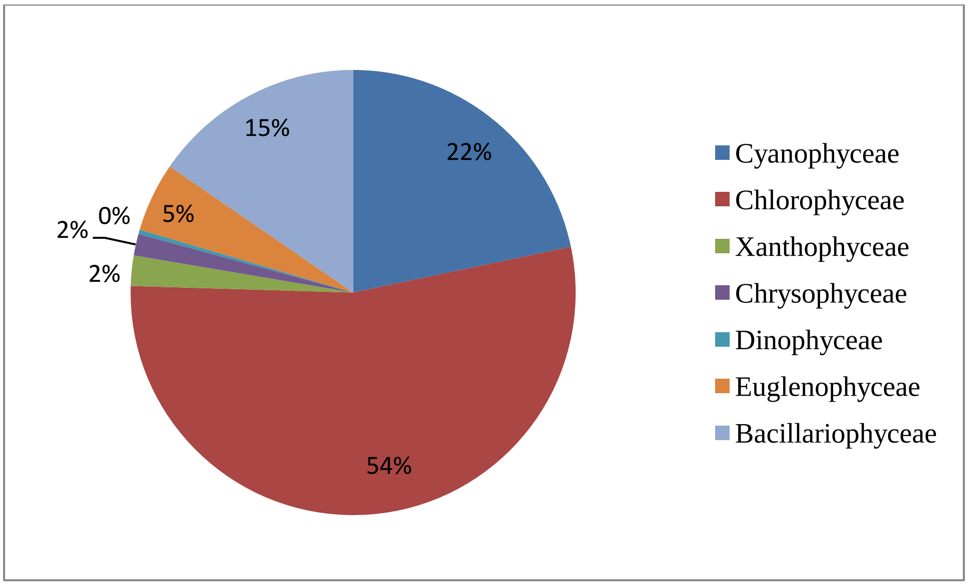


Fig.9: Algal community composition in the study sites.

Among Chlorophyceaean members, desmids outnumbered in terms of species. *Cosmarium* was the largest genus with 20 species, followed by *Scenedesmus* with 15 species and *Closterium* with 12 species. Though desmids are indicator of unpolluted water (Mahadev *et al.* 2010), *Closterium* and *Cosmarium* of the family Desmidaceae were reported as pollution tolerant genera by Palmer (1969). Singh and Gaur (1989) and Bordoloi and Baruah (2015b) also recorded desmids in crude oil refinery effluent contaminated water bodies. Some other Chlorophycean members showing their significant presence in the ponds of Tinsukia District were *Staurastrum* (9 species), *Coelastrum* (7 species). *Pediastrum, Monoraphidium* and *Euastrum* were represented with 6 species; *Tetraedron, Ankistrodesmus, Crucigenia, Ulothrix* and *Micrasterias* were represented with 5 species; *Kirchneriella, Oedogonium, Spirogyra, Pleurotaenium* were represented with 4 species; *Eudorina* and *Uronema* were represented with 3 species each. *Pleodorina, Nephrocytium, Botryococcus, Dictyosphaerium, Desmodesmus, Selenastrum, Zygnema, Docidium* and *Arthrodesmus* were represented with 2 species. *Pandorina, Haematococcus, Gloeocystis, Gloeodendron, Tetrasporidium, Ankyra, Chlorococcum, Chlorella, Hydrodictyon, Sorastrum, Podohedra, Quadrigula, Treubaria, Radiococcus, Dimorphococcus, Diplochloris, Dicloster, Tetrastrum, Triploceros, Tetmemorus, Spondylosium, Desmidium, Xanthidium, Hyalotheca* and *Trochiscia* were represented with single species only (Table-7). Presence of *Pediastrum, Scenedesmus, Closterium, Ankistrodesmus* and *Chlorella* also indicated the nutrient enriched condition of the study sites which is again in conformity with Kumar, (1990) and Zargar and Ghosh (2006). Borowitzka and Borowitzka (1998) opined that *Scenedesmus* is a ubiquitous species showing dominance in various polluted water bodies. In this study, a total of 76 chlorococcales were also recorded from all the study sites (Table-7). The wide diversity and distribution of chlorococcales also indicated eutrophic nature of the study sites (Reynolds, 1984). Baker (1971) and Cowell (1971) opined that green algae exhibit tolerance to crude oil contamination and have the ability to grow in the areas polluted by crude oil. McCauley (1966), Rao *et al.* (2011) and Sivasubramanian and Muthukumaran (2012) also reported *Chlorella, Chlorococcum, Ankistrodesmus, Chlamydomonas, Closterium, Gonium, Scenedesmus* as crude oil tolerant genera.

Oscillatoria was the largest genus represented with 8 species among the group Cyanophyceae. According to Round (1965) and Gadage *et al*. (2005) dominance of *Oscillatoria* was always associated with high level of organic pollution which also confirms the pollution status of the studied water bodies of Tinsukia District. The other major Cyanophyceaen genera recorded in this study were *Lyngbya* with 6 species and *Chroococcus* with 5 species. *Aphanothece, Merismopedia, Phormidium* and *Anabaena* were represented with 4 species each. Regular occurrence of *Chroococcus, Lyngbya, Phormidium* and *Anabaena etc*. was reported as indicator of organic pollution by Vashisht and Sra (1979), Nandan and Ahar (2005), Naik *et al*. (2005) and Shekhar *et al*.(2008). Three Cyanophycean members namely *Microcystis, Aphanocapsa* and *Nostoc* were represented by 3 species each. Naik *et al*. (2005) and Shekhar *et al*, (2008) opined that presence of *Microcystis* indicated organic pollution in any aquatic body. Another 8 genera namely *Coelosphaerium, Synechococcus, Dactylococcopsis, Spirulina, Cylindrospermum, Scytonema, Calothrix* and *Heplaosiphon* were represented by 2 species each. *Gomphosphaeria, Cyanosarcina, Symploca* and *Aulosira* were represented with single species only. Several members of Cyanophycea like *Microcystis , Chroococcus, Aphanothece, Coelosphaerium, Oscillatoria, Lyngbya, Aulosira, Cyanosarcina, Scytonema* and *Spirulina* which were reported as crude oil tolerant by Mc Cauley (1966), Kauss *et al.*, 1973, Singh and Gaur (1988), Joseph and Joseph

(2002), Baruah *et al.* (2009) and Rajasulochana *et al*. (2009). These Cyanophycean members were growing luxuriously in the studied oil contaminated ponds.

Bacillariophyceae was the third largest algal group in the study ponds as per our investigation. Of them, *Navicula* was the largest genera with 8 species followed by *Cymbella* with 6 species and *Fragilaria* and *Pinnularia* with 5 species each. *Navicula* is considered as a good indicator of organic pollution as the genus can grow in most heavily polluted conditions in which other species can not grow (Butcher, 1949). Other significant representatives of this group were *Synedra* and *Nitzschia* with 4 species and *Cyclotella* and *Gomphonema* with 3 species each. Patrick (1948) and Archibald (1972) opined that *Synedra*, *Nitzschia* and *Gomphonema* are found to be dominant in mild to highly organically polluted water. *Himantidium* and *Amphora* were represented by 2 species. Whereas, *Aulacoseira, Melosira, Eunotia, Diadesmis, Mastogloia, Hantzschia* and *Suriella* were represented by single species only (Table-7). *Amphora* was also reported to grow in water affected by high organic content (Patrick, 1948). *Melosira, Cyclotella, Fragilaria, Synedra, Achnanthes*, *Navicula*, *Pinnularia, Gomphonema*, *Cymbella*, *Nitzschia* which were recorded to be tolerant to oil contamination by Mc Cauley (1966). Bordoloi and Baruah (2015a and 2015b) confirmed the organic contamination of the ponds.

Euglena was the dominant genus with 7 species among Euglenophyceae followed by *Phacus* with 3 species. Other 2 genera *Lepocinclis* and *Trachelomonas* were represented with 2 species. Remaining member of Euglenophyceae *Strombomonas* and *Petalomonas* were represented by single species only. *Euglena*, *Lepocinclis* and *Phacus* were reported as pollution tolerant genera by Palmer (1969). Basavaraja *et al.* (2013) also reported *Euglena, Phacus* and *Trachelomonas* as pollution tolerant species in a fresh water reservoir in Westernghat region of India. Among the group Xanthophyceae, *Ophiocytium* with 3 species was the dominant genera. Remaining 4 members of this group namely *Goniochloris, Centritractus, Pseudostaurastrum* and *Tetraedriella* were represented by single species only. Among the class Chrysophyceae, the genus *Dinobryon* was represented with 2 species and *Phaeplaca* and *Synura* were represented by single species only. Dinophyceae was represented by single genus *Ceratium* (Table-7).

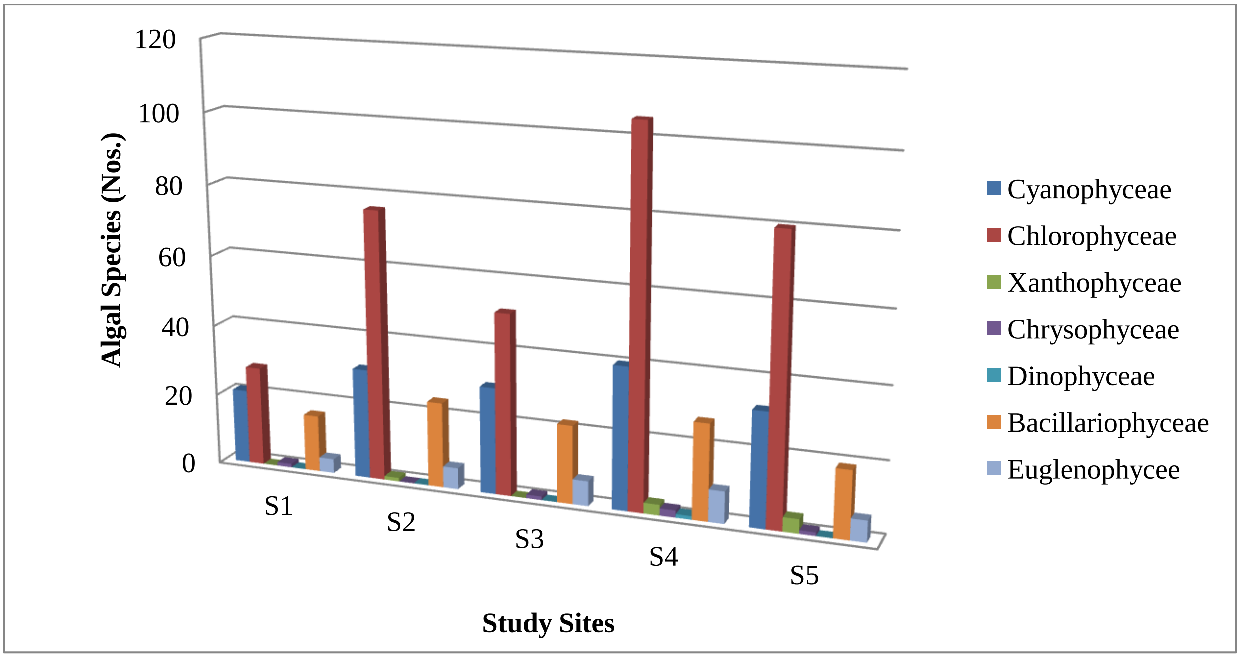


Fig-10: Group wise distribution of algae among the study sites

Among the studied aquatic bodies highest algal species richness was observed in the study site S4 followed by the study site S5. The sequence of algal species richness among the study sites were recorded in the sequence as - **S4>S5>S2>S3>S1**.

In the studied pond S4 a total of 187 species of algae were reported of which 105 species were belongs to Chlorophyceae, 40 belongs to Cyanophyceae, 27 species to Bacillariophyceae, 9 species to Euglenophyceae followed by Xanthophyceae (3 species), Chrysophyceae (2 species) and Dinophyceae (1 species). In this study site, *Cosmarium*, *Scenedesmus*, *Closterium*, *Oscilatoria*, *Merismopedia* , *Lyngbya*, *Navicula*, and *Euglena* were recorded as dominant genera (Table-7).

The study site S5 harboured 143 algal species of which Chlorophyceae (80 species) was the dominant group followed by Cyanophyceae (32 species), Bacillariophyceae (19 species), Euglenophyceae (6 species), Xanthophyceae (4 species) and Chrysophyceae (1 species). In this pond also desmid member *Cosmarium* (14 species) was the dominant genus followed by another green algae *Pediastrum* (5 species) (Table-7).

A total of 138 numbers of algal species were noted in the study site S2. The algal community of this aquatic body composed of Chlorophyceae (76 species), Cyanophyceae (31 species), Bacillariophyceae (24 species), Euglenophyceae (6 species) and one species of Xanthophyceae (Table-7). Species of *Scenedesmus* and *Cosmarium* were found dominant with 7 species each in this pond followed by *Coelastrum* with 5 species (Table-7).

The study site S3 inhabited by 111 numbers of algal species which included Chlorophyceae (51 species), Cyanophyceae (30 species), Bacillariophyceae (22 species), Euglenophyceae (7 species) and Chrysophyceae (1 species) (Table-7). Dominance of *Scenedesmus, Gloeocapsa* and *Navicula* indicated polluted nature of this pond Palmer (1969).

The study site S1 represented with 69 species showed the least algal species richness among the study sites. The algal community of this pond composed of Chlorophyceae (28species), Cyanophyceae (21 species), Bacillariophyceae (16 species), Euglenophyceae (4 species) and Chrysophyceae (1 species) (Table-7). Significant presence of Chlorophycean genera *Scenedesmus, Cosmarium Ankistrodesmus, Botryococcus* and *Coelastrum;* Cyanophycean members *Oscilatoria, Microcystis* and *Chroococcus;* Bacillariophycean member *Navicula, Synedra, Pinnularia, Gomphonema* and *Nitzschia* and Euglenophycean members *Euglena* and *Phacus* indicated high organic pollution in this study site (Palmer, 1969; Nandan and Aher 2005). According to Shekhar *et al.,* (2008), presence of the BGA genera *Microcystis* is the best single indicator of high organic pollution.

Algal Seasonality

Distinct seasonal changes in algal community composition was observed in the study sites S1 to S5 during this two years investigation (Fig.11 to Fig.15). Except during the premonsoon season in the study sites S1 and S3, Chlorophycean algae were dominant in all the study sites throughout the year.

In the study site S1, during premonsoon season Cyanophyceae (35%) and Bacillariophyceae (35%) were the dominant groups followed by Chlorophyceae (24%), Euglenophyceae (3%) and Chrysophyceae (3%). Higher temperature and free CO_2 and lower pH and DO values in water favoured dominance of Cyanophyceae during premonsoon season (Fig-11 A). It was in conformity with the observations made by Hulyal and Kaliwal (2009) and Kumar and Oommen (2011). From the monsoon season onwards Chlorophycean algae

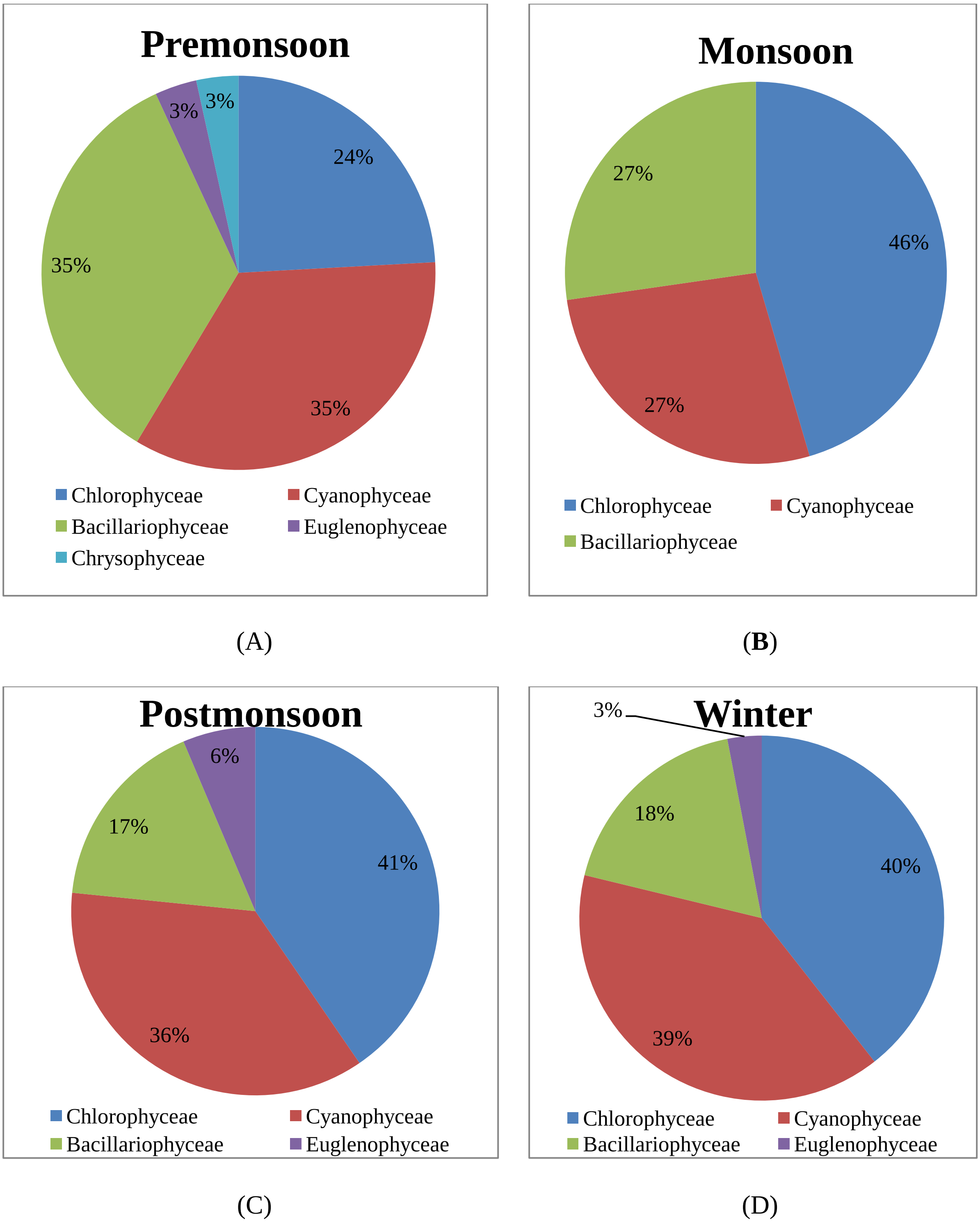
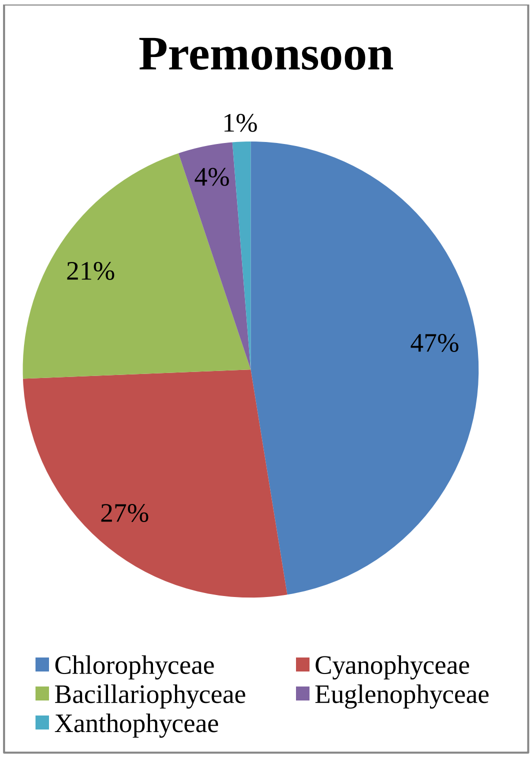
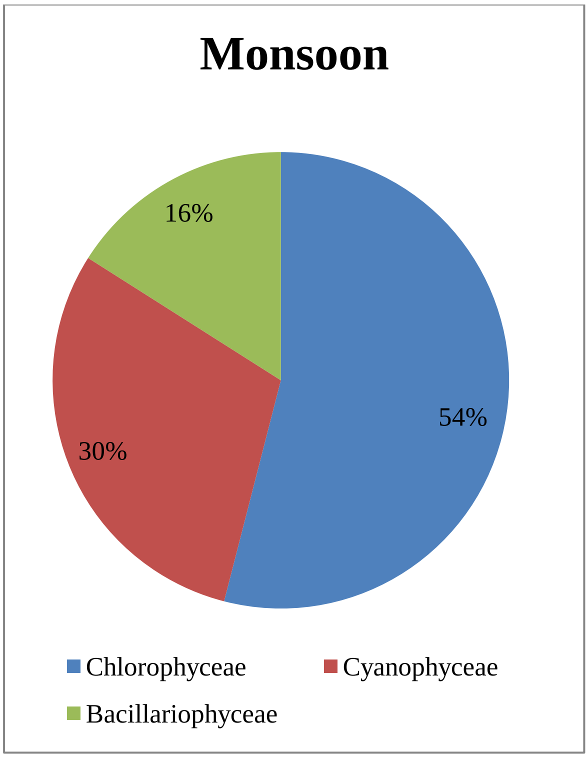


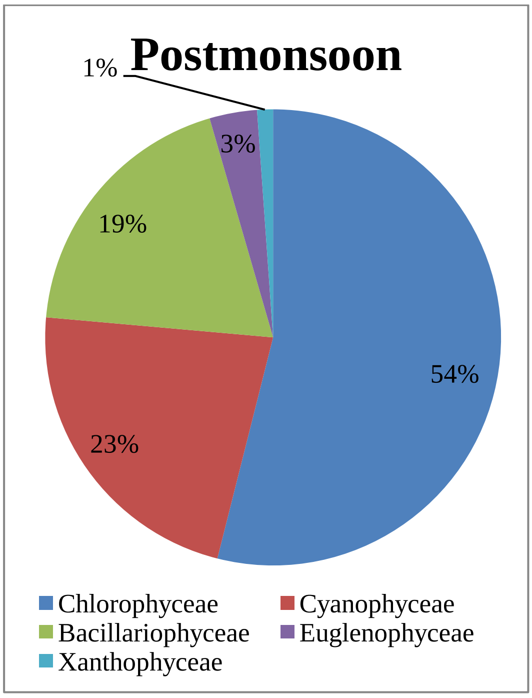
Fig-11(A-D): Algal seasonality at Study Site S1.



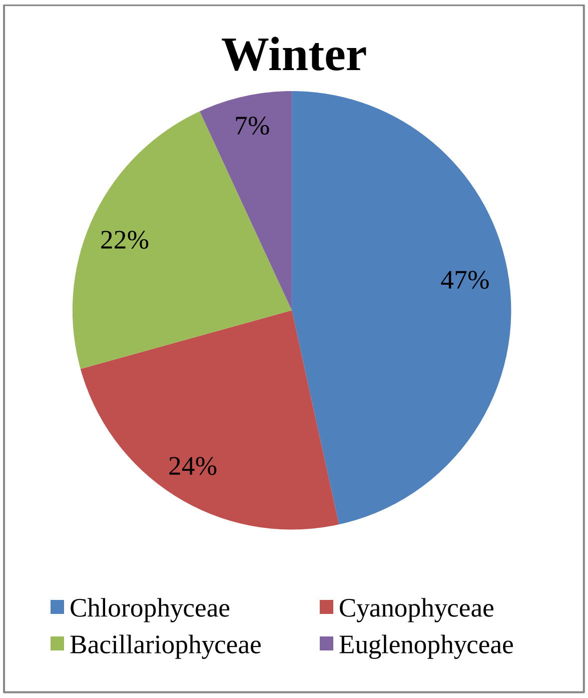
(A)



(B)

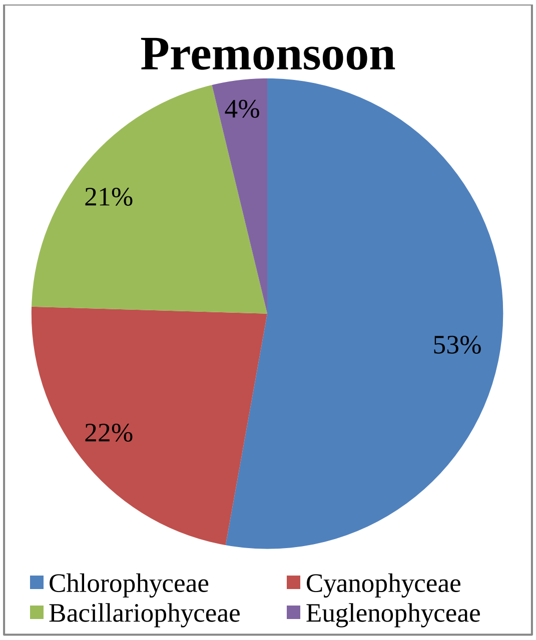


(C)

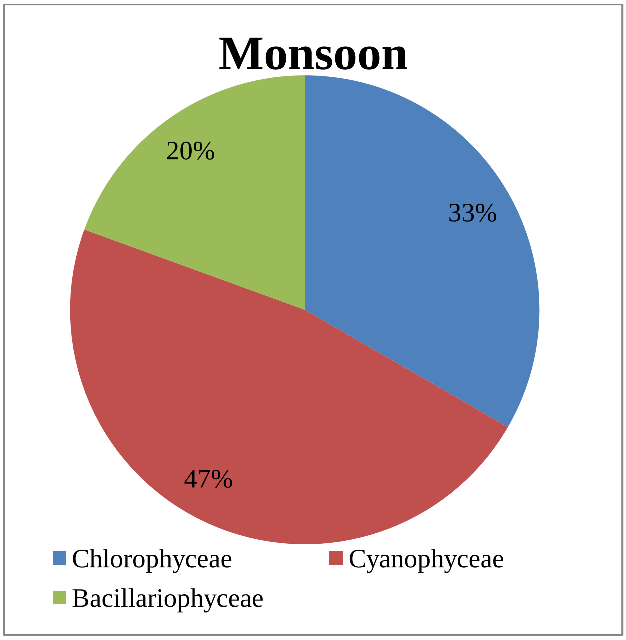


(D)

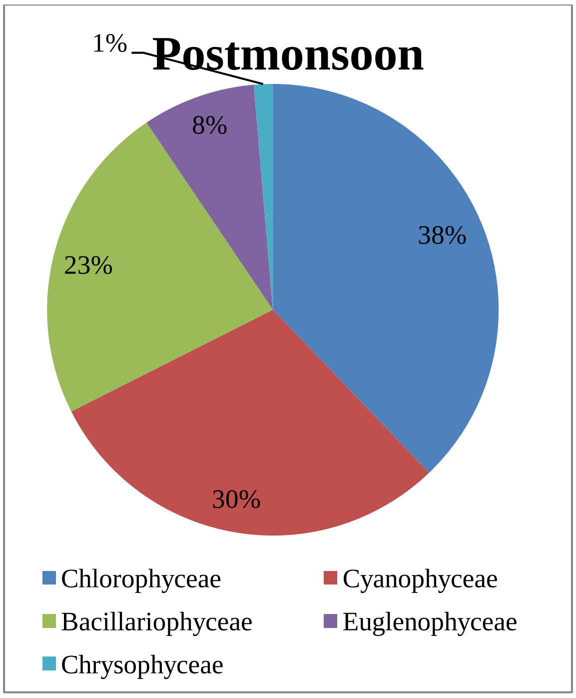
Fig-12(A-D): Algal seasonality at study site S2.



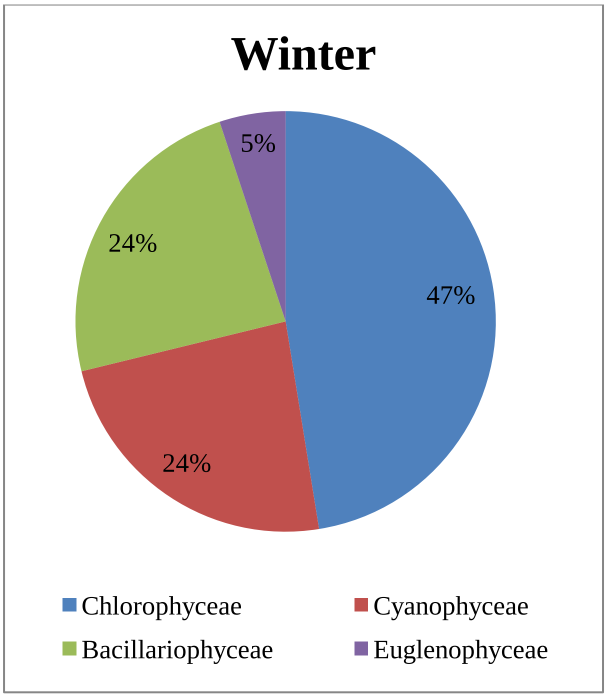
(A)



(B)

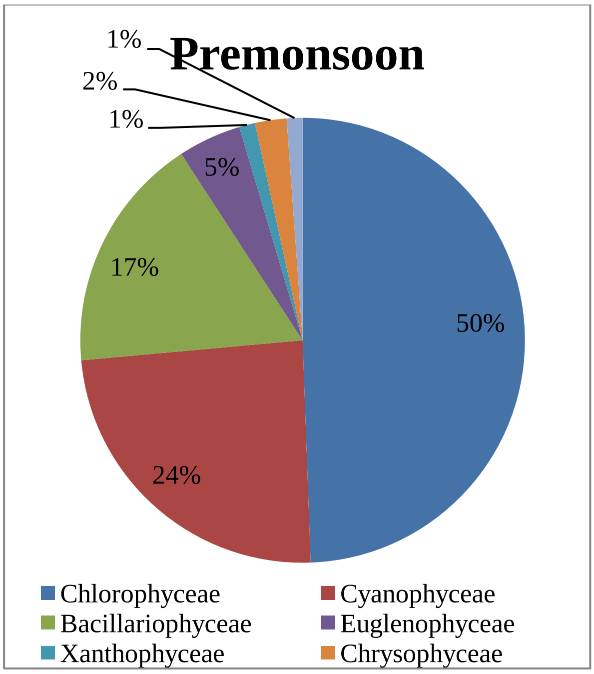


(C)

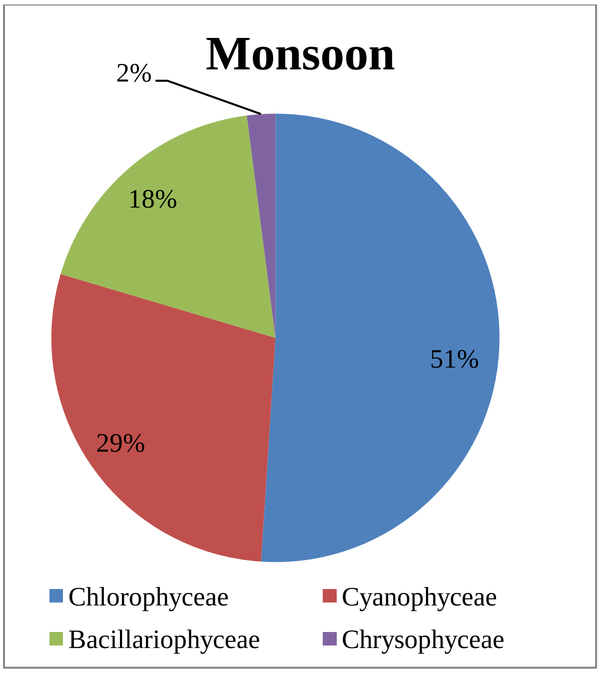


(D)

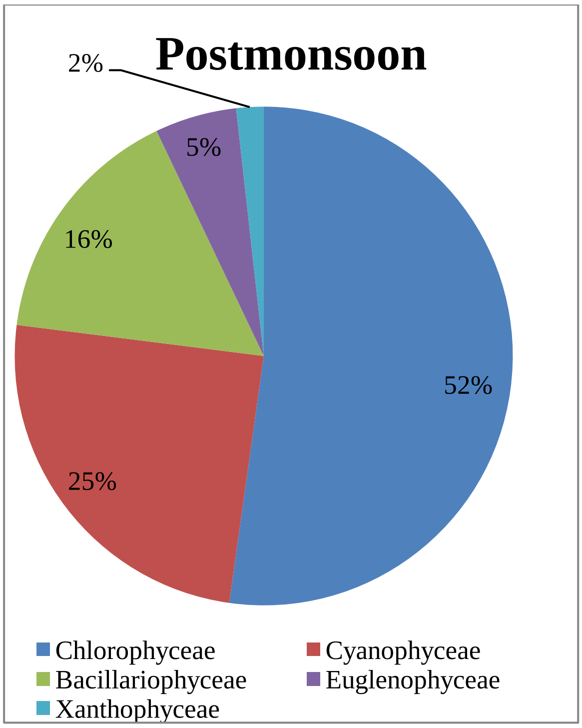
Fig-13(A-D): Algal seasonality at study site S3.



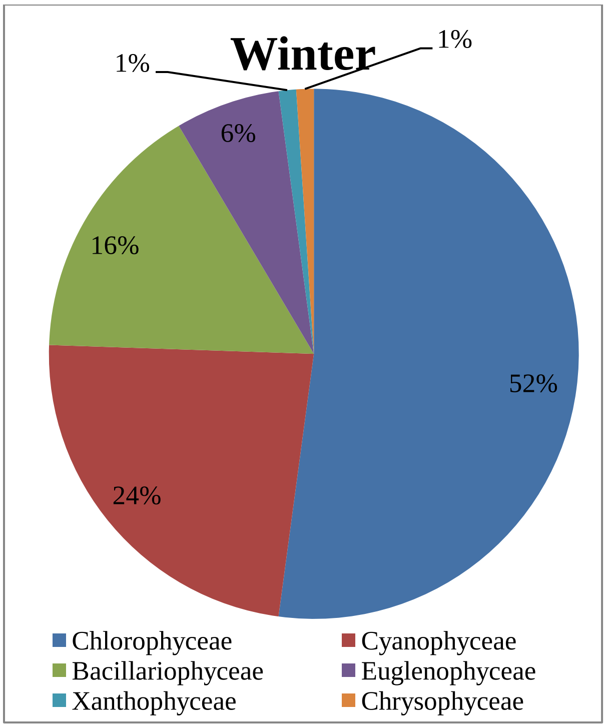
(A)



(**B**)

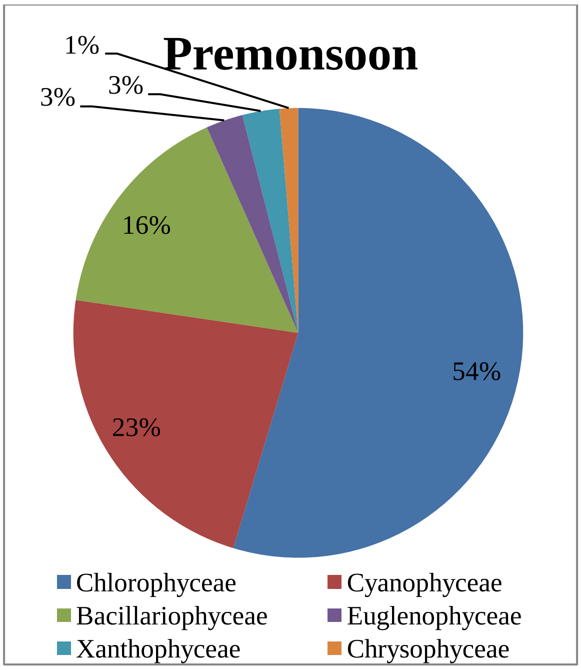


(C)

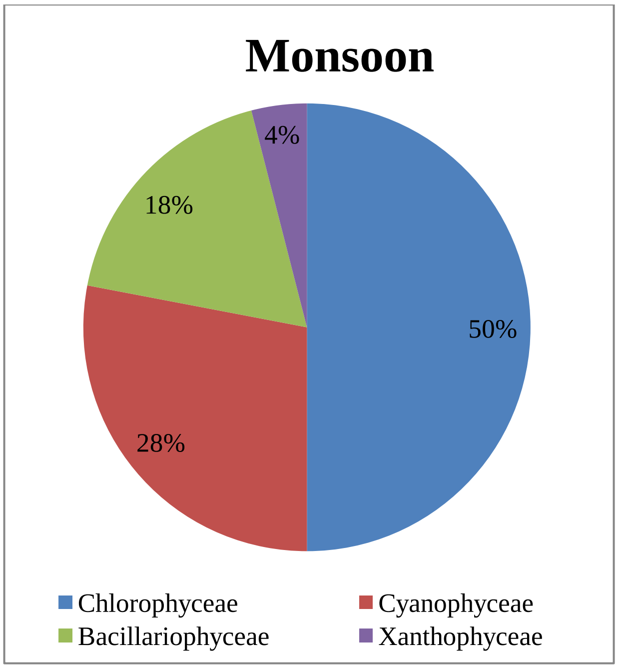


(D)

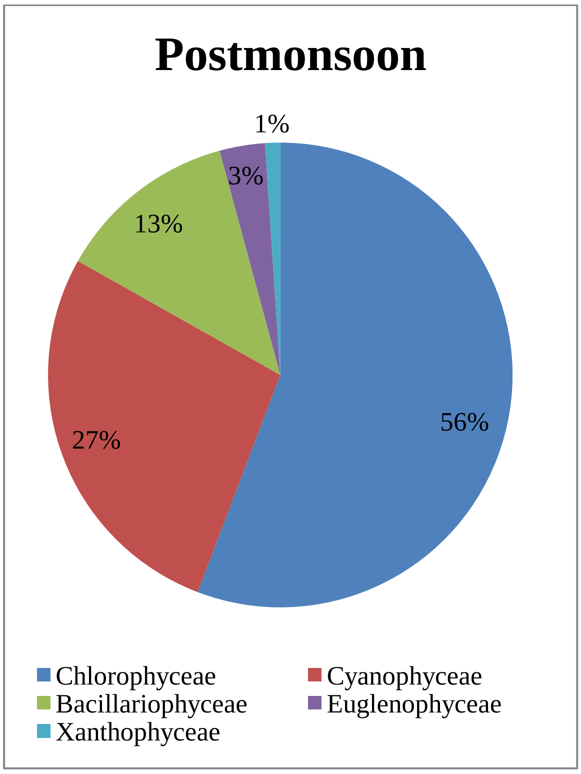
Fig-14(A-D): Algal seasonality at study site S4.



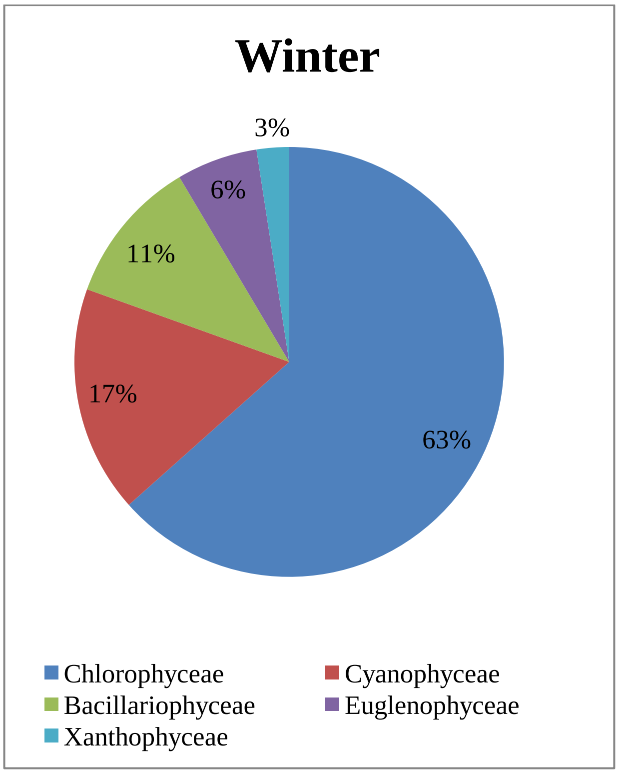
(A)



(B)



(C)



(D)

Fig-15(A-D): Algal seasonality at study site S5.

started to show its dominance over other groups. During monsoon, algal community in the pond consisted of Chlorophyceae (46%), Cyanophyceae (27%) and Bacillariophyceae (27%) (Fig.11B). Increase in water temperature, pH, DO, nutrient content was associated with Chlorophycean dominance from the monsoon season which is in conformity with the observations made by Sedamker and Angadi (2003), Sharma and Lyngdon (2003) and Sheeba and Ramanujan (2005). In postmonsoon , percentage composition of algal community in this pond was 41% of Chlorophyceae, 36 % of Cyanophyceae, 17% of Bacillariophyceae and 6% of Euglenophyceae (Fig.11C). During the winter also Chlorophyceae (40%) was the dominant class followed by Cyanophyceae (39%), Bacillariophyceae (18%) and Euglenophyceae (3%) (Fig.11D).

The present study also showed that Chlorophyceae was the dominant algal group over all the groups reported in the study site S2 in all the seasons. The percentage of Chlorophyceae was recorded as 47% in premonsoon, 54 % both in monsoon and postmonsoon and 47% in winter season. The Cyanophyceae was second dominant group during all the seasons throughout the year with percentage composition of 27%, 30%, 23% and 24% in premonsoon, monsoon, postmonsoon and winter season respectively. Bacillariophyceae was the third major group in this study site with percentage composition of 21%, 16%, 19% and 22% in premonsoon, monsoon, postmonsoon and winter season respectively (Fig.12A-D).

In the studied water body S3, Chlorophyceae was dominant in all the seasons except the monsoon. During the premonsoon season percentage composition of algal flora in this sited showed Chlorophyceae 53%, Cyanophyceae 22 %, Bacillariophyceae 21 % and Euglenophyceae 4 %. However Cyanophyceae was dominant over Chlorophyceae during the monsoon season. In monsoon the algal community of S3 constituted of 47 % Cyanophyceae, 33 % Chlorophyceae and 20 % Bacillariophyceae. From postmonsoon season onwards Chlorophyceae again became dominant over other groups. Algal flora in postmonsoon season composed of Chlorophyceae 38%, Cyanophyceae 30%, Bacillariophyceae 23%, Euglenophyceae 8% and Chrysophyceae 1%. In winter also, similar composition of algal community was observed with 47% of Chlorophyceae, 24 % both of Cyanophyceae and Bacillariophyceae and 5 % Euglenophyceae (Fig.13A-D).

Chlorophyceae was the dominant group of algae in the study site S4 during all the seasons throughout the years. It consisted of 50 % in premonsoon, 51% in monsoon, 52 %

both in postmonsoon and winter algal community. Cyanophyceae was the second largest algal group in all the seasons in S4 constituting 24%, 29%, 25% and 24% of community during premonsoon, monsoon, postmonsoon and winter season respectively. Percentage of Bacillariophyceae was recorded 17% in premonsoon, 18% in monsoon and 16% both in postmonsoon and winter season. Euglenophyceae composed 5% of algal community both during premonsoon and postmonsoon season. In winter Euglenophyceae constituted 6 % of algal composition in the pond S4 (Fig.14A-D).

In the studied pond S5, the trend of change in seasonal composition of algal community throughout the years was similar with the pond S4. Here also Chlorophyceae was the dominant class in all the seasons. The percentage compositions of Chlorophyceae were 54 %, 50 %, 56% and 63% in premonsoon, monsoon, posmonsoon and winter season respectively. It was followed by Cyanophyceae with 23%, 28%, 27% and 17% respectively in premonsoon, monsoon, posmonsoon and winter season algal community. Bacillariophyceae was the third major algal group among the algal community of all the seasons in study site S5. It constituted 16%, 18%, 13% and 11% of algal community during premonsoon, monsoon, posmonsoon and winter season respectively. Except in monsoon, Euglenophyceaean members also contributed 3 % of both premonsoon and postmonsoon season and 6 % of winter season algal community. Xanthophyceae also gave minor contribution in the community composition of the site S5 in all the seasons. It was 3%, 4%, 1% and 3% in premonsoon, monsoon, posmonsoon and winter season respectively. Chrysophyceae constituted 1 % of algal community of the premonsoon season only (Fig.15A-D).

From the above observations it was revealed that Chlorophyceae was the dominant group of algae contributing maximum proportion of algal diversity in all the studied aquatic bodies. Dominance of Chlorophyceae throughout the study period was also reported by Sakhare and Joshi (2002) in Yeldari reservoir of Nanded District (Maharashtra), Pawar and Pulle (2006) in Pethwadaj dam (Maharashtra), Jayabhaye *et al*., (2007) in Parola dam (Maharashtra), Kakati (2011) in Historical ponds of Kamrup district, Assam, Patil *et al*., (2015) in major freshwater bodies of Ajara Tahsil of Kolhapur District (M.S.) and Mahajan and Harney (2016) in Mohabala Lake of Bhadrawati, District Chandrapur (M.S.). Round (1957) opined that the presence of Chlorophyceae in eutrophic water is due to its high nutrient content. Rama Rao *et al.* (1978) also found green algae to be indicator of highly polluted waterbodies.

Similarity and Clustering Analysis:

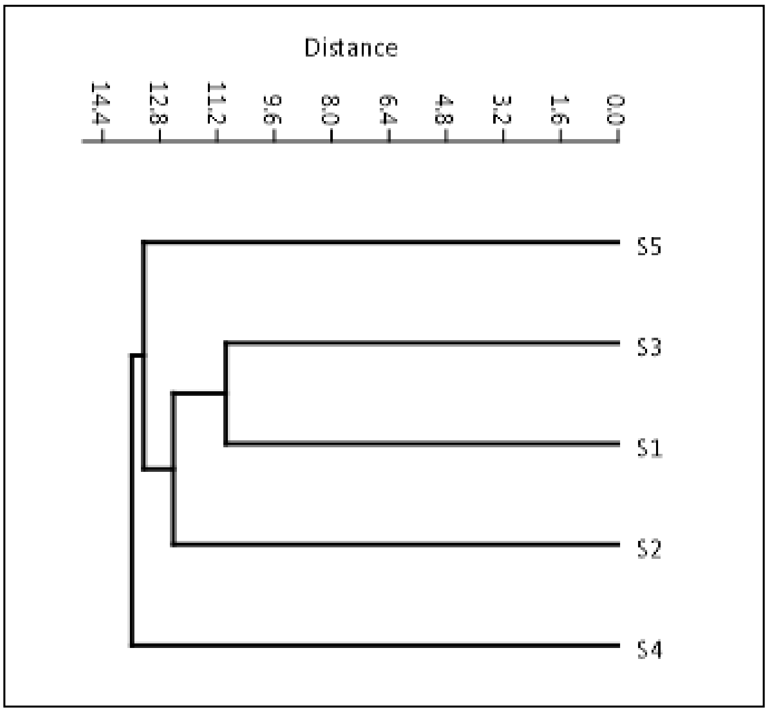


Fig.16: Dendrogram showing hierarchical clustering of the study sites.

Highest similarity index (0.47) was observed between study sites S2 and S4 and lowest value (0.08) was observed between S1 and S4 (Table-14). Hierarchical cluster analysis (HCA) was also performed to find out the similar groups among the five study sites based on the presence and absence of species in the respective study papers. HCA thus created had five variables (study sites) and observations (species). The diagram generated from HCA was represented as Fig.16 which revealed two distinct groups, one group was constituted of oil contaminated study sites S1, S2 and S3 and the other group constituted of non oil contaminated study sites S4 and S5. Study sites S1 and S3 formed a cluster which was distantly related to S2. Though S4 and S5 were located a distance from one another, the water bodies inclined to be in the same group. This distribution could be due to the oil contamination gradient, temporal gradient caused by seasonal change and the existence of similar conditions in the water bodies of the same group.

Algal Density

In this two years investigation, algal density in five study sites was showed distinct seasonal fluctuation. Among the study sites, S4 showed highest mean average algal density (275.98 x 10^3 individual/l) followed by S5 (165.44x 10^3 individual/l). Study site S1 showed lowest mean average algal density (18.84 x 10^3 individual/l) during this study period (Table-13). The sequence of algal density among the study sites was **S4>S5>S2>S3>S1**.

Higher algal density was observed during postmonsoon season in all the studied aquatic bodies which is in associated with higher values of nutrients in water attributed by surface runoff during the monsoon which was in conformity with Panigrahi and Patra (2013).

It was also found that in all the study sites algal density showed declining with the onsets of winter from winter which again showed gradual increase during premonsoon and monsoon season (Table-13). Rajan *et al*. (2007), Senthikumar and Sivakumar (2008), Kakati (2011) observed similar trend of fluctuation in algal density in fresh water bodies studied by them.

Species diversity index

Species diversity index of the study sites were varied from 0.13 during monsoon season in the study site S1 to 3.14 during postmonsoon season in the study side S5 (Table-15). The average values of Shannon and Weaver diversity of in all the study ponds except S5 were recorded below 2 (Fig.18). According to Trivedy (1980, 1981), diversity index below 2 indicated high organic pollution in the aquatic ecosystem. Thus, it was found that all the study ponds except S5 were highly organically polluted. The average species diversity index in site S5 (2.41) indicates moderate organic pollution in that pond. Among the study sites, it was observed that diversity index was comparatively higher in the study sites S5 and S4 (Fig.18). Hence, it can be perceived that study sites S5 and S4 might be comparatively less polluted than rest of the three sites S1, S2 and S3. Considering values of Shannon and Weaver diversity Index, the study sites could be arranged in a sequence as follows: **S5>S4>S2>S3>S1**

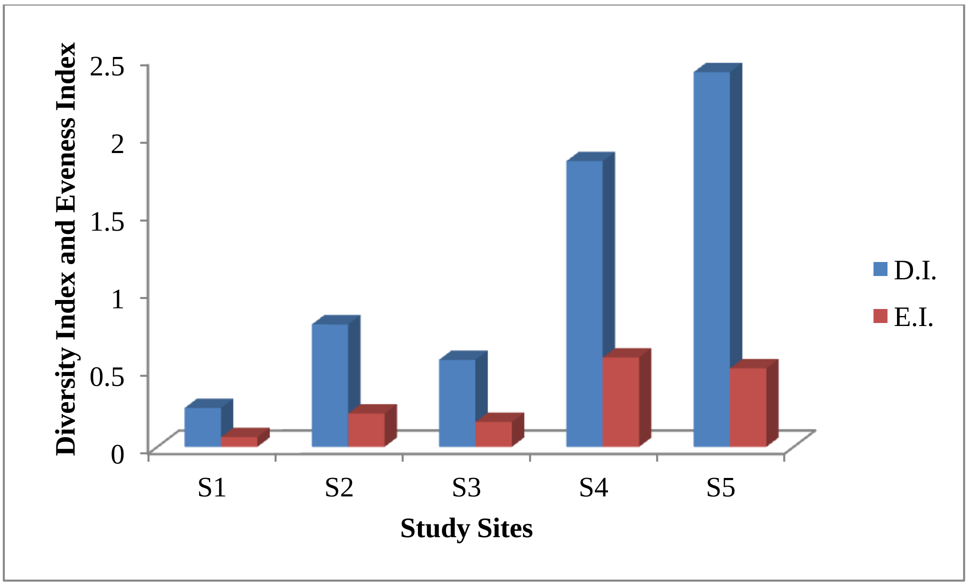


Fig.17. Species diversity index and evenness index in study sites.

Shannon and Weaver Diversity Index exhibited seasonal variation throughout the study period (Table-15). In the premonsoon it ranges from 0.21 in S1 to 2.49 in S5. During the monsoon the highest value was recorded as 1.85 in S5 and the lowest was as 0.13 in the S1. The maximum diversity of 3.14 was recorded during postmonsoon in the S5 and minimum was 0.37 in S1. During the winter it was maximum of 2.16 recorded in S5 and minimum of 0.29 recorded in S 1 (Table-15). From the observations it was found that the diversity was higher during postmonsoon season in all the study sites. It indicated that postmonsoon season is the most favourable for algal growth. This increase of density might be due to the moderate water temperature along moderate increase in nutrient caused by recession of water level (Panigrahi and Patra, 2013). This observation was in conformity with De *et al*. (1994), Vareethiah and Haneefa (1998), Krishnakumari and John (2003) and Kakati (2011). Low species diversity during the monsoon season compared to the rest of the seasons may be due to the dilution of the nutrients in water due to high rainfall in the region (Nair *et al.*, 1988).

Pielou's evenness index

The mean average evenness index was highest in the study site S4 (0.58) and lowest (0.06) in site S1 (Fig.17). Evenness value of the other study sites were ranged in between these values. The evenness value observed in the study period showed lower values in all other study sites except S4 and S5. The highest value of evenness in S4 indicated that in the pond S4, algal species composition was with high equality and uniformity than the other study sites. As per Pielou's evenness indexes the ponds may be arranged as- **S4>S5>S2>S3>S1**

Pielou's evenness index also exhibit seasonal fluctuation during this study period. During the premonsoon season evenness index varied from 0.05 in the pond S1 to 0.61 in the pond S4. In the monsoon season the maximum and minimum evenness were 0.03 in S1 to 0.54 in S4 respectively. The highest evenness of 0.91 in S5 and lowest of 0.10 in S1 were recorded during postmonsoon season. During winter, evenness value was maximum of 0.36 in S 4 and minimum of 0.07 in S1 (Table-16).

Palmer's Index

Palmer's pollution indices for all the study ponds were above 20. It indicated that all the studied ponds were highly organically polluted. It was recorded maximum of 35 in the study site S4 and minimum of 28 in the study site S5 (Table-17). As per Palmer's pollution index values among ponds may be categorized as- **S4>S2>S3>S1>S5**.

The highest value of Palmer's index in the pond S4 was associated with the highest concentration of nutrients *viz.*nitrate and phosphate in water of that study site (Palmer, 1969 and Patrick, 1965).

Canonical Correspondence Analysis (CCA)

CCA based on algal occurrence data and water quality variables was carried out to explore the potential correlation between them. All the CCA triplots produced an ordination where first two axes were statistically significant, thus alone explained a large proportion of variance in algal composition and environment relationship. The length of environmental variables and their orientation on the CCA triplot indicated their importance to each axis. The CCA plot showed that the algal taxa were well separated along both axes indicating different physico-chemical demands of different taxa. The water quality parameters were also differently distributed, which allowed the separation of algal genera at different seasons (Fig.18 to Fig.22).

CCA triplot of the study site S1 (Fig.18) showed that algae belonging to *Pleodorina* (GN13), *Synura* (GN31), *Euglena* (GN32), *Pinnularia* (GN 40) were abundant in winter when K, Na, DO content were relatively high. During premonsoon, algae *Gloeocystis* (GN 15), *Chlorella* (GN 18), *Ankistrodesmus* (GN 22) and *Fragilaria* (GN 36) were showed their significant occurrence associating with higher conductivity, hardness, alkalinity and high concentration of Ca and Cl. Similarly, in monsoon season *Pediastrum* (GN 20), *Nephrocytium* (GN 23), *Botryococcus* (GN 34), *Eunotia* (GN 38) and *Nitzschia* (GN 43) were abundant in water which could be correlated with high surface water temperature, turbidity and free CO_2. In postmonsoon, abundance of *Chlorococcum* (GN 17), *Dimorphococcus* (GN 25), *Cyclotella* (GN 35), and *Cymbella* (GN 42) were recorded as influenced by high pH and TDS (Fig.18).

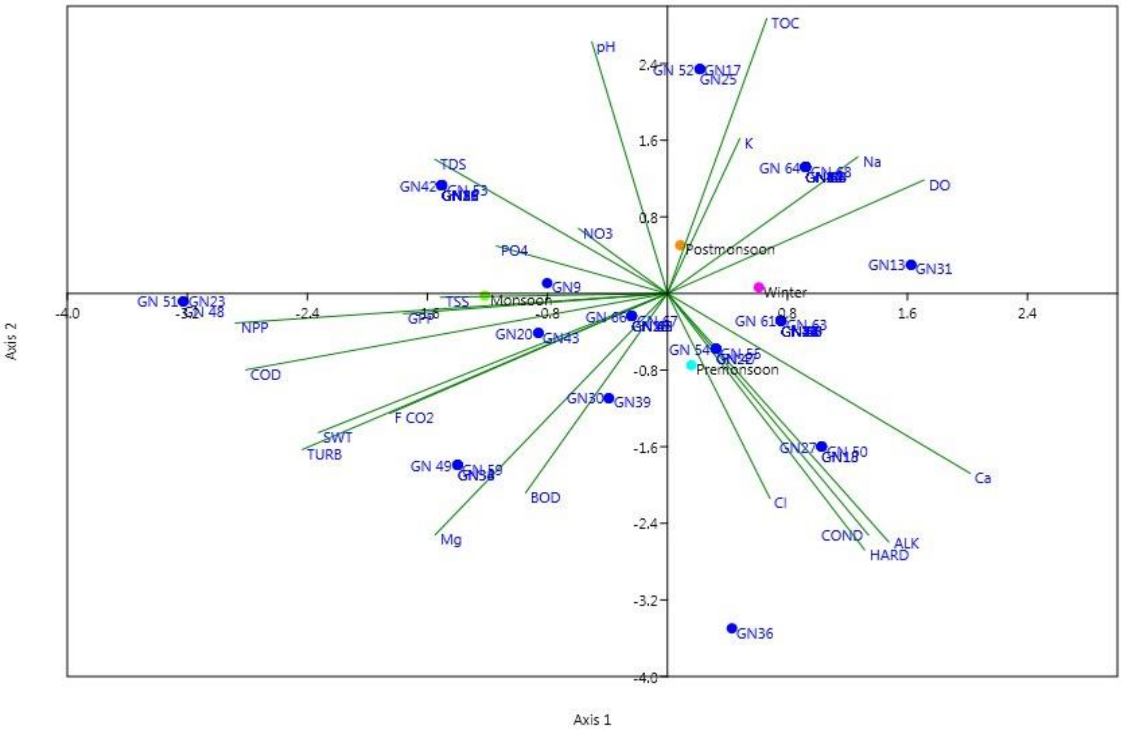


Fig.18: CCA triplot showing relationships between algal occurrence, seasons and water quality variables in the study site S1.

Abbreviations are:

GN1=*Microcystis*,GN2=*Chroococcus*,GN3=*Coelosphaerium*,GN4=*Cyanosarcina*,GN5=*Gloeocaps*,GN6=*Aphanocapsa*,GN7=*Aphanothece*,GN8=*Synechococcus*,GN9=*Dactylococcopsis*,GN10=*Oscilatoria*,GN11=*Lyngbya*,GN12=*Eudorina*,GN13=*Pleodorina*,GN14=*Haematococcus*,GN15=*Gloeocystis*,GN16=*Gloeodendron*,GN17=*Chlorococcum*,GN18=*Chlorella*,GN19=*Tetraedron*,GN20=*Pediastrum*,GN21=*Sorastrum*,GN22=*Ankistrodesmus*,GN23=*Nephrocytium*,GN24=*Botryococcus*,GN25=*Dimorphococcus*,GN26=*Coelastrum*,GN27=*Desmodesmus*,GN28=*Scenedesmus*,GN29=*Selenastrum*,GN30=*Cosmarium*,GN31=*Synura*,GN32=*Euglena*,GN33=*Phacus*,GN34=*Aulacoseira*,GN35=*Cyclotella*,GN36=*Fragilaria*,GN37=*Synedra*,GN38=*Eunotia*,GN39=*Navicula*,GN40=*Pinnularia*, GN41=*Gomphonema*, GN42=*Cymbella*, GN43=*Nitzschia*

In the study pond S2, *Sorastrum* (GN 43), *Tetraedron* (GN 48) and *Triploceros* (GN 51) were dominant in monsoon season which was associated with higher values of alkalinity and nitrate in water. During premonsoon, *Gloeocystis* (GN 31), *Pediastrum* (GN 39), *Tetrasporidium* (GN 49) and *Amphora* (GN 59) showed significant growth supported by increasing concentration of Ca, Mg and hardness. In winter *Chlorella* (GN 18), *Treubaria* (GN 50) and *Cymbella* (GN 61) were the dominant genera which were correlated with higher concentration of conductivity, Na and K. *Symploca* (GN 14), *Trochiscia* (GN 52), *Melosira* (GN 64) and *Synedra* (GN 68) showed their significant presence in postmonsoon season associated with higher dissolved oxygen content in water (Fig.19).

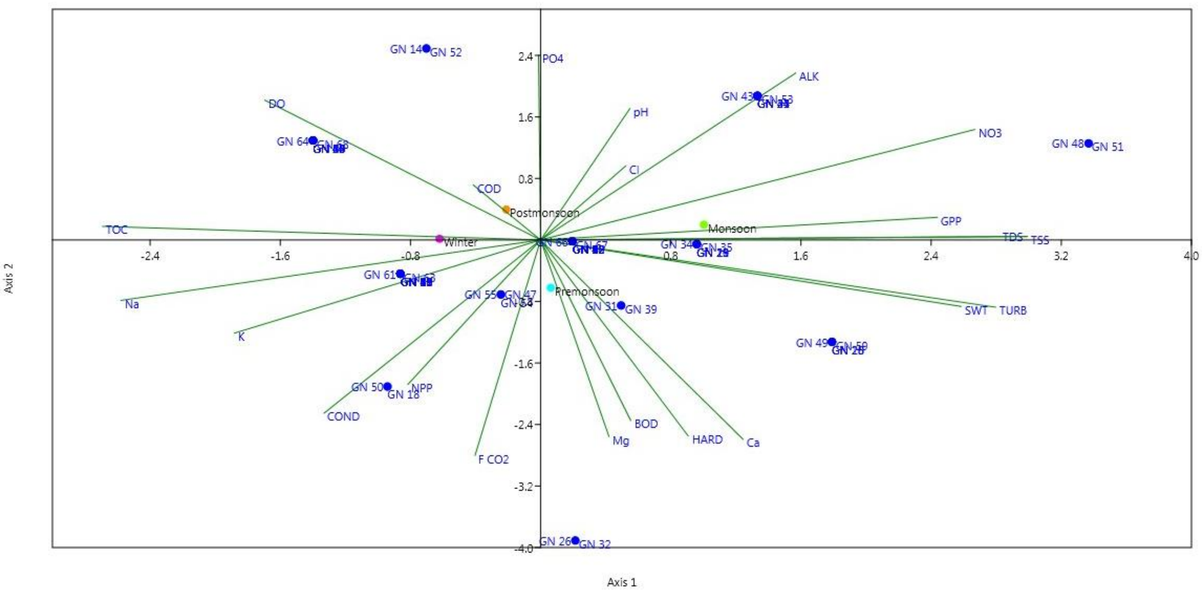


Fig.19: CCA triplot showing relationships between algal occurrence, seasons and water quality variables in the study site S2.

Abbreviations are:

GN1=*Aphanocapsa*,GN2=*Aphanothece*,GN3=*Calothrix*,GN4=*Chroococcus*.GN5=*Coelosphaerium*,GN6=*Cyanosarcina*,GN7=*Gloeocapsa*,GN8=*Gomphosphaeria*,GN9=*Lyngbya*,GN10=*Merismopedia*,GN11=*Nostoc*,GN12=*Oscilatoria*,GN13=*Phormidium*,GN14=*Symploca*,GN15=*Ankistrodesmus*,GN16=*Arthrodesmus*,GN17=*Botryococcus*,GN18=*Chlorella*,GN19=*Chlorococcum*,GN20=*Closterium*,GN21=*Coelastrum*,GN22=*Cosmarium*,GN23=*Crucigenia*,GN24==*Crucigenia*,GN25=*Desmodesmus*,GN26=*Dictyosphaerium*,GN27=*Dimorphococcus*,GN28=*Docidium*,GN29=*Euastrum*,GN30=*Eudorina*,GN31=*Gloeocystis*,GN32=*Gloeodendron*,GN33=*Haematococcus*,GN34=*Kirchneriella*,GN35=*Micrasterias*,GN36=*Monoraphidium*,GN

37=*Nephrocytium*,GN38=*Pandorina*,GN39=*Pediastrum*,GN40=*Pleodorina*,GN41=*Podohedra*,GN42=*Scenedesmus*,GN43=*Sorastrum*,GN44=*Spirogyra*,GN45=*Spondylosium*,GN46=*Staurastrum*,GN47=*Tetraedriella*,GN48=*Tetraedron*,GN49=*Tetrasporidium*,GN50=*Treubaria*, GN51=*Triploceros*,GN52=*Trochiscia*,GN53=*Uronema*,GN54=*Xanthidium*,GN55=*Zygnema*, GN56=*Euglena*,GN57=*Phacus*,GN58==*Trachelomonas*,GN59=*Amphora*,GN60=*Cyclotella*, GN61==*Cymbella*,GN62=*Fragilaria*,GN63=*Gomphonema*,GN64=*Melosira*,GN65=*Navicul*, GN66=*Nitzschia*,GN67=*Pinnularia*,GN68=*Synedra*

In the study pond S3, *Chroococcus* (GN 5), *Radiococcus* (GN 35), *Sorastrum* (GN 38), *Staurastrum* (GN 40), *Tetmemorus* (GN 41), *Diadesmis* (GN 52) and *Nitzschia* (GN 59) were the dominant genera during premonsoon season which in concomitance with higher values of turbidity, TDS and TSS. In monsoon, *Tetrasporidium* (GN 43), *Uronema* (GN 44), *Eunotia* (GN 53) and *Himantidium* (GN 57) were found dominant which was associated with higher concentration of surface water temperature, free CO_2 and nitrate. Dominance of *Spirulina* (GN 15), *Ankyra* (GN 19), *Eudorina* (GN 26), *Pleurotaenium* (GN 33), *Dinobryon* (GN 45), *Petalomonas* (GN 48), *Aulacoseira* (GN 50) and *Hantzschia* (GN 56) were showing significant impact on raising NPP of the pond in postmonsoon. Dominance of algal genera *Chlorella* (GN 20), *Dictyosphaerium* (GN 24), *Selenastrum* (GN 37), *Fragilaria* (GN 54) and *Navicula* (GN 58) were found to be associated with high values of pH, conductivity, DO, alkalinity, hardness, Ca, Na, K and COD (Fig.20).

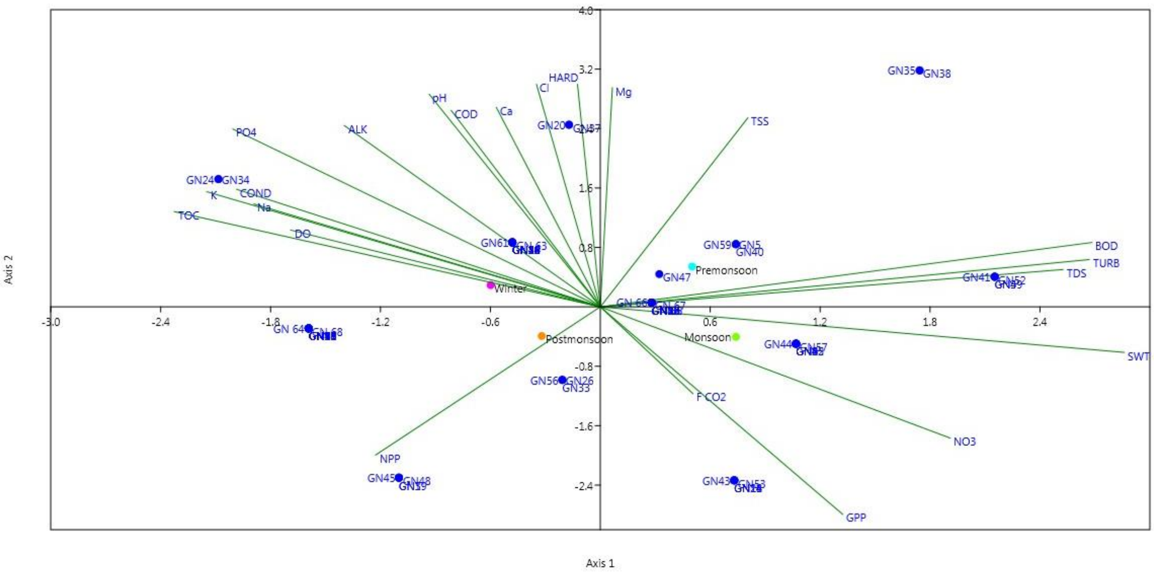


Fig.20: CCA triplot showing relationships between algal occurrence, seasons and water quality variables in the study site S3.

Abbreviations are:

GN1=*Anabaena*,GN2=*Aphanothece*,GN3=*Aulosira*,GN4=*Calothrix*,GN5=*Chroococcus*,GN6 =*Coelosphaerium*,GN7=*Cylindrospermum*,GN8=*Gloeocapsa*,GN9=*Gomphosphaeria*,GN10

=*Lyngbya*,GN11=*Merismopedia*,GN12=*Microcystis*,GN13=*Oscilatoria*,GN14=*Scytonema*,GN15=*Spirulina*,GN16=*Symploca*,GN17=*Synechococcus*,GN18=*Ankistrodesmus*,GN19=*Ankyra*,GN20=*Chlorella*,GN21=*Closterium*,GN22=*Cosmarium*,GN23=*Crucigenia*,GN24=*Dictyosphaerium*,GN25=*Euastrum*,GN26=*Eudorina*,GN27=*Haematococcus*,GN28=*Krichneriella*, GN29=*Micrasterias*,GN30=*Monoraphidium*,GN31=*Pandorina*,GN32=*Pediastrum*,GN33=*Pleurotaenium*,GN34=*Quadrigula*,GN35=*Radiococcus*,GN36=*Scenedesmus*,GN37=*Selenastrum*,GN38=*Sorastrum*,GN39=*Spirogyra*,GN40=*Staurastrum*,GN41=*Tetmemorus*,GN42=*Tetraedron*,GN43=*Tetrasporidium*,GN44=*Uronema*,GN45=*Dinobryon*,GN46=*Euglena*,GN47=*Lepocinclis*,GN48=*Petalomonas*,GN49=*Phacus*,GN50=*Aulacoseira*,GN51=*Cymbella*,GN52=*Diadesmis*,GN53=*Eunotia*,GN54=*Fragilaria*,GN55=*Gomphonema*,GN56=*Hantzschia*,GN57=*Himantidium*,GN58=*Navicula*,GN59=*Nitzschia*,GN60=*Pinnularia*,GN61=*Synedra*.

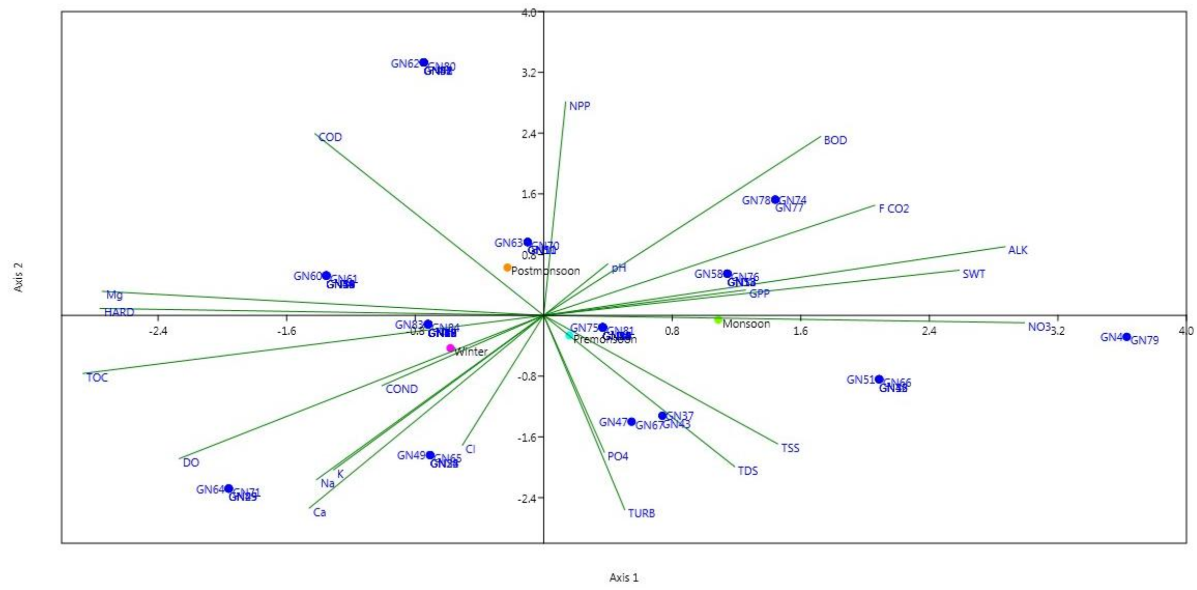


Fig.21: CCA triplot showing relationships between algal occurrence, seasons and water quality variables in the study site S4.

Abbreviations are:

GN1=*Anabaena*,GN2=*Aphanocapsa*,GN3=*Aphanothece*,GN4=*Calothrix*,GN5=*Chroococcus*,GN6=*Cyanosarcina*,GN7=*Cylindrospermum*,GN8=*Dactylococcopsis*,GN9=*Gloeocapsa*,GN10=*Hepalosiphon*,GN11=*Lyngbya*,GN12=*Merismopedia*,GN13=*Nostoc*,GN14=*Oscilatoria*, GN15=*Phormidium*,GN16=*Scytonema*,GN17=*Spirulina*,GN18=*Synechococcus*,GN19=*Ankistrodesmus*,GN20=*Ankyra*,GN21=*Arthrodesmus*,GN22=*Botryococcus*,GN23=*Chlorella*,GN24=*Chlorococcum*,GN25=*Closterium*,GN26=*Coelastrum*,GN27=*Cosmarium*,GN28=*Crucigenia*,GN29=*Desmidium*,GN30=*Desmodesmus*,GN31=*Dicloster*,GN32=*Dictyosphaerium*,GN33=*Docidium*,GN34=*Euastrum*,GN35=*Gloeodendron*,GN36=*Hyalotheca*,GN37=*Hydrodictyon*, GN38=*Kirchneriella*,GN39=*Micrasterias*,GN40=*Monoraphidium*,GN41=*Nephrocytium*,GN42=*Oedogonium*,GN43=*Pandorina*,GN44=*Pediastrum*,GN45=*Pleodorina*,GN46=*Pleurotaen* *ium*,GN47=*Podohedra*,GN48=*Quadrigula*,GN49=*Radiococcus,*GN50=*Scenedesmus,*GN51=*Selenastrum*,GN52=*Sorastrum*,GN53=*Spirogyra*,GN54=*Spondylosium*,GN55=*Staurastrum*, GN56=*Tetraedron*,GN57=*Triploceros*,GN58=*Ulothrix*,GN59=*Uronema*,GN60=*Xanthidium*, GN61=*Zygnema*,GN62=*Centritractus*,GN63=*Ophiocytium*,GN64=*Tetraedriella*,GN65=*Phaeoplaca*,GN66=,*Dinobryon*,GN67=*Ceratium*,GN68=*Lepocinclis*,GN69=*Phacus*,GN70=*Strombomonas*,GN71=*Amphora*,GN72=*Cyclotella*,GN73=*Cymbella*,GN74=*Diadesmis*,GN75=*Fragilaria*,GN76=*Gomphonema*,GN77=*Hantzschia*,GN78=*Himantidium*,GN79=*Mastogloia*,GN80=*Melosira*,GN81=*Navicula*,GN82=*Nitzschia*,GN8=*Pinnularia*,GN84=*Synedra*.\

Similarly, in the pond S4 algal genera *Hydrodictyon* (GN 37), *Pandorina* (GN 43), *Podohedra* (GN 47), *Selenastrum* (GN 51) and *Ceratium* (GN 67), *Fragilaria* (GN 75) were have significant relation with high values of turbidity, TDS, TSS and phosphate in premonsoon. Higher values of DO, Na, K, Ca and TOC favoured significant occurrence of *Desmidium* (GN 29), *Radiococcus* (GN 49), *Tetraedriella* (GN 64), *Phaeoplaca* (GN 65) and *Amphora* (GN 71) in the pond during winter. Whereas, in postmonsoon *Xanthidium* (GN 60) and Zygnema (GN 61) showed significant relation with higher value of magnesium and hardness in this pond. However, occurrence of *Ulothrix* (GN 58), *Diadesmis* (GN 74), *Hantzschia* (GN 77) and *Himantidium* (GN 78) did not show significant relation with any season. Rather, they were associated with high surface water temperature, free CO_2 and alkalinity (Fig.21).

In S5, CCA triplot showed that the algal genera were separately distributed along both axes of CCA triplot, indicating differences in their physicochemical demand. The occurrence of *Calothrix* (GN 5), *Scytonema* (GN 16), and *Xanthidium* (GN 51) had significant relation with high value of pH, NO_3 and COD in monsoon. During premonsoon, high value of surface water temperature and alkalinity were found significant with occurrence of *Hepalosiphon* (GN 10), *Spirulina* (GN 17), and *Navicula* (GN 69). *Trachelomonas* (GN 62) and *Cymbella* (GN 64) had significant correlation with DO, TDS, Mg and Cl in winter season. Occurrence of *Eunotia* (GN 65), *Melosira* (GN 68), *Navicula* (GN 70) and *Nitzschia* (GN 71) were found significant with high values of Na, K and Ca in the pond. However, they did not show significant association with any season (Fig.22).

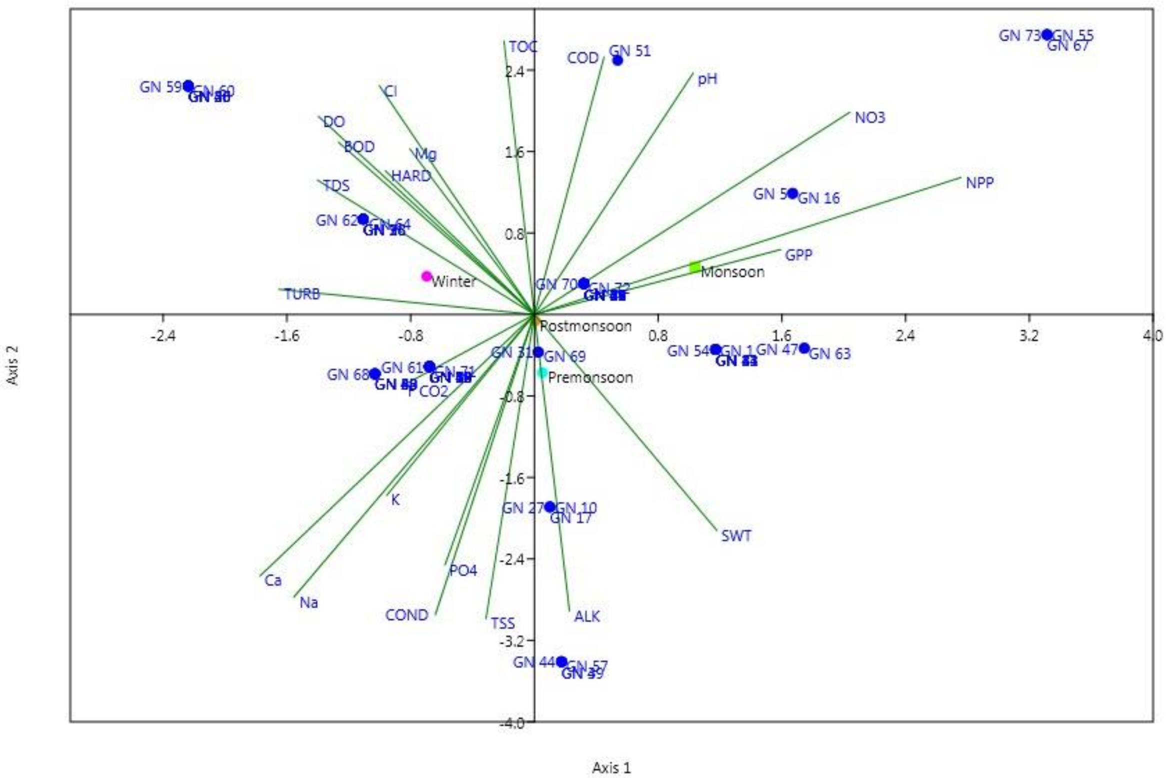


Fig.22: CCA triplot showing relationships between algal occurrence, seasons and water quality variables in the study site S5.

Abbreviations are:

GN1=*Anabaena*,GN2=*Aphanocapsa*,GN3=*Aphanothece*,GN4=*Aulosira*,GN5=*Calothrix*,GN6=*Chroococcus*,GN7=*Coelosphaerium*,GN8=*Cylindrospermum*,GN9=*Dactylococcopsis*,GN10=*Hepalosiphon*,GN11=*Lyngbya*,GN12=*Merismopedia*,GN13=*Nostoc*,GN14=*Oscillatoria*,GN15=*Phormidium*,GN16=*Scytonema*,GN17=*Spirulina*,GN18=*Synechococcus*,GN19=*Ankistrodesmus*,GN20=*Arthrodesmus*,GN21=*Closterium*,GN22=*Coelastrum*,GN23=*Cosmarium*,GN24=*Crucigenia*,GN25=*Dicloster*,GN26=*Dictyosphaerium*,GN27=*Diplochloris*,GN28=*Docidium*,GN29=*Euastrum*,GN30=*Eudorina*,GN31=*Hyalotheca*,GN32=*Hydrodictyon*,GN33=*Kirchneriella*,GN34=*Micrasterias*,GN35=*Monoraphidium*,GN36=*Oedogonium*,GN37=*Pediastrum*,GN38=*Pleodorina*,GN39=*Pleurotaenium*,GN40=*Podohedra*,GN41=*Scenedesmus*,GN42=*Selenastrum*,GN43=*Spirogyra*,GN44=*Spondylosium*,GN45=*Staurastrum*,GN46=*Tetmemorus*,GN47=*Tetraedron*,GN48=*Tetrastrum*,GN49=*Ulothrix*,GN50=*Uronema*,GN51=*Xanthidium*,GN52=*Zygnema*,GN53=*Goniochloris*,GN54=*Ophiocytium*,GN55=*Pseudostaurastrum*,GN56=*Tetraedriella*,GN57=*Phaeoplaca*,GN58=*Euglena*,GN59=*Lepocinclis*,GN60=*Petalomonas*,GN61=*Phacus*,GN62=*Trachelomonas*,GN63=*Amphora*,GN64=*Cymbella*,GN65=*Eunotia*,GN66=*Fragilaria*,GN67=*Hantzschia*,GN68=*Melosira*,GN69=*Navicula*,GN70=*Navicula*,GN71=*Nitzschia*,GN72=*Pinnularia*,GN73=*Suriella*.