CHAPTER 5
DISCUSSION
5. DISCUSSION

Wetlands are valuable ecosystems that occupy about 6% of the world’s land surface. They comprise both land ecosystems that are strongly influenced by water, and aquatic ecosystems with special characteristics due to shallowness and proximity to land (Roggeri, 1995). Wetlands also perform an enormous variety of functions (Groot, 1992). They regulate ecological processes that contribute to a healthy environment like recycling of nutrients, watershed protection and climate regulation. Often called “nurseries of life,” wetlands provide habitat for wildlife and are critical in supporting biodiversity. The spatial and temporal variations in the hydrochemical properties of the wetlands reveal some of the significant ecological tendencies of the ecosystem. The interpretation of the result of the current study at Pariej and Malwar wetland has been discussed below.

5.1 ABIOTIC COMPONENTS

5.1.1 Hydrochemical properties

Water chemistry has a profound influence on the development and structure of the aquatic ecosystem. The physical and chemical characters of water can be used to assess the ecological nature of the wetland. Seasonal changes in physical and chemical properties of water are the most important variables which determine the composition and abundance of various biotic communities in the wetlands. Their qualitative and quantitative estimates provide good indices of quality and productive capacity of water (Janjua et al., 2009).

Temperature of surface water is depends on latitude, altitude, season, time of the day, air circulation, flow and depth of the water body. In turn, physical, chemical and biological characteristics of the water are influenced by temperature. Water temperature regulates various abiotic characteristics and biotic activities of an aquatic ecosystem (Sharma and Sarang, 2004; Radhika et al., 2004). Temperature is one of the most important ecological factors, which controls the physiological behavior and distribution
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of organisms (Moundiotiya et al., 2004). Temperature is one factor in determining which species may or may not be present and affects the feeding, reproduction, and metabolism of aquatic animals.

During the present study it was observed that temperature varied according to the seasonal fluctuations of atmospheric temperature with maximum during summers and minimum during winters in both the wetlands. Shastri and Pendse (2001) also made similar observation of the Dahikhura Reservoirs. A comparison of the average of surface-water temperature during the study period showed that the variations in temperature across the different stations were insignificant but the differences in temperature over the three different seasons were highly significant. The surface-water temperature at all the stations during a particular season throughout the period of study, showed a maximum fluctuation of 1-2°C only. Water temperature was found to be lower than atmospheric temperature. The present observation of surface water temperature in the wetlands agrees with the observations of Kaul and Handoo (1980) that surface water temperature usually remains lower and close to the air temperature. During the winter season water temperature might be low due to low atmospheric temperature, frequent interference of clouds, high humidity, high current velocity and high water level. Higher temperatures were observed during summer due to clear atmosphere, greater solar radiation, and low water level. Similar observations were made by Nirmal Kumar et al. (2005a) and Demir and Kirkagac (2005). Swaranlatha and Rai (1998) made a similar observation in Banjara Lake.

pH is the indirect measure of the intensity of acidity or alkalinity and measures the concentration of hydrogen ions in water. It has no direct adverse affect on health, however, a low value, below 4.0 will produce sour taste and higher value above 8.5 shows alkaline taste. pH balance in an ecosystem is maintained when it is within the range of 5.5 to 8.5 (Chandrasekhar et al., 2003). High value of pH (more than 8.5) is recorded in waters with high organic content and eutrophic condition (Kalff, 2002). pH of a water body is a diurnally variable property according to temperature variation in the system (Ojha and Mandloi, 2004). Significant changes in pH occur due to disposal of industrial wastes, acid mine drainage etc. In natural waters pH also changes diurnally and

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seasonally due to variation in photosynthetic activity which increases the pH due to consumption of carbon dioxide in the process. In the current study pH of water samples of various sites for different periods varied from 7.5 to 8.2 which fall within permissible limit prescribed by WHO.

Mohanta and Patra (2000) observed seasonal fluctuations of pH varying between 7.01 and 8.31. The surface water of Pariej and Malwar in general always showed a neutral or slightly alkaline pH. Two year average pH of surface water during different seasons showed that the variations in it across the different stations were insignificant whereas that over the different seasons were significant. Thus, it seems that pH is a more seasonal dependent characteristic in freshwaters surrounded by undisturbed watersheds as was found in the two wetlands. Chandra Prakash (1983) registered high pH values during summer which could be affected by low water level, poor assemblage of phytoplankton community and low DO content (Shaji, 1990; Nirmal Kumar, 1991). In the present study similar results have been obtained in both water bodies. The pH of water depends upon relative contents of free CO$_2$, carbonates, bicarbonates and calcium. The water tends to be more alkaline when it possesses carbonates, but lesser alkaline when it supports more bicarbonates, free CO$_2$ and calcium. Rao (1972), Sharma and Rathore (2000) have also observed similar behavior of these nutrients with pH.

Solar radiation is the major source of light energy in an aquatic system, governing the primary productivity and diurnal variations and rhythms. It measures the light penetration through the water body. Transparency is a characteristic of water that varies with the combined effect of colour and turbidity. Turbidity is caused due to suspended solid materials such as clay, silt, colloidal organic matter, planktons and is the reason for less transparency (Krishnan, 2008). Transparency can be affected by factors such as time of the day, clarity of the sky at the time of measurement (cloudy or not), and suspended solids in water including phytoplankton. In shallow waters it is affected by disturbance such as boat movement for measurement (Amarasinghe and Viverberg, 2002). This could be the reason in the present investigation transparency at the Pariej wetland was subjected to all these factors whereas at the Malwar wetland it was affected by the presence of suspended solids.

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Dissolved oxygen is an important parameter of the wetland which is essential to the metabolism of all aquatic organisms that possess aerobic respiration (Moundiotiya et al. 2004). It usually reflects the physical and biological processes prevailing in water and is influenced by aquatic vegetation and phyto-plankton population apart from the temperature and organic matters present. In summer with the increase in water temperature, there was reduction in DO, whereas in winter months due to decrease in temperature, the level of DO increased. These results were in conformity with Masood and Krishnamurthy (1990) and Srivastava et al. (2003). Comparatively low values of DO in the Malwar wetland indicate an oxygen deficient condition, which could be due to the more respiratory activity of the biota present over there (Alom and Zaman, 2006). Low oxygen content in water is usually associated with organic pollution. Organic waste may overload a natural system causing a serious depletion of the oxygen supply in the water that in turn leads to fish kills (Laluraj et al., 2002). Likewise, eutrophic waters, rich in nutrients, achieve the same result through causing massive proliferation of algae (algal blooms) whose eventual decomposition utilize the available dissolved oxygen (Shanthi et al., 2002).

Moreover, DO content was found to be considerably high in colder months. Reid (1961) stated that the solubility of oxygen in water increased by lowering the temperature, that is, solubility of oxygen in water was known to be affected inversely by the rise in temperature (Moss 1988). The seasonal variation of DO is influenced by the temperature of waterbody and has been largely studied by several researchers (Nirmal Kumar, 1992a and Gopal and Chauhan, 2001) who observed that DO remained high during winter but low in summer. This might be due to the fact that the oxygen holding capacity of water was decreased at high temperature during summer months and vice-versa (Mali 2003) which substantiated with the current findings. With the progression of winter, DO raised to its peak values, which could be due to high rate of photosynthesis of dense phytoplankton population that form the major source of DO (Sharma and Rathore, 2000). The present study revealed that DO content was comparatively higher in the water of less polluted Pariej wetland as compared to Malwar that indicated high degree of
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pollution. The DO concentration of polluted water is in general lower than the unpolluted water due to the low concentration of nutrients (Das and Handique, 1998).

The total solids is a direct measure of all the dissolved and suspended nutrients /matters in water. Taheruzzaman and Kushari (1995) observed TS of 50 to 2240 mgL⁻¹ in Ganga waters and also found that it was lower during the lean months of winter. Similar results were obtained during the present investigation, the Malwar wetland recorded as high a value of TS (760 mgL⁻¹). TDS comprises dissolved salts both organic and inorganic, suspended particles, soil particles, discharged effluents and decomposed organic matter. It is also due to the presence of dissolved nutrients calcium, magnesium, sodium, potassium, bicarbonate, chloride and sulphate ions. The values for TDS were observed to be higher during the summer months in the current study and were in conformity with the results of Hegde (1990) in fish tanks of Dharwad, Karnataka, Sharma and Rathore (2000) in Lake Sarsai Nawar, Etawah Uttar Pradesh, Mali (2003) in village fish culture ponds of central Gujarat and Nirmal Kumar et al. (2008b) in wetland Nal Sarovar Bird Sanctuary.

Dwivedi and Sonar (2004) reported TDS value of 150 mgL⁻¹ in a small reservoir in eastern Himalayan state of Arunachal Pradesh in India, which correlated with values observed at Pariej wetland. Malwar showed the higher concentration of TS, TDS and TSS which might be due to the leaching of salts along with calcium, magnesium and chloride contents (Shastree et al., 1991). However, the contents of these solids were least during monsoons due to excess runoff water (Kant and Raina, 1990) and moderate in winter months. The present observations were in agreement with the results of Borse and Bhave (2000) and Mahadev and Hosmani (2002). Overall, the solid contents of water were greater in Malwar than Pariej which might be due to more amount of dissolved organic matter and mineralized salts released from surrounding area (Borse and Bhave, 2000).

Free carbon dioxide is one of the essential constituents of an aquatic ecosystem. When dissolved in water, CO₂ forms carbonic acid which lowers pH. The limit of free CO₂ as per acceptable standards is 10 mgL⁻¹ of surface water. Free CO₂ and bicarbonates is essential for photosynthesis and its concentration affects the phytoplankton and its
productivity and also has its impact on large rooted plants. The free carbon dioxide in any water body varies somewhat rapidly due to biological activity. Increase in CO₂ indicates increase in pollution load (Koshy and Nayar, 1999). In the present study, the increase in free carbon dioxide during early winter can be attributed to the higher rate of decomposition during the season and the favorable temperature (Sukhija, 2007). Free CO₂ peak observed during winter months might be due to the accelerated decomposition of organic matter by microbes resulting in the rapid production of free CO₂. In the waters of both the study areas of Pariej and Malwar, the erratic seasonal behavior could be attributed to the partial utilization of CO₂ during photosynthesis by planktonic and periphytonic algae (Koshy and Nayar, 1999). Singh (1965) claimed that the concentration of carbonates, bicarbonates and calcium are influenced by the presence of free CO₂ which change the pH (Munawar 1970). Free CO₂ has a profound influence on pH in the present data in Pariej wetland, where, free CO₂ correlated positively with pH which is also reported by Borse and Bhave (2000) and Mali (2003). A good correlation between free CO₂ and DO content was also observed by Singh (1965). In the present study, DO and free CO₂ exhibited parallel trend with each other but negative correlation with other nutrients. The similar correlation was established by Rana and Nirmal Kumar (1992) and Borse and Bhave (2000).

The alkalinity of water is a measure of its capacity to neutralize acids. It is important for aquatic life in a freshwater system because it equilibrates the pH changes that occur naturally as a result of photosynthetic activity of phytoplankton (Kaushik and Saksena, 1989). Total alkalinity is caused by bicarbonates, carbonates, OH ions, borates, silicates and phosphates (Kataria et al., 1995). These constituents result from dissolution of mineral substances in the soil and atmosphere (Mittal and Verma, 1997). Carbonate and bicarbonate may also originate from microbial decomposition of organic matter. Alkalinity determines the buffering capacity of water and is significant for aquatic life in a freshwater system because it equilibrates the pH changes that occur naturally as a result of photosynthetic activity of phytoplankton (Kaushik and Saksena, 1989).

During the present investigation, phenolphthalein alkalinity (PA) remained absent in most of the months except summer, while total alkalinity (TA) was recorded throughout
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the year. In both the wetlands, the values of PA always remained less than half of TA which showed that alkalinity was mainly present due to the presence of carbonates and bicarbonates but hydroxides were least concerned with the alkalinity. The higher values of TA were observed during summer months at all study sites of Pariej and Malwar. This is in accordance with the results of Moundiotiya et al. (2004) observed in the wetland of Jamwa Ramgarh Lake, located at Jaipur, Rajasthan.

The observations of seasonal difference in total alkalinity in the current investigation in general agree with the opinions of Radhika et al. (2004), (Koshy and Nayar, 2000) and Bhatt et al. (1999) who argued that alkalinity is usually higher during the pre-monsoon than the monsoon. In the existing analysis, the wetland Pariej recorded high alkalinity values in summer which were in agreement with the findings of Jayaraman et al. (2003). However, the wetland Malwar showed a different trend with the highest concentration of alkalinity during monsoon. Similar results were obtained by Iqbal and Katariya (1995) and Venkiteswarulu (1969) who also observed that alkalinity is affected by rain fall. Alkalinity level is also used as a criterion for assessing the nutrient status (Sorgensen, 1948; and Moyle, 1949). According to their classifications waters are grouped into three different nutrient status groups on the basis of alkalinity: (a) 1 to 15 mgL⁻¹ as nutrient poor, (b) 16-60 mgL⁻¹ as moderately rich, and (c) more than 60 mgL⁻¹ as nutrient rich. Accordingly alkalinity values recorded during the current investigation classified both Pariej and Malwar wetland nutrient rich.

During the present investigation, the carbonate content was found nil in most of the months and bicarbonates contents were observed more during summer fluctuating in accordance with the values of total alkalinity. The above findings were well substantiated with the findings of Ramlal et al. (1991). Sreenivas (1991), Nath et al. (1994) and Nirmal Kumar et al. (2008a). Jamson (1993) observed high carbonates during summer period in certain polluted rivers of Gujarat which is also observed during the present investigation. During the study period, the carbonate and bicarbonate alkalinity showed direct relation with pH also observed by Ahmad and Siddiqui (1996) in Darbhanga Ponds of Bihar. The PA and TA were directly proportional to the contents of carbonates and bicarbonates.
Pollution studies of two distinct tropical lentic wetlands of central Gujarat with reference to spatial and temporal heterogeneity of biotic and abiotic components respectively, during the present study which largely agrees with the findings of Gupta and Sharma (1994).

Chloride is one of the major anions to be found in water and sewage. Chloride occurs naturally in all types of waters. The most important source of chlorides in the waters is the discharge of domestic sewage. Therefore, the chloride concentration serves as an indicator of pollution by sewage (Trivedy and Goel, 1986). In the present study, the Malwar wetland witnessed high concentrations of chloride which could be well attributed to the fecal contamination in the wetland especially at site 1. Besides, industries are also important sources of chlorides. The seasonal concentration of chloride in the present study was well corroborated by the findings of Koshy and Nayar (2000) who recorded highest chloride level during the premonsoon period in Pamba river. Similar findings were documented in the study where both the Pariej and Malwar wetlands exhibited their peaks during the summer months. Low quantity of water level during spring and postmonsoon may be the reason for the increase of the chloride concentration which corroborated with the study of Sukhija (2007).

Harish and Gajaria (1997) and Mali (2003) have also reported the poor values of chloride in winter season and greater in summer. During the present study, chloride showed significant direct relationship with temperature, phenolphthalein alkalinity, total alkalinity, total hardness and sulphate, and inverse correlation with DO and free CO$_2$ in both the wetlands. These findings are well substantiated with Jamson (1993) and Kaur et al. (1996), who studied certain polluted rivers of Gujarat and freshwater pond of Patiala, Punjab, respectively. Kaur et al. (1996) reported the change in chloride contents of water due to seasonal fluctuations.

The total hardness is defined as the sum of Ca and Mg ion concentrations, both expressed as CaCO$_3$ in mg L$^{-1}$. Hardness is the property of water which prevents the lather formation with soap and increases the boiling point of water. Calcium and magnesium are the principal cations causing hardness by mainly bicarbonate, carbonate, sulphate, chloride, nitrate, silicates etc (Taylor, 1949). Carbonates and bicarbonates of Ca and Mg cause temporary hardness where as sulphates and chlorides cause permanent hardness. Total hardness in the two wetlands was observed to be high during the summer...
season which may be due to high evaporation of water which led to the addition of calcium and magnesium salts. Moundiotiya et al. (2004) recorded similar findings in Jamwa Ramgarh Lake, Jaipur. Bhatt et al. (1999) reported a total hardness of 352 mg L\(^{-1}\) (during summer) to 280 mg L\(^{-1}\) (during monsoon) in Taduaha lake, Katmandu. Kataria et al. (1995) reported a hardness of 20-410 mg L\(^{-1}\) in Tawa reservoir, Madhya pradesh, India. Dwivedi and Sonar (2004) registered a hardness of 84 mg L\(^{-1}\) (during summer) to 58 mgL\(^{-1}\) (post-rainy season) in reservoirs in Arunachal Pradesh State, India. Iqbal and Katariya (1995) also reported higher hardness values in summer and lower in monsoon in Upper Lake of Bhopal, MP State, India.

Krishnan (2008) stated that water with total hardness 0-60 mg L\(^{-1}\) is considered soft; 61-120 mg L\(^{-1}\) is considered moderately hard, 121-160 mg L\(^{-1}\), hard and greater than 180 mgL\(^{-1}\) very hard. Using these criteria, the water of the Pariej wetland can be included in the moderately hard water while that of Malwar wetland as very hard water. Higher values of hardness were observed during summer, which may be due to low water level and high rate of decomposition due to high temperature and evaporation thus concentrating the salts (Chatterjee and Raziuddin, 2007). The increase in the values of hardness might be due to evaporation of the surface water, besides as addition of Ca and Mg salts from soaps and detergents used for washing and bathing, whereas excessive dilution by rain water during monsoon can be one of the important factors responsible for lowering the hardness during monsoon (Bozniak and Kennedy, 1968). The present findings are well corroborated with observations of Kant and Raina (1990) and Jain and Sharma (1997). In the present investigation, total hardness showed positive correlation with chloride, calcium and magnesium could be due to calcium-carbonate complex in the lake water (Jain and Sharma, 1997; Mali 2003). Similar findings were also obtained by Kant and Raina (1990) in freshwater ponds of West Bengal.

It is evident that both the wetlands are with 'calcium rich' waters due to presence of rich calcium content. The calcium content showed gradual peak from winter to summer and drastically declined during monsoon. The continuing rise in calcium content during cold winter days could be due to its greater solubility at moderate temperature (Saunders et al. 2007), while during hot summer months it might be due to rapid
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oxidation of organic matter, increased rate of microbial decomposition of bottom deposits and respiration of aquatic organisms (Ahmad and Siddiqui, 1996). The decline in the values of Ca from July onwards might be due to influx of rain water as observed by Jamson (1993) in polluted rivers of Central Gujarat.

Magnesium is one of the most abundant cation present in freshwater, absolutely essential for chlorophyll bearing plants (Ahmad and Siddiqui, 1996), and is always associated with calcium in all kinds of waters (Nath et al., 1994). Magnesium is supposed to be non-toxic at the concentrations generally met within natural waters. In the current study, high magnesium content was observed at Malwar and minimum value at Pariej. At Malwar, the high magnesium content at site 1 can be attributed to dumping of industrial waste from the ceramic and tile factory located nearby the wetland.

Phosphorus is one of the major nutrients required for all phytoplankton growth and the limited availability of these nutrients in water usually limits phytoplankton growth in natural aquatic systems. Phosphorus exists in both inorganic and organic forms and the present study restricts the estimation of phosphorus in the inorganic form (PO$_4^{3-}$). The major sources of phosphorus are domestic sewage, detergents, agricultural effluents with fertilizers, and industrial wastewater. The higher concentration of phosphorous, therefore, is an indication of pollution (Kataria et al., 1995).

Surface water phosphate concentration of the Pariej wetland was found varying from 0.01 to 0.2 mg L$^{-1}$, throughout the study period whereas Malwar wetland exhibited a higher phosphate concentration ranging from 0.01 to 2.0 mg L$^{-1}$. According to Jeppesen et al. (1997), phosphates content of 0.05 to 0.1 mg L$^{-1}$ is threshold of it as a nutrient for natural waters. Romero et al. (2002) considered Lake Pamvotis with a phosphates content of 0.11 mg L$^{-1}$ as one of intermediate nutrient status. In the present investigation, high phosphate concentration was observed in Malwar and a relatively low value at Pariej. The high concentration of phosphates could be the reason for the *Microcystis* bloom observed at Malwar wetland at site 1 in summer months. Both the wetlands are sites for the domestic chores for the community inhabiting the wetland. High phosphate concentration indicates fertilizer runoff, domestic waste discharge and detergents. Higher values of orthophosphates were found during summer and lower values during winter season. The
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higher values during summer season could be ascribed to a higher rate of microbial decomposition of macrophytes and phytoplankton at high temperature (summer). The low amount of phosphates during winter season might be due to the uptake of phosphates by young developing flora and a slow rate of decomposition.

Significant positive correlation of phosphate was observed with nitrate, carbonate, temperature and inverse correlation with free CO₂ and DO during the study period. Romero et al. (2002) concluded from the nutrient studies on small lakes of various types that phosphorus often acts as a limiting nutrient for productivity. The phosphate concentration of the Pariej wetland was between 0.01 and 0.2 mgL⁻¹ indicating the trophic status of the wetland to be mesotrophic (Blum, 1957). The higher value of phosphate 0.01 to 2.0 mgL⁻¹ at Malwar wetland classified it as a eutrophic wetland (Likens, 1975).

Sulphate is a naturally occurring anion in all kinds of natural waters. In arid and semiarid regions, it is found in particularly higher concentrations due to the accumulation of soluble salts in soils and shallow aquifers. Biological oxidation of reduced sulphur species to sulphate also increases its concentration (Gitanjali, 2010). Rain water has quite high concentrations of sulphate particularly in the areas with high atmospheric pollution. Discharge of industrial wastes and domestic sewage in waters tends to increase its concentration. Sulphate is a vital constituent of hardness with calcium and magnesium. High amounts of various sulphate salts (250 to 1,000 mg L⁻¹) may give drinking water an offensive taste (Factsheet, 2003).

In the current investigation, sulphate content was found to be high at Malwar than at Pariej. Decaying plant and animal matter may release sulphate into water (Factsheet, 2003). This could be the reason of high sulphate concentration at site 2 of Pariej and site 1 of Malwar wetland where decaying macrophytes add to the sulphate pool of wetland. This increase might be also due to accumulation of rainwater, domestic sewage entry and agricultural runoff. Likens (1975) stated sulphate as an index of eutrophication and its dynamic in many lake ecosystems is subjected to transformation by micro organisms. Higher values were found during summer in both the wetlands. The sulphate concentration at Pariej wetland ranged up to 40 mg L⁻¹ further reaffirming the trophic status of the wetland to be mesotrophic according to Blum (1957) however, the Malwar
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wetland exhibited the sulphate concentration as high as 82 mg L\(^{-1}\), thus establishing it as a eutrophic wetland (Likens, 1975).

Nitrogen is one of the major nutrients for all phytoplankton growth and the limited availability of nitrogen in water usually limits phytoplankton growth in natural aquatic systems. On the contrary, its excess availability in aquatic ecosystem triggers eutrophication. In natural waters 150 \( \mu \text{g L}^{-1} \) of N is a critical value and when the content crosses the limit, algal blooms occur (Sawyer et al., 1945). Nitrogen is generally considered to be the primary limiting nutrient for phytoplankton biomass (Rabalais, 2002).

The most important source of the nitrate is biological oxidation of organic nitrogenous substances which come in sewage and industrial wastes or produced indigenously in the waters. Domestic sewage contains very high amounts of nitrogenous compounds and runoff from agricultural fields is also high in nitrate. In the present study, high concentration of nitrates was observed at the Pariej wetland and Malwar wetland during the summer months. The higher values during summer season could be ascribed to a higher rate of microbial decomposition of macrophytes and phytoplankton during summer. The nitrate concentration in both the Pariej and Malwar wetland were below 0.5 mg L\(^{-1}\). The results thus indicated that the wetlands were oligotrophic as far as the concentration of nitrate was concerned.

High concentrations of nutrients like phosphate, sulphate, chloride, nitrate, were recorded in Malwar wetland than Pariej wetland. The monthly variation of hydrochemical properties also indicated that concentration of nutrients was greater during warmer months in both the wetlands which could be attributed to high atmospheric temperature, evaporation and high amount of entry of waste-discharge from surrounding villages which corroborated with the findings of Piyankarage et al. (2004). The addition of nutrients and changes in water and land use due to agriculture, human settlements, and small industries may induce reversible or irreversible ecological changes in wetlands (Piyankarage et al., 2004).

The statistical interpretations were well in sync with the trends observed in the wetlands. Temperature and DO showed a negative correlation with each other at both the
sites of the wetland during two years of study period. Total alkalinity, chloride, phosphate, sulphate and nitrate exhibited a positive correlation with temperature and a negative correlation with DO. One way ANOVA depicted significant differences in the nutrient content of both the wetlands ($p<0.005$). However, in both Pariej and Malwar wetland the spatial differences were found to be insignificant ($p>0.005$) at the two sites. There was a marked significant temporal variation ($p<0.005$) in the physio-chemical parameters at the two wetlands.

5.1.2 Geochemical properties
Numerous studies have demonstrated that wetlands, in general, are sinks for sediment and nutrients (Craft 2000). The role of sediment in the degradation of organic matter and the recycling of nutrients has been studied intensively (Middelboe et al., 1998; Rasheed et al., 2002, 2004; Al-Rousan et al., 2004). The recycling of nutrients can be explained by temperature gradient. During winter when water is low, the sediment decomposition is slow and release of nutrients in the surface water also decreases, resulting in low concentration of nutrients and poor growth of plankton. With the increase in water temperature the rate of decomposition and release of sediment nutrients increases and a growth of phytoplankton peak is observed in summer. The seasonality of sediment characteristics has been discussed below in both the wetlands.

The pH of sediment in the current investigation at Pariej and Malwar ranged between 7.1 and 8.2, indicating neutrality. This pH range could maximize macronutrient availability, but could also reduce micronutrient solubility. In addition, organic matter decomposition tends to increase as pH nears neutrality since these conditions are more favorable for microbial activity (Collins and Kuehl, 2001). These trends seem to be quite common in created wetlands as well. Sediment pH showed higher values during the premonsoon months and lower values during the monsoon months. Similar observation was reported by Selvam et al. (1991) and Vasantha (2009). Low pH values were due to the increased rate of decomposition in the organic matter and conversion of released carbon dioxide into carbonic acid (Saha, 1985; Vasantha 2009). The sediment pH was high in summer and low during monsoon possibly due to redox changes in the sediments.
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and water column apart from the influence of freshwater (Ramanathan, 1997; Rajasegar et al., 2002). A one-way ANOVA on the results showed significant differences in pH with seasons (p<0.005). The lower values of pH recorded during monsoon was due to inflow of fresh water. The pH of both the stations indicated the alkaline nature of the stations at both Pariej and Malwar wetland. The values of pH didn’t significant spatial variation in both the wetlands (p≥0.005).

Sediment analysis revealed a higher concentration of chloride in Malwar wetland. The values were higher during winter season, while they decreased in the summer. This indicates that the concentration of most nutrients is poorer in water when sediment contains higher quantities of these nutrients. The poor growth of most plankton observed during winter can be explained as most of the nutrients are locked up in the sediment during this period (Skov and Hartnoll, 2002).

In the current study, phosphorus in sediment was higher than in water suggesting that sediment is the main component for phosphorus storage. Similar results were obtained by Daniel et al. (2006a) who suggested that sediment is the main compartment for phosphorus storage and it is the compartment through which rooted macrophytes obtain phosphorus. In the present study, phosphorus levels were very high at Malwar wetland. Long-term inputs of high phosphate fertilizers and manures to agro-ecosystems in intensive crop areas have contributed for several decades which have resulted in significant P enrichment in soil profiles. Similar reasons can be attributed to increased P concentration in the wetland through agricultural runoff during monsoon.

In the current study, the concentration was high at Malwar wetland and low at Pariej. The wetlands had insignificant spatial variation in terms of concentration of phosphorus. However, marked significant temporal variations (p<0.005) were observed in both the wetlands. In the present study, seasonal variation of the phosphorous concentration showed the maximum value during monsoon and minimum during premonsoon. Variation between seasons in both the wetlands was found to be significant at 5% level. Significant negative correlation with temperature and organic carbon at 5% level was observed. High values of phosphorous might have been promoted by the deposition of inorganic phosphate due to runoff from the land during monsoon, domestic
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sewage and agricultural effluents (Bradley, 2007). Increased application of fertilizers, use of detergents and domestic sewage play a great role in contributing to the heavy loading of phosphorus in sediments (Vasantha, 2009). Further, higher concentration may also be due to the release of phosphate from the decaying and dead organisms in the sediment (Ayyakkannu and Chandramohan, 1971; Vasantha 20C9).

Accumulation of sulphur towards the water/sediment interface is probably the result of redistribution processes which involve the organic cycle and oxidizing /reducing condition. It has been observed by many workers that nutrients like phosphorus, nitrogen and sulphate etc are recycled through sediment and water of pond during different season. In contrast when a peak of most nutrients in water together with phytoplankton was observed during summer, a low nutrients level of sediment was encountered. These observations support the view that sediment chemistry controls the aquatic flora (Vasantha, 2009).

5.1.2.5 Nitrate

The data on the seasonal variations in the sediment nitrogen showed maximum value during monsoon at Malwar wetland when the temperature, pH and organic carbon were low and it was minimum during premonsoon. Low values of sediment nitrogen during premonsoon were attributed to the combined effects of biological utilization and desorption from suspended particulates (Nasnolkar et al., 1996). However at Pariej wetland, nitrogen in sediment was high during summer and low in monsoon due to the oxidation of dead plant organic matter, which has settled on the top layer. The lower value of total nitrogen during monsoon season may be ascribed to low level of organic matter. The total nitrogen of sediments was higher during summer season due to the oxidation of dead plant organic matter, which has settled on the top layer. The increasing values of nitrogen in the sediments are related to the oxidation of dead planktonic matter which has settled from the top layer, whereas the subsequent decrease of nitrate is due to the utilization of nitrate by high planktonic production (Nasnolkar et al., 1996; Skov and Hartnoll, 2002).

Sediment rich in organic matter generally, have higher water content. The sediments of Malwar wetland were blackish muddy and rich in organic matter. In the Discussion Page 163
present investigation, the composition of organic carbon was found to be high during premonsoon season and low during monsoon months. ANOVA test indicated that the variation in organic carbon against seasons was found to be significant (P<0.05). Murugan and Ayyakkannu (1991) observed highest organic carbon values during the premonsoon and the lowest during monsoon season in the Cuddalore Uppanar backwater. The high organic carbon content in premonsoon in the present study would have resulted from the decomposition of organic matter deposited in sediment (Rajasegar et al., 2002). During summer season, the large amount of dead planktonic matter which settles at the bottom, gets oxidized and decomposed releasing high level of organic carbon in the sediment (Vasantha 2009). The present study is in conformity with several earlier studies (Jegadeesan and Ayyakkannu, 1992; Vasantha 2009). In the present study organic carbon content was relatively high in the sediments at Pariej wetland. This may be due to the discharge of large amount of humus brought the wetland along with the sewage inputs from the nearby villages. Similar results were obtained by Vasantha (2009). In addition to this an increase in organic matter content in the sediments may be due to the decomposition of foliage and other vegetative remains in the sediments (Ramanathan, 1997). The accumulation of organic matter in sediment is strongly influenced by temperature and availability of oxygen (Manahan, 1974, Ingole and Dhagalkar, 1988).

The seasonal variation of sodium showed maximum range during monsoon and minimum during premonsoon at both the wetlands. The high runoff during monsoon can be attributed to this trend of sodium (Evgueni et al., 2002). The seasonal variation of potassium showed maximum range during monsoon and minimum during premonsoon at both the wetlands. Seasonal variation of potassium against stations was found to be significant (P<0.05). Significant negative correlation with temperature and organic carbon at 5% level was observed. In the present study, the heavy runoff mainly causes the higher concentration of potassium during monsoon. Similar results were obtained by Evgueni et al. (2002). Leaching of potassium from the nearby fields, by way of potash fertilizers may be the reason for the higher concentrations of potassium at site 2 of Pariej wetland. Low values recorded during premonsoon period may probably be due to its
utilization by biological activity and low freshwater flow (Seralathan and Seetaramaswamy, 1979).

5.2 BIOTIC COMPONENTS

5.2.1 Phytoplanktons

Biodiversity of all systems forms a vital resource that needs to be carefully conserved for our future generation, and planktons are especially important as they form the most sensitive component of the ecosystem and signal environment disturbances. Phytoplankton and its seasonal successions can be a better predictor of long term environmental changes in the aquatic systems than the more usual descriptors of biomass and productivity indices (Moline and Prezelin, 1996). Algae serve as bio-indicator of water quality and pollution analysis (Saladia, 1997). Palmer (1969) listed 60 genera and 80 species, tolerant to organic pollution. Toxic algal blooms and avian botulism are linked (Murphy et al., 2000). Several methods of assessment of water quality based on algal community composition exist (Coesel, 2001).

The phytoplankton in a reservoir is an important biological indicator of the water quality. Certain groups of phytoplankton, especially blue green algae, can degrade the recreational value of surface water, particularly thick surface scum, which reduces the use of amenities for contact sports, or large concentrations, which cause deoxygenation of the water leading to fish death (Whitton and Patts, 2003). Generally, different planktonic species can tolerate different ranges of temperature as well as having light and nutrient limitations. These tolerance levels determine the dominance of species at different times and seasons (Fogg, 1975). In a multi-species algal community, the growth among different species is likely to be limited by the resources, including different nutrients (Wetzel, 2001).

5.2.1.1 Cyanophyta

Diversity of plankton population is fairly dependent on quality of water and climatic factors. Phytoplankton diversity and productivity are strongly related to water quality (Moss, 1988) as well as to other biotic factors (Scheffer, 1998). Temperature, pH,
alkalinity, phosphate are the chief factors which control the population of Cyanophyceae members. Many reports on positive correlations between density of specific groups of phytoplankton and temperature are available (Sarojini, 1996; Unni and Pawar, 2000). The summer months show a marked increase in the density of Cyanophyceae members because of high nutrient concentration and temperature. Singh (1965) stated that temperature, pH, alkalinity and phosphate have been emphasized to be significant factors for controlling distribution of Cyanophyceae which is also corroborated with the present study. Alkalinity range of 50 to 110 mg L\(^{-1}\) has been reported optimum for the Cyanophyceae (Jackson 1971) which coincide with current findings where alkalinity is within the range. At Pariej, the same range was observed which accounts for the luxuriant growth of Cyanophyceae members. Positive correlation between Cyanobacteria and P indicates that P highly stimulates Cyanophycean growth (Iqbal and Katariya, 1995; Sarojini, 1996; Gulati and Donk, 2002; Calijuri et al., 2002; Johnston and Jacoby, 2003; Izaguirre et al., 2004) appears relative to other factors as well. The blue-green algae were also observed to be higher in this study where Oscillatoria sp. is the most abundant. Nwankwo (2004) stated that the blue-green algal forms found in the creek were mostly filamentous forms and could also be opportunistic forms which by biomodification of physical processes usually proliferate to advantages of other species. The presence of Oscillatoria sp. may suggest eutrophic highly organic water. However, a high DO content of Pariej and relatively fresh water status of the wetland is the reason for the abundant presence of genera Merismopoedea.

During the pre-monsoon months, Microcystis aeruginosa was found to be abundantly present in the Malwar wetland. According to Reynolds (1988), M. aeruginosa is a stress-strategist, which is stress tolerant having low growth rate, low metabolic activity, high nutrient storage capacity with enhanced resistance to sinking and grazing losses and apparently characteristic of waters with phosphate oscillations, is a specialist in phosphate storage and efficient in regulating its density. According to Kilham and Hecky (1988), and Kromkamp et al. (1992) this species requires high temperatures, tolerates low light intensity and is not subject to predation by herbivores. According to Brunberg and Blomqvist (2002) Microcystis is a widely distributed organism, which
Pollution studies of two distinct tropical lentic wetlands of central Gujarat with reference to spatial and temporal heterogeneity of biotic and abiotic components
dominate the phytoplankton community in nutrient rich lakes. *M. aeruginosa* is one of the main microcystin producers of lakes (Lindholm et al., 2003). Blooms of cyanobacteria in fresh water ecosystems are attributed to nutrients, particularly to phosphorus enrichment. Increased detection of ‘cyano-toxins’ in water bodies generates a complex challenge for water resource managers all over the world (Johnston and Jacoby, 2003). Other factors are high water temperature, stable water column, low light availability, high pH, low dissolved CO$_2$, and low total N to P ratio (Welch, 1992; Hyenstrand et al., 1998).

5.2.1.2 Chlorophyta

The group Chlorophyceae showed its peak abundance during March of first year but no trend was discernible during the following year. The peak concentration of this group of algae during March coincided with the maximum concentration of PO$_4^-$ in the lake, suggesting that PO$_4^-$ stimulated the high growth of the algae during March of first year. In the present study, monsoon months were characterized by low density of Chlorophyceae. Similar findings were recorded by Krishnan (2008) in Periyar lake, Kerala. Rojo and Rodriguez (1994) were of the view that diatoms are important in temperate rivers; while tropical rivers were mainly dominated by Chlorophyceae. *Pediastrum, Staurastrum, Cosmarium, Euastrum* were species of Chlorophyceae found in the wetland, also reported in other Indian lakes. However, typical species of nutrient rich waters such as *Mougeotia, Oocystis, Ulothrix, Micractinium* (Sreenivasan et al., 1997) were not found in either of the two wetlands. The algal community structure thus suggested that the system is still under natural control as was evidenced by the dominance of sensitive species. However, the general occurrence of certain pollution tolerant species such as *Scenedesmus* (Tewari and Srivastava, 2004), and the rare occurrence of *Spirogyra* at Pariej wetland is a tendency to be monitored intensively.

A high DO content of Pariej and relatively fresh water status of the wetland is the reason for the presence of members of Chlorophyceae. The predominance of desmids at Pariej was further indicative of its unpolluted status. Desmids in general indicate good quality of water (Hosmani et al., 2002). The establishment of the diatom-desmid assemblage is typical for mesotrophic ecosystems (Reynolds, 1980) and absence of
desmids is an indication of heavy pollution of water (Hosmani et al., 2002). Among aquatic microbes, desmids lend themselves particularly well for the assessment of water quality and nature conservation value and the algae indicate a tendency of oligotrophication and acidification of aquatic habitat (Coesel, 2003). Low nutrient contents, low electrical conductivity and a slightly acid pH are known to promote an optimal development of the desmid flora (Coesel, 2001).

5.2.1.3 Bacillariophyta

The winter months recorded a predominance of Bacillariophyceae members on account of high DO content, alkaline pH conditions and low nutrient concentration in both the wetlands. Similar findings were observed by Bhatt et al. (1999). Bacillariophyceae members were found to be the most abundant among all and appeared round the year particularly during winter because of high DO and low nutrient condition of waters and their community became smaller as the summer progressed at both the wetlands. Sarojini (1996) observed positive correlation between Bacillariophyta and DO whereas Tripathy and Panday (1990), Rana et al. (1995), Hegde and Sujata (1997) and Nirmal Kumar (1991) reported that high water temperature, phosphate, nitrate, low DO and CO_2 supported the growth of Chlorophyceae and Bacillariophyceae. Harish (2002) concluded that phosphates, nitrates and nitrites control the growth of Chlorophyceae and Bacillariophyceae in lentic waters. Perhaps this could be the reason in the present study, species of Chlorophyceae and Bacillariophyceae were found abundant, which was having phosphate, nitrate and high DO concentrations at both wetlands. Zafar (1964) reported that *N. palea* and *C. meneghiniana* are nitrogen heterotrophs and that *N. palea* is a very good indicator of pollution. Similar results were obtained in the current study as these species were found to be abundantly present at Malwar wetland.

Patrick (1973) observed that the acidic waters do not support an abundance of Bacillariophyceae, while in alkaline waters with pH above 8.0, their density is more. In the current investigation, pH was found to be in the neutral range (7.0-8.0) supporting a good population of Bacillariophyceae. The especially high pH and dissolved oxygen concentration also suggest more active algal production. Zafar (1964) and Singh and Swarup (1979) reported that higher concentrations of calcium promote the growth of
Bacillariophyceae but Harish (2002) pointed out that there is no relationship between abundance of Bacillariophyceae and calcium. In Pariej, the Bacillariophyceae were the most dominant and occurred throughout the period of study.

5.2.1.4 Euglenophyta

Euglenophyta was the group represented in the lowest density percentage in the two wetlands during the study. There were only 5 species of Euglenophyta belonging to 2 genera representing just 12% of the total diversity of species in the Malwar wetland. Euglenophyta are known to be abundant in eutrophic waters and sediments polluted with organic matter. The growth and development of euglenophytes depend on the combination of a set of factors such as sunlight, temperature and nutrient concentrations. In accordance with Nwankwo (1995), higher number of euglenoid species were recorded when water temperature and nutrient values were high. High carbon dioxide content and oxidisable organic matter with low oxygen content favours the abundance of euglenophytes (Munawar, 1970). Similar conditions at Malwar wetland were favourable for the growth of euglenophytes. Similar results were recorded at Malwar wetland, where oxygen content was poor as compared to Pariej and hence supported growth of euglenophytes.

The presence of species of *Euglena* and *Phacus*, at Malwar was a simple and direct indication of higher pollution load at this site, because both these species, in general, are considered to be highly tolerant genera of polluted ponds (Alam and Khan 1996). However, Tewari and Srivastava (2004) found *Euglena* and *Phacus* in industrially polluted and non polluted waters in North India and also observed that they are species with greater ecological amplitude to their occurrence in aquatic systems exhibiting varying levels of pollution load. Sreenivasan et al. (1997) reported these genera in a shallow polluted lake in Tamil Nadu. stated that environments with extremely high levels of organic matter favour the development of euglenoids. Munawar (1970) found that species of *Phacus* were among the most versatile heterotrophic feeders and grew extremely well under high organic content and low light conditions. This could be the reason in the current study that first site at Malwar wetland receives direct waste from
the Ravikiran ceramic and tile factory and also receives waste with higher organic matter due to open defecation.

In general, higher phytoplankton density was much more pronounced during the non-monsoon than the monsoon periods in both the wetlands. The results obtained suggested that, a decrease in nutrients due to high rainfall accounted for the subsequent reduction in dissolved oxygen levels, which could result in a reduction in phytoplankton taxa. The nutrients values were higher in the dry months and coincidentally, the highest phytoplankton species diversity hence an increase in nutrient levels probably affects phytoplankton composition. The addition of nutrients and changes in water and land use due to agriculture, human settlements, and small industries may induce reversible or irreversible ecological changes in wetlands (Piyankarage et al. 2004).

The non-monsoon months recorded higher phytoplankton densities when compared to the monsoon months. The fall of the phytoplankton community in monsoon months could be attributed to a major dilution of the phytoplankton biomass due to runoff. The positive correlation coefficient values of sulphate and nitrate with the density of algal groups indicate that they stimulate the growth of different algal groups. However, the negative correlation coefficient values of phosphate at both the wetlands signify that phosphate seems to limit the growth of algal groups like desmidae and diatoms. Singh (1965) stated that temperature, pH, alkalinity and phosphate have been emphasized to be limiting factors for controlling distribution of Cyanophyceae which also corroborated with the present study.

The current investigation of phytoplankton suggested that the nutrient impact on the system in general was quite evident. Throughout the seasons the dominance of Chlorophyta, i.e. desmids over Chlorococcales among Chlorophyta and Bacillariophyta at Pariej wetland suggested a low trophic structure expected of a typical unpolluted freshwater system. However, the presence of euglenophytes coupled with increased concentration of nutrients at Malwar wetland indicated its eutrophic character. The value of Shannon and Margaleff’s diversity indices indicated high diversity at site 2 of Pariej wetland and Malwar wetland that reinforces the presence of favourable environmental conditions for the growth of phytoplanktons (Sarojini, 1996). However, the value of
Palmer index (1969) at both the wetlands indicated eutrophic status. The high value of Jaccard’s similarity index between sites at Pariej has been attributed by Sharma and Rawat (2009) to similar environmental conditions. The value at Malwar was low indicating dissimilarity between the sites which were well confirmed with the physicochemical characterization. Correlation studies of hydrobiology with physico-chemical parameters revealed that the relationship between phytoplankton density in general and that of the specific groups are highly complex and often controlled by interactions of different factors.

5.2.3 Coliforms

Total coliforms indicate degree of pollution and their higher density portrays the difference between clean and polluted waters (Rai and Hill, 1978). Clark and Pogel (1977) considered coliforms as a reliable indicator of contamination of water. Fecal coliforms have long been used as indicators of pollution in water (McMath et al., 1999; Perkins and Hunter, 2000) due to the potential for introduction of pathogens and other pollutants along with these bacteria (Ricca and Cooney, 1999). High levels of nutrients can also increase the growth rate of bacteria. In the present study too, the highest total and fecal coliform counts were observed in winter months. This could be due to the high oxygen supply to the water column along with moderate nutrients like phosphate, sulphate and nitrate (Syouhei et al., 2008). Further, a higher coliform count confirms various anthropogenic factors, such as, release of human excreta in open spaces, cattle and pet waste in the wetland (Gearheart, 1999) at both the study sites.

5.2.3 Vegetation

Wetland ecosystems are among the world’s most productive of ecosystems (Kansiime, 2007) and store large quantities of carbon, which is sequestered into organic matter through the synthesis of plant biomass (Trumbore et al., 1999; Turunen et al., 2002). Aquatic macrophytes are macroscopic forms of aquatic vegetation, including macroalgae, mosses, ferns and angiosperms found in aquatic habitat. They have evolved from many diverse groups and often demonstrate extreme plasticity in structure and morphology in relation to changing environmental condition (Wetzel, 1983). Aquatic macrophytes such
as *Eichhornia crassipes* and *Phragmites* sp., exhibit high growth rates and net primary production, compared to agricultural crops like sugar cane (Kansiime, 2007). Aquatic macrophytes in different growth forms represent the most important biotic element of the littoral zone in an aquatic ecosystem (Pieczynska, 1990). Two factors, number of species and importance values (numbers, biomass, productivity) of individuals, determine the species diversity of a community (Odum, 1996).

In terms of the number of species at Pariej, floating species constituted the largest group, followed by submerged and emergent species. The observation was contradictory to that of Sheerwani (1962) and Shrestha (1996) who stated that emergents outnumbered submerged and floating species. The Malwar wetland however, witnessed dominance of floating aquatic macrophytes. These findings were similar to those of Nahlik and Mitsch (2006) who reported that tropical wetlands are dominated by floating aquatic macrophytes. The number of aquatic macrophyte species was higher during winter and lower during the spring. The dense growth of rooted floating-leaved species, in summer, may be attributed to better adaptability of the rooted floating-leaved species to the stresses of water level fluctuation, to the tearing action of water turbulence, and to turbidity of water (Papastergiadou and Babalonas, 1992). The dense growth of *Ceratophyllum* sp. in the summer season at Malwar wetland can be attributed to the high growth potential of this species to the eutrophic condition of lake (Zutshi and Vass, 1976).

During the present investigation, emergents were the most persistent form throughout the year at the embankment at Pariej wetland. This can be attributed to the emergents high tolerance for fluctuation of water level (Van der Valk and Davis 1976). Seasonally, emergents were highest in the summer, followed by winter and monsoon. In the Malwar wetland, the dense growth of free-floating species like *Eichhornia crassipes* prevented colonization of submerged species in the summer and the winter season (Kaul et al. 1978). Among the free-floating species, *Eichhornia crassipes* was highly dominant throughout the year. Its dominance can be ascribed to its invasive nature and also its preference for highly eutrophic and stagnant water. Gopal and Sharma (1990) also found a similar relation between growth pattern and level of eutrophication.
Among the submerged species, *Hydrilla verticillata* was observed to be the most dominant species throughout the year at Pariej wetland. The vigorous year-round growth of *H. verticillata* indicates its ability to adapt in diverse conditions. Shingal and Singh (1978) also found this species in a lake area characterized by high silt load and cultural eutrophication. Species richness appears to be influenced by seasonal variations. *Marsilea quadrifolia* was found to grow during summer in low depth areas near the embankment at Pariej. The seasonal variation in requirements of the diverse growth forms may cause the variation in the species diversity (Shrestha, 2000).

Macrophytes have been used as indicators of water pollution by various workers. Pandit, (1999) related the growth and abundance of *Ceratophyllum demersum* to the eutrophic conditions of water. The most commonly used method for biological assessment of water pollution in aquatic ecosystem are based on the kind of species present, number of species, abundance, productivity etc.

According to Junk (1984) the rapid growth and high rate of vegetative reproduction of macrophytes are related to a rise in water level and ensure rapid colonization of newly available areas. Camargo and Esteves (1996) verified that annual pattern of biomass variation and chemical composition of macrophyte *Eichhornia azurea* in the Lagoa do Mato, an oxbow lagoon of the Mogi-Guap River, neighbor to Lagoa do InfernBo, is relational to flood pulse (Pompeo and Moschini-Carlos, 1996). In lake sediments, oxygen diffusion from the water column to the sediment is very low and results in reduced conditions a few millimeters below the interface (Sergei et al. 2006). The presence of submersed vegetation may contribute to both oxygenation and/or increase of the reducing power due to accumulation of organic matter. Rooted aquatic plants may release oxygen to the sediment to overcome phytotoxic compounds in flooded soils (Amstrong et al. 1991).

The Shannon’s index and Margaleff’s index exhibited high diversity of macrophytes at site 2 of Pariej wetland and in Malwar wetland diversity was higher at site 1. The moderate concentration of nutrients must have been the cause of this diversity at the wetlands (Junk, 1984). The high value of Jaccard similarity index between sites at Pariej has been attributed by Sharma and Rawat (2009) to similar environmental
conditions. The value at Malwar was low indicating dissimilarity between the sites which were well confirmed with the physicochemical characterization.

5.2.4 Avifauna

The bird species richness significantly correlated with the aquatic macrophytes at Pariej wetland. This corroborates with the earlier findings (Gassaway et al., 1977; Johnson and Montalbano, 1984). Weller and Spatcher (1965) and Weller and Frederickson (1974), emphasized that individual bird species may require different types and quantities of aquatic macrophytes. For example, cattail (*T. angusata*) is reported to be a primary habitat for least bitterns (Palmer, 1962). Colle and Shireman (1980) and Savino and Stein (1982) stated that cormorants are fish eaters and they can have difficulty capturing prey in lakes full of aquatic vegetation; thus they are less likely to inhabit lakes with large coverage of aquatic macrophytes. In the present study, this might be the reason that the cormorants appeared to be less prevalent in areas of abundant aquatic vegetation. Johnson and Montalbano (1984) reported that coots use aquatic vegetation as a direct food source and show a high frequency of detection in lakes with high aquatic coverage. These birds probably are attracted to matted vegetation as a food source and have a higher probability of occurring on a lake with large populations of aquatic macrophytes. Similar findings were observed in the current study which harbors large population of coots in the winter months.

Changes in bird abundance over an annual cycle are quite prevalent in lake systems depends on nutrient status and macrophyte composition besides environmental factors (Johnson and Montalbano, 1989). More bird species at Pariej than Malwar reveals low nutrient capacity in Pariej indicating that lake trophic status determines bird abundance and species richness (Nilsson and Nilsson, 1978; Murphy et al., 1984). Increased biomass indicates increased nutritional conditions and production potential, whereas decreased biomass indicates declined potentials. The main reason for this large heron numbers was the establishment of a roosting and breeding colony in the large area of *Typha angusata* that developed in the fringes of the Pariej wetland (Kaplan et al., 1998).
Among avifauna of Pariej wetland, the migratory waterfowl occupy a significant position and they range from small waders, teals to considerably larger ducks and geese. They obtain food, usually small invertebrates like insects, worms, larvae and mollusks by wading in the shallow water or probing into the mud. Besides, these other waterbirds species seen at Pariej wetlands were coots, moorhens, jacanas, cormorant etc. The floating leafy species occupy a very important position to support avian diversity. The member of the water lily family with larger leaf diameter like Nymphaea, Nelumbo provide good running base for wetland birds like bronze-winged jacanas. Birds are known to consume all parts of grasses, sedges and rushes, including tubers, rhizomes, stems, foliage, inflorescences and seeds. The purple moorhen (Porphyrio porphyrio), a vegetarian, often has a feeding platform on which it stands and pulls up the surrounding water plants. Coots (Fulica atra) also are major wetland plant consumers and prefer to feed on Potamogeton and bottom growing Chara sp. (Gorenzel et al., 1981).

The winter visitor Northern pintail favors plant materials such as seeds, tubers and rhizomes of Potamogeton, Vallisneria, Ceratophyllum (Cramp and Simmons, 1977). Northern Shoveller, Anas clypeata is attracted by lush grassland of Pariej wetland and feeds on Nymphaea, Ceratophyllum, Scirpus seeds, shoots and buds of aquatic plants (Sridharan, 1989). The diving ducks in the wetland were common pochard, red crested pochard that feed on protein rich common duckweed Lemna sp. (Fredrickson and Reid, 1988). Open water formed the highest preferred feeding habitat of cotton teals and it feeds on submerged vegetation such as Hydrilla and Najas (Sridharan, 1989).

The avifaunal community at Malwar wetland showed a marked diversity in the second year of the study. This could be attributed to wetland rehabilitation, restoration and excavation that lead to an increase in species richness and number of individuals of many species as suggested by Weller (1995) and Creighton et al. (1997). The total bird species richness tends to be larger in older restored wetlands than in younger ones (VanReesSiewert and Dinsmore, 1996). Similar reasons could be well credited to the greater species richness in Pariej than Malwar. Birds are heavily influenced by human disturbance and they could be encouraged to move to Malwar wetland for roosting only if adequate restrictions of human activity were imposed (installation of fences). Actions to
manage the aquatic vegetation (species, quality and abundance/densities) should be undertaken at Malwar wetland to promote the avifaunal density and diversity. Regulation of water levels is critical to the maintenance of species diversity and abundance. Areas of open water need to be created to cater to the requirements of some bird species, particularly diving ducks for feeding and many other species for resting.

It was observed during the current investigation at Pariej and Malwar wetland that the avifaunal diversity was more in January, February and March as there was low temperature, shallowness and optimum water storage, availability of abundant food, increased vegetation and the arrival of migratory birds. The minimum diversity was recorded in July due to heavy rain, increased flow of water, non-availability of food and return of migratory birds. Many of the birds were displaced during this season and spread in the neighboring areas of agricultural activities, which form their feeding ground. Some birds find their breeding grounds elsewhere in this season. They start returning to the pond by September. The bird density or the number of individuals were more in December, January and February and less in May, June and July. Similar observations were made by Bhat et al. (2009) at Anekere wetland and Saxena (1975) on avifauna of Keoladeo National Park, Bharatpur. Abundant food supply was also the cause of increased density of avifauna in January every year. The result suggests that one of the major factors that accounts for avian species diversity in the study sites is water. This result is in agreement with Neave et al. (1996) findings that environmental attributes such as temperature, precipitation and floristic structure determine the abundance, distribution and diversity of avifauna species across the regions.

The results of the study indicated that only Pariej wetland had stable diversity of avifauna species. However, Malwar wetland recorded major diversity in the winter season for three months (December, January and February). This variability in species richness of the sites might not be unconnected with human activities and the effects of microclimate. Jaensch (1997) and Neave et al. (1996) observed that species diversity is often affected by unsustainable subsistence and commercial fishing and arable farming within catchment areas of wetlands as well as environmental attributes such as temperature, precipitation and relative humidity. Usually the month of March and April

Discussion

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was characterized by intense fishing activities in the Malwar wetland that generates competition between the birds and human beings. Thus further, suggests that the availability of the avian species in the study sites depends on the preservation of the wetlands.

The diversity of waterbirds as analyzed by Shannon’s index and Margaleff’s index exhibited high diversity of waterbirds at site 2 of Pariej wetland and in Malwar wetland diversity was higher at site 1. The availability of food, nesting and roosting conditions can be attributed to the diversity documented at the wetlands (Neave et al., 1996). The high value of Jaccard similarity index between sites at Pariej has been attributed by Sharma and Rawat (2009) to similar environmental conditions. The value at Malwar was low indicating dissimilarity between the sites which were well confirmed with the physicochemical characterization.

The biodiversity in the two wetlands was assessed using various diversity indices. In the present study high values of Shannon–Wiener species diversity index ($H'$) for phytoplankton, macrophytes and waterbirds were obtained in the Pariej wetland. It has been reported that higher the values of Shannon– Wiener diversity index ($H'$) the greater is the diversity (Rajagopal et al., 2010). Margalef index is a measure of the number of species present for a given number of individuals. The values of Margaleff index can come more than 1 unlike in the other index where the values will be varying from 0 to 1. This way comparing the species richness between the two wetlands is easy (Senthilkumar, 2006). Similar findings were obtained in Pariej wetland where high diversity of the biotic components was registered. In Malwar however, due to increased organic pollution and anthropogenic interventions, the community of the biotic components is less diverse. The presence of pollution indicators in Malwar also reinforces the stressful environment in the Malwar wetland. The comparison between sites was performed by using quantitative presence–absence type, Jaccard’s similarity index (S). The lower values of Jaccard’s similarity indices was observed in Malwar that revealed marked change in community structure from site 1 to site 2 (Rajashekhar et al., 2009). The higher similarity index between sites has been attributed by Sharma and Rawat (2009) to similar environmental conditions as observed in Pariej wetland.