CHAPTER 5

DISCUSSION
5. DISCUSSION

Estuaries have for long been important to mankind, either as place of investigation, or as locations on their banks for towns and cities. Now-a-days, they are under pressure either as repositories for the effluent of industrial processes and domestic waste or as prime sites for land-claim to create sites for industry or urban development. Estuaries have been claimed to be amongst the most productive natural habitats in the world (McLusky and Elliott, 2004). The estuarine environment is characterized by having a constantly changing mixture of salt and fresh water which differs from both biotic and abiotic conditions. The dynamic nature of estuaries proves to be a great challenge to the biotic community, which few are able to adapt to it (Deeley and Paling, 1999). Studies showed that the change in nutrient status, whether due to pollution or natural cause can have a significant impact on distribution of estuarine organisms (Kimmerer, 2002; Paul et al. 2008). Anthropogenic inputs frequently cause changes in the chemical characteristics and water quality of ecosystem which ultimately can lead to various ecological consequences (Martin et al. 2008). The hydrochemistry, geochemistry with reference to biotic component of Narmada and Tapi estuarine regions were analyzed in the present study and the results obtained were discussed in the following session.

5.1. Hydro-chemistry

Estuarine environment are subjected to varied change in physicochemical properties due to continuous mixing of fresh water with marine water. Estimating the water quality is very important in determining the quality of ecosystem (Chang, 2008). Water temperature is an important parameter which influences the chemical process such as dissolution-precipitation, adsorption-desorption, oxidation-reduction and physiology of biotic community in an aquatic habitat (Aken, 2008). Stenseth et al. 2004 suggested that variability in temperature may induce variations in marine and estuarine ecosystems at all levels of the food chain, from primary productivity to the top predators including fisheries. Annual changes of temperature as observed in this
study shows a gradual fall from the rainy season to winters and a steady raise in summer till the onset of rains in both the estuaries.

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 average temperature in the present study ranged from 22 °C to 33.6 °C in Tapi and 22.7 °C to 32.7 °C in Narmada estuary. 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 results found to be well agreed with investigations carried out by Martin et al. (2008) for Cochin estuary of south India where they reported a temperature variation of 28 °C to 32 °C during pre-monsoon period. Bhardwaj et al. (2010) also recorded a wide variation in temperature ranging from 29.7 °C to 38.7 °C while estimating the water quality of the Chhoti Gandak river of Ganga Plain. 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. The change in water temperature may be attributed to the change in solar radiation received at different seasons along the study sites (Ozaki et al. 2003).

pH is known as the master variable in water since many properties, processes and reaction are pH dependent. The principal system that regulates pH in the sea water is carbonate system consisting of CO₂, H₂CO₃, HCO₃⁻, salt content and alkalinity due to borates (Lower, 1999). In shallow biologically active tropical waters, large diurnal pH changes from 7.3 to 9.5. It may occur naturally because of photosynthesis. Due to the buffering capacity of the sea water, generally the pH ranges from 7.8 to 8.3 in estuaries (Millero, 1986). Abel (1996) reported that even though the pH of 5 to 9 is not directly harmful to aquatic life, such changes can make many common pollutants more toxic. Significant changes in pH occur due to disposal of industrial wastes, acid
mine drainage etc. In natural waters pH also changes diurnally and seasonally due to variation in photosynthetic activity which increases the pH due to consumption of carbon dioxide in the process.

In the present study low pH was observed at the upper reaches of both Narmada and Tapi estuaries and high pH in lower reaches. The recorded pH values ranged between 6.9 to 8.7 in Narmada estuary and 6.9 to 8.6 in Tapi estuary. Similarly, Prakash et al. (2009) observed a wide range in pH change from 6.9 to 8.8 during monsoon to pre-monsoon period in tropical Cauvery river system. Satpathy et al. (2009) also observed a pH range of 7.7 to 8.3 along the coastal waters of Kalpakkam, South east coast of India. The pH of water also depends upon relative contents of free CO₂, carbonates, bicarbonates and calcium. The water tends to be more alkaline when it possesses carbonates, but lesser alkaline when it supports more bicarbonates, free CO₂ and calcium. Omstedt et al. (2010) reported that the marginal change in pH from one month to other month may be due to the excessive buffering activity of sea water. The high pH might be due to the marine water influence in the sites which was observed prominent during pre-monsoon period. The decrease in pH value in upper reaches can be attributed to the fresh water influence on these areas (Islam, 2007) which was mostly observed in monsoon season.

Dissolved oxygen is an important constituent of water and its concentration in water is an indicator of prevailing water quality and ability of water body to support a well balanced aquatic life. It is the characteristic of a water body under typical hydrology, hydrographic, waste loading and environmental conditions. Influx of anthropogenic discharges containing oxidisable organic matter and certain pollutants consume DO more than that the water body can replenish, thereby degrading the ecological quality. However, in a dynamic coastal environment the impact is considerably lowered because of tidal action and turbulence (Pena, 2010). In the present study higher DO of 9.7 mgL⁻¹ was observed in Narmada estuary and 12.3 mgL⁻¹ was reported from Tapi estuary. Similarly, Jack et al. (2007) while working on coastal waters of Benghazi reported dissolved oxygen level of 9.2 to 10.1
mgL\(^{-1}\) during post-monsoon period. Higher dissolved oxygen present in the upper reaches of Narmada and Tapi estuaries might be due to the freshwater influence in these areas. The positive correlation of DO with chlorophyll-a value indicates the role of phytoplankton in contributing DO in water. Moreover, highest DO concentration was observed during post-monsoon period because of maximum occurrence of the phytoplankton density (Morgan, 2006). With the progression of winter, DO raised to its peak value, and it might be due to high rate of photosynthesis by phytoplankton population that forms the major source of DO (Sharma and Rathore, 2000). The seasonal variation of DO is influenced by the temperature of water body and has been largely studied by several researchers. Gopal and Chauhan (2001) observed that DO remained high during winter but low in summer. The present study also revealed the same trend. 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).

Lower dissolved oxygen concentration was reported from the lower reaches of both estuaries. In Narmada estuary lower dissolved oxygen concentration of 0.90 mgL\(^{-1}\) was reported from Ambata whereas 0.10mgL\(^{-1}\) was reported from Tapi estuary. The lowest DO concentration observed at the lower reaches might be because of the influence of salinity, temperature, conductivity, currents and upwelling tides (Davis, 1975). Roegner et al. (2011) while working on Columbia river estuary suggested that low concentration of dissolved oxygen at the estuarine mouth may be attributed to wind stress, tidal stress and ocean forcing and eutrophic condition of water at lower reaches might be because of the above said factors. High biological activity during pre-monsoon can also lead to low dissolved oxygen concentration in estuaries as observed in Chesapeake Bay (Levinton, 2001). The lower dissolved oxygen concentration reported at middle reaches of Tapi river during pre-monsoon might be due to the domestic as well as industrial effluent released into the region as these are the main source of oxidisable organic matter (Abdullahi, 2008).
Based on dissolved oxygen concentration Philipose (1960) differentiated trophic status of water into oligotrophic, mesotrophic and eutrophic. The mesotrophic condition existed at the upper reaches of Narmada and upper and middle reaches of Tapi which is indicative of freshwater influence and increased phytoplankton occurrence at these zones (Pinckney et al. 2001).

**Total solids (TS)** is the sum total of suspended solids plus dissolved solids present in the water (Jayakumar et al. 2009). The concentration of total solids in estuarine regions of Narmada and Tapi was observed to be high particularly in the mouth parts. The concentration of total solids ranged from 338 mgL\(^{-1}\) to 29261 mgL\(^{-1}\) in Narmada estuary and in Tapi estuary it was observed in the range 2278 mgL\(^{-1}\) to 32649 mgL\(^{-1}\). The results are in concordance with the studies carried out by Prasanna and Ranjan (2010) in Dhamra estuary of western India in which they reported 63850 mgL\(^{-1}\) of total solids during pre-monsoon period and 12550 mgL\(^{-1}\) in monsoon period. The total concentration of TS was observed higher during pre-monsoon period which may be because of the high tidal influence and low freshwater inflow. Soundarapandian et al. (2009) suggested that tidal current forms the main factor influencing the total solid concentration by constant turbulence of bed sediments. The heavy tidal influence experienced at study sites might be the reason of higher TS concentration particularly along the lower reaches of both Narmada and Tapi estuaries.

**Salinity** is the indicator of freshwater incursion in the near shore coastal water as well as extrusion of tidal water in inland water bodies. Salinity influences several processes such as dissolution, dispersion and dilution in seawater due to high dissolved salt content and higher density. Shiel et al. (2006) stated that biotic communities present in estuarine regions are acclimatized for certain range of salinity where they thrive. Wide ranges in salinity can result in adoption with modification and dominance of selected species in the lower order while higher order biota may migrate. Sudden change in salinity can cause high mortality including fish due to salinity shock. In the present study salinity ranging from 0.06 ppt to 33.8 ppt was
reported from Narmada estuary and in Tapi estuary it was in the range of 0.8 ppt to 33.2 ppt. In both estuaries higher concentration was recorded mostly during pre-monsoon period which signifies the role of tidal influence in increased salinity at lower and middle reaches. In Kalpakkam Coast of South east India, a similar observation was made by Satpathy et al. (2009). They recorded salinity ranging from 23.4 to 35.9 ppt and the highest being recorded during pre-monsoon season. Also similar results have been registered by Martin et al. (2008) from Cochin estuaries in which the salinity was in the range of 0ppt during monsoon to 30ppt in pre-monsoon which found to be corroborated with present results. During summer the evaporation exceeds precipitation which ultimately results in increased salinity (Joseph and Ouseph, 2009). The upper reaches experienced less salinity because of the fresh water dominance in the area, however in Tapi the upper reaches experienced high salinity compared to Narmada because of the less fresh water inflow. Chloride concentration is closely related to salinity and the amount of chloride concentration gives a direct measure of salinity in water. During monsoon high freshwater inflow can leads to a decrease in salinity along the estuarine regions (Froneman, 2002) and this might be the reason for low salinity range observed during monsoon season.

**Electrical conductivity (EC)** estimates the amount of total dissolved salts (TDS), or the total amount of dissolved ions present in the water. Areas around estuarine environments represent zones of interaction and transition between the two systems where dissolved constituents such as pollutants are diluted, exchanged, transformed or destroyed. The more total dissolved solids in water, particularly salts, the greater its electrical conductivity (Westbrook et al. 2006). The high conductivity values were observed at lower reaches of Narmada (52 mS) and Tapi (58 mS) estuarine regions followed by middle and upper reaches. Similar trend was observed by Kathiresan (2002) in studying the of Pichavaram mangrove ecosystem of South east India. The study revealed 32mS to 57mS range of EC in mangrove water which showed similarity with our present results. The rise in EC during summer months suggests the influence of marine water on contributing dissolved ions like Na, K and
Environmental studies on biotic components in relation to nutrient status of selected sites of Narmada and Tapi estuaries, Gulf of Khambhat, Gujarat, India.

Cl into estuarine environment because of the low freshwater inflow and enhanced precipitation (Satheeshkumar and Anisakhan, 2009).

Sodium and Potassium are two major nutrients entering into estuarine ecosystem through sea water sources. Sodium and potassium play a major role in directing the distribution of marine organisms and in supporting their existence in a particular saline habitat by osmoregulation. The estuarine area experiences high sodium and potassium concentration as compared with freshwater zones and less concentration than marine water. In lower reaches maximum sodium concentration observed was 9368 mgL⁻¹ in Narmada estuary and 9884 mgL⁻¹ in Tapi estuary. The negative correlation of sodium and potassium with DO and significant positive correlation with salinity indicates the marine water influence of these nutrients in water. The concentration of sodium and potassium was observed high during pre-monsoon period and this might be attributed to the increased tidal influence and low freshwater inflow during this period (Solai et al. 2010). In the present study the higher concentration of sodium and potassium were found at lower reaches followed by upper and middle reaches in both of the estuaries. Hoz et al. (2003) also observed similar spatial variation in sodium and potassium concentration in Coatzacoalcos River of Southeast Mexico. The proximity of lower reaches towards the sea and tidal influence at this zone contribute sodium and potassium at higher concentration.

Alkalinity (also known as “buffer capacity”) is a measure of the capacity of water to neutralize acids. Alkaline compounds such as bicarbonates, carbonates, and hydroxides, remove hydrogen ions and lower the acidity of the water (thereby increasing pH). Alkalinity is influenced by rocks and soils, salts, certain plant activities and certain industrial wastewater discharges. Measuring alkalinity is important in determining the estuary’s ability to neutralize acidic pollution from rainfall or wastewater. 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). Without this acid-neutralizing capacity, any acid
added to a body of water would cause an immediate change in pH. Stevenson et al. (1993) suggested that the buffering capacity of water, or its ability to resist pH change, is critical to aquatic life and an estuary's capacity to neutralize acids will vary between the freshwater reaches of the estuary and the portions with higher salinity. In the present study it was observed that the value of alkalinity is directly proportional to the concentration of natural salts present in water. The maximum alkalinity of 210 mgL⁻¹ was observed from the lower reaches of both the estuaries during pre-monsoon period, which is an indicative of marine water influence on alkalinity. The results obtained were similar to studies carried out by Shaikh and Mandre (2009) in Khed (Lote) Industrial water, Western India in which they reported 350 mgL⁻¹ alkalinity during summer season and a minimum of 120 mgL⁻¹ during monsoon season. Saksena et al. (2006) in their study on certain saline ponds of Ratnagiri also emphasized the role of marine water intrusion affecting the alkalinity of water. Minimum alkalinity range of 40 mgL⁻¹ was reported from the upper reaches of Narmada estuary. Meera and Nandan (2010) on their study on Valanthkad backwaters of Kerala suggested that, low alkalinity value at post-monsoon may be attributed to increased uptake or release of carbon dioxide by organisms there by changing the proportion of carbonate and bicarbonate ions in water.

Ammonium (NH₄⁺) represented 80% of Dissolved Inorganic Nitrogen (DIN) and its highest values were always associated with fresh water inflow (Martin et al. 2008). Ammonia, the chief excretory product of the marine invertebrates, is also well known as a nutrient, which is preferred over nitrate by the phytoplankton community in certain environmental conditions which significantly affects the concentration of ammonia. Harbin and Berg (1993) observed that ammonia concentration was higher at freshwater receiving region probably due to increased fresh water influence. Peak surface water ammonia concentration showed positive correlation with chlorophyll-a which indicates the contribution of ammonia due to phytoplankton proliferation. In the present study ammonia concentration was observed in the range from 0 to 1.11 mgL⁻¹ in Narmada estuary and 0 to 0.88 mgL⁻¹ in Tapi estuary. Satpathy et al. (2009) also observed ammonia concentration ranging from 0.009 to 0.2 mgL⁻¹ along
Kalpakam coastal water which supports the lower ammonia concentration observed at lower reaches in the present study. The negative correlation of salinity with ammonia indicates the freshwater source of this nutrient into the estuarine environment.

**Castane et al. (2006)** has also reported similar ammonia concentration in the range from 0.7 to 11.2 mgL$^{-1}$ from river waters of Reconquista river of Argentina. **Sankarnarayanan and Qasim (1969)** suggested that the spatial and temporal variation in ammonia concentration might also be due to its oxidation to other forms or reduction of nitrates to lower forms in coastal waters. The present results found to be well corroborated with findings of **Damotharan et al. (2010)** on their study on Point Calimere coastal waters of south east coast of India found maximum concentration of ammonia at the fresh water receiving sites.

**Phosphate** concentration in coastal waters depend upon its concentration in the freshwater that mixed with the seawater within the sea-land interaction zone, phytoplankton-uptake addition through localized upwelling, and replenishment as a result of microbial decomposition of organic matters (Paytan and Mclaughlin, 2007). Phosphate constitutes the most important inorganic nutrient that can limit the phytoplankton production in tropical coastal marine ecosystems and thereby the overall ecological processes (Cole and Sanford, 1989). In the present study phosphate concentration was reported higher at middle reaches and upper reaches of estuaries during post-monsoon period. Phosphate concentration in Tapi river (0.00 to 0.88 mgL$^{-1}$) was found higher than that of Narmada (0.02 to 0.38 mgL$^{-1}$). Domestic as well as industrial effluents released from in and around Surat city may be the major contributors of phosphate into estuarine environment of Tapi estuary. **Silveira and Ojeda (2009)** emphasized the role of urban release on phosphate concentration on their study on Yutacan Coast and their results found to be corroborated with the present studies. **Liu et al. (2009)** reported that sea water serves as the main source of phosphate in estuarine and coastal waters except those receives freshwater contaminated with domestic wastes containing detergents as well as wastes from agro field rich with phosphate-phosphorous fertilizers and pesticides. **Gabche and Smith**
while working on two estuaries of Cameron concluded that the increased concentration of phosphate after monsoon was the result of agricultural run-off along with city drainage which in-turn will serve as important phosphate contributors to the coastal environment. Vidal (1994) suggested that re-suspension of phosphate from sediments also add significant portion of these nutrient to the estuarine water. The noticeable seasonal variation in phosphate concentration as observed in this study might be due to various processes like adsorption and desorption of phosphate and buffering action of sediments under varying environmental conditions (Pomeroy et al. 1965). Lee et al. (2008) suggested that biological processes and adsorption reactions at lower pH values will remove dissolved phosphorus at lower reaches and this might be the reason for maximum concentration of dissolved inorganic phosphorus at the upper and middle reaches of both estuary and decrease moving towards downstream. Phosphate act as a limiting nutrient in aquatic ecosystem and the potential for nutrient limitation may impact the nature of biotic communities in estuaries. Ganapati (1956) differentiated trophic status based on phosphate concentration and in the present study it was observed that upper-reaches and middle reaches reported mesotrophic and lower reaches as oligotrophic in both the estuaries. Gonzales et al. (2008) on his study on water quality of tropical coastal lagoons of the Yucatan peninsula observed meso-eutrophic condition of phosphate and it was mainly due to waste waters from surrounding urban areas. Similar trend in trophic status has been observed in upper and middle reaches of Narmada and Tapi estuaries.

Nitrogen cycle involves elementary dissolved nitrogen oxides; NO₃, NO₂ and reduced forms: NH₄, NH₃ play a significant role in sustaining the aquatic life in marine environment. Nitrate nitrogen is one of the most important indicators of pollution of water which represents the highest oxidized form of nitrogen. In the present study nitrate concentration was observed greater at upper reaches when compared to middle and lower reaches. The highest nitrate content was observed during post-monsoon (1.84 mgL⁻¹) in Narmada and (1.5 mgL⁻¹) Tapi estuaries indicating the source of run-off water in adding this nutrient in to estuarine region. Similar results were obtained by Prasannakumar et al. (2002) on their study on
eastern Arabian Sea in which they have reported 1-2mgL\(^{-1}\) of nitrates during pre-monsoon period. Satpathy et al. (2009) also reported the range of nitrate from 0-4.28mgL\(^{-1}\) in the coastal waters of Kalpakkam. The most important source of the nitrogen is biological oxidation of organic nitrogenous substances, which derived from sewage and industrial waste or produced indigenously in the water (Sharma et al. 2008). Zepp (1997) observed that variation in nitrate and its reduced inorganic compounds are predominantly the result of biologically activated reactions. Quick assimilation by phytoplankton and enhancement by surface run-off results in large scale spatio-temporal variation of nitrate in the coastal regions. Edokpayi (2010) had observed negative correlation of nitrate with salinity also concluded that freshwater influx is the main source of nitrate in coastal waters which corroborated with results of our study. Likens (1975) explains the trophic status of water on bases of nitrate concentration and in the present study the upper reaches of both estuaries were found to be mesotrophic whereas lower reaches oligotrophic. Mesotrophic condition of trophic status on basis of nitrate was also observed by Gonzales et al. (2008) in tropical coastal lagoons of the Yucatan peninsula. Balachandran et al. (2008) from his study on north-western Bay of Bengal and north eastern Arabian sea concluded that the tidal influence and vertical mixing has a prominent influence on oligotrophic nature of coastal regions which is in concordance with observed results from lower reaches of Narmada and Tapi estuaries.

Silicate is one of the important nutrients which regulates the phytoplankton distribution in estuaries. The variation of silicate in coastal water is influenced by physical mixing of seawater with freshwater, adsorption in to sedimentary particles, chemical interaction with clay minerals, co-precipitation with humic components, and biological removal by phytoplankton, especially by diatoms and silicoflagellates (Satpathy, 2009). In the present study, freshwater discharge from the backwaters rich in silicate in to the coastal water could be the reason for higher value during post-monsoon period. The higher post-monsoon values of silicate could also be due to heavy influx of freshwater derived from land drainage carrying silicate leached out from rocks and also from bottom sediments exchanging with overlying water because
of turbulent nature of water in the estuaries (Saravanakumar, 2008) which is supported by positive correlation between freshwater fractions and silicate.

The silicate concentration was observed in the range from 0.8 to 12.8 mgL\(^{-1}\) in Narmada estuarine region and 0.3 to 9.5 mgL\(^{-1}\) in Tapi estuarine zone. The highest concentration was reported from the upper reaches during post-monsoon period. Silicate showed strong negative correlation with salinity and strong positive correlation with DO. This showed that freshwater, which is rich in DO could be the main source of silicate in these coastal water regions as entry of silicate mainly takes place through land drainage rich with weathered silicate material (Lal, 1978). The results obtained in the present study were found to correlate the results obtained by Martin et al. (2008) in Cochin estuary, west coast of India in which they reported silicate range from 2 to 9.5 mgL\(^{-1}\). Sridhar et al. (2006) also reported a low silicate concentration of 0.5 to 1.5 mgL\(^{-1}\) in Palk Bay, southeast coast of India which showed similarity with our present results in lower reaches. Satpathy et al. (2009) and Rajasegar (2003) had suggested that the low concentration of silicate observed during pre-monsoon might be because of adsorption of reactive silicate into suspended sedimentary particles, chemical interaction with clay minerals, coprecipitation of soluble silicon with humic compounds and iron, and biological removal by phytoplankton, especially by diatoms and silicoflagellates. Shehata and Badr (2010) in their study on water quality of river Nile suggested that the positive correlation of silicate with other hydro-chemical parameters like ammonia, nitrate, chlorophyll-a indicates the freshwater origin of this nutrient which is similar to our present observed results.

Sea water entering into estuarine regions during tidal influxes is the major contributor of sulphate in to this region. In the present study there is a distinct spatial variation in sulphate concentration along the estuaries which showed a declining trend from lower reaches to middle reaches and upper reaches. The present investigation revealed that the concentration of sulphate was higher during pre-monsoon season (2142 mgL\(^{-1}\) in Tapi and 2074 mgL\(^{-1}\) in Narmada) followed by post-
monsoon season and the lowest during monsoon season (120 mgL\(^{-1}\) in Tapi and 48 mgL\(^{-1}\) in Narmada). The ratios of freshwater flow directly influence the sulphate concentration by its diluting nature (Rosenbauer et al. 1979). Similar sulphate concentration ranging from 497 mgL\(^{-1}\) to 1200 mgL\(^{-1}\) was reported by Mithra et al. (2011) from the lower Gangetic plains of West Bengal. The positive correlation of sulphate with salinity, pH and chloride indicates the marine water influence on this nutrient (Matson and Brinson, 1985). Beck et al. (2008) suggested that heavy fresh water inflow during monsoon might have lower the concentration of sulphate during monsoon season whereas less inflow and increased transpiration rate from estuarine zone resulted in increased concentration during pre and post-monsoon period. Beeton (1965) described the trophic status of water body based on the sulphate concentration. In the present study based on the sulphate concentration all sites of Narmada and Tapi are found to be eutrophic because of the high amount of sulphate contributed by marine water influx.

Primary productivity potential of the marine environments depends upon the phytoplankton, which alone contributes 90% of the total marine primary production. Thus chlorophyll-a which constitutes the chief photosynthetic pigment of phytoplankton, is an index that would provide the primary production potential upon which the biodiversity, biomass and carrying capacity of that system depends upon (Sarma et al. 2006). In Narmada and Tapi the maximum values of Chlorophyll-a were reported from upper reaches. In Narmada chlorophyll-a was observed in the range 0.12 mgm\(^{-3}\) to 9.5 mgm\(^{-3}\) whereas in Tapi it was in the range 0.23 mgm\(^{-3}\) to 15.4 mgm\(^{-3}\). The higher concentration of chlorophyll is reported during post-monsoon period and it might be due to the higher phytoplankton abundance during this period. Sridar et al. (2006) reported similar chlorophyll-a concentration in lower reaches (0.28 mgm\(^{-3}\) to 1.48 mgm\(^{-3}\)) in the Palk Bay of south coast of India. Prasannakumar et al. (2000) from their studies on plankton productivity of Bay of Bengal, suggested that high phytoplankton production during post-monsoon period could be attributed to the upwelling that brings the nutrient rich deeper water to the surface and as riverine run-off during monsoon period. Low concentration of chlorophyll-a was observed
during pre-monsoon period. Madhuprathap et al. (2001) also observed a sharp decline of chlorophyll-a value in Arabian sea during pre-monsoon period. They suggested that this fall in chlorophyll-a value might be because of less freshwater inflow and precipitation which makes the habitat unsuitable for phytoplankton. Senthilkumar et al. (2008) reported that the positive correlation of chlorophyll-a with nitrate, phosphate and DO specifies the freshwater influence on phytoplankton productivity particularly at the upper reaches.

Multivariate statistical techniques have been applied to characterize and evaluate surface water quality, since they are useful in verifying temporal and spatial variations caused by natural and anthropogenic factors linked to seasonality (Kowalkowski et al. 2006). The application of multivariable statistical methods offers a better understanding of water quality for interpreting the complicated data sets (Pradhan et al. 2009). Principal component analysis (PCA) is one of the best statistical techniques for extracting linear relationships among a set of variables. Principal components are the linear combinations of original variables and the eigenvectors (Iyer et al. 2003). In the present study a total of three principal components were obtained after analysis, each explained the variation in hydro-chemical and geochemical properties of estuaries. In Narmada estuary, three principal components explained 91.23% of variation observed during 2009-10 and 81.17% variation during 2008-09. In Tapi estuary Principal components explains more than 85% of variation during the study period. In both the estuaries Principal Component 1 found to explain more than 60% of the cumulative variance.

In Narmada estuary Principal Component 1 explained the variance with strong positive loading by pH, salinity, sodium, potassium, sulphate and EC indicating the marine water influence in contributing these nutrients. Component- 2 was positively loaded with DO, phosphate and ammonia indicating release of these nutrients through urban, industrial run-off and riverine influence on this component. Study on the water quality of Reconquista river by Castane et al. (2006) revealed the river water influence on contributing ammonia and phosphate in to Principal components. The
clustered occurrence of closely related groups in component plot diagram indicated the close association between each parameters as well as the source of these nutrients (Pardhan et al. 2009). This is further supported by correlation analysis which revealed a close association between parameters like DO, phosphate, nitrate, silicate, ammonia and chlorophyll-a in fresh water dominated sites and sulphate, chloride, salinity, sodium and potassium in marine water influential zones.

5.2. Geo-chemistry

Sedimentary deposits, or muds, are a most characteristic feature of estuaries, and indeed the estuarine ecosystem has been defined as a mixing region between sea and inland water that the net resident time sedimentary materials exceeds flushing. Sedimentary materials are transported into the estuary from rivers or the sea, or are washed in from the land surrounding the estuary (Mclusky, 2004). Estuaries are generally rich in nutrients and the presence of suspended sediments in estuaries may cause substantial modifications to supply of nutrients which results in increased overall recycling efficiency of nutrients (Corbett, 2010). Analysis of geochemical properties helps to evaluate the anthropogenic impact on aquatic ecosystems as their role in accumulation of contaminants and nutrients for bioavailability in aquatic systems (Golterman, 2000). The exchange of nutrients between sediment and water depends upon the sediment type, aerobic and anaerobic conditions, biotic community of water, temperature and tidal influences (Golterman, 2005).

Temperature plays a major role in controlling various physicochemical processes, distribution of organisms, nutrient cycling...etc (Tabuchi et al. 2010 and Gudasz et al. 2010). In the present study sediment temperature was observed high during pre-monsoon period followed by post-monsoon and monsoon period. The temperature was reported in the range from 19°C to 29°C in Narmada estuary and 20 °C to 30 °C in Tapi estuary. Higher sediment temperature was observed at lower reaches than upper reaches. Jackson and Richardson (2002) proposed that seasonal variation in reception of solar radiation is the main factor behind observed spatial and temporal change of temperature while working on Fort Walton beach of Florida.
The study of distribution and behaviour of various forms of phosphorous in sediments has significance to understand the dynamic cycling of phosphorous in estuary and bay water areas, induced by wastewater discharge and the phosphate exchange across the sediment-water interface (Min et al. 2003). Mesnage and Picot, (1995) observed that sediments act as reservoir for various nutrients like phosphate or as a source when this phosphate is released under certain conditions. In the present study, sediment phosphate concentration was observed maximum at middle reaches and upper reaches particularly during pre-monsoon and post-monsoon period. Mean phosphate concentration obtained in Narmada estuary was 0.59 mgKg$^{-1}$ and in Tapi estuary it was 0.53 mgKg$^{-1}$. Comparable results were reported by Pant and Reddy, (2001) from Indian river lagoon, Florida where mean phosphate concentration was 0.75 mgKg$^{-1}$. In Tapi, sediment phosphate was found to exhibit positive correlation with organic carbon indicating more anthropogenic contribution of this nutrient as compared to Narmada estuary. Organic effluents released from industrial and domestic purposes followed by its accumulation might be the reason for higher phosphate concentration especially during pre-monsoon and post-monsoon period (Howell, 2010). Salinity plays a major role in adsorption-desorption properties of phosphate which along with tidal forces have a major role in release of phosphate ions in to water (Millero et al. 2001) which might be the cause of low phosphate concentration during pre-monsoon period and in the lower reaches.

The knowledge of the sources of organic matter in estuarine and coastal sediments and factors controlling their distribution are important in understanding of global biogeochemical cycles. In these transitional systems, primary production generates large amounts of organic matter of which a significant portion sinks and ultimately gets preserved in sediments (Hu et al. 2006). In Narmada and Tapi estuarine areas higher concentration of organic carbon was encountered from upper reaches where more anthropogenic activities including diverse inputs from fall, stream flow, inappropriate animal waste applications and disposals, agricultural practices etc occur. In the present study the organic carbon was observed in the range
0.03 mgKg⁻¹ to 0.6 mgKg⁻¹ in Narmada estuary and 0.03 mgKg⁻¹ to 0.86 mgKg⁻¹ in Tapi estuary. The sediment samples from the upper reaches of the estuaries through which urban wastes from the Bharuch and Surat cities, carried higher amounts of organic carbon. This could be because of some natural biological processes and human activities like diverse inputs from fall, stream flow, inappropriate animal waste applications and disposals, agricultural practices, etc. which results in elevated content of organic carbon in sediments (Moore and Jackson, 1989). Bragadeeswaran et al. (2007) also observed high concentration (0.53 mgKg⁻¹ to 1.12 mgKg⁻¹) of organic carbon during pre-monsoon period while studying sediment texture and nutrients of Arasalar estuary, India. Ghosh and Choudhury (1989) explained that sediment texture also plays a major role in retaining the organic components. As the texture decreases it can hold more organic matter which probably explains the higher percentage of organic carbon in upper reaches. Kumary et al. (2001) on basis of study on Poonthura estuary reported that the level of organic carbon in sediments is a reliable index of nutrient regeneration and the productivity of a water body. The study also suggested that oxidation-reduction activities at the sediment-water interface bear marked influence upon the estuarine chemistry and upon the type of organism present in the sediment.

The concentration of sodium, potassium and chloride was observed higher at lower reaches, which possibly explains the role of marine water influence in contributing these nutrients in sediments. Mackereth (1965) suggested that the increased concentration of these nutrients during summer season may be due to the low fresh water inflow followed by high transpiration rate in both the estuaries. Sodium, potassium and chloride were found to be positively correlated with each other indicating the marine water influence on contributing these nutrients into estuarine sediments (Jordan et al. 2000). Ramanathan et al. (1988) reported that due to mixing of sea water with estuarine water, saline water gets enriched in interstices of sediments and gets precipitated in pre-monsoon months resulting in increased concentration during pre-monsoon and post-monsoon reason.
Principal component analysis of geochemical properties revealed that three principal components were responsible for variation among the estuarine regions. In Narmada estuary three Principal components were found to be responsible for 88.62% and 85.31% during 2008-09 and 2009-10 respectively, in Tapi it was observed 86.41% and 84.96% respectively during 2008-09 and 2009-10. As observed in water analysis, the influence of marine water on PC1 for sediment is evident from the strong positive loadings of sodium, potassium and chloride. In the present study principal component two explains strong positive load of phosphate and organic carbon indicating the freshwater influence in contributing these nutrients. Vaalgamaa and Conley (2008) carrying out PCA analysis of nutrient status of estuaries in Finland, stated that the concentration of phosphate, organic matter can be better correlated with the urban land-use type and industry together with the anthropogenic discharges. Study carried out by Wenchuan et al. (2001) also revealed the influence of anthropogenic influence in contributing nutrients into estuarine sediments by multivariate analysis studies of Taihu Lake in China. Rajasegar et al. (2002) suggested that positive correlation of sodium, potassium, indicated the strong association between these parameters in the sediments.

5.3. Biotic components

One of the major characteristics of an estuarine zone is mixing of turbid, nutrient rich and colored river discharge with relatively clear and nutrient-poor ocean water. The result of this mixing is the creation of continuum in salinity and the availability of nutrients and light. These gradients strongly influence the spatial and temporal distribution and abundance of plankton in estuaries (Quinlan and Philip, 2007).

5.3.1. Phytoplankton

Estuarine phytoplankton communities usually comprise several taxonomic groups, and contribute to primary production and interaction between trophic levels (Roy et al. 2006). Jouenne et al. (2007) stated that phytoplankton composition varies with season and this can be ascribed to variation in nutrient access, light and temperature. Rey et al. (2004) suggested that besides their importance as the primary
producers in food webs and ensuring ecological balances, species of phytoplankton can be useful indicators of water quality. Kitner and Poulickova (2003) carried out studies on use of diatoms as indicators of eutrophication in some shallow lakes of Czech Republic. Morais et al. (2003) stated that the dynamics of phytoplankton are a function of some environmental factors like salinity, temperature and nutrients that can affect species diversity and distribution. As demonstrated in other geographical areas and variety of habitat types, fresh water influence is known to have profound effect on phytoplankton biomass, productivity and community composition (Harnstrom, 2009). Short term phytoplankton blooms are often triggered by differences in salinity or from the resultant water column stratification. Indeed in some areas, temporal changes of the phytoplankton community are very dynamic because of short term tidal variability; but other factors, such as zooplankton grazing and exchange between sediment and water column, also affect species diversity (Carstensen, 2007). The species composition, biomass, relative abundance, spatial and temporal distribution of phytoplankton are an expression of the environmental health or biological integrity of a particular water body (Khattak et al. 2005; Eletta et al. 2005).

Phytoplankton communities in marine tropical areas are known to be less dynamic than in temperate waters, from an annual perspective, with smaller seasonal variation in net phytoplankton growth (Qasim et al. 1972). In the present study, phytoplankton assemblage was observed higher at upper and middle reaches in both Narmada and Tapi estuarine regions where there is a dominance of fresh water. In Narmada estuary a total of 48 species belonging to 31 genera were observed during the entire study period. The phytoplankton was represented by five dominant groups viz. Cyanophyceae, Chlorophyceae, Bacillariophyceae, Euglenophyceae and Dinophyceae. The genera present in different groups were Cyanophyceae (6 genera), Chlorophyceae (7 genera), Bacillariophyceae (13 genera), Euglenophyceae (2 genera) and Dinophyceae (3 genera). In Tapi estuary 66 species belonging to 37 genera were observed during the study period. The genera present in different groups were Cyanophyceae (6 genera), Chlorophyceae (7 genera), Bacillariophyceae (19 genera),
Euglenophyceae (2 genera) and Dinophyceae (3 genera). Bacillariophyceae was found to be the most dominant group followed by Chlorophyceae, Cyanophyceae, Dinophyceae and Euglenophyceae. Nabout et al. (2006) also observed the predominance of Bacillariopycean members followed by Chlorophycean and Cyanophycean members during his study on phytoplankton community of Brazilian lakes which was in relevance with our present study. Redekar and Wagh (2000) from their studies on Bacillariopyceans of Zuari coast of India concluded that salinity has a direct influence on distribution of Bacillariopycean members which supports the predominance the group than other groups in our study. Palleyi (2011) observed that in Dhamra Estuary phytoplankton of Bacillariophyceae appeared throughout the year and represented in majority of population (75-94%) at all the sampling stations, followed by Dinophyceae (3-14%), Cyanophyceae (3-8%) and Chlorophyceae (0-4%) classes, these results corroborated with our present study. Seasonal variations of phytoplankton in Mahanadi estuary, east coast of India was worked out by Naik et al. (2009) which revealed Bacillariophyceae to be the most dominant group followed by Dinophyceae and Cyanophyceae as observed in our present study. The maximum phytoplankton count was observed during post-monsoon season by Naik et al. (2009) which was also found in similar trend with our results.

During the present study Bacillariophyceae emerged as the most dominant group comprising of 19 genera. Ekeh and Sikoki (2004) also reported class Bacillariophyceae to be the most abundant group of phytoplankton among many tropical estuaries. Perumal et al. (2009) also recorded more than 50 percent of Bacillariophycean members in their studies of phytoplankton diversity of Kaduviyar estuary. Bacillariophycean members can be used as suitable bio-indicators for water quality assessments as they have short generation time and many species have a specific sensitivity to ecological characteristics (Stevenson and Pan, 1999; Goma et al. 2005). During present study, both the estuaries showed highest density and diversity of Bacillariophycean members at middle reaches and lower reaches. This may be due to the role of salinity in their distribution (Redekar and Wagh,
The Bacillariophycean members reported in Narmada and Tapi estuaries were *Eunotia amphioxys*, *Pleuromamma aeustuarri*, *Amphipora alata*, *Amphora elliptica*, *Biddulphia mobilens*, *Chaetoceros affinis*, *Chroococcus gigantium*, *Coscinodiscus marginatus*, *Cymbella Cistula*, *Fragilaria crotonensis*, *Leptocylindrus minus*, *Navicula amphirhynclius*, *Nitzschia amphibian*, *Synedra ulna*. Salomoni et al. (2006) working on phytoplankton of Gravatai river recorded the presence of Bacillariophyceae such as *Nitzschia, Eunotia, Pinnularia* and described them as indicators of organic pollution. They also reported them as pollution tolerant species. Palleyi (2011) observed that nutrients like phosphate, nitrate and silicate have significant role in distribution of Bacillariophycean group in estuarine environment. Thessen et al. (2005) reported diatoms to be prominent during the pre-monsoon and post-monsoon where there was a dominance of marine water in the estuarine region and the results were found to be corroborated with our studies. Tiwari and Nair (1998) and Senthilkumar et al. (2002) supported the dominance of diatoms in near coastal waters in west coast of India. This was reflected during the present study too, diatoms were found to flourish at mouth of both the estuaries due to hydro-chemical conditions.

The Chlorophyceae is the second largest and important group of freshwater green algae. It includes some of the most common species, as well as many members that are important both ecologically and scientifically. The Chlorophyceans were represented by 7 genera and the dominant members found during the study period included * Ankistrodesmus, Spirogyra, Clorella, Closterium and Scenedesmus.* In the present study the dominance of Chlorophycean members was found in the upper and middle reaches of estuary. Similar results in Nigeris estuary were reported by Ekwu and Sikoki (2006) where the dominance of Chlorophyceans was observed in middle and upper reaches of estuary. In present study the density of Chlorophycean members was found higher in upper reaches of Narmada estuary than in Tapi which might be due to freshwater dominance and less saline water intrusion in the area. Dissolve oxygen, pH, alkalinity play a significant role in distribution of Chlorophycean members in freshwater zones (Rajagopal, 2010). Rao and Pragada (2010) reported...
that the absence of Chlorophyceans forms in the lower reaches indicated the influence of salinity on the distribution of Chlorophyaceae members. The Chlorophyceans were reported to be dominant during winter season, as also reported by Tiwari and Chauhan (2006), that might be due to high DO, high nutrient status and slow water current during this period. The growth of certain green algae (Scenedesmus, Ankistrodesmus falcatus and Chlorella vulgaris) is favored by higher concentration of nitrate and phosphate in water (Thomas et al. 2006) and hence these species are designated as pollution indicators (Nagarathna and Hosmani, 2002).

Cyanophyceae is one of the major groups of phytoplankton which is mostly confined to the freshwater zones. The relative abundance of Cyanophycean members may be a function of nutrient (N:P) ratios in water bodies (Smith, 1983). The occurrence of this group could be attributed to the high temperature, slightly alkaline conditions and nutrient rich freshwater discharge, turbidity due to suspended sediment which favours the growth (Harsha and Malammanavar, 2004). In the present study the occurrence of Cyanophycean members was reported from upper and middle reaches of both estuaries. A total of 6 genera were observed during the current study period. The main species representing the genera are Oscillatoria, Spirulina, Microcystis, Anaebena, and Merismopodium. The density was observed the highest during post-monsoon period in the upper reaches. Salinity plays a major rôle in determining the distribution of Cyanophycean members in an estuarine ecosystem (Evagelopoulos et al. 2009) which explains the dominance of Cyanophycean members in upper reaches when compared to lower reaches. Ning et al. (2000) observed high abundance of Cyanobacteria, but their contribution to the total phytoplankton community was relatively small in estuaries, which is substantiating the results of present study. Constant input of waste water not only contains waste of organic nature but also contains silt and other pollutants which might also be attributed to higher Cyanophycean at upper reaches, this is in agreement with Saxena and Shrivastava (2001), while studying the sewage fed Shahpura lake of Bhopal. Muhammad et al. (2005) and Tas and Gonulol (2007) have suggested spatial differences in distribution of blue green algae which may occur due to high organic
pollution load leading to nutrient rich condition. The Cyanophyceae group was found to be the third dominant group among all phytoplankton and the highest density was observed during post-monsoon period. The observed results were found to be corroborated with studies conducted by Rao and Pragada (2010) in backwaters of Godavari estuary where they reported the dominance of Cyanophyceae in post-monsoon period. The distribution of Cyanophyceae in the present study also showed similarity with results obtained by Sassi (1991) in which the dominance of Cyanophycean were observed in post-monsoon period particularly in the upper reaches.

The Class Dinophyceae is a large group of flagellate protists. Most of them are marine plankton, but they are common in fresh water habitats as well. Their population is distributed depending on temperature, salinity, or depth. In the present study Dinophyceae were observed in more density in Tapi estuary compared to Narmada estuary. Present study reported 3 genera belonging to genus Peridinium, Gymnodium and Ceratium from the study sites. The distribution is regulated by salinity, temperature and pH as their occurrence is more in areas having significant marine water influence (Cremer et al. 2007). Studies carried out at Cross river estuary of Nigeria by Ekwu and Sikoki (2006) observed Dinophycean to be the least dominant group and mostly reported from lower reaches which shows similarity with our results. Dinoflagellate community was appeared relatively less in abundance in the estuaries throughout the year as compared to the diatoms and other groups. This might be due to the preferential oligotrophic nature of dinoflagellate and their competition with diatoms (Cushing, 1989).

The Euglenophyceae is basically a group of unicellular flagellates. The abundance of Euglenophyceae members in a water body can be attributed to the entry of nutrients through the influx of domestic sewage which is an indication of organic pollution (Kumar and Hosmani, 2006; Laskar and Gupta, 2009). In the present study the group Euglenophyceae was represented by Euglena and Phacus genera. The representatives of class Euglenophyceae inhabit freshwater basins as well as marine
It is established that macro-algae of this class develop widely in waters with high concentration of organic matter and basins subjected to anthropogenic eutrophication (Lee, 1999). Over 10% of the species are used as indicators of water saprobility (Kiriakov, 1987). In Narmada and Tapi estuaries Euglenophycean members were observed at upper and middle reaches where there occurs more anthropogenic pollution as compared to lower reaches. Their occurrence and distribution is mostly reported during post-monsoon and pre-monsoon period where the freshwater flow is low. Tiwari and Chauhan (2006) also observed similar temporal variation in Euglenophycean distribution at Kitham lake, Agra. A higher number of Euglenophycean species was recorded in upper reaches of Tapi that might be due to increased water temperature and nutrient status, mainly because of increased anthropogenic discharges (Nwankwo, 1995). High carbon dioxide content and oxidisable organic matter with low oxygen content favors the abundance of Euglenophytes (Munawar, 1970).

Biological assessment is useful for measuring the ecological quality of aquatic ecosystems since biological communities integrate the environmental effects of water chemistry. Phytoplankton encountered in the water body reflects the nutrient condition and therefore, may be used as an indicator of water quality (Jafari and Gunale, 2006). In the present study Palmer pollution index was used to determine the ecological quality based on phytoplankton composition. The results revealed that in Narmada estuary Zadeshwar and Bhadbhut were found to be highly organic polluted whereas Ambata was less organic polluted. In Tapi all three sites were observed to be organic polluted based on phytoplankton occurrence. In Narmada estuary the sites at upper and middle reaches tend to receive more organic load due to increased anthropogenic interventions at this area. In Tapi river, Surat city and areas at upstream releases much organic waste making the sites heavily organic polluted. Studies carried out by Jafari and Gunale (2006) on assessment of freshwater pollution index using Palmer and Niggard’s indices with special reference to phytoplankton reported high organic pollution in upper and middle reaches.
Evaluation of pollution in the lake Masunda, Thane by Somani and Pejaver (2007) revealed similar findings which corroborated with our present results.

A diversity index is a statistics, which is applied to measure the species biodiversity in an ecosystem. A stressed environment typically has a lower number of species with one or two dominant species (those adapted to the stress) having many more individuals than the other species (Gao and Song, 2005). During the post monsoon season, as a result of fresh water flushing and changes in salinity, the estuarine region experiences the most dramatic change in phytoplankton species composition, as is evident from the diversity index data. In the present study the diversity of phytoplankton community among three sites was estimated by Shannon's diversity index ($H'$). In upper reaches of both the estuaries the diversity index ranged from 2.00 to 4.20 which revealed high species biodiversity among the study sites. Harnstrom et al. (2009) suggested that tidal influence experienced in the estuarine region act as a major factor in distribution of species along the salinity gradient.

Canonical Correlation Analysis (CCA) was aimed to find the relationship between environmental variables and phytoplankton distribution (Ariyadej, 2004). In the present study phytoplankton have shown a positive correlation with salinity value at all the sampling stations because estuarine regions are subjected to considerable fluctuations and these micro flora were well adapted to such dynamic environment (Lionard et al. 2005). Phytoplankton needs a wide variety of chemical elements but the two critical ones are nitrogen and phosphorous (Dawes, 1981). In the present study it was registered that phytoplankton showed positive correlation with phosphate and inorganic nitrogenous nutrients but the relationship was not very significant. This may be due to lower concentration or may be rapid recycling of these nutrients. Similar observations were made by Steinhart et al. (2002) on southern Chilean lakes and Hergenrader (1980) in salt valley reservoirs, California where they have reported the positive correlation between phytoplankton and nitrogenous organic nutrients. Dawes (1981) had reported a negative relationship of phytoplankton with temperature and turbidity which supports our present observed results. Studies carried
"Environmental studies on biotic components in relation to nutrient status of selected sites of Narmada and Tapi estuaries, Gulf of Khambhat, Gujarat, India".

out by Yi and Cai (2011) suggested that the occurrence of Cyanophycean and Chlorophycean members were directly proportional to the concentration of dissolved inorganic nitrogen and phosphate which corroborated with our studies.

Most of the species found to be correlated with the environmental variables, and this might be due to cosmopolitan characteristic of the species which indicates the species tolerance to large range in water quality (Bonilla et al. 2005). A negative correlation was observed for Cyanophycean members like Oscillatoria perornata and Merismopedium glauca with environmental variables like chlorophyll-a and silicate. Most of the species belonging to Bacillariophyceae showed a positive correlation with environmental parameters like chlorophyll-a, silicate and phosphate. Chlorophycean members like Ankistrodesmus flactus, Closterium acerosum and Spirogyra indica showed a positive correlation with nitrate, DO and ammonia. Similar results were also obtained by Ye and Cai (2011) for their assessment on spring phytoplankton bloom of Xiangi Bay.

Navicula amphirhynclus and Navicula radiosa showed a positive correlation with pH and salinity which may have prominent effect on its distribution. The close association of salinity and pH revealed the effect of tidal influence in the estuarine area. Temperature was found to have a positive relation with Clorella vulgaris and Merismopedium punctata. However, the negative correlation of temperature with ammonia and silicate showed the freshwater influence on these nutrients during post-monsoon season. Navicula cuspidate, Surirella nervosa, Thalassionema nitzschioides, Amphiprora alata, Amphora ovalis, Coscinodiscus marginatus and Amphora elliptica showed a positive correlation with chlorophyll-a, silicate and phosphate which indicates the significant role of these parameters in phytoplankton distribution (Harnstrom et al. 2009). Anaebena anomala, Nitzschia amphibian and Gymnodium sp. showed a negative correlation with inorganic nutrients, which showed their adaptability to a wide range of variations in physicochemical properties (Varis, 1991).
Zooplankton are group of animal organisms that drift with current. By virtue of sheer abundance and intermediary role between phytoplankton and fish, they are considered as the chief index of utilization of aquatic biotope at the secondary level. The zooplankton can be used as the indicator organisms for the physical, chemical and biological processes in the aquatic body. They occur at different depths and constitute a complicated ecological system (Howe and Jones, 1986).

The estuarine zooplankton species have to be highly adaptive and are reported to show mechanisms to detect changes in salinity and DO. The physico-chemical boundaries play a significant role in the distribution of zooplankton in the sea as there are strong gradient in the terms of light, temperature and salinity from surface to bottom layers (Colebrook, 1982). The zooplankton exhibited uneven distribution along the horizontal and vertical planes. The zooplankton are dispersed according to the scale of water turbulence. The intensity of zooplankton aggregation will depend on their ability to counter dispersion, phytoplankton growth, grazing rates, predatory/prey relationship and reproduction strategies of zooplankton (Robin et al. 2009). Zooplankton also play an integral role by serving as bio indicators and is a well-suited tool for understanding water pollution status (Contreras et al. 2009).

In the present study of Narmada estuary a total of 37 species belonging to 29 genera of zooplankton, Protozoa (4), Rotifer (7), Cladocera (3), Copepoda (9), Chaetognatha (1) and larval forms (8) were reported. In Tapi estuary a total of 29 zooplankton and 35 species belonging to groups viz., Protozoa (4), Rotifer (2), Cladocera (4), Copepoda (7), Chaetognatha (1) and larval forms (8) were registered. Zooplankton density was reported maximum during pre-monsoon period in both Narmada and Tapi estuaries. Upper reaches was found to harbour maximum population density than middle and lower reaches in both the estuaries. In the present study the low density of zooplankton occurred during monsoon period that might be due to the mixing and dilution effect of run-off water along with change in
Environmental studies on biotic components in relation to nutrient status of selected sites of Narmada and Tapi estuaries, Gulf of Khambhat, Gujarat, India.

Environmental variables like salinity, temperature and nutrient concentration (Madhu et al. 2007). Multivariate analysis of Mission Bay hyper saline estuary was carried out by Elliot and Kaufmann (2007) which revealed that variation in zooplankton species composition was best related to measured abiotic factors (temperature, salinity, rainfall and tidal velocity) that shows resemblance with our observed results.

**Copepoda** was the most dominant group among the zooplankton group reported. Current study has reported 9 genera from Narmada estuary and 7 genera from Tapi estuary. The major species representing this group are *Acartia erythraea*, *Calanus sp.*, *Diaptomus sp.*, *Mesocyclops*, *Paracalanus sp.*, *Eucalanus sp.* and *Pseudodiaptomus sp.* The maximum density of copepods was observed during pre-monsoon period and minimum density during monsoon period. The dominance of species suggests the significant role in trophic food web and studies showed that most of the copepods are either herbivorous or omnivorous (Mathupratap, 1979). The increase in copepod density during pre-monsoon season could be also suggestive of their active grazing of phytoplankton independently or in combination with microzooplankton because the herbivorous copepods are capable of grazing up to 75% of the phytoplankton in a tropical estuary (Tan et al. 2004). Similar results were also obtained by Padmavathi and Goswami (1996) in Mandovi and Zuari estuaries and Sastry and Chandramohan (1990) in Godavari estuary. CCA analysis revealed that *Acartia erythraea* to be positively correlated with phosphate, nitrate and DO indicating its dominance in upper reaches and middle reaches whereas, *Calan anus* and *Chydorous* showed close association with salinity, sodium and potassium which supports its existence in lower reaches. Similar results were observed by Tackx et al. (2004) from Schelde estuary of Belgium on their study on spatial and temporal patterns in zooplankton distribution in which they have reported the dominance of copepods along the lower reaches.

**Rotifers** were found to be the second dominant group among zooplankton comprising of 7 genera. Rotifers are the most sensitive bio-indicators of water quality and their presence may be used as a reference to the physico-chemical characteristics.
Environmental studies on biotic components in relation to nutrient status of selected sites of Narmada and Tapi estuaries, Gulf of Khambhat, Gujarat, India."

of water (Saksena, 1987). The members of this group were represented mainly by *Brachionus sp*, *Keratella sp.*, *Ploesoma sp.* and *Rotaria sp.* In Narmada middle reaches reported the highest density while in Tapi the highest density was observed at upper and middle reaches. Kruger and Strydom (2011) has reported that salinity has a prominent role in determining the distribution of Rotifers along salinity gradient. Canonical correlation analysis showed that phosphate, nitrate, chlorophyll-a, DO have significant role in determining the distribution of rotifers (*Keratella sp.*, *Ploesoma sp.* and *Rotaria sp*) in Narmada and Tapi estuarine regions (Tasevska, 2010). Summer peak obtained for Rotifera members at both estuaries may be due to optimal nutrient concentrations and temperature conditions and low DO contents in this season (Padmanabha and Belagi, 2006). Okogwu et al. (2010) suggested that low rotifer density during the rainy season can be attributed to turbulence generated by the excess water flow during this season.

Cladocerans are major group of zooplankton thriving in freshwater as well as marine water zones (Mialet et al. 2011). In the present study a total of 4 genera were reported which includes *Alonella, Bosminia, Keratella* and *Daphnia*. In tropical environments, rain and wind action are the major forces influencing Cladocerans population structure, promoting the water column mixing, and stimulating nutrient cycling (Sampaio et al. 2002). In the present study highest density of Cladoceran population was observed at upper reaches and middle reaches of Narmada and Tapi estuaries. Moreover, the highest density was observed during pre-monsoon period. Ojha et al. (2007) reported that dominance of Cladocera among zooplankton during summer peak might be due to optimal thermal and nutritional conditions and lower concentration of oxygen. Species like *Daphnia, Keratella* recorded to be positively influenced by salinity where as species like *Bosminia* was regulated by changes in fresh water. Mikhailova and Isupova (2007) stated that spatial variation was influenced mainly by morphometrical characteristics of the estuary while, temporal variation by climatic changes during the sampling period, especially water inflow and water temperature in tropical regions. Seasonal and temporal variation of species
richness and population densities described in this study could be due to alterations in the hydrological and biological characteristics of the estuary (Ghidini, 2009).

In the present study *Acrella, Golbigernia, Polystomella* and *Vorticella* are the dominant protozoan species registered from Narmada and Tapi estuarine region. The maximum density was observed during post-monsoon period in upper and middle reaches. Moreover, CCA analyses revealed a positive correlation of *Golbigernia* and *Polystomella* with physicochemical parameters like nitrate, phosphate and ammonia. Protozoans can be used as a suitable bio-monitoring agent especially in water quality determination (Ricci, 1995). Moderate numbers of protozoan member representatively obtained upper reaches of estuaries may be indicative of mild pollution (Sharma et al. 1999) at these areas.

**Chaetognaths** play an important role in marine food webs, being active predators. Their diet includes a variety of pelagic organisms, consisting mainly of copepods, but they may also prey on fish larvae thus impacting the zooplankton and ictioplankton communities (Casanova, 1999). Current study revealed the occurrence of only one genus (*Sagitta*) along the study sites of both estuaries. Chaetognaths are mainly found in zones where marine water influence is higher. In the present study the species belonging to this group were reported only from lower reaches in Narmada estuary and from middle and lower reaches in Tapi estuary. The results obtained in the present study shown that the Chaetognath species found in the estuarine area are due to the tidal effect, not being typical residents (Casanova, 1999). This was further supported by CCA, in which *Sagitta* has shown a positive correlation with salinity. The dominance of this group was observed at pre-monsoon season which is very well corroborated with the studies of Fernandes et al. (2005) in a tropical estuary of southern Brazil.

Zooplankton diversity index like Shannon-Weaver species diversity (H'), Marglef species richness (d) and Pielou’s evenness (J) were recorded higher at middle reaches followed by lower reaches and upper reaches. Wang et al. (2011) on studies
conducted in Zhanjiang harbour water observed maximum Shannon-Weaver diversity during pre-monsoon and post-monsoon period at upper reaches which corroborated with our present results. Khalil and Rahman (1997) on their studies on zooplankton of Gulf of Aqaba, Egypt also registered higher diversity index and spatial distribution as evident from our studies. Are et al. (2010) reported the role of marine water in distribution of marine zooplankton which might be a reason for maximum diversity at upper reaches followed by middle and lower reaches.

5.3.3. Benthic organisms

Benthic invertebrate communities are integral components of both freshwater and estuarine systems. The benthos — those organisms that live on or within sediments — influence sediment and bottom-water chemistry, alter sediment organic and structure and serve as major prey species for crustaceans and fish (Borja, 2008). Estuarine benthos typically includes Nematode worms, Polychaeta worms, Amphipods, Crustaceans, marine gastropods, and marine Molluscs. Most aquatic habitats particularly free flowing streams and water with acceptable water quality and substrata conditions, support diverse benthic communities in which there is a reasonably balanced distribution of species among the total number of individuals. Such communities respond to changing habitat quality by adjustment in community structure (Chainho et al. 2007). The number of group differs, however, from place to place due to the interaction of factors such as sediment type and composition (Warwick and Gee, 1984; Austen and Warwick, 1989) and availability of food (Moens et al. 1999).

Salinity is the major natural environmental factor controlling regional distributional patterns of the estuarine benthos. Differences in sediment characteristics and levels of bottom dissolved oxygen concentrations that occur from shallow to deep habitats control local benthic distributions. Sediment nutrient compositions like phosphate, organic carbon have a positive role in determining the distribution of benthic organisms (Martin, 2011). In the present study of Narmada estuary, Crustacean members were found to be the most dominant followed by
species of Mollusca and Foraminifera. Species of Nematode are the least represented group with only 5% of total proportion. In Tapi estuary Mollusca was encountered to be the most dominant group contributing about 52% of the total benthic organisms. Crustacean forms the second dominant group with 21% composition followed by Nematodes and Polychaeta. Similar results were obtained by studies conducted by Kastoro (1989) in the estuarine waters of East Java and Giberto (2007) in the Rio de la Plata system.

Due to their economic and ecological importance, as well as sedentary life, molluscs have assumed to have a major role in monitoring contaminants worldwide (Feldstein et al. 2003). Bresler et al. (2003) reported molluscs to be abundant, sedentary and easy to collect, which makes them ideal for bio-monitoring. Bivalve and molluscs are among the most useful organisms for environmental monitoring (Boening, 1999). In Narmada and Tapi the highest number of Molluscsans were reported from middle and lower reaches. A total of 12 species dominated by Bullia, Busycon, Campelpma, Dosinia, Lymnaeae, Torbo, Pomacea and Mactra were reported from the study sites. In the present investigation, specimens were found to occur on mud banks, mud flats, mangrove forest, sandy area, swamps and hard substratum such as wooden blogs, poles and pillars. Maximum species were collected from estuary banks and mud flats which might have deposited mainly by tidal waves. Peeters et al. (2000) from their studies on distribution of macro-invertebrate community along salinity gradient suggested that the sediment grain size, together with salinity and depth, acts as an important factor to explain the dominance of Molluscan community at lower reaches in the present study. Mucha et al. (2003) also observed similar results showing higher diversity of Molluscs in sediment rich zones. Nematoda group is the most representative meiofaunal group found in almost all aquatic environments. Current study has revealed the occurrence of Juvinile forms, nematode worms and Adenophorea from the study sites. The taxonomic diversity and sensitivity to pollutants makes it an important tool in studies into environmental disturbance (Platt et al. 1984). In estuarine environments, salinity is an important
factor determining the structure of Nematode communities (Soetaert et al. 1995). In the present study the maximum occurrence of this group was observed at lower and minimum was reported from middle reaches. Communities found on sandy bottoms are more resilient to natural physical disturbances, such as those created by currents and waves, than those found on muddy bottoms (Schratzberger and Warwick, 1998). In the present study nematodes were mostly recorded during monsoon and post-monsoon seasons. The highest diversity was registered in upper reaches followed by middle reaches and lower reaches. The environmental conditions found in the estuarine regions with lower hydrodynamics, a predominance of fine sand, a higher level of organic matter, higher mean levels of oxygen and pH, and total transparency, associated with shallow water, could favour the establishment of Nematodes (Kapusta, 2006).

Crustaceans are a group of animals that have a hard exoskeleton, jointed legs, and a segmented body that is bilaterally symmetrical. They are a very successful group of animals, distributed in a number of different habitats including marine, terrestrial and freshwater environments. The main species comprising the crustacean groups includes Alona, Balanus and Hemigrapus. In both the marine and freshwater environment, crustaceans may live in the benthos as well as in the pelagic zone (Akbulut et al. 2009). The distribution of crustaceans was encountered throughout the study sites with majority of organisms reported from upper reaches and lower reaches. The extreme diversity of adaptations in morphology, physiology, and way of life and reproduction to the different conditions probably enable crustaceans to establish themselves in almost any water body (Vernberg and Vernberg, 1983). In Narmada, members of crustaceans were registered the most dominant group. Species belonging to Acetes, Bosmina, Daphnia, Diaptomus were reported from the upper and middle reaches. While Uca lateral and Nematopaleomon were observed in Ambata only. The variety of adaptations of crustaceans to different habitats is also reflected in a variety of feeding mechanisms (Dorit et al. 1991 and Ruppert and Barnes, 1994). Moreover, in Tapi Crustaceae were reported to be the second dominant group and found mostly at middle and lower reaches sites during pre-monsoon and post-
The class Polychaeta contains most of the living marine species and in the current study it was mainly represented by Neris, Neritia and Polychaeta worms. Species of Polychaeta are an important component of benthic communities, because of their high species richness, their high biomass and density and their high level of tolerance to adverse effects (pollution and natural disturbance). Polychaeta are usually the most abundant taxa in benthic communities and have been most often utilized as indicator species of environmental conditions (Dean, 2008). In the present study the presence of species belonging to Neris and Neritia along the upper reaches and middle reaches are indicative of the pollution load experienced at these regions. The highest diversity was found in upper reaches followed by middle reaches in both the estuaries. Tomassetti and Porrello (2005) had reported that the organic content percentage in sediment have a positive role in distribution of Polychaeta species and the results were found to be corroborated with our findings. Jegadeesan and Ayyakannu (1992) also evaluated the seasonal variation of benthic fauna in marine zone of Coleroon estuary of south east coast of India and suggested that the occurrence of Polychaeta in upper reaches might also be due to the higher percentage of silt and clay along with organic matter in these sites.