V. DISCUSSION

5.1. Meteorology

5.1.1. Rainfall

The rainfall data indicated that the study area received maximum precipitation during monsoon season when compared to pre and post monsoon period. The amount of annual rainfall recorded in the study area was in the range of 2746.20 to 3860.10 mm with highest quantum of precipitation in 1994. The pattern of rainfall along the west coast of India revealed that a bulk of precipitation was recorded during the south west monsoon season. The post monsoon months experienced a moderately heavy rainfall and similar observations were made by Lingadhal (1995) Gowda (1996) and Raveesha (2007) from the same study area.

5.1.2. Air temperature

The annual air temperature fluctuated from 26.61 (1992) to 27.52°C (1996). The lower temperatures prevailed during the winter part of the year. The hottest climate conditions prevailed along this coast during pre monsoon as reported by earlier workers (Suresh, 1987, Lingdahl 1995, Gowda 1996 and Raveesha 2007). The fluctuation in the air temperature was closely related to the seasonal changes in the insulation, wind and precipitation.

The decadal differences of the annual air temperature showed an increase of 0.09°C with an average air temperature of 27.03°C from 1990-2000 and 27.11°C from 2001 to 2011. Air temperature is the single most widely used indicator of the state of the
global climate and the average temperature of the earth is 14\textdegree{}C. The average global temperature has warmed by more than 0.7 over the past century and at present warming rate is 0.2\textdegree{}C per decade (IPCC, 2000).

5.2. Hydrography

5.2.1. Water temperature

Water temperature influences organisms directly on the physiological parameters and indirectly to the changes in the physico-chemical properties of the water. Hence sea surface water temperature plays a vital role in the environmental studies. The decadal difference i.e. from 1990-2000 and 2001 to 2011 was found to be 0.05\textdegree{}C. The total annual average temperature fluctuated between 28.48 and 30.56\textdegree{}C with a difference of 2.08\textdegree{}C. Many authors reported similar observations with short term studies with annual variation of 2.90 to 6.20 \textdegree{}C in the coastal waters of Mangalore (Menon \textit{et al.} 1997, Kumar 1984, Reddy and Harihara 1986, Ramesh \textit{et al.}, 1992, Rajanna 1997, Mridula 1999, Ronald 2001, Raghavendra 2004 and Raveesha 2007). Surface water temperature displayed an oscillating pattern with the highest values coinciding with the strong El Nino Southern Oscillation (ENSO) during 1997 to 1998. During this warm period the surface water temperature was most affected from November to January. Trimodal temperature observed with shallower depth recording higher values. Similar tri model oscillation is observed by Mridula (1999) in the same area. Kumar (1984) and Rajanna (1997) both recorded tri model oscillation trend in their short period of study.

The first peak from 1993 to 1998 coincided with a drop in rainfall in the particular year and increase in temperature was clearly related to decrease in precipitation. In a
typical study of global SST variability, Moran et al. (1998) found that ENSO scale variability at periods of about 5, 4 and 2 years dominated sea surface temperature variability in the Pacific from 1901 to 1994 while they detected longer scale near decadal oscillations in the Atlantic and Indian oceans, none was statistically significant in the Pacific.

Chao et al. (2000) tentatively identified a 70 year mode in Pacific SST variability. Mestas-Nézet and Enfield (2001) found that ENSO accounted for 79% of the total variability. Analysis of longer time series resolve variability scales longer than decadal as expected and they found that the late 1970’s climate shift has warmed the eastern equatorial Pacific by about 0.5°C. Sridhar et al. (2006) recorded a variation of 27.5 to 32.0°C at Palk Bay and found that water temperature was influenced by rainfall and air temperature besides water currents and Shravanakumar et al. (2008) recorded a range from 21.8 to 33.5°C in Gulf of Kutchchh – Gujarat. Smita et al. (2010) recorded an annual range of 3.98°C with a pronounced variation from 26.90°C to 30.88°C in east coast of India.

5.2.2. pH

The total annual surface water pH variation during 1990-2011 ranged from 7.10 to 8.30 in 1991 and 2007 respectively. The decadal differences showed a variation of 0.25 decrease with an average pH from 1990-2000 being 8.35 and from 2001 to 2011 being 8.10. Benakappa (1980) while working in the coastal waters of South Kanara recorded pH values from 8.0 to 8.6, while, Kumar (1984), Ramesh (1989) Rajanna (1997) and Raveesha (2007) observed that pH values ranged from 8.2 to 8.8, 8.2 to 8.6, 8.12 to 8.14 and 7.69 to 8.60 respectively. Katti et al. (2003) recorded the pH values of 7.6 to 8.26 in
the coastal waters of Chitrapur. A probating trend was observed throughout the study duration with lowest values recorded at 12 m depth decreasing in 1994. This coincided with the increase trend of water temperature and the decrease decadal annual variation of pH clearly indicating about the climate change. Chen-Tuang et al. (2008) observed a decadal difference of 0.1 units from 1920 to 1997 and also predicted further decrease by 0.1 units by 2050 in South China Sea.

In the present study, at all the depths, the oscillation was same and no clear trend was observed. Same observation without any trend was also observed by Smita et al. (2010) along Kalpakanm coast, Karolina et al, (2009) in Mangalore coast, Kadam et al. (2011) in west coast of India. You-Shao et al. (2006) observed pH variation of 8.12 to 8.24 for 4 years in Daya Bay, China no trend was observed in his study.

5.2.3. Salinity

The annual average surface water salinity ranged from 29.67 to 35.23 ppt. Deeper due to freshwater inflow at the lower depths. The decadal differences exhibited a decrease of 1.65 ppt with average surface water salinity of 33.22 ppt from 1990-2000 and 31.56 ppt from 2001 to 2011. Rajanna (1997) recorded annual difference of 2-3 ppt along the same coast, Goswami and Padmavathi (1996) recorded an annual difference of 1.7 ppt in the coastal waters of Goa. Mridula (1999), Raghavendra (2004) and Raveesha (2007) documented an annual variation of 2.78, 2.03 and 2.87 ppt respectively. The negative trend of salinity observed in this 2 decadal study clearly indicates that there is more freshwater inflow and the seawater is getting diluted which is an evidence for climate change. From 1990-2000 salinity and water temperature exhibited a clear relationship with rainfall having an effect on the salinity concentration.
Throughout the study period the surface water salinity range of 29.07 (2011) to 35.37 ppt (1993) was documented with no clear oscillating trend. In the coastal waters of Mangalore, Rajanna (1997), Mridula (1999), Raghavendra (2004), Raveesha (2007) and Karolina (2009) observed unimodal oscillation while Benakappa (1980), Ramesh (1989) and Ronald (2001) documented bimodal variation. The decrease in shallow surface water salinity could be due to the discharge of copious amounts of treated effluents from the industries and also the ocean currents playing role in mixing and direction of flow. You-Shao et al. (2006) observed an annual average variation of 31.58 to 32.70 in his 4 years investigation in Daya bay, China. Kadam et al. (2011) recorded an annual average salinity of 32.06 ppt. and Smitha et al. (2010) observed an annual variation of 24.45 to 36.72 ppt in coastal waters of Kalpakkam.

5.2.4. Dissolved Oxygen

The total annual dissolved oxygen in the study area fluctuated from 3.35 to 6.24 mg/l with maximum value being documented in the year 2011 with 6.87 mg/l and minimum in 2005 with 3.11 mg/l. Kumar (1984), Lingadhal (1991), Mridula (1999), Raghavendra (2004), Raveesha (2007), Karolina et al. (2009) documented an annual difference of 2.70, 1.86, 1.47, 3.40, 3.13 and 1.82 mg/l respectively along the coastal water of Mangalore. The spatial variation was not clear as the trend was same at all the depths with a very narrow variation. The total annual dissolved oxygen concentration exhibited a minor pulsating trend with a deep in 2005 which coincided with decrease in salinity as well but the relationship is not clear.

The decadal difference of dissolved oxygen exhibited a variation of 0.03 mg/l decrease with annual average being 4.46 mg/l from 1990-2000 and 4.43 mg/l from 2001
to 2011. The higher dissolved oxygen content during 2010-2011 could be directly related to high photosynthetic activity whereas lower levels dissolved oxygen during 2005 could be due to utilization by organic matter and by various groups of heterotrophic planktons. The similar trend was observed by Ramesh (1989), Mridula (1999), Ronald (2001), Katti et al. (2003) and You Shao (2006) Saravanakumar et al. (2008) recorded an annual variation of 4 to 5 mg/l in gulf of Kutch. Kadam et al. (2011) documented an annual variation of 4.1 mg/l in west coast of India. Sridhar et al. (2006) and Smitha et al. (2010) recorded an annual variation of 6.21 to 9.35 and 4.15 to 7.18 mg/l in east coast of India.

5.2.5. Biological oxygen demand

The BOD at the study area showed an total annual average variation of 0.95 to 2.74 mg/L. Maximum value of BOD$_3$ is documented in the year 2006 with 3.34 mg/l while the decadal variation exhibited an difference of 0.33 mg/l with an increase from 1990-2000-2001 – 2011. Spatially at 8m depth maximum values of BOD$_3$ were recorded which indicated that the outflow of treated effluents from the industries may be having an effect on this parameter. You-Shao et al. (2006) recorded an annual variation of 0.33 – 3.61 mg/l in Daya bay, China. Kadam et al. (2011) documented an variation of 0.85 to 2.76 mg/l in Kalpakkam coast. Temporal variation exhibited an bimodal oscillation with primary peak in 1993 and secondary peak in 2006 which clearly exhibited a direct relationship with dissolved oxygen composition where the dissolved oxygen values decreased during the peaks of BOD$_3$. The same trend was observed by You-Shao (2006) and Kadam et al. (2011).
5.2.6. Extinction coefficient

The extinction coefficient values indicate the rate of illumination in water column. The transparency of water is a function of portion of sun in the sky, degree of cloudiness and its variability. Generally 4 and 8 m depth contours recorded higher range of extinction coefficient value when compared to 12 and 15 m contour. Higher extinction coefficient indicates lower light penetration in sea water and also transparency of sea water is inversely proportional to the turbidity. Therefore it could be said that waters at deeper depth were more transparent than the shallower water, also higher values recorded at shallower depths could be due to turbid water resulted from wave and tidal actions. In the present study, the total annual average extinction coefficient varied from 0.50 to 1.48. The decadal differences showed a decrease of 0.49. The same spatial difference was observed by Mridula (1999), Raveesha (2007) and Mohan (2007) in the west coast of India. While investigating on the hydrological characteristics of the Gulf of Kutch, Lande (2001) documented the same depth variation.

5.2.7. Ammonia – Nitrogen

Ammonia in the form of ammonium salts is one of the most important nitrogenous plant nutrients, the concentration of which is known to determine the fertility of sea. The ratio of ammonium salts to phosphates is not only known to determine the abundance of phytoplankton but also its species diversity. It is also understood that among all the nitrogenous nutrients, ammonium salt is considered to be the most preferred form of marine plants. The total annual variation of ammonia-nitrogen varied between 2.85 and 10.72 µg-at/l and Raghavendra (2004) documented a range of 3.76 to 14.76 µg-at/l while Raveesha (2007) recorded 2.40 to 15-30µg-at/l in the same area. It is important to note
that Verlecar et al. (2006) recorded a maximum value of 4.0 µmol/l in Mangalore waters during 1997-1998. The spatial variation exhibited shallower waters recording higher values compared to deeper waters. While, the temporal variation showed 3 clear peaks with one minor peak in 1998. Lingdhal (1991) reported trimodal pattern of distribution while Mridula (1999) and Katti et al. (2001) documented the similar trend. Raghavendra (2004), Raveesha (2007) recorded similar variation in the same study area. The lower values during 2006 to 2009 could be due to the variation of abundance of plankton during the same period and no clear cut variation could be observed. The decadal difference from 1990-2000 and 2001- 2001 was found to be an increase of 0.623 µg-at/l. You-Shao et al. (2006) during his 4 years of investigation in Daya Bay china, recorded an annual variation of ammonia nitrogen from 0.016 – 4.25 µmol/l with annual average variation of 2.66 µmol/l. Karolina et al. (2009) found a variation of 16.67-61.1µmol/l. While, Smitha et al. (2010) documented annual variation of 5.93 µmol/l. Kadam et al. (2011) recorded a annual variation of 0.83 to 3.75 m mol /l with annual difference of 2m mol/l.

5.2.8. Nitrite-nitrogen

Nitrite - nitrate being the intermediate and unstable in nature among all the three nitrogenous nutrients and is present at lower concentration. In the present investigation, the total annual average nitrite-nitrogen concentration varied from 0.44 to 3.25 µg-at/l. The levels of nitrite recorded by several workers in the coastal waters of Dakshina Kannada varied from traces to 6.95 µg-at/l (Reddy, 1977; Eknath 1978; Sahu 1981; Sagar 1982; Krishnamurthy 1985; Manjappa 1987; Lingdhal 1991). Katti et al. (2002) observed a range of 0.10 to 3.17 µg-at/l, Verlecar et al. (2006) documented a maximum value of 0.57 m mol/l and Raveesha (2007) recorded annual variation of 0.19 to 4.79 µg-
at/l along the Mangalore coast. Sridhar et al. (2006) documented a range 0.12 to 0.62 µM/l in Palla bay while Smitha et al. (2010) recorded an annual variation of 0.20 µmol/l in Kalpakkam waters.

The decadal difference of nitrite nitrogen exhibited an increase of 0.667 µg –at/l with average being 0.9942 µg-at/l (1990-2000) and 1.66 µg-at/l (2001 to 2011). Spatially shallower depths recorded higher values with maximum at 4m depth contour and which may due to the coastal water mixing with freshwater inflow carrying lots of nutrients with the help of wave action and currents. Temporally nitrate-nitrogen concentration exhibited a slight pulsating trend with maximum values recorded during 1990 to 2010, as it is a most unstable nutrient in the coastal environment. Post monsoon months recorded higher values, which is due to the land run off carrying nutrient load to the marine environment. You-Shao et al. (2006) noticed the same temporal trend during his 4 years investigation in Daya Bay, China.

5.2.9. Nitrate – Nitrogen

Nitrate is the stable form of nitrogen and in well oxygenated waters it provides nitrogen as a chief nutrient to all autotrophic forms in the marine environment. Nitrate is the end product of nitrification and starting point of denitrification which is usually present at higher concentration than that of nitrite and ammonia. The total annual average nitrate-nitrogen concentration varied from 1.38(1990) to 14.73(2006) µg-at/l. The lower values were recorded in 1990 and maximum in 2006. Reddy (1977) and Eknath (1978) observed nitrate values varying annually by 23.70 and 16.63 µg-at/l respectively in the same area. Lingadhal (1991) documented a variation of 0.32 to 33.62 µg-at/l in the near shore waters of Mangalore. While, Lingadhal (1995) observed a range which fluctuated
from traces to 80.73 µg-at/l in the same coast. In the present investigation reported an annual range which is similar to the observations of many authors in the same study area. Katti et al. (2002) recorded nitrate values ranging from 1.65 to 13.39 µg-at/l while, Verlekar et al. (2006) recorded a maximum value of 0.86 µ mol /l in the Mangalore coast.

Spatially shallower waters dominated throughout the study but at 12m depth contour highest value were recorded in the year 2003. The temporal variation showed a pulsating trend with 3 major peaks and several minor peaks. The decadal difference showed an increase of 3.26 µg-at/l of nitrate-nitrogen with an average of 5.99 µg –at/l in the first decade (1990-2000) and 9.26 µg-at/l during the second decade (2001-2011). In the present investigation nitrate nitrogen concentration dominated among all the nitrogenous nutrients. You-Shao et al. (2006) reported the same in Daya bay, China while Karolina et al. (2009) also reported the same dominance of nitrate in the old port of Mangalore. The present study results are in agreement with the work done by many others in the same decadal studies.

5.2.10. Phosphate-Phosphorous

Orthophosphate is the inorganic form of phosphorous which at times limits phytoplankton production. They have a terrigeneous origin and find their way into coastal ecosystem through river and land runoff. The total annual average composition of phosphorus varied from 0.39 to 4.81 µg-at/l. The maximum value was recorded during 2005 while the minimum value in 1990. Along the Mangalore coast, Katti et al. (2002) observed the phosphate values which ranged from 0.05 to 3.00 µg-at/l and Karoline et al. (2009) in the same study area reported a range of 0.01 to 0.09 µ mol/l while Verlecar et al. (2006) recorded the phosphate concentration as high as 1.73 m mol/l along the
Mangalore coast. Goswami and Padmavathi (1996) documented a range of 2 to 2.0 µg – at/l in the coastal waters of Goa. Lande (2001) documented the phosphate concentration range of 2.14 to 8.62 µg-at/l at the Gulf of Kutch. Whereas Ouseph and Pillai (2004) reported the phosphate concentrations range from 0.09 to 5.56 µg-at/l along the south west coast of India. In Kalpakkam waters, Sathpathy and Nair (1996) recorded a range of 0.19 to 2.66 µg-at/l of the phosphate-Phosphorus concentration.

Spatially deeper waters dominated the phosphate concentration in the first decade and it increased during the second decade in the shallower depth (4m) recording maximum values. The domination in first decade is in agreement with the total phytoplankton distribution at the same depth and also the output of treated effluents from the industries at this depth. The temporal variation of the total annual average phosphate – phosphorus concentration showed a single prolonged peak from 1999 to 2005 and then a sudden decrease from 2006 onwards. Therefore from the data gathered it could be stated that the spatial and temporal variation of this nutrients gets affected by seasons, wave action and anthropogenic inputs. Lingadhala et al. (1991), Katti et al. (2001) and Raveesha (2007) reported trimodal oscillation along Mangalore coast.

5.2.11. Silicate - silicon

Silicate is an essential nutrient since it is required for the construction of siliceous frustrules and synthesis of RNA in diatoms. As a result of exploitation of silicate by many organisms this nutrient exhibit wider fluctuations in time analysis.

During the study, total annual average concentration of silicate –silicon varied from 3.33 to 24.51 µg-at/l with a maximum during 1990 and maximum during 2002.
Lingadhal (1988) documented a range which fluctuated from traces to 66.06 µg-at/l where as Katti et al. (2001) recorded a minimum of 0.97 to a maximum of 46.57 µg-at/l in the coastal waters of Dakshina Kannada. Joseph and Pillai (2004) recorded comparatively low silicate concentration which was in the range of 0.44 to 6.94 µg-at/l in the south west coast of India. Raveesha (2007) recorded a range of 8.6 to 32.32 µg-at/l in the coastal waters of Chitrapur.

Spatially not much variation was observed, but shallower depths recorded slightly higher values compared to deeper depths with a maximum average value of 28.83 µg-at/l at 8m depth during 2002. This is mainly due to the freshwater inflow and also extent of utilization by phytoplankton. Temporally total pulsating trend with maximum values being from 1999 to 2003 were observed in the present investigation. The maximum value of 24.51 µg-at/l was recorded during 2002 while the minimum of 3.33 µg-at/l during 1990. The decadal differences of silicate-silicon showed a 1.69 µg-at/l increase of silicate-silicon with the total annual average of 13.458 µg-at/l during 1990-2000 and 15.15 µg-at/l during 2001-2011. Many researchers who investigated in the same area observed similar trimodal to multimodal seasonal oscillation trends.

5.3. Phytoplankton

A marked seasonal and spatial abundance of different species of phytoplankton is a well-established feature of phytoplankton ecology. However in the tropical areas the growth of phytoplankton exhibited little seasonal change particularly along west coast of India. In the present investigation the species of phytoplankton belonging to diatoms, dinoflagellates and blue green algae were enumerated numerically.
5.3.1. Net phytoplankton

Throughout the study period, 39 different phytoplankton genera belonging to 3 groups were reported with a major contribution by diatoms to the total phytoplankton production. All the three groups were pooled to check the total phytoplankton production which exhibited an increasing trend from 1990-2011. The 22 years of data on phytoplankton assemblages clearly showed an temporal change with highest numbers during 2009 with 10,68,99,482 cells/m$^3$. The minimum number was reported during 1992 with 125442 cells/m$^3$.

In the present investigation diatoms formed the bulk of the phytoplankton community throughout the study period. Similar observations were made by Naik et al. (1980) in Konkan coastal waters. Along the west coast of India Kumar (1984), Ramesh (1989), Jiyalalram et al. (1990), Naïk et al. (1990), Ramesh (1992), Sawant and Madhuprathap (1996), Ronald (2001), Katti et al. (2002), Raveesha (2007), Saravanakumar (2008), Karolina et al. (2009) and Kadam et al. (2011) reported the dominance of diatom. While, Gouda and Panigrahi (1996), Sarojini et al. (2001) and Prabhakar et al. (2011) and Smitha et al. (2010) reported the dominance of diatoms in east coast of India. Spatially shallower depths reported maximum number of phytoplankton with a minimum abundance of 46,991 to a maximum of 5, 92, 33,054 cells/m$^3$ (5.9×10$^7$ cells/m$^3$) at 4m depth contour. The shallower depths supported maximum number of phytoplankton mainly due to the nutrient availability and the favourable hydrographical conditions. Temporally an increasing trend was observed with many minor peaks in between and the decadal difference data showed a difference of 2.4×10$^6$ cells/m$^3$. 
5.3.2. Diatoms

5.3.2.1. Biddulphia

The presence of the genera *Biddulphia* was recorded throughout the period of study. Spatially shallower depths reported maximum number of *Biddulphia* with an annual average range of 1179 to 612000 cells/m$^3$. *Biddulphia* showed a significant difference to different depths. The highest cell counts of *Biddulphia* were recorded from 2009 to 2011 with many minor peaks in the early year. The *Biddulphia* population was observed to be drastically increasing in the entire study duration with a pulsating trend. Totally *Biddulphia* showed a variation of $0 \to 4.8 \times 10^6$ cells/m$^3$ during the entire study duration. The increasing trend indicated a clear cut positive relationship with decreasing surface water salinity.

5.3.2.2. Chaetoceros

The most dominant genus among all the diatoms and a major contributor to the total phytoplankton production with a variation of $0 \to 4.4 \times 10^8$cells/m$^3$ during the entire study period. Spatially shallower waters (4m depth contour) reported higher values and the variations between the depths were more during 1990-2001 and later on the variation become narrow during 2004. Temporally an increasing trend was reported with maximum number during 2009 with 687025cells/m$^3$. A bimodal oscillation is exhibited with primary increasing trend from 1990 to 1999 and later on a decreasing trend from 2000-2008 but again second peak started from 2009. The increasing trend of *Chaetoceros* is in agreement with decreasing sea surface water salinity in the present investigation.
5.3.2.3. *Coscinodiscus*

Species of Coscinodiscus were present at all the depth throughout the study period except at 12 and 15m depth. As a whole this genera did not exhibit much variation with various depths as the variation is very narrow. Throughout the period of investigation at 4m depth contour maximum number of *Coscinodiscus* was reported. These genera varied from 0 to $5.2 \times 10^6$ cells/m$^3$ in the entire study duration. Temporally a unimodal oscillation was observed with a slight increase in the total number over the time. This trend is not having any clear relationship with any of the hydrographical parameters.

5.3.2.4. *Ditylum*

*Ditylum* exhibited a variation of 0 to $7 \times 10^7$ cells/m$^3$ in the entire study duration. Spatially no clear variation among various depths was reported but maximum values were recorded at 4m depth with a maximum number of 8703260 cells/m$^3$. Among all the depths the variation was narrow with the same increasing and decreasing trend over the period of investigation. Temporally a major peak was exhibited during 2001 and later a pulsating trend. Totally not much clear trend was observed in the study duration but it showed a positive response in terms of numbers to the sea surface water temperature. The absence of the data on *Ditylum* at 12 m and 15m depths has affected the temporal trend otherwise it could have been exhibited a clear trend.

5.3.2.5. *Nitzschia*

In the present study the genus *Nitzschia* has exhibited abundance in maximum number at 8 m depth contour with a maximum number of 1031513 cells/m$^3$ during 2004. 4m depth reported maximum number after 8m depth with a clear domination in shallower
waters. Except at shallower depth (4m) all other depth contours reported a peak in 2004. Temporally, an increasing trend was exhibited with 2 major peaks in 2003 and 2011 and few minor peaks during 1993 and 1995. The increasing trend of Nitzschia from 1990-2011 is in agreement with the decreasing sea surface water salinity and increasing sea surface temperature.

5.3.2.6. Planktoniella

The variation in abundance and distribution of Planktoniella cells was observed with spatially and temporally. Spatially shallower depth reported maximum number of Planktoniella with a variation of 327 to 42171 cells/m$^3$. The absence of Planktoniella data at 15m depth from 1990 to 1997 became a setback to exhibit a clear cut spatial variation. Temporally an increasing trend was observed with maximum number being reported during 2011 at all the stations. A trimodal oscillation was being exhibited by Planktoniella with a distribution ratio of 0 to 5.1×10$^5$ cells/m$^3$ for the entire study. The increased temporal trend is in agreement with the increasing surface water temperature during the period of investigation.

5.3.2.7. Pleurosigma

Pleurosigma distribution did not exhibited any clear cut spatial variation as the variation between the depths was narrow and also due to the absence of the Pleurosigma distribution data at 12 and 15m depth from 1990 to 1997. The highest number of Pleurosigma was reported in 2011 at 15m depth. The temporal variation showed no trend except a major peak during 2011 with a pulsating trend from 1998 to 2009. A slight increase is the total number if Pleurosigma cells are reported over the period of study
duration. A positive response to the increasing sea surface temperature is reported along with the decreased sea surface salinity.

5.3.2.8. Rhizosolenia

*Rhizosolenia* cells were abundant at 4m depth during the entire study duration except during 2004 and 2005, with a variation of 246 to 1756095 cells/m$^3$. Their presence was reported frequently at shallower depths with a clear domination by 4m and 8m depth contours. Temporally a bimodal oscillation was reported with a first peak during 1996 and second during 2011. An increasing trend was reported from 1990 to 1996 and then a decline till 2005 and again it exhibited an increasing trend till 2011. This increasing temporal trend is in agreement with the increase in sea surface temperature.

5.3.2.9. Other Diatoms

Apart from these 8 dominant diatoms, 21 other diatoms were reported with less than 80% abundance during the entire study period. Totally 29 species of diatoms are reported in the study.

The occurrence and abundance of phytoplankton in general and diatoms in particular has been carried out by many workers along southwest coast of India. In the present study, studies carried out by various researchers on the quality composition of phytoplankton have been used for the purpose of comparison. Gopalakrishnan (1971) reported 57 species of diatoms in Okha port, Gujarat While Bhaskaran and Gopalakrishnan (1972) recorded blooms of *Chaetoceros* in the same area. Along Vizhinjam coast, Mathew (1980) recorded 89 species of diatoms and along the Konkan coast, Nair *et al.* (1980) observed the dominance of *Rhizosolenia, Cerataulina, Ditylum,*

Ramesh et al. (1992) along the coast of Mangalore observed the dominance of the Cosinodiscus and Chaetoceros among the central diatoms. Sawant and Madhupratap (1996) recorded the dominance of Nitzschia, Chaetoceros, Rhizosolenia and Thallasiothrix in the Arabian Sea during summer. Mridula (1999) and Ronald (2001) observed the dominance of Cosinodiscus, Chaetoceros, Biddulphia, Rhizosolenia, Ditylum, Nitzschia and Pleurosigma in the coastal waters of Dakshina Kannada. Lande and Sangolkar (2002) observed the Thallasosera, Cosinodiscus, Chaetoceros, Navicula, Nitzschia and Skelitonema in the coastal waters of Kakinada. Verlecar et al. (2006) observed the dominance of centric diatoms such Rhizosolenia, Cosinodiscus and Chaetoceros of the Kulai coastal waters.

along both the coast of India. The predominance of species belonging to genera Chaetoceros, Cosinodiscus, Rhizosolenia, Thalassiosera, Pleurosigma, Nitzschia, Asterionella and Navicula. Sridhar et al. (2006) recorded 43 species of diatom in the Palk bay, south east coast of India. Sarvanakumar et al. (2008) recorded 82 species of diatoms in the Gulf of Kutch-Gujurat. 153 species of diatoms in the coastal waters of kalpulkam is reported by Smita et al. (2010). Pradha har et al. (2011) reported dominance of diatoms among all the groups contributing to the total phytoplankton production in Kadalur coastal zone Tamilnadu. Karolina et al. (2009) reported 57 genera of phytoplankton with domination by Cosinodiscus, Rhizosolenia, Biddulphia and Melosira in the Dahana creek, west coast of India.

Although all the forms listed above were common in the present study however as observed by few authors in the coastal waters of west coast of India, the species belonging to Biddulphia, Cosinodiscus, Ditylum, Chaetoceros, Planktoniella, Pleurosigma and Rhizosolenia were also very common in the present study.

5.3.3. Dinoflagellates

Dinoflagellates are the second largest group of phytoplankton after the diatoms, but the abundance of dinoflagellates are very less when compared to diatom population during the entire period of investigation. Spatial variation exhibited greater numbers abundance at shallower depth especially at 4m depth contour with a range of 2161 to 1160000 cells/m³. Temporally two peaks are exhibited with first peak during 1996-2001 coinciding with the El-nino occur duration. The second peak was in 2011. The dinoflagellates distribution responded to the increased sea surface temperature and decreased seas surface salinity. Three main genus of dinoflagellates showed the
abundance at >80 percentage of the period investigation which include *Ceratium, Dinophysis* and *Peridinium*.

5.3.3.1. *Ceratium*

During the study period, *Ceratium* was the most dominated dinoflagellates with largest contribution to the total dinoflagellates population. Greater members were reported at shallower depths with a variation of 1208 to 278171 cells/m$^3$ at 4m depth. The highest members of *Ceratium* are reported in the year 2001 and lowest in the year 2006. Spatially a narrow range of variation is observed throughout the study duration except in the year 2000-01 and 2004-05.

Temporally a pulsating trend is observed with maximum peak during 1998-2001. The distribution from 1990-2011 showed a gradual increasing trend which is in positive map use of increased sea surface temperature and decreased sea surface salinity. *Ceratium* population dominated among all other dinoflagellates and majorly contributed to total dinoflagellates population with an increasing member over the time and mainly abundant at shallower depths which is favoured by sea surface temperature and salinity.


5.3.3.2. Dinophysis

The occurrence and abundance of Dinophysis was spundaic and wager colour compound to other dinoflagellates at all the depths. It varied from 0 to $1 \times 10^4$ cells/m$^3$ throughout the study period. Deeper water reported greater numbers of Dinophysis compound to shallow waters. The spatial variation exhibited wider variation from shallow to deeper waters. At this depth it reported highest number with 1505529 cells/m$^3$.


5.3.3.3. Peridinium

Peridinium population was the second most dominant dinoflagellates with a variation of $0 - 2.2 \times 10^5$ cells/m$^3$ throughout the study period. The data revealed that this dinoflagellate reported in greater numbers at shallower depths with maximum number of 41666 cells/m$^3$ at 4m depth in 1998.
Temporal variation of *Peridinium* exhibited a pulsating trend with several peaks and an increasing trend from 1990-2011. The peak during 1996 to 1999 is in agreement with the El-nino process occurred and it clearly indicates this *Peridinium* abundance is favoured by sea surface temperature. Ramesh (1989), Sawant and Malwapvarap (1996) recorded *Peridinium* species along the west coast of India. Mridula (1996), Ronald (2001) Raveesha (2007), Mohan (2007) reported abundance of *Peridinium* in the west coast of India with major contribution to total dinoflagellates after *Ceratium*. Verlecar *et al.* (2006) observed presence of *Peridinium* with almost 6% contribution among major dinoflagellates in the coastal waters of Mangalore.

5.3.4. Blue Green algae

The total blue green algae abundance throughout the study period varied from $0 - 2.4 \times 10^6$ filaments/m$^3$. All the spp. were pooled together to from a single group as the occurrence and abundance of various spp. were less. Spatially no clear variation was exhibited due to the absence of BGA in many years at various depths and it was dominant in the year 2011. Temporal variation indicated a decreasing trend over the time with lowest number during 2008 and maximum number at 2011. Totally a decreasing pulsating oscillation is exhibited which favoured by increased sea surface temperature. *Trichodesmium* spp. contributed majorly to the total Blue green algae population and also the decreased temporal variation of this spp. was also reported, which proves the impact on primary production and the nitrogen budget of coastal Arabian Sea. Tiwari and Nair (1998) observed *Trichodesmium* bloom in the coastal waters of Bombay. Sarojini and Subbarangaiah (2000) recognized 12 spp. of dinoflagellates along the Tuticorin coast, Mridula (1999) Ronald (2001), Raveesha (2007) and Mohan (2007) reported less
numbers of BGA in the west coast of India. Geetha et al. (2004) reported 131 spp. Of dinoflagellates in the coastal waters of east coast of India.

5.4. Diversity index of phytoplankton

Productivity is the main function of the ecosystem where structure of which can be studied through the diversity index. Phytoplankton diversity index is quite often used to periodic fish production in polyculture for efficient utilization of cultured food organisms and also in assessing the health status to the environment. Specific investigation on their lives is neatly. In the present investigation Shannon’s diversity index, Margalef species richness and Pielou’s species evenness were used to discuss the dynamics of phytoplankton assemblages in space and time.

The diversity index showed greater value in the shallower waters with a variation of 0.5726 to 2.4540. As the depth increased the diversity index reduced from 4m depth to 15m depth contour. At 8m depth the Shannon diversity index varied from 0.3821 to 2.333, at 12 m depth it varied from 0.2598 to 2.3160 and at 15m depth, 0.3751 to 2.2390. Spatially it was clear that the shallow coastal waters dominated with the highest diversity index and which is in agreement with plankton productivity. Temporally a decreasing trend is exhibited with lowest diversity index of 0.5305 in the year 2004. By comparing the two decadal data of diversity index it is evident that there was a reduction by 0.3964 diversity index. Over the period even though the total phytoplankton numbers increased the diversity index reduced.

Margalef species richness values were more at deeper waters compared to shallower waters. At 12m depth contour the species. Richness varied from 0.9498 to
2.2230 and at 15 m depth it was 0.8909 to 2.2160. As the depths increased the species richness increased to a certain extent in most of the observation duration. The highest value of species richness is reported in the year 1996 and lowest in the year 1991. Temporal variation exhibited a decreasing trend with 2 major peaks and several minor peaks. The first peak was observed during 1996 – 1998 which is agreement with the El-nino process. The second peak was found to be during 2005 to 2007, where the surface water temperature was low. The decadal differences of species richness exhibited a decrease of 0.1628 with annual average of 1.9725 during 1990-2000 and 1.8097 during 2001-2011.

The Pielou’s species evenness exhibited a clear higher values at shallower depths compared to deeper waters which mean that the distribution of the species are very much even when we compare to deeper waters where the species evenness values are less. As the diversity is more, the evenness of the species is less in the present study area where the deeper waters had lesser diversity but more evenness among the phytoplankton community. Temporal variation of phytoplankton species evenness exhibited a slight decreasing trend with a pulsating oscillation throughout the study period. The decadal differences exhibited a difference of 0.1348 decreases from 1990-2011, which indicates that, as the time progress the species evenness in the environment gets decreased making the phytoplankton community with unevenness distribution.

Santhanam et al. (1975) calculated the diversity indices for diatoms which varied from 0.10 to 1.63. Lande and Sangolkar (2002) documented species diversity of phytoplankton which ranged from 1.85 to 3.28 and the species. Richness index varied from 1.04 to 3.8. Madhav and Kondalarao (2004) have reported high diversity index from
24 to 28 to low index along the east coast of India. The working Verlecar et al. (2006) indicated Shannon-wiener diversity index which ranged from 1.16 to 3.52 at Padubidri and 1.42 to 2.99 at Kulai. Raveesha (2007) reported the phytoplankton diversity fluctuation from 1.38 to 3.69 in the coastal waters of Chitrapur which indicated that the lower diversity index is caused due to the stressed conditions prevailed in the study area.

Saravanakumar et al. (2008) recorded species diversity value ranging from 0.56 to 4.05 and species richness of 0.80 to 0.99 and species evenness index of 0.38 to 0.98 in the Gulf of Kuchchh. Karolina et al. (2009) reported the Shannon index value varying between 1.62 to 3.42 in the old port of Mangalore and found that when the index value was high, the proportion of diatoms was also significantly higher. Smita et al. (2010) reported no marked variation in sp. Diversity and evenness but a pronounced variability of species richness in the Kalpakkam coastal water. Diversity index of phytoplankton ranging from 2.61 to 6.37 was recorded by Kadam et al. (2011) in west coast of India. Prabhahar et al. (2011) reported less values of species diversity due to the higher values of population density in Tamil Nadu coast.

5.5. Two-Way Analysis Of Variance

The data on hydrographical parameter and phytoplankton groups was subjected to two way ANOVA to find out any significant difference in its spatial and temporal distribution. Statistically all the water quality parameters except surface water pH, ammonia-nitrogen (μg-at/l) and nitrite-nitrogen (μg-at/l) exhibited a significant differences due to the years, due to the depths and between the years and depths at 5% (p>α=0.05), whereas the surface water pH showed no significant difference due to years and due to depths but between years and depths it was significant at 1% (p≤α=0.01) with
F value 1.3851. The surface water ammonia-nitrogen (μg-at/l) exhibited significant difference due to years and due to depths at 5% (p>α=0.05) while it was non-significant between years and depths. Nitrite-nitrogen (μg-at/l) exhibited no significant difference due to years but significant due to depths at 5% (p>α=0.05). Likewise, between years and depths it was significant only at 1% (p≤α=0.01) with a F value of 1.3990.

The most dominant genera with more than 80% abundance throughout the study period were used individually to check the significant difference due to years, due to depths and between the years and depths. Biddulphia, Chaetoceros, Coscinodiscus, Ditylum, Nitzschia, Planktoniella, Pleurosiga, Rhizosolenia, Ceratium, Dinophysis, Peridinium, and Blue Green Algae all the dominant species exhibited significant difference due to depth, due to years and between years and depths at 5% (p>α=0.05). The high F-values of phytoplankton are mainly influenced by the ecosystem. Similar high values were reported by Mridula (1999), Raveesha (2007) and Mohan (2007) in the coastal waters of Karnataka.

5.6. Simple correlation

Simple correlation between various hydrographical parameters and phytoplankton was carried out using SYSTAT package. The analysis indicated a mixed relationship between environmental parameters and phytoplankton. However only few relationships could be identified when they were repeatedly observed at different depths and time.

5.7. Hierarchical cluster analysis

Hierarchical cluster analysis of various hydrographical parameters and various phytoplankton species revealed that similarity in the temporal distribution, the similarity
was of mixed type which varied based on the environmental conditions. Species closely related and dissertated are obtained in this technique which exhibited many species closely related.

**5.8. Multidimensional scaling (MDS)**

Multidimensional scaling analysis was used as a multivariate procedure for detecting natural groupings in the present data. Multidimensional scaling provides a set of related statistical technique often used in the visualisation of data to explore similarities or dissimilarities in data. This clearly showed the conditions prevailed in particular years with similarity in phytoplankton distribution due to the hydrographical parameters. This cluster analysis results coincided with the El Niño process indicating the effect on the coastal waters of Mangalore.