2.1. Introduction

The study of water quality deals with the physical, chemical and biological characteristics of water and its relationship to all other hydrological properties (Iqubal et al., 2004.) Nearly 40% of the total open ocean area and 30% of the total area of the world’s continental shelves lie within the tropics (Alongi, 1990). The quality of surface water in the coastal regions is influenced by both natural processes and anthropogenic activities (Pejman et al., 2009). The hydrological study of any aquatic ecosystem is a prerequisite to assess its potentialities and to understand its different trophic levels and food webs. Further, environmental conditions such as topography, water movement, salinity, oxygen, temperature and nutrient characters of that particular water mass also determine the composition of its biota. Good quality of water resources depends on a large number of physico-chemical characteristics, the magnitude and the source of any pollution load; to assess that, monitoring of these parameters is essential (Manikannan et al., 2011).

Marine water quality has become a matter of serious concern because of its effects on human health and aquatic ecosystem including marine life (Gupta et al., 2009). Pollution, urbanization and human population growth are increasing along tropical coastlines at an alarming rate. The coastal environment is being altered at ever-increasing rates, often without looking ahead at future consequences. The coastal zone receives a vast quantity of sewage waste, dredge spoils, industrial effluents and river runoff, markedly affecting the composition and quality of coastal environment. In addition to its physical structure, the water mass type can be characterized by salinity, depth, oxygen, temperature and turbidity. These dynamic water quality parameters are variable on both temporal and spatial scales. Coastal area is the most dynamic and productive ecosystems and are also foci of human settlements, industry and tourism. Thus, the coastal water quality plays very important role in the well-being of humans, animals and plants inhabiting the area. Several recent studies have summarized the potential nature and consequences of global change on coastal areas and marine resources (Boesch et al., 2000). In addition to natural
impacts, human activities on coastal water qualities have become widespread and varied in the degree, disrupting the coastal ecosystem.

Similar to water, role of sediment in determining the biological and chemical processes of the overlying water and thereby its influence on the biotic component of benthic and pelagic realm is significant. Sediment is the indicator of quality of overlying water and its study is a useful tool in the assessment of environmental pollution status. The nature and fluctuation in the composition of sediments can indicate the extent of stress on aquatic environments. Primary production, upwelling, rate of decomposition, redox conditions in the sediments, rate of sedimentation and sediment texture all influence the content of organic matter in sediments. Sediment provides habitat to benthic organisms; some of them are major food sources to humans. Oil contamination is being recognized with increasing frequency as a major hazardous contributor to aquatic life by contaminating the sediments, particularly due to increased anthropogenic activity (Neff, 1979; 2002). In the coastal waters, benthic habitat and its sediment are most vulnerable to the human activity and hence assessment of sediment quality forms an important aspect of any monitoring program. Total organic carbon plays a major role in keeping fertility of the soil and its biological activities (Sunilkumar, 1996). Organic carbon in the coastal sediments is derived from primary production with aquatic ecosystem (autochthonous) and also from terrestrial biota (allochthonous) by the transportation of leached and eroded material (Likens, 1992). Long term and seasonal sediment quality assessment not only enables us to gain an insight into the benthic habitat’s health status, but it also help us tract sources of contaminants and device proper management measures.

Southern coastal stretch of Gulf of Kachchh, of late, is witnessing a significant change in terms of increased human activities through aggressive industrial development. An assortment of industries like thermal power plants, ports and jetties, mining, cement and chemical industries have come up in this coastal belt in the last few decades rendering it one of the most highly industrialized coastal belt of India. This coastal belt harbours two of the largest oil refineries of Asia. In the light of this development, it became imperative to document the present status of coastal water quality of Southern coast of Gulf of Kachchh which will both serve as a benchmark and a tool for coastal management. Presence of Marine National Park and Sanctuary (MNP & S) in this water further
underlines the importance of periodic study of water and sediment quality. In view of this importance, the present study investigated seven crucial water quality and two sediment quality parameters in the six study sites namely, SBM Surface water, Jetty Surface water (JSW), NJW (Near Jetty water) and PCW (Pipeline Corridor water) and two sediment abiotic parameters namely sediment texture, Total Organic Carbon (TOC) in four station off the Vadinar coast for 24 months (Nov 2010-Oct 2012). This chapter presents consolidated results of this two year long study.

2.2. Review of Literature

2.3. Water quality

2.3.1. International Status

Several workers all over the world have investigated physico-chemical parameters of various marine water ecosystems. The hydrochemistry and plankton dynamics of the Ologe lagoon, Nigeria was investigated by Onuoha et al. (2011). Moskovchenko et al. (2009) worked out the spatial and seasonal variation of stream water chemistry, including pH, temperature, salinity, DO, nitrate, phosphate, sulphate, chloride and ammonia of Vatinsky Egan River catchment, West Siberia. They studied spatial and seasonal variations of the water quality and assessed the anthropogenic chemical inputs into the river system. Their study revealed high concentration of chloride and total petroleum hydrocarbon in the aquatic system. Similar work on changes in the tropical estuarine system of Imo River, Nigeria was carried out by Akoma (2008). Alvin et al. (2008) investigated the seasonal and spatial dynamics of nutrients and phytoplankton biomass at Victoria harbor in Hong Kong waters. Pannard et al. (2008) investigated physical and chemical conditions of two coastal zones and recorded the short-term changes in phytoplankton community structure. Bouillon and Dehairs (2007) explored the distribution, sources and processing of particulate and dissolved organic carbon and inorganic carbon in the estuarine mixing zone of Tana River in Kenya.

The influence of surface run-off in contributing nutrients like sodium, potassium, silicate and carbon into river water was studied at lower reaches of Wu Jiang River in China by Zhu et al. (2005). Huang et al. (2003) analyzed the status and characteristics of nutrients
and eutrophication through a 24-h time series and synchronization of vertical profiles of NO$_3$-N, NO$_2$-N, NH$_3$-N, PO$_4$-P, Chlorophyll-α, total solids, salinity, temperature and other chemical parameters at different stations in Pearl River estuary in China. The interaction between the Atchafalaya river and the Atchafalaya delta estuarine complex was examined by estimating suspended sediments, inorganic nutrients (NO$_3$, NH$_4$ and PO$_4$), Chlorophyll-α and salinity by Lane et al. (2002). Magni et al. (2002) worked out the physical and chemical variability of the water column at subtidal station of an estuary in the Seto Inland Sea, Japan, during a spring tide in May 1995. Eyre and McKee (2002) explored carbon, nitrogen and phosphorus budget in a shallow subtropical coastal embayment of Moreton Bay in Australia.

Akpan and Offem (1993) analysed data on the seasonal variations in temperature, salinity, dissolved oxygen, biochemical oxygen demand, ammonium, nitrite, nitrate, phosphate, silicate, pH and Secchi disc transparency. They stated that main influencing factor is the seasonal variation of rainfall, but biological cycles may also play a significant role on chemical variables. Spatial and temporal variations in nutrients and their importance to estuarine primary producers have been extensively studied by Cowan and Boynton (1996).

2.3.2. National Status

The pioneering work on coastal water quality at national level is that of Sewell (1928, 1929) who made an extensive oceanographic survey in the Bay of Bengal and Arabian Sea. After a long gap (Bal et al., 1946) conducted preliminary observation on physical and chemical conditions of the Bombay harbour waters. The physical and biological features and seasonal changes of dissolved oxygen in the inshore waters of Malabar Coast were documented by Kasturirangan (1957); Benakappa et al. (1979) and Reddy et al. (1979). Qasim (1982) described oceanographic features of the northern Arabian Sea Gajbhiye et al. (1995) investigated the hydrographic characters of coastal waters of Murud in Mumbai. Vertical distribution of temperature and salinity of the coastal waters off Cochin was documented by Hareesh Kumar et al. (1995). Lakshmanan et al. (1987) studied the distribution and seasonal variation of temperature and salinity in Cochin back waters. Sathyanarayanan et al. (1994) after investigating the physico-chemical
characteristics of coastal environment of Visakhapatnam concluded that the harbor waters were polluted with nutrients and organic matter. Govindasamy et al. (2000) studied the seasonal variation in physico chemical properties and primary production in coastal water biotopes of Coramandal coast, India. Rajasegar (2003) studied the physico chemical characteristics of Vellar estuary south east coast of India. Ouseph and Pillai (2004) recorded the hydrography of coastal waters from Veli in Kerala to Karwar in Karnataka while reviewing the coastal pollution along southwest coast of India. Rakesh et al. (2006) reported that the changes in the zooplankton community structure across water bodies could be associated with varying salinity. Anilakumary et al. (2007) carried out water quality study of Adimalathura estuary in Kochi, Kerala exposed to pollution from the domestic wastes and coconut husk retting. Their results revealed the deleterious effects of waste disposal on the water quality and marked increase in the concentration level of nutrients and a decrease in dissolved oxygen.

A comparative study on the physico-chemical variability of Parangipettai and Cuddalore coastal and estuarine waters of Bay of Bengal by Sundaramanickam et al. (2008) brought out how significantly these two coastal environments differ from each other. Prabhu et al. (2008) studied the seasonal variation in physico-chemical characteristics of pichavaram mangroves, South east Coast of India. The temporal and spatial variation of surface water quality collected from different points of Dhamra estuary was studied by Prassana and Ranjan (2010). Seasonal variations in physico-chemical parameters was investigated by Prabhahar et al. (2011) in Vellar River, Vellar Estuary and Portonovo Coastal Waters, Southeast coast of India. Prabhahar et al. (2011a) studied seasonal variation in physico chemical parameters of Kadalur coastal zone, Tamil Nadu. Point Calimere Wildlife Sanctuary, South-east coast of India was studied by Manikannan et al. (2011). Gadhia et al. (2012) studied the important physico-chemical parameters in Tapi estuary in Hazira Industrial area. Archana and Babu (2013) investigated the physicochemical characteristics of coastal waters at four stations along the coast of Visakhapatnam, East coast of India. Behera et al. (2014) studied the physico-chemical parameters of water samples collected from mangrove ecosystem to study the pollution status of Mahanadi River Delta, Odisha, India.
2.3.3. Regional Status

At regional level many studies have been carried out with special reference to Gujarat and Gulf of Kachchh waters. About 16 large, medium and small rivers flowing westward in southern part of Gujarat state was studied by Shirodkar et al. (2010). Physicochemical characteristics of water and sediment and the textural aspects of sediments in western mangroves of Kutch-Gujarat, west coast of India, were studied by Saravanakumar et al. (2008). Flushing characteristics and pollution assessment of Purna estuary were worked out by Zingde et al. (1986; 1987) who also carried out environmental studies of the Ambika and associated river estuaries. An assessment of spatial and temporal fluctuations in water quality of a permanent estuarine system of Tapi was carried out by Nirmal Kumar et al. (2009). Nirmal Kumar et al. (2012) have also worked out physico-chemical characteristics of the coastal water of Narmada estuary, Gujarat and gave statistical evaluation of its seasonal changes. Paulinose et al. (1998) observed environmental parameters like salinity, temperature, dissolved oxygen and nutrients in the Gulf of Kutch. Lande (2001) studied the coastal hydrography of Gulf of Kutch considering the industrial development. Desa et al. (2005) investigated the spatial and temporal variation of dissolved oxygen and biological oxygen demand in Gulf of Kachchh to study the BOD assimilation capacity of coastal water around Marine National Park (MNP) and Marine sanctuary (MS).

Based on field measurements and model simulations Vethamony et al. (2007) for the first time studied the GoK thermohaline structure and its variability Shirodhkar et al. (2010) studied the water characteristics of Kandla creek, Gulf of Kachchh influenced by anthropogenic activities seasonally based on overall index of pollution he calculated water quality index. Vethamony et al. (2010) studied the stratification in temperature and salinity in the eastern Gulf, where a cold and high saline tongue is observed in the subsurface layers. George (2012) studied the influence of hydro-chemical parameters on phytoplankton distribution along Tapi estuarine area of Gulf of Khambhat, India. Bignesh et al. (2014) studied the variations of physicochemical parameters of water during winter season in the coral formations at three different sites of Poshittra cluster in the Gulf of Kachchh (GoK).
2.4. Sediment Texture and Total organic carbon (TOC)

2.4.1. International Status

Textural characteristics of sediment are the important parameters, which influence the type of benthos. Smaller size of the meiofaunal species, a major benthic form, renders it highly sensitive to changes in textural characteristics of the sediment (Parsons et al., 1977). Analyses of organic matter content, organic carbon, nitrogen, sulfur and granulometric variables were performed by Burone et al. (2003) on 101 surface sediment samples from Ubatuba Bay in order to investigate the spatial distribution of organic matter, its origin and the relationships among its components. Ouyang et al. (2006) reported temporal and spatial distributions of sediment total organic carbon (TOC) and its relationships to sediment contaminants in the Cedar and Ortega rivers, USA, using three-dimensional Kriging analysis which revealed a negative correlation between TOC and polycyclic aromatic hydrocarbons (PAHs) or polychlorinated biphenyls (PCBs).

A study of ecological conditions associated with bottom sediments in the Neuse estuary at Pamlico Sound, U.S.A. was undertaken by Balthis et al. (2002). The role of coarse material (sand fraction) in the distribution of metals in polluted marine sediments was investigated in the harbors and the coastal zone of Mytilene, island of Lesvos, Aegean Sea by Aloupi and Angelidis (2002). The factors influencing the biogeo-chemistry of sedimentary carbon and phosphorus in the Sacramento-San Joaquin Delta in California were worked out by Nilsen and Delaney (2005). They characterized the organic carbon and phosphorus geo-chemistry in surface sediments of the delta. Biochemical characteristics like temperature, salinity, dissolved organic carbon (DOC), total dissolved nitrogen, dissolved macronutrients (NO₃, NO₂, PO₄, Si(OH)₄), Chlorophyll-α, pigment composition, total suspended matter (TSM), particulate organic carbon (POC), and particulate nitrogen (PN) were evaluated in lower Mississippi River, USA by Dagg et al. (2005). Yemenicioglu and Tunc (2013) studied the geology and geochemistry of recent
2.4.2. National Status

Organic carbon in sediment is basically derived from within the ecosystem and also by transportation of leaf and eroded materials (Likens, 1972). Ramachandra (1981) documented organic carbon in Mulki estuary, which varied from 0.01 to 1.65%. Similar range of organic carbon was recorded by Bhat (1979), Reddy (1983) and Shanthanagouda (2001) in Nethravati-Gurupur estuary and Alagarsamy (1991) in Mandovi estuary, Goa. However, Nasnolkar et al. (1996) recorded sediment organic carbon as high as 32.77 mg C/g in Mandovi estuary, Goa. Nair et al. (1993) while studying the sediment characteristics of Cochin estuary stated that sediment texture in the estuary gets influenced by the monsoon and mixing process in the environment.

Along the east coast Chandran et al. (1982) documented sediment organic carbon as high as 14.88 mg C/g in Vellar estuary while Sasamal et al. (1986) documented sediment organic carbon percentage, in the range of 0.59 and 4.12%. However, Prabha Devi (1994) observed as high as 27.8 mg C/g in Coleroon estuary during post-monsoon season. Prabhu et al. (1993) observed dominance of sand, which gradually changes to clayey silt as the distance increased from the shore along the coast of Gangoli, Dakshina Kannada. Varying characteristics of sand, silt and clay of sediments of Marmagoa harbour, Goa were documented by Ansari et al. (1994). Nasnolkar et al. (1996) although observed dominance of sand in the sediment during monsoon and post-monsoon season, higher percentage of silt and clay at some stations were also recorded during monsoon and post-monsoon season in Mandovi estuary, Goa. Badarudeen et al. (1998) observed highest percentage of sand in the sediment of Kannur mangrove region in southwest coast of India. Prabhu et al. (1997) observed clayey nature of sediment of Honnavara, North Karnataka district. Shanthanagouda (2001) while working in Nethravati-Gurupur estuary documented sediment texture, which varied between stations and seasons. Mohan (2000) while working on sediment transport mechanism in Vellar estuary observed predominance of sand at the head of the estuary with silt and clay as subordinate constituents. Greater percentage of sand followed by silt and clay was observed by Kailasam and Sivakami (2004) in the sediment collected from Tuticorin Bay, east coast of India. Babu (2004) observed the dominance of sand faction dominated at all the
stations in all the months followed by silt and clay. Suspended sediment dynamics on a seasonal scale in the Mandovi and Zuari estuaries, central west coast of India was studied by Rao et al. (2011). In order to gain insight into the formation dynamics of mud banks off the Kerala coast of India, extensive surveying of the near shore bathymetry along with sediment characterization was undertaken by Narayana et al. (2008) and the textural and geotechnical properties of the surface sediments were determined during pre-monsoon, monsoon and post-monsoon periods.

Rajasegar et al. (2002) emphasized effect of nutrient rich water from the shrimp farms on sediment composition, organic carbon, total phosphorus and total nitrogen content of sediments in Vellar estuary. Venkataraman et al. (2010) studied the textural characteristics and organic matter distribution patterns in Tirumalairajanar River Estuary, Tamilnadu, East Coast of India. Kumary et al. (2001) documented sediment organic carbon which varied between 2.4 and 83.3 mg C/g in Poonthura estuary. A study was conducted by Shaikh and Tiwari (2012) to assess the sediment physico-chemical parameters of Sewri mudflats, Mumbai.

2.4.3. Regional Status

The Gulf of Kachchh one of the largest macrotidal regime in Asia, has been studied extensively for its offshore dynamics and suspended sediment concentration by Nair et al. (1982), Chauhan, (1994) Kunte et al. (2003), Babu et al. (2005) Chauhan et al. (2006) and Ramaswamy et al. (2007). Geomorphic assemblage of the Gulf of Kachchh Coast was reviewed by Prizomwala et al. (2010) to understand the pathways of coastal sediments in GoK. The study shows sandy segment between Jakhau and Mandvi and sandy coast to muddy coast between Mandvi to Mundra. The spatial distribution of mica minerals along the Gulf of Kachchh coast was studied by Prizomwala et al. (2012) which showed in general decreasing trend as we move along the northern and southern coast of the Gulf of Kachchh but an increase in amount near the southern mouth at Okha. Prizomwala et al. (2013) studied the granulometric, heavy mineral content and mineral magnetic properties of southwest Kachchh coast to characterize different segments provenance and multiple end members contributing to coastal setup of Gulf of Kachchh, India. Prizomwala et al. (2014) made an attempt to understand the sediment routing
system in the semi-arid margin of the Gulf of Kachchh, which is one of the largest macrotidal regimes in the northern Arabian Sea.

2.5. Materials and Methods

Various methods adapted to carry out the analysis and the instruments used are presented in Table 2.1.

2.5.1. Hydrogen Ion Concentration (pH), Temperature and Salinity

Temperature and pH and were determined in situ on board using a pre-calibrated Fisher pH/Conductivity/Temp/TDS Meter (accuracy- 0.01 pH unit; Temperature accuracy- 0.1°C) by taking 50 ml of water in a beaker. Mohr-Knudsen Argentometric titration method was used for determining seawater salinity. The samples were titrated with silver nitrate solution which gives values of chlorinity. From chlorinity values, salinity was determined from the Knudsen hydrographic table (Strickland and Parson, 1972).

2.5.2. Dissolved Oxygen (DO)

The samples for dissolved oxygen (DO) analysis for both surface and bottom waters were collected using a thoroughly rinsed BOD bottle of 300 ml capacity without air bubbles. Bottom water samples collected using Niskin sub sampler were filled in a BOD bottle ensuring no air bubbles were trapped. Dissolved Oxygen content of the water samples was analysed by Winkler’s method using manganese chloride and alkaline Iodide solutions with sodium thiosulphate as the titrant.

Normality of sodium thiosulphate was determined using the standardization procedure by titrating against potassium dichromate.

Calculation

\[ \text{DO mg l}^{-1} = \frac{V \times N \times 8 \times 1000}{\text{volume of sample taken for titration}} \]

Where, \( V \) = volume of sodium thiosulphate,
\( N \) = normality of sodium thiosulphate
2.5.3. Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) of the water samples were assessed by collecting the samples in 300 ml glass BOD bottle and incubating for 3 days at 27°C before titrating with sodium thiosulphate solution. Direct unseeded method was followed for BOD estimation. BOD was determined by the same procedure of Winkler's method as that for DO, after 3 days of incubation. The difference in the amount of oxygen on the 1st and 3rd day gave the measure of Biochemical Oxygen Demand.

2.5.4. Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) of the water samples were estimated by acidifying a known quantity of sample with sulphuric acid to reduce the pH. The organic matter in the sample was oxidized completely by potassium permanganate (K₂MnO₄) in the presence of H₂SO₄ to produce CO₂ and H₂O. The excess K₂MnO₄ remaining after the reaction was titrated with sodium thiosulphate, using starch as indicator. The volume of dichromate consumed is equivalent to the oxygen required for the oxidation of the organic matter.

2.5.5. Total Dissolved Solids (TDS)

Gravimetric method was employed for determination of TDS. About 100 ml of the water sample, taken in a beaker was filtered which was then dried totally in a Hot air oven at 105°C. The amounts of total dissolved solids were calculated using the difference in the initial and final weight. Values obtained were cross checked with a hand-held TDS meter (Hanna Instruments).

2.6. Sediment Quality Analysis

Sediment samples were collected at all the four stations of the study area where water samples were also collected (JSW, SBM, NJW, PCW). Seabed sediments were collected using Van-Veen grab whereas intertidal sediments were collected using a handheld shovel. After collection, the scooped samples was transferred to polythene bags, labeled and stored under refrigerated conditions. The sediment samples were thawed, oven dried at 40°C and ground to a fine powder before analyses.
2.6.1. Sediment Texture

For texture analysis, specified unit of 2.0 mm - 0.05 mm sediment samples were sieved using sieves of different mesh size as per Unified Soil Classification System (USCS). Cumulative weight retained in each sieve was calculated starting from the largest sieve size and adding subsequent sediment weights from the smaller size sieves. The percent retained was calculated from the weight retained and the total weight of the sample. The cumulative percent was calculated by sequentially subtracting percent retained from 100%.

2.6.2. Total Organic Carbon

Total Organic Carbon (TOC) in sediment was estimated by Walkley and Black (1934) titration method. In this method, carbon is oxidized by the dichromate ion. Excess dichromate ion is then back titrated with ferrous ion. Soil sample of 0.5 gm was taken in 500 ml conical flask; to this 10 ml of 1 N K$_2$Cr$_2$O$_7$ was added and shaken to mix thoroughly. Twenty ml of concentrated H$_2$SO$_4$ (Containing AgSO$_4$) was further added and the mixture was allowed to stand for 30 minutes on asbestos sheet. To this, 200 ml of distilled water and 10 ml H$_3$PO$_4$ was further added and shaken vigorously. The content was then titrated against 0.5 N ferrous ammonium sulphate solution using Diphenyl amine as an indicator.

2.7. Reagents and Standards

Analytical grade chemicals were used throughout the study. All the reagents and calibration standards required for this study was prepared using deionized water. Samples were analyzed in triplicate for all parameters of water and sediment.

Table 2.1 Materials and methods used for Water and Sediment Analysis

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Instrument / Method used</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH / Temperature (°C)</td>
<td>Digital pH/ EC/ Temp/TDS meter (Fischer)</td>
</tr>
<tr>
<td>Salinity (%)</td>
<td>Refractometer</td>
</tr>
<tr>
<td>Dissolved oxygen (mg/L)</td>
<td>Winkler’s method</td>
</tr>
<tr>
<td>Biochemical oxygen demand (mg/L)</td>
<td>Titrimetry</td>
</tr>
<tr>
<td>Chemical oxygen demand (mg/L)</td>
<td>Open refluxion method</td>
</tr>
<tr>
<td>TDS (mg/L)</td>
<td>Gravimetry</td>
</tr>
<tr>
<td>Total Organic carbon (mg/L)</td>
<td>Digestion and Titrimetry</td>
</tr>
<tr>
<td>Sediment Texture</td>
<td>Sieve Method</td>
</tr>
</tbody>
</table>
2.8. Results

2.8.1. Hydrogen Ion Concentration (pH)

Water pH during the first year study varied from 7.3 (Jetty Bottom Water-September, 2011) to 8.6 with a mean and ± SD of 8.14±0.24 (PCW-March, 2011) at all stations (Fig. 2.1). During the second year study, the minimum pH value was 7.1 (NJW – Nov 2011) and the maximum was 8.2 during March – May 2012 at Jetty Bottom water and PCW. Overall, range of pH in this two year study was from 7.1 to 8.8 with a mean and ± SD of 7.86±0.21 (Fig. 2.2). All the recorded values were well within the limit and did not show any abnormality.

Fig. 2.1. pH variation in the study stations

Fig. 2.2. pH variation in the study stations
2.8.2. Temperature

Surface and bottom temperature varied from 20.5°C (SBM - Bottom Water - February, 2011) to 32.2°C (PCW - May, 2011) with a mean and ± SD of 26.9±3.02°C in all the stations (Fig.2.3). The temperature in the PCW station was high during May 2011 apparently due to increased radiation and shallowness of the water. During the second year, temperature varied from 20.0°C (NJW and SBM Bottom waters – March 2012) to 32.4°C (NJW – June 2012) with a mean and ± SD of 26.6 ± 3.78°C at all 4 stations (Fig.2.4). As expected, a clear season linked temporal variation in temperature could be seen in both the years of study.

Fig. 2.3. Temperature in the study stations

Fig. 2.4. Temperature in the study stations
2.8.3. Dissolved Oxygen (DO)

The monthly variation of DO in the first year was from 2.8 mg/L (NJW-October, 2011) to 7.7 mg/L (PCW-November, 2010) with a mean (±SD) of 5.14 ±1.16 mg/L at all 6 stations (Fig.2.5). The monthly variation during the second year was from 2.1 mg/L (PCW – March 2012) to 8.4 mg/L (SBM Surface water – September 2012) with a mean (±SD) of 5.08 ± 1.5 mg/L at all 4 stations (Fig.2.6).

Fig. 2.5. Dissolved oxygen in the study stations

Fig. 2.6. Dissolved oxygen in the study stations
2.8.4. Biochemical Oxygen Demand

Levels of BOD in the first year varied from 0.2 mg/L (NJW- June, 2011) to 5.9 mg/L (PCW-May, 2011) with a mean and ±SD of 1.84 ±1.12 mg/L at all 4 stations (Fig.2.7). In second year, BOD levels in the study area varied from 0.2 mg/L (NJW-November 2011) to 4.8 mg/L (NJW-September 2012) with a mean and ±SD of 1.68 ±0.89 mg/L at all 6 stations (Fig.2.8).

Fig. 2.7. Biochemical Oxygen Demand in the study stations

Fig. 2.8. Biochemical Oxygen Demand in the study stations
2.8.5. Chemical Oxygen Demand (COD)

Values of COD showed a maximum of 40 mg/L during September 2011 in Jetty Surface water whereas the minimum of 0.6 mg/L during May 2011 was recorded in SBM Bottom water with the mean of 7.64 ±10.59 mg/L among all the four stations (Fig.2.9.). Values of COD were comparatively higher during August, September and October, 2011. During the second year study, the values of COD showed a maximum of 26.7 mg/L during November 2011 in PCW station waters whereas the minimum of 2.7 mg/L during September 2012 was recorded at SBM Bottom waters with the mean of 12.32 ± 6.74 mg/L among all the six stations (Fig.2.10).

Fig. 2.9. Chemical oxygen Demand in the study stations

![Figure 2.9](image)

Fig. 2.10. Chemical oxygen Demand in the study stations

![Figure 2.10](image)
2.8.6. Salinity

Values of salinity showed maximum of 43.8 ppt during April 2011 in PCW and minimum of 33.4 ppt during June 2011 at SBM Bottom water, with the mean of 37.7 ± 1.86 ppt among all stations and months (Fig.2.11). During the second year study, values of salinity showed maximum of 42.5 ppt during May, 2012 in PCW and minimum of 35.0 ppt during November 2011 at Jetty Bottom water, with the mean of 37.89 ± 1.6 ppt among all stations and months (Fig.2.12).

Fig. 2.11. Salinity in the study stations

![Salinity in the study stations 2011](image1)

Fig. 2.12. Salinity in the study stations

![Salinity in the study stations 2012](image2)
2.8.7. Total Dissolved Solids (TDS)

During the first year study maximum TDS value of 68.2 mg/L was recorded during November 2011 at PCW and minimum of 37.8 mg/L was during March 2011 in the bottom waters of Jetty, with the mean of 43.0 ± 69.8 mg/L among all the four stations (Fig.2.13). During the second year of the study, maximum TDS value of 50.9 mg/L was recorded during June 2012 in the PCW and minimum of 33.7 mg/L was during December 2011 in the NJW location, with the mean of 41.35 ± 2.94 mg/L among all the four stations (Fig.2.14).

Fig. 2.13. Total Dissolved Solids in the study stations

Fig. 2.14. Total Dissolved Solids in the study stations
2.8.8. Sediment Texture

Sediment texture is defined as the relative proportion of sand, silt and clay. The ranges of diameters of the three separates are 0.05 - 2.0 mm for sand, 0.002 - 0.05 mm for silt and <0.002 mm for clay. The textural classes are based on the relative proportions of these components. In the present analysis in all the months and stations, sand was recorded predominantly followed by silt and clay. Distribution of different components shown in Table 2.2 and 2.3. The average mean percentage was 69.1% for Sand, 19.7% for silt and 11.1% for clay during 2010-11 followed by 67.4%, 20.2% and 12.1% for sand, silt and clay during 2011-12.

Table 2.2. Sediment texture in the study stations during Nov 2010-Oct 011

<table>
<thead>
<tr>
<th>Place</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
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Table 2.3. Sediment texture in the study stations during Nov 2011-Oct 2012

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2.8.9. Total Organic Carbon

Values of total organic Carbon during first year showed maximum of 2.65% during Feb 2011 in SBM whereas minimum of 0.1% during Nov. 2011 were recorded in all the sampling point, with the mean of 0.55±0.53% among all stations and seasons (Fig. 2.15). Levels of TOC during July and October 2011 were higher at SBM and Jetty stations. In the second year study, the values of total organic carbon showed minimum of 0.3% during March 2012 at NJW and PCW and a maximum of 2.3% during December 2011 at NJW. Levels of TOC during September 2012 were also higher (2.2%) at SBM and Jetty stations (2.16). During summer months of March to June, 2012, a reduction in percentage of TOC could be discerned in all the stations.

Fig. 2.15. Total Organic Carbon variation in study stations

![Total Organic Carbon variation in study stations](image1)

Fig. 2.16. Total Organic Carbon variation in study stations

![Total Organic Carbon variation in study stations](image2)
2.9. Discussion

In any environmental water quality study, major objective is to analyze the physical and chemical characteristics of water in order to determine its suitability for biota. The final status of a water body is conditioned by physical and chemical factors as they interact to determine the overall health of the aquatic system. Characterization of Vadinar coastal waters for selected parameters in general showed spatial and temporal variations in the investigated stations. The properties of aquatic habitats are influenced by regional and local climate, geology and natural and anthropogenic disturbance regime. Anthropogenic impacts due to increased pollutant and waste discharges, changes in water bodies' morphology impact all the basic habitat characteristics and affect the performance of associated biological communities.

Ambient water temperature is instrumental in regulating chemistry and biological reactions of aquatic organisms. Water temperature was strictly related to seasonal condition, waves, currents, motions and time of sample collection. During the study, perceptible surface water temperature variation of 20.5 to 32.2°C reflect the arid nature of the coast where fluctuations are pronounced. Surface water temperature was clearly temporal with summer recording higher values followed by post-monsoon and winter. Another factor that influences temperature significantly in coastal waters is tide and its amplitude. A vertical temperature gradient related with tides was earlier shown in Gulf of Kachchh waters by Vethamony et al. (2007). Summer and pre-monsoon maximum (June and August) and winter minimum (December-February) indicated in the present study was apparently due to atmospheric warming and cooling. Atmospheric variation played a major role in governing temperature variation and water exchange between the sea and the creek system was of less significance. In addition, factors like clear atmosphere, greater solar radiation and lack of intensive rain during summer and frequent clouds during winter play a significant role in influencing seasonal temperature variation. (Ajitkumar et al., 2006; Saravanakumar et al., 2008).

Fluctuations in pH of the sea water alter the marine environment drastically and hence it is one of the best indicators to identify zones of pollution in coastal waters. All biological activities take place within a narrow range of pH. The pH of marine waters is usually
quite stable due to its buffering capacity and range between 7.1 to 8.8 ±0.2 (Wetzel, 1983). Throughout the study period pH remained alkaline in all the stations with post monsoon and summer registering maximum whereas minimum values were recorded during monsoon. Ananthan (1994) stated that the higher value of pH during summer was due to the uptake of CO$_2$ by photosynthesizing organisms. The low pH observed during the months of January to March is quite clearly related with CO$_2$ influx dynamics. With an overall range of 7.1 to 8.8 (avg 8.14±0.2) the values were well within the limit and did not show any abnormality. Similar to temperature, pH values did not show much spatial variation. Marginal fluctuations observed could be attributed to local environmental conditions such as seasonal variation in photosynthetic rates, dilution of seawater by freshwater influx, low primary productivity, reduction of salinity and temperature and decomposition of organic matter (Paramasivani and Kannan, 2005; Bragadeeswaran et al., 2007).

Of all the dissolved gases in water, oxygen is the most important one for the survival of aquatic biota. (Paul and Mukherjee, 2006). Dissolved oxygen concentration varies mainly due to photosynthesis and respiration by plants and animals in water. In addition to these, DO is affected largely by the waste influx, especially the organic particulate matter which causes depletion of DO due to organic degradation. Generally, the coastal waters are saturated with DO due to wind driven turbulence and freshwater influx. This was also evident in the present study area. Similarly, BOD is an important tool to indicate the assimilative capacity of the coastal waters (Thomann and Mueller, 1987). Biological Oxygen Demand is employed as a gross measure of the oxygen demanding potential of the effluent. Assimilative capacity of a water body varies in accordance with the hydrodynamic conditions and other ecological processes.

Dissolved Oxygen for the two year study varied from 2.1 mg/L to 8.4 mg/L with a mean (±SD) of 5.08 ± 1.5 mg/L at all stations. The PCW station recorded a significant fluctuation in the DO concentration due to the shallowness of water and frequent shift in water column depth due to tidal condition. The DO value was low during summer when the temperature was high and it was maximum during post-monsoon when temperature was low due to high tidal activity and windy monsoonal conditions coupled with heavy rainfall and the resultant freshwater influx. From the present investigation it is apparent
that oxygen concentration is influenced by temperature and salinity in association with other physical and biological process. Observed variation in DO could also be attributed to photosynthesis and respiration by plants and animals in water. Majority of the stations showed a homogenous distribution of dissolved oxygen with the exception of a sharp decline recorded at station PCW (2.1 mg/L). Other than this, the observed DO was above 5 mg/L conforming earlier results from east and west coast of India (Raghunathan et al., 2004; Desa et al., 2005; Kalaiarasi et al., 2012; Archana et al., 2013; Badhja and Kundu 2012; Selvam et al., 2013).

The BOD has the capacity to alter the species diversity at a particular environment if it increases beyond a limit. Input of organic matters from terrestrial sources will increase the BOD level. Biological oxygen demand estimates organic pollution of aquatic biotopes and a measure of pollution effect. The BOD levels in present study varied from 0.2 mg/L to 5.9 mg/L with a mean and ±SD of 1. 84 ±1.12 mg/L at all stations. BOD in all the stations in the first year recorded higher values during the month of August 2011 and in the second year during the month September and October 2012. This could be due to microbial utilization of oxygen influenced by freshwater input (Nandan and Aziz, 1990). Joe (1993) opines that very high organic load would result in greater microbial decomposition and depletion of oxygen with high BOD values and eventually form a state of anoxia. Perceptible inverse relationship could be distinguished between DO and BOD values during the present study.

The amount of oxygen required to oxidize dissolved and particulate matter, called the chemical oxygen demand (COD), is a practical measure of organic contamination. Chemical Oxygen Demand (COD) is a measure of oxygen requirement of a sample that is susceptible to oxidation by strong chemical oxidant. Industrialization in coastal stretch causes severe organic contamination which is a most serious problem for water quality. The amount of oxygen required to oxidize dissolved and particulate matter, called the chemical oxygen demand (COD), is a practical measure of organic contamination, which is an environmentally serious problem. Since organic matter is mainly produced by photosynthesis of phytoplankton in the heavily eutrophied water body, COD is therefore well correlated with the biological quality of water. In the present study, the values of COD showed a maximum of 40 mg/L and minimum of 0.6 mg/L with the mean of 7.6±
10.5 mg/L among all the six stations. The maximum COD was observed in the month of August, September and October in station PCW during the first year of the study which could be due to decrease in fresh water inflow, land drainage and domestic sewage input and increase in salinity, temperature and phytoplankton productivity and microbial utilization of oxygen at the time of decomposition. Low chemical oxygen demand was due to increased mixing of domestic waste and fresh water influx into the coast and decreased biological activity due to decreased salinity and temperature as opined by Raman (1995) and Jameel (1998).

Water salinity profoundly influences the abundance and distribution of the biota in coastal, marine and estuarine environments. Salinity is the basic and primary factor among the environmental variables in the marine environment especially in coastal waters. Salinity is influenced by the inflow of fresh water and evapo-transpiration of the water body. Water salinity profoundly influences the abundance and distribution of the biota in coastal environments. In the present study, values of salinity showed maximum of 42.5 ppt and minimum of 35.0 ppt with the mean of 37.89 ± 1.6 ppt among all stations and months. Similar value was observed by Gohary et al. (2011) in Mediterranean Sea and Saravanakumar et al. (2008) in Kachchh coastal waters. Salinity in all the stations was high during pre-summer and summer months (March - May) and low during the monsoon season. The recorded summer high could be attributed to shallowness of water, low rainfall and high aridity of the region along with neritic water influence (Balasubramanian and Kannan, 2005; Sridhar et al., 2006). Poor rainfall induced aridity in the Gulf of Kutch region renders Gulf waters hypersaline round the year. In addition GoK is known to be a negative water body where evaporation exceeds precipitation (Vethamony et al., 2010).

Most often, high levels of TDS are caused by presence of potassium, chloride and sodium ions. It also indicates the presence of toxic minerals. Some dissolved solids come from organic sources such as leaves, silt, plankton and industrial waste and sewage. Others include runoff from urban areas and inorganic materials such as rocks and air that may contain calcium carbonate, nitrogen, iron, phosphorous, sulfur and other minerals. Total dissolved solids varied between a maximum of 68.2 g/L and minimum of 37.8 g/L during the two year study with the mean of 43.02± 6.98 g/L. These values are almost within the
range reported by Bhadja and Kundu (2012) in Saurashtra coastal waters among all the stations.

The sand, silt, clay groups are commonly referred to as the soil separates. Soil texture is defined as the relative proportions of each class. In the present study soil texture was predominantly sandy followed by silt and clay. The highest sand percentage was observed in all the stations which could be attributed to the strong tidal influence and wave actions. No significant difference was observed between stations and seasons. The increase in sand content along the southern coast of the inner GoK is caused by the presence of a few ephemeral rivers in the vicinity namely, Aji, Machchhu and Demi. The coastal geomorphic setup of the Gulf of Kachchh exhibits two distinct zones. The western part is dominantly the sandy landforms like beaches, berm plain, beach ridges and coastal dunes that eventually merge into a monotonous wide mudflat zone, which covers a vast area of around 1500 km² (Prizomwala et al., 2010; Shukla et al., 2010). The central narrow part, which acts as a transition zone contains an admixture of sandy and muddy sediments (Prizomwala et al., 2010; Shukla et al. 2010). There have been number of studies of suspended sediments from gulf waters for clay mineralogy and geochemical compositions (Nair et al., 1982; Chauhan et al., 2004, 2006; Ramaswamy et al., 2007), but their significance is limited to suspended sediments dynamics only. The sediment variability of the sea bottom of GoK was studied by Hashimi et al. (1978) who showed that the mouth of GoK is marked by rocky outcrops, whereas the inner Gulf of Kachchh (i.e. eastwards) is mantled by a thick column of fine grained sediments before being dissected into creeks.

The soil plays an important role in the CO₂ capture, a major gas in climatic change (Andres et al., 2011). According to the observation and field data, total organic carbon ranged from 0.1% to 2.65% during the entire study period. Generally the reported TOC content in the study stations was low which could be attributed to rapid mineralization and depletion due to intensive demand for nutrients by macro fauna and flora. Organic matter content is commonly associated with the amount of silt and clay present in the sediment. Fine sediment particles have larger relative surface areas than coarse particles and can absorb colloidal and dissolved organic matter forming sedimentary complexes. Once deposited, these complexes are capable of incorporating organic matter into the
bottom. The range of organic matter suggested that the sediments are low to moderately
organic in nature. Sediments with organic matter values exceeding 1% usually called
organically rich (Griggs, 1995).

During the present study, the average value of organic carbon contents were relatively
higher during pre-monsoon season (1.5%) compared to post-monsoon season (0.9 ±
0.63%) during 2010-11 and whereas in 2011-12 no such seasonal fluctuations were seen
and the values observed were uniform which ranged from 0.3 to 0.8%. Higher organic
content was observed (2.65%) in SBM during the month of Feb (2.3%) and in NJW
during the month of Dec (2.3%) 2011. The higher percentage of organic carbon during
the pre monsoon could be attributed to organic detritus as a result of biological activity
and the recorded increase during post monsoon could be attributed due to influx of land
run off and considerable amounts of terrigenous organic matter. Low organic content
during the second year (2011-12) in all the stations might be due to low bio-productivity,
active hydrodynamics as well as granulometric composition of bottom sediments which
are unable to accumulate organic carbon supplied from the water mass.

It can be concluded that the contents of organic carbon in sediment is much influenced by
many factors such as physical, biological and chemical processes. Besides, seasonal
changes also affect the distribution of organic carbon in the study area.