Petroleum hydrocarbons (PHc) are organic chemicals composed of fused benzene rings formed during incomplete combustion of coal, oil, petrol and wood (Shereet, 2009). Petroleum hydrocarbons assume significance as a highly deleterious pollutant to marine organisms. The origin of hydrocarbons is either biogenic (endogenic) which are synthesized by marine organisms or exogenic due to oil pollution accumulated by marine organisms. Petroleum hydrocarbons are an extracted, ubiquitous, organic contaminant (Faure et al., 2004). They are readily adsorbed onto the surface of particulate matter and ultimately deposited in the soil or sediments (Volkman et al., 1992; Chouksey et al., 2004). The source of oil pollution are oil fields, oil refineries and/or shipment activities, marine operations, land based discharge, and atmospheric and natural inputs (Chouksey et al., 2004). However, the natural content in seawater is affected by several means such as river inputs, industrial, agricultural and sewage effluents of the surrounding. The problem of oil pollution in marine environment due to different crude oil fractions like polyaromatic hydrocarbons (PAHs), petroleum hydrocarbons (PHCs) and phenols has become a global concern because of the accumulation of their residues in the tissues of various species of marine organisms and their pervasive impact on low dynamic ecosystems like mangroves, corals, and mudflats. Studies of such toxic compounds in general and toxic action of these contaminants in particular are of great importance to understand their impact on the ecosystem. Although a considerable fraction of petroleum hydrocarbons entering the marine environment is removed by evaporation, some of them get dispersed in water, accumulate in sediment and transferred to biota. The world production of crude oil is more than three billion tons per year, and about the half of this is transported by sea (Harayama et al., 1999). Many catastrophic oil spills from large tanker accidents have attracted public attention to the fate of petroleum hydrocarbons in marine environments.

Phenols and their derivatives commonly exist in the environment, these compounds are used as the components of dyes, polymers, drugs and other organic substances. The presence of phenols in the ecosystems is also related with production and degradation of
numerous pesticides and the generation of industrial and municipal sewages. Some phenols are also formed during natural processes. Phenol and alkyl phenols are dangerous to marine environment because these compounds can be endocrine disrupters especially for fish.

The problem of these pollution to the marine environment has brought a scientific attention with respect to effect of petroleum spills since it inherits the toxicities to specific biological ecosystem components and individual species. The behaviour and fate of oil pollutants, as well as their toxicity to marine organisms largely depend on the physical and chemical state in which they are present, and the prevailing environmental conditions. Impact of oil is known more due to its physical rather than its chemical properties.

The practical interest to study the PHc in marine environment of Gulf of Kachchh gained importance due to increasing activities of oil refineries on its shore. Gulf of Kachchh waters handle nearly 55% of the crude oil requirement of India, rendering it a highly vulnerable coastal realm to oil pollution. Presence of high biodiversity hotspots such as mangroves, corals, mudflats and numerous creek systems increases its vulnerability to oil pollution manifol. Its strategic location and proximity to oil producing Middle East countries makes it a favourable site for oil based industries. Presence of two major and 16 minor ports apart from 15 Single Buoy Moorings (SBMs) expose the gulf waters to chronic oil pollution. It is estimated that about 50 million tons of crude oil per year being handled in GoK, highest for one single coastal stretch in India.

Unlike PHc, the major source of phenol in the sea water is industrial effluents, agricultural runoff, chlorination of wastewater prior to discharge in the waterways and transformation products from natural and synthetic chemicals. Oil spills, engine washings of vessels and petroleum related products are responsible for the elevated levels of phenols in the seawater. This chapter presents the results of a two year study dealing with levels of PHc and Phenol in the waters of Vadinar of GOK.
3.2. Review of Literature

3.2.1. Petroleum Hydrocarbon

3.2.1.1. International status

Petroleum hydrocarbons products of crude oil are widespread in the marine environment due to variety of anthropogenic and natural activities. Hydrocarbons contained in crude are categorized on the basis of molecular composition as alkanes, naphthenes, aromatics, and alkenes (Scholz et al., 1999) Petroleum hydrocarbons and petroleum products are highly complex and varied mixtures of chemicals. Hydrocarbons (Carbon and hydrogen) compose majority of the components in petroleum (Wiseman, 1998). When crude oil is released into the environment, the compounds undergo physical, chemical and biological changes collectively referred to as weathering. Petroleum hydrocarbon enter the marine environment through riverine discharge, shipping activities, sewage disposal, offshore oil production and transport, oil spills as well as from pyrolysis/combustion form fossil fuels, vehicles, power plants, industrial process and refuse burning (Mostafa et al., 2009; Guitart et al., 2008).

Other human mediated sources of petroleum hydrocarbon include offshore oil production, marine transportation, atmospheric or aerial deposition from combustion of coal and gas flaring, direct ocean dumping, coastal, municipal and industrial wastes and runoff (NRC, 2000). However, among the anthropogenic sources, point discharges, contamination by urban runoff, refineries and other coastal effluents are substantial and are important in causing chronic pollution in the vicinity of estuaries, creeks, harbours and coastal settlements (Abu-Hilal and Khordaugi, 1994). Compared with other marine ecosystems, coastal habitats are particularly exposed to anthropogenic pollutants; especially to petroleum hydrocarbons (Yunker et al., 1993; Hostettler et al., 1999; Halpern et al., 2008). Concentration of PHc in the environment often exceeds the environmental quality guidelines, which have emerged as an ecological and human health issue of concern in recent years. Benson and Essien (2008) collected a baseline distribution of total hydrocarbons in both the epipelagic ad benthic sediments of the Qua Iboe estuary, Nigeria Delta Region, Nigeria. The sources of PHc in sediments from the largest hypersaline coastal basin, Laguna Madre in United States have been extensively
studied by Sharma et. al. (1997). Marine and estuarine environment around Australia have been studied by Volkman et. al. (1992) to illustrate the use of modern analytic technique to identify, quantify and determine the origin of hydrocarbon in aquatic sediments.

Page et. al. (1996) reported that the natural regional PHc background has been identified in Subtidal sediments of Prince William Sound, Alaska, USA that is readily distinguished from Exxon Valdez oil by chemical fingerprinting methods. Zanardi et. al. (1999) studied the distribution and origin of hydrocarbon in water and sediment in Sao Sebastiao, Brazil. The abundance and composition of aliphatic and aromatic hydrocarbons were investigated in bottom sediments of the Southwestern Amur Bay, Japan by Nemirovskaya (2007). The levels and distribution of PHc in coastal waters and sediments of the United Arab Emirates along the Arabian Gulf and Gulf of Oman were extensively investigated by Shriadah (1998). The status of oil pollution in the Arabian Gulf has been studied by Masoud et. al. (1998). Li et. al. (2009) studied the spatial and temporal distribution of total petroleum hydrocarbon in the sea water of Tianjin Bohai Bay, China during 1996-2005 which showed that the concentrations varied highly, ranging from 23.7 to 508 µg/l. TPH concentrations in the seawater varied with seasons, showing a decreasing order of winter > spring > summer.

3.2.1.2. National Status

Nair et al. (1972) studied the tar distribution in the select sandy beach coasts along central west coast of India. Diwedi and Paulekar (1974) investigated the intensity of tar ball deposition and the possible origin along the west and east coast of India. Qasim (1975) gave a general review of tar ball deposition along the beaches of West and East coast of India. Sengupta et. al. (1980) studied dissolved petroleum hydrocarbon in some regions of Northern Indian Ocean. Ramamurthy (1982) studied the oil pollution in the west coast of India off Arabian Sea from 1971 to 1980. Fondevkar and Alagarsami (1984) reported petroleum hydrocarbon contamination along the oil tanker routes in the Arabian Sea. Fondevkar et. al. (1980) studied the distribution of PHc in coastal waters of Goa and reported an average PHc value in water and sediment were 30.9 µg/l and 7.1 µg/g dry weight. Sengupta et. al. (1993) studied the oil pollution in the northern Arabian Sea after
the 1991 Gulf oil spill. Kadam and Chouksey (2002) studied the status of oil pollution along the Arabian Sea and Bay of Bengal and estimated that annually around $5 \times 10^6$ and $4 \times 10^5$ tonne per year petroleum, respectively are discharged from oil tankers and other ships plying the shipping lanes originating from the Middle East. Chouksey (2002) studied the migration and fate of selected contaminants from anthropogenic discharges in coastal marine environment. Nair (2002) and Chouksey et. al. (2004) reported PHc contamination in water, sediment and biota of the coastal area of Bassein-Mumbai region. They reported considerable fraction of PHc entering the marine environment and part of it dispersed in water and accumulates in sediment and finally transferred to biota. In the same Bassein-Mumbai waters, Chouksey et. al. (2004) reported that concentration of PHc varied widely from 2.9- 39.2 µg/l. Other than these, PHc in sediment from west coast of India is the subject of extensive investigation by many authors (Kadam 1987; Ingole et. al., 1989, 1995; Ram and Kadam, 1991; Kadam and Bangale, 1993; Ansari and Ingole, 2002). Muthukumar et. al. (2013) studied the seasonal variation of petroleum hydrocarbon in sediments from three different ecosystems such as Vellar and Coleroon estuaries, Pichavaram mangroves and Parangipettai coast from the southeast coast of India.

3.2.1.3. Regional Status

In Gulf of Kachchh, Petroleum hydrocarbons (PHc) are of particular significance due to its widespread handling which has led to the release of these products into the environment through accidental spills, long-term leakage and operational failures. Limited information is available with regard to petroleum hydrocarbon in Gulf of Kachchh coast. Kadam (1987) studied distribution of PHc in the surface sediments of Kandla Creek, Gujarat. Movement and fate of oil pollutants in Gulf of Kachchh was studied by Kankara and Subramanian (2007). Vethamony et. al. (2007) worked out the carrying capacity (CC) of Gulf of Kachchh with respect to PHc and compiled 27 years of data in this water. He observed the PHc level of 24.0 µg/l for all the 8 SPMs in Gulf of Kachchh and conclude that the PHc level is well within the limit. Kankara and Subramanian (2007) studied the Oil Spill Sensitivity Analysis and Risk Assessment for Gulf of Kachchh, India, using Integrated Modelling. Deshkar et. al. (2012) studied
various physico-chemical parameters and major nutrients along with petroleum hydrocarbon in three estuaries namely Narmada, Sabarmati and Mahi in Gulf of Kambhat. Sukumaran et al. (2013) investigated the distribution of PHc in Marine National Park and Marine Sanctuary and recorded PHc in water <10 µg/L and ≤1.7 µg/g in sediments.

3.2.2. Phenol

3.2.2.1. International Status

The main source of polluting phenols is anthropogenic activities such as petrochemical, pharmaceutical and textile industries, and as constituents of resins, dyes, paints, non-specific insecticides, herbicides, bactericides and fungicides (Gupta et al., 1983). In polluted coastal waters, the concentration of phenol was found to be in the range of 2.0-15.0 and 1.0-19.0 µg/l (Baetman and Vyncke 1979). Krajnovic, (1988) suggested that moderate concentration of phenol in the marine environment do not represent a serious problem of pollution. Basheer and Tan et al. (2004) studied the Endocrine disrupting alkylphenols and bisphenol-A in coastal waters from Singapore. Ermin and Sumartono (2006) reported the phenol concentration in sea water samples of Jakarta coast. Oketola and Taiwo (2013) studied the endocrine disrupting compounds such as Nonylphenol, Octylphenol and Bisphenol-A in water and sediments of two major Rivers in Lagos, Nigeria.

3.2.2.1. National and Regional Status

Only limited studies at national and regional levels investigated the distribution of phenol along the coastal waters of India. Zingde et al. (1980; 1987) studied the phenol concentration in Par and Mindola estuaries in Kolak River, Gujarat receiving waste water and industrial discharge. Kadam and Bhangale (1996) investigated phenol concentration along the Northeast Coast of India from Okha to Ratanagiri and from Ulhas estuary, Bombay. Concentration of phenolic compounds in this estuary was in the range of 0.00 to 23.5 and 1.0-19.0 µg/l. Kalesh et al. (2001) studied the distribution of dissolved Folin phenol active substances (FPAS) such as tannin and lignin in the seawater along the west
coast of India. Generally, investigation on the distribution of phenol and its compounds in Indian waters are few.

3.3.3. Materials and Methodology

Water samples were collected for the analyses of PHc and Phenol from the pre-designated stations as indicated in the chapter one. The surface waters were collected using a clean bucket. Niskin sub sampler (Partex model-2.5 litre capacity) with self closing mechanism was used for collecting the bottom water samples. Sampler bottles were rinsed with the sample waters before collection. Collected samples of two and half litres were stored in Amber glass bottles directly from the water sampler. Standard methods (APHA, 1995) were followed for the analysis of the samples.

3.3.3.1. Petroleum Hydrocarbon in water

The water samples were extracted with HPLC grade N-hexane. The organic layer was separated and dried over anhydrous sodium sulfate and the fluorescence of the extract was measured using Shimadzu RF-5301 PC, Spectrofluorometer (excitation – 310 nm; emission – 360nm) with calibration using Saudi Arabian Crude Oil. Analytical grade chemicals were used throughout the study. All the reagents and calibration standards required for this study was prepared using deionized water. All the samples were collected and analysed in triplicates.

3.3.3.2. Phenol in Water

The sample for phenol was collected in a pre cleaned one litre polyurethane plastic container. Reagents like Sodium hydroxide (NH₄OH, 12ml), Phosphate buffer solution (10 ml) 4-amino antipyrine (4-AAP, 3ml). Ferric cyanide (K₂Fe(CN₆) 3ml) were added to the sample (500ml) in sequence with stirring after dilution. pH was adjusted to 7.9 ± 0.1 during the addition of buffer solution The formed orange colour complex was then extracted in chloroform (25 ml). The separated organic layer was dried over anhydrous sodium sulphate and its absorption was measured at 460 nm on Shimadzu 1601 UV/VIS Spectrophotometer using phenol as a standard. Blank was also used during the analysis (Kadam and Bhangale, 1996).
3.3.3.3. Petroleum Hydrocarbon in Sediment

Seabed sediments were collected using Van-Veen grab whereas intertidal sediments were collected using a handheld shovel. After collection, the scooped samples were transferred to polythene bags, labelled and stored under refrigerated conditions. Collected samples were thawed, oven dried at 40°C and ground to a fine powder before analyses. Petroleum Hydrocarbons were isolated from the sediment samples by saponifying with methonolic KOH followed by extraction with hexane. Hydrocarbons were then separated using aluminium oxide (alumina) and estimated by RF-5301 PC, Spectrofluorometer (excitation – 310 nm; emission – 360nm).

3.3.4. Result

3.3.4.1. Petroleum Hydrocarbon in Water

During the first year of the study, concentration of PHc in the surface water varied from 0.1 µg/L (SBM-January, 2011) to 28.1 µg/L (PCW-May, 2011) (Fig. 3.1). During the second year, it varied from 0.03 µg/L (PCW- March 2012) to 20.1 µg/l (PCW-August 2012). The recorded values in the 4 stations during the two year study were within the limit of the CPCB of 100 µg/L. Maximum average value of PHC during 2010-2011 was recorded in Jetty (13.6 µg/L) and NJW (13.2 µg/L ) and minimum in SBM (7.6 µg/l) and PCW (10.5 µg/L). During 2011-2012 the maximum average value was observed in Jetty (5.9 µg/L) followed by SBM (4.42 µg/L) and NJW (4.68 µg/L) and minimum in PCW (2.81 µg/L). Higher values were recorded in the month of September and October 2012 (Fig. 3.2). Seasonal trend was not observed during the entire study period.
3.3.4.2. Phenols in Water

Phenols during the first year of study varied from 0.02 µg/L (SBM-March, 2011) to 52.1 µg/L (JSW-July, 2011). Station wise, the higher concentration of phenol was observed in month of January, May, July and October in all the stations (Fig. 3.3). Average phenol concentration was maximum in Jetty which recorded 12.7 µg/L followed by NJW and
PCW which recorded an average value of 11.08 and 10.58 µg/L. Minimum average value was recorded in SBM with a value of 7.06 µg/L. During the second year, minimum value varied from 0.5-0.7 µg/L in the month of July 2012 in all the stations and in Jetty surface water in May 2012 and maximum value of 33 µg/L in SBM Surface water in the month of November 2012 (Fig. 3.4). Average phenol concentration was similar in all the stations recording a value of 9.0 µg/L in Jetty surface water 8.3 µg/L in SBM surface water 7.8 µg/L and 8.1 µg/L in NJW surface water and PCW.

**Fig. 3.3. Phenol in study stations**

![Phenol in study stations](image)

![Phenol in study stations](image)
3.3.4.3. Petroleum Hydrocarbon in Sediment

In the present study, values of PHc in sediment showed minimum of 0.2 µg/g during Jan 2011 at JSW and maximum of 16.2 µg/g (wet weight) during November, 2010 at SBM. (Fig. 3.5) Station wise average value was higher in SBM surface water with a value of 3.4 µg/g and in JSW it recorded a value of 2.07 µg/g and in NJW and PCW it recorded a value of 2.07 and 1.6 µg/g. During the second year, values of PHc showed a minimum of 0.03 µg/g during Mar 2012 at Jetty and a maximum of 3.80 µg/g (wet weight) during Oct. 2012 at JSW. Higher values were recorded during October 2011 and November 2012 (Fig. 3.6). Station wise average value was higher in Jetty surface water with a value of 0.8 µg/g and in SBM surface water it recorded a value of 0.7 µg/g and in NJW and PCW it recorded a value of 0.9 and 0.6 µg/g.

Fig. 3.5. Petroleum Hydrocarbon in study station

![Petroleum Hydrocarbon in study station](image1)

Fig. 3.6. Petroleum Hydrocarbon in study station

![Petroleum Hydrocarbon in study station](image2)
3.3.5. Discussion

3.3.5.1. Petroleum Hydrocarbon in Water

Gulf of Kachchh, as a highly industrialized coastal belt has numerous source of oil that can reach its waters. Number of oil related industries in the northern and southern coastal belt of GOK is staggering. About 2590 lakh tones of cargo was handled during 2011-12 in GOK waters probably the largest quantum of oil handled in a single coastal stretch of India. Regular oil handling in the near coastal terrestrial environment is also a good source of oil reaching the coastal waters of GOK. Paradoxically, GOK is endowed with rich biological diversity with flagship ecosystems like mangroves, corals, mudflats, creek systems and Islands. Conducive factors like less tidal dynamics and highly oil receptive substrate nature in ecosystems like mangroves and mudflats readily traps the water borne oil fractions compounding its impact on different ecosystem components manyfold.

This two year study showed variation in the PHc of the surface water from 0.1 µg/l (Nov 2010-Oct 2012) to 28.1µg/L and in the second year it varied from 0.03 to 20.1 µg/L. The recorded values in the 4 stations were within the limit of the CPCB of 100 µg/l. Generally, total hydrocarbon concentration in seawater can induce harmful effect on the aquatic organisms in the range of 50 µg/l and above. This limit was not exceeded in any of the four stations in the present study and the results were well within the prescribed standard of CPCB. Obviously, the recorded levels of PHc in the Gulf waters were associated with the high ship traffic and crude oil handling. The levels, however, were much below the concentration of oil and grease recommended (100 µg/l) for salt pans, shell fishing and ecologically sensitive zones by Environmental (protection) Rules (1986). The variable concentrations of PHc often occur in areas of shipping lanes because fractions of petroleum being sparingly soluble in water, its distribution is patchy when it enters the aquatic environment through an anthropogenic source such as ship-related releases.

Central Pollution Control Board during 2002 recorded a PHc value of 116 µg/l at this same Vadinar waters. Compiled data for 27 years by Vethamony et al. (2007) showed that concentrations of PHc varied between 1.0 and 16 µg/l. and opined that in an event of an accidental discharge of 100m³/year from one SPM, the PHc level is likely to reach
24.0 µg/L for all the 8 SPMs as on 2007. Though this projected level is within the recommended safer limits of 100 µg/L there has been a gradual elevation in PHc values. Presently a maximum of 28.1 µg/L forewarning that the carrying capacity of Gulf of Kachchh is reaching its threshold limit.

Sengupta et al. (1978) reported very high values of PHc along the oil tanker routes and the Bombay high region. Higher values of oil and grease (3.8-20.0 µg/l) have been recorded in the Dock waters of Mumbai port (NEERI, 1985), while, Kadam and Bhangale (1992) found much exceptionally high levels lower levels of PHc (7.5-87.7 µg/l) in selected ports including the Mumbai Port, along the West coast of India. The high PHc concentration of 3388 µg/L was recorded in the coastal waters of Murud, near Mumbai, after a major oil spill in the Bombay high area that under the prevailing tidal currents and winds, preferentially drifted towards the Murud coast (NIO, 1993). Sengupta et al. (1995) reported levels of 0.32-1.85 µg/l in the surface water of great channel (Andaman Sea), 15 days after the disaster of the Danish Tanker VLCC Maersk Navigator.

Shereet (2009) recorded a concentration of seawater petroleum hydrocarbon between 14.54 and 65.45 µg/L with an average of 28.66 µg/L at New Damietta Harbor, Egypt. Stelmaszewski (2009) measured the oil content in Gulf of Gdansk seawater sampled at Gdynia-Orłowo between January 2006 and September 2008. The 174 measurements made during this period ranged from 1 to 120 µg/kg, but the majority did not exceed 20 µg/kg. Ragunathan et al. (2004) recorded higher concentration of petroleum hydrocarbons which showed 23.28 mg/L at Veraval and lower value of 9.38 mg/L at Mahuva, Saurashtra coast of Gujarat. Ingole et al. (1995) studied the concentration of petroleum hydrocarbons in the Intertidal ecosystem along the Bombay coast and reported that the values from three different stations (Madh, Worli, Colaba) ranged from 0-93.5 µg/l. Higher values of PHc (11.5-123.8) was recorded in Visakhapatnam harbor by Mohan and Prakash (1998) and Selvaraj et al. (1999) in Chennai Harbor. The concentration of PHc off basin Mumbai varies widely in the range of 2.9-39.2 µg/L compared with an average 2.8 µg/l. These levels are low though they would be influenced by the traffic of fishing vessels and other ships voyaging along the north–south navigational route (Chouksey et al., 2004). All these reported values indicate that levels of PHc and Oil in coastal waters though transitory will have its on chronic or acute
impact on the local biota. The reported values in the present study in comparison with the earlier data of Vethamony et al. (2007) and CPCB (2002) points to the fact that there has been a cumulative accumulation of PHc levels in the waters of GOK. It is possible that with accelerated oil based industrialization, levels of PHc in GOK will further be elevated in due course of time with its concomitant impact on its vital ecosystems.

3.3.5.2. Phenol in Water

Phenols in marine environment generally originate through onshore anthropogenic discharges. They are generated as by-products in manufacturing processes of coke, paper and pulp processing, coal gas liquification and produced from hydrocarbons in petrochemical industries. They are manufactured on a large scale because of their wide use in fungicides, antimicrobial products, wood preservatives, pharmaceuticals, dyes, pesticides, resins, etc. Hence, they become important constituent of domestic and industrial effluents. They are widely distributed in nature and free phenols are frequently liberated as metabolic intermediates during the degradation of plant materials. In recent years the natural supply of phenolic substances has been greatly increased due to the release of industrial byproducts into the environment. Moreover, nitrophenols and chlorophenols occur in the environment as degradation products of the organophosphorus and chlorinated phenoxyalkanoic acid pesticides, respectively.

In the present study the phenol content varied from 0.02 to 52.1 µg/l which shows that the Vadinar Coastal water is moderately polluted. It has been reported that sub lethal doses may cause endocrine disfunction, liver disfunction, genotoxic effect and reduced growth (Gad and Sad, 2008). Studies conducted by Kadam and Bhangale (1992) along the North East Coast of India from Okha to Ratanagiri reported that the phenol concentration of 18.7 µg/l in polluted stations and less than 5 µg/l in less polluted stations. Kadam and Bhangale (1996) recorded an average value of 16.5 µg/l in the Ulhas estuary, Bombay. Ermin et al. 2006 reported the phenol concentration in sea water samples of Jakarta Gulf varied from 9 µg /l to 1364.0 µg /l. Negative impacts of phenol on reproduction of aquatic animals have been reported for fish (Gosh, 1983) and invertebrates such as gastropods (Kordylewska, 1980), and sea urchin (Anderson et al., 1994). Reduction of egg production copepod was observed in copepod (Acartia clausi)
after exposure to phenol of 0.5mg/L for 8 days (Buttino, 1984). Au and Yurchenko (2003) found that chronic exposure to phenol of 0.1mg/L could lower the quality of sperm and reproductive success of Sea urchins, which may threaten the survival of these ecologically important species. Brauner et al. (1999) found that the exposure of a facultative air breather, *Hoplosternum littorale* to 12.5, 25 and 37.5% of the water soluble fraction of Urucu crude oil affected gas exchange and ion regulation.

Since Gulf of Kachchh has numerous industries, especially oil refineries which are the main source of phenol there is occurrence of ecological pressure within the aquatic system, but still in moderate. The chronic and long term exposure of these phenolic compounds to coastal biota is deleterious. But the risks to aquatic biota are difficult to assess due to complex nature of the hydrocarbons.

### 3.3.5.3. Petroleum Hydrocarbon in Sediment

In the water column, it is estimated that 70% of petroleum hydrocarbons are precipitated to the bottom (Knap and Williams, 1982). The sediment layer of 1-5 cm will explain clearly the extent of pollution (Edgern, 1977). The residue of PHc's in the sediments is affected by different factors among which are the rate of biodegradation (Lee et al., 1978), which interferes with the other factors such as temperature, photo oxidation, nutrient and sediment texture. (Gardner et al., 1979) The seasonal variation of temperature affect the degradation rate of petroleum hydrocarbons present in the surface layer, (Hughes and Mckenzie, 1975). In addition to that the deposition of petroleum hydrocarbons toward the bottom lead to increase the bacterial aggregates which feed upon them, then the biodegradation will increase in the area following the increase of oxygen and nutrients like phosphate and nitrate (Zobell and Prokop, 1966).

The levels of petroleum hydrocarbon in the all the four stations shows there is no significant pollution observed in Vadinar coastal stretch. In the post monsoon the petroleum hydrocarbon varied from 0.2 µg/g to 16.2 µg/g. The maximum was measured at SBM and minimum at JSW during 2010-11. In 2011-2012, it varied from 0.2 to 3.8 µg/g. The maximum was measured at JSW and minimum at Jetty. In rest of the seasons and stations the petroleum hydrocarbon ranged between BDL to 2.9 µg/g. Much of the variation can be attributed to temporal differences in petroleum input combined with
variation in sediment type and deposition history. Since the inputs are added to the water column before being collected by sediment, sedimentation patterns also strongly influence the distribution of Petroleum hydrocarbons. The interplay of input and sedimentation patterns can be seen in numerous well-studied coastal systems (Farrington and Quinn, 1973; Emira and Mirjana, 2007; Ololade et al., 2009). The result of the present study suggested that concentration of PHc during post-monsoon season was higher during the first year than that of other two seasons.

Sediment texture also plays a major role in the distribution of petroleum hydrocarbons. Fine grained sediments have higher concentrations of petroleum hydrocarbons than coarse grained sediments due to the higher capacity of fine particles to adsorb organic compounds and its higher surface area relating to the smaller particles (Sengupta et al., 1993). It has been recommended (NAS, 1975) that petroleum hydrocarbon level in polluted coastal areas may range from 100-1000 µg/g while from unpolluted coastal areas and basins are usually below 100 µg/g.

Rokade (1994) noticed that average high content of petroleum hydrocarbon of 673 µg/g wet weight in sediment of mudflats near oil jetty near Bombay harbor, while Pelletier et al. (1991) reported a concentration of polyaromatic hydrocarbons in the range of 63-963 µg/g dry weight for intertidal sediments in St.Lawrence estuary. Ingole et al. (1995) reported high level of petroleum hydrocarbon (10.3 µg/g) along the Bombay coast. Clark and Macleod (1977) have reported a range in hydrocarbon content of the sediments in the polluted coastal regions from 100 to 12,000 µg/g and in unpolluted coastal areas or basins to be usually 70 µg/g. The national academy of science (1975) has concluded that level of petroleum hydrocarbon in polluted coastal regions may be upto 12,400 µg/g dry weight. Kadam (1987) reported a value of 6.5 to 23.3 µg/g in Kandla creek. Kadam and Chouksey (2002) recorded a value of ND-20.7 µg/g in Gujarat coast and NIO reported an average value of 0.5 µg/g in 1999 in Gujarat coast. Ram and Kadam (1991) reported a value of 0.04 to 0.3 µg/g along the west coast of India. In the present study the average value recorded ranged between 0.8 to 2.0 µg/g during the entire period. An analysis of 27 years of data indicated that in GoK sediments, the average PHc concentration was 0.7 µg/g (Vethamony et al., 2007). Sukumaran et al. (2013) reported an average PHc concentration of 0.8 µg/g across Gulf of Kachchh. Role of the good tidal flushing system.
of the GoK, which is attributed to the strong tidal currents, in dispersing PHc contaminants has been observed by Vethamony et al. (2007). Shereet (2009) recorded the concentrations of petroleum hydrocarbon in surface sediment which ranged from 0.15 to 4.16 µg/g with an average of 1.44 µg/g.