MARINE WEALTH OF SAURASHTRA COAST: SPATIAL AND TEMPORAL VARIATIONS IN THE SEAWATER QUALITY AND ITS ROLE IN INTERTIDAL ASSEMBLAGE AND MACROFAUNAL DIVERSITY AROUND ANTHROPOGENICALLY INFLUENCED SHORES

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I have pleasure forwarding this thesis of **Ms. Poonam Bhadja** entitled, "**Marine Wealth of Saurashtra coast: Spatial and Temporal variations in the seawater quality and its role in intertidal assemblage and macrofaunal diversity around anthropogenically influenced shores**", for acceptance of the Degree of Ph.D. in Zoology.

This thesis contains interpretation of original experimental findings observed by the candidate in the field of Marine Biology and Coastal Ecology.

It is further certified that **Ms. Poonam Bhadja** has put in more than six terms of research work in my laboratory.

Dr. Rahul Kundu
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Chapter 1 INTRODUCTION

It is widely believed that life on Earth probably started around 3.5 billion years ago in the oceans. Today, nobody knows the number of organisms living there, merely that it is very large and that only a small fraction is known to humans. While marine regions cover about 71% of the Earth‘s surface and include oceans and associated ecosystems like estuaries, tidal marshes and swamps, sea shores and coral reefs. Oceans are the largest of all ecosystems and play a key role in controlling the World‘s climates, the atmosphere, and the functioning of major mineral cycles. Marine ecosystems are a complex of habitats defined by the wide range of physical, chemical and geological variations that are found in the sea. An important feature of sea is that it is very deep and life extends to all its depth but is much denser near the margins of continents and islands.

Marine biodiversity is the variety of life in the sea, encompassing variation at levels of complexity from within species to across ecosystems. The coastal zone is also endowed with a very wide range of coastal ecosystems like mangroves, coral reefs, sea grasses, salt marshes, sand dunes, estuaries, lagoons, etc., which are characterized by distinct biotic and abiotic processes. The coastal areas are assuming greater importance in recent years, owing to increasing human population, urbanization and accelerated developmental activities. These anthropogenic activities have put tremendous pressure on the fragile coastal environment.

The coastal zone is continuous and is in continual circulation via the major surface currents, upwelling and seasonal turnover in the upper waters, waves and tidal action. Waves and tides can dislodge the animals if not attached firmly to the substratum and throw them away or against rocks. Coral reefs are shaped and modified by wave action. Wave action also brings about mixing of oxygen and nutrients. The major zones in marine ecosystem are the littoral, neritic, pelagic and benthic. The littoral or intertidal zone is the shoreline between land and open sea. It is subject to the physical violence of waves and tides and to fluctuations, sometimes extreme, of temperature, moisture and light intensity. Along rocky shores, find more sessile organisms (algae, barnacles, etc.) than in any other type of ecosystem (Sebens, 1991). Along sandy shores, organisms are adapted by burrowing in or adhering to sand (e.g. ghost crabs, sand dollars, polychaetes). Mud flats, which occur in bays, harbour algae on the surface and often photosynthetic bacteria beneath the algae, along with an abundance of clams, worms, and crustacean. Coral reefs, fringes of coral formed around islands by colonial coelenterates, also may be regarded as littoral ecosystems. Because of their generally higher temperatures, depth of light penetration, and richer nutrient levels, coral reefs are among the most highly productive of all ecosystems (Dubinsky, 1990). Salt marshes are also intriguing ecosystems as are wetlands because they are havens of biodiversity (Burkett and Kusler, 2000).

Among the major zones of marine ecosystems, the intertidal zone is one of the most interesting regions of the marine environment. Organisms that live in the intertidal zone frequently need to deal with changing environment extreme physiological stress during the low tide period and those species inhabiting the upper intertidal zone are often more tolerant of thermal and desiccation stress than those found in other zones (Sokolova and Berger, 2000). The intertidal zone is an astonishing glimpse at the food chains, interactive life cycles and many special adaptations to this difficult environment. This zone is considered as the most productive with greatest diversity of life of any ecological area of the World. Throughout the intertidal area, a very fascinating phenomenon known as zonation occurs. Zonation is the vertical banding of the organisms. These distinct bands occur in part from many complex physical and biological factors that affect marine organisms. The zonation of organism along altitudinal, latitudinal or intertidal gradients is a reflection of their response to both physical and biological factor (Mettam, 1994). Harsh environment factors such as thrashing waves and temperature stress from exposure all contributes to the formation of this phenomenon. Zonation is not, however, entirely the result of adaptation of physical conditions. Distribution of intertidal animals is usually stratified along the vertical gradient of the littoral zone (Underwood, 1979). Intertidal invertebrate communities show vertical zonation patterns, which are more evident on rocky shores (Raffaelli and Hawkins, 1996).

The rocky shores present solid substratum for growth of wide variety of algae and for attachment of many sessile animals. Sessile animals abound to the rocks are many sponges, colonial hydrozoans, anthozoans (e.g. sea anemones) and bryozoans. The sedentary animals inhabiting the rocky shores are a variety of mollusks like limpets, mussels and oysters, barnacles and tunicates. Also abundant are the tubiculous polychaetes and others like crabs and *Zoanthus* which live in the crevices of hard rocks. Echinoderms, especially sea urchins and star fishes are found here. Macro-benthic organisms of rocky shores are ecologically important and they also function as integrators of ecological processes and disturbance over long time scale (Beuchel, et al., 2006). Macrobenthic can act as bio-indicator and can be monitored to assess whether their populations are experiencing ecological change as a result of various anthropogenic actions (Ikomi, et al., 2005). Biodiversity is threatened in these coastal zones, usually resulting from various anthropogenic affects (Gray, 2000). Macrofauna form vital links within food webs of marine and coastal environments. The community structure and function of these assemblages are therefore likely indicators of the amount and extent of damage caused by man-made impacts within these ecosystems (Gee and Warwick, 1996). Rocky shores are often greatly complicated by cracks and crevices, rock pools and overhangs, bounders, and variations in slope, aspect, and rock type. Cracks and crevices provide protection from waves and from desiccation, and (depending on size and number) will increase species richness of a shore and the abundance of some species. Rock pools provide relatively sheltered microhabitats at all levels on the shore, and support many organisms such as decline algae which could not survive on the open shore surface. Thus the presence of rock pools increases the species richness of the shore.

Biodiversity and community structure are now recognized to be important determinants of ecosystem functioning. A plethora of benthic indices have been developed to assess the effects of anthropogenic disturbance on the benthic environment (ICES, 2005). These include primary and derived univariate indices, number of individuals (N) species number (S), species richness (d), species diversity (Shannon-Wiener H‘) and taxonomic distinctness and diversity.

The main aim of indices is to summarize environmental quality to a number which can then be used within ecosystem based management structures (Borja and Elliott, 2007). Measures of species diversity play a central role in ecology and conservation biology

(Magurran, 1988). The variations in the distribution of benthic macro-invertebrates could be as a result of differences in the local environmental conditions and the composition, abundance and distribution can be influenced by water quality (APHA, 1995; George, et al., 2010). Differences in physical and chemical processes are the main cause of variation in intertidal communities, both in time and space (Terlizzi, et al., 2002). Macrofaunal communities are subject to a variety of abiotic and biotic disturbances and their interactions (Posey, et al., 1995). These include both natural (e.g. waves, currents and storms) and anthropogenic events. The organisms are dependent upon their environment. The environment refers to the surrounding of an organism which has direct influence on the activities of the organisms. The environmental factors include physical or abiotic, living or biotic.

The coastal environment is being altered at ever-increasing rates, often without looking ahead at future consequences. This is due to a multitude of human activities. The coastal zone receives a vast quantity of sewage waste, dredge spoils, industrial effluents and river runoff. These markedly affect the composition and quality of coastal environment, causing marine pollution. 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. Seawater resources are considered to be one of the major components of environmental resources that are under threat either from over exploitation or pollution, caused by human activities. Coastal area is the most dynamic and productive ecosystems and are also foci of human settlements, industry and tourism. Thus, the water quality plays very important role in well-being of human, animals and plants inhabiting the area. The quality of surface water within a region is influenced by both natural processes and anthropogenic activities. Marine water quality has become a matter of serious concern because of its effects on human health and aquatic ecosystems including marine life. Physico-chemical characteristics are indeed vital water quality parameters for monitoring due to their instability, where significant variations in physico-chemical parameters affect the quality of water resources.

Water quality, involves physical, chemical, hydrological and biological characteristics of water and their complex and delicate relations. As per the EMECS (2007), main water quality parameters considered for water bodies are pH, DO, BOD and COD. Total nitrogen and phosphorus were added to the standards to prevent eutrophication in coastal waters in 1993. Several factors were considered in the selection of water quality parameters while some were omitted intentionally. For coastal waters, COD was given high priority. Because of its significant effect on fisheries, oil was added to coastal water quality standards.

Temperature is a very important in the determination of various other parameters such as pH, conductivity, saturation level of gases and various forms of alkalinity etc. Increasing in temperature is often associated with hot water discharge from power stations and industries that use water as a coolant. Metabolic rate and the reproductive activities of aquatic life are controlled by water temperature. Seawater temperature is an important factor controlling the distribution of marine flora and fauna in the Northern Arabian Sea (IOSEA, 2006). Most marine animals typically cannot tolerate as wide range pH as freshwater animals, thus the optimum pH is usually between pH 7.5 and 8.5 (Boyd, 2000). At lower pH, the organism‘s ability to maintain its salt balance is affected (Lloyd, 1992) and reproduction ceases. Conductivity is the ability of a substance to conduct electricity. The conductivity of water is a more-or-less linear function of the concentration of dissolved ions. Conductivity itself is not a human or aquatic health concern, but because it is easily measured, it can serve as an indicator of other water quality problems. If the conductivity suddenly increases, it indicates that there is a source of dissolved ions in the vicinity. Therefore, conductivity measurements can be used as a quick way to locate potential water quality problems. Suspended solids can come from silt, decaying plant and animals, industrial wastes, sewage, etc. They have particular relevance for marine organisms that are dependent on solar radiation and those whose life forms are sensitive to deposition. High concentrations have several negative effects, such as decreasing the amount of light that can penetrate the water, thereby slowing photosynthetic processes which in turn can lower the production of dissolved oxygen; high absorption of heat from sunlight, thus increasing the temperature which can result to lower oxygen level; low visibility which will affect the fish‘ ability to hunt for food; clog fish‘ gills; prevent development of egg and larva. It can also be an indicator of higher concentration of bacteria, nutrients and pollutants in the water.

Dissolved solids, on the other hand includes those materials dissolved in the water, such as, bicarbonate, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. These ions are important in sustaining aquatic life. However, high concentrations can result to damage in organism's cell (Mitchell and Stapp, 1992), water turbidity, reduce photosynthetic activity and increase the water temperature. Factors affecting the level of dissolved solid in water body are urban and fertilizer run-off, wastewater and septic effluent, soil erosion, decaying plants and animals, and geological features in the area.

Turbidity measures the amount of light that is scattered or absorbed. High turbidity is an indicator of either runoff from disturbed or eroded soil or plankton blooms from excess nutrients. Very clear water is typical of the open ocean, which support little plant and animal life. Moderately low levels of turbidity with enough plankton to support the food chain are ideal for a healthy ecosystem. High levels of turbidity can cause several problems for aquatic systems. It can result in low dissolved oxygen levels by preventing photosynthesis by blocking sunlight and raising water temperature by absorbing more heat from the sun. It is damaging to gills and can bury eggs and benthic invertebrates when particles settle. Suspended particles may also carry nutrients, pesticides, and bacteria throughout waterways.

Many aquatic organisms can only survive in a narrow range of salt concentration since salt controls their osmotic pressure. Salinity affects marine organisms because of osmosis transports water towards higher concentrations through cell walls. Salinity is formally defined as the total amount of dissolved inorganic solids in seawater. The salinity in marine ecosystem may be affected by a number of factors. An increase in freshwater runoff due to high rainfall, coastal land clearing and urban development may cause a reduction in salinity, whereas evaporative concentration near shallow reefs may lead to an increase in salinity levels. The average salinity of seawater is 35‰ of which about 80% is contributed by sodium chloride and the rest by calcium, magnesium and potassium salts.

Dissolved oxygen is basic physiological requirement for nearly all aquatic biota and for the maintenance of balanced populations. Dissolved oxygen concentration throughout the water column can vary widely with tide, time of day, wind pattern and biological activities. Its presence is essential to maintain the higher forms of biological life in the water. Dissolved oxygen in water is replenished through photosynthesis, dissolution from atmosphere and addition of oxygen-rich water such as through runoff. Simultaneously, DO is consumed during heterotrophic oxidation of organic matter and respiration by aquatic flora and fauna as well as oxidation of some naturally occurring constituents in water. Thus, equilibrium is maintained between consumption and replenishment of dissolved oxygen. Influx of anthropogenic discharge containing oxidizable matter such as sewage and certain pollutants consume dissolved oxygen more than that the water body can replenish creating under saturation which, in extreme cases, may lead to onset of septic conditions with malodorous emissions thereby degrading the ecological quality. Low oxygen concentration is generally associated with heavy contamination by organic matter. Low oxygen in water can kill fish and other organisms present in water.

Biochemical oxygen demand is the amount of oxygen utilized by microorganisms in stabilizing the organic matter. On an average basis, the demand for oxygen is proportional to the amount of organic waste to be degraded aerobically. Hence, rate of aerobic utilization of oxygen is a useful tool to evaluate the intensity of deterioration in an aquatic medium. Increase in BOD can be due to animal and crop waste and domestic sewage. Chemical oxygen demand is the oxygen required by the organic substances in water to oxidize them by a strong chemical oxidant. The determination of COD values is of great importance where BOD values cannot be determined accurately due to the presence of toxins and other such unfavorable conditions for growth of microorganisms.

The concentration of nutrients in the ocean is low. Nitrates, phosphates, and other nutrients, which constitute about 96 percent of the ocean‘s elements, the major elements (Those constituting 0.3 to 1.9 percent) in descending order are chlorine, sodium, magnesium, sulfur, calcium, and potassium (Klemm, et al., 1990). Minor elements (0.00013 to 0.0067 percent), also in descending order, are bromine, carbon, nitrogen, strontium, boron, silicon, and fluorine. There is a wide spectrum of trace elements (less than 0.000063 percent) from argon to zirconium, some 45 in all.

Nutrients such as phosphorous and nitrogen are essential for the growth of algae and other plants. Aquatic life is dependent upon these photo synthesizers, which usually occur in low levels in surface water. Excessive concentrations of nutrients, however, an over stimulate aquatic plant and algae growth. Dissolved nutrients, though in low concentration, are essential for the production of organic matter by photosynthesis. Among several inorganic constituents such as phosphate, nitrogen compounds, silicate, trace metals etc., the traditional nutrients namely phosphate and nitrogen compounds have a major role to play in primary productivity. However, their occurrence in high levels in areas of restricted water exchange can lead to an excessive growth of algae which in extreme conditions result in eutrophication. Anthropogenic sources of nutrients in coastal marine environment include domestic sewage, detergent, effluents from agro-based and fertilizer industries, agricultural runoff, organic detritus etc. High concentrations of ammonia causes an increase in pH and ammonia concentration in the blood of the fish which can damage the gills, the red blood cells, affect osmoregulation, reduce the oxygen-carrying capacity of blood and increase the oxygen demand of tissues (Lawson, 1995).

One of the highest primary productions among the World oceans occurs in the Arabian Sea due to a variety of physical processes introduced by the semiannual reversal of monsoon winds (Qasim, 1982; Banse, 1987). Climate factors such as temperature and humidity are able to modify zonation pattern on a rocky shore. In the lower shore the temperature is similar to that of the sea, but higher up the range and rate of change vary. Temperature therefore a more significant factor for littoral organisms than sublittoral once, as desiccation is much more likely. Although constant in open sea, salinity varies considerably in the Intertidal zone, directly affecting shore life. In the Intertidal zone, salinity may increase by evaporation or decrease by dilution with fresh water drainage or rainfall. Many invertebrates are adapted to living in environments of fluctuating salinity. Berger and Kharazova (1997) found marine molluscs were able to survive salinity ranges from 4-5 up to 75-80 ppt. Organisms have mechanical adaptations including the ability to close shells or burrow away from extreme salinity variations. Oil content, total nitrogen and phosphorus were added to the standards to control oil pollution and eutrophication. However, the other use for coastal waters is fisheries.

Light is an important factor in the life of marine organisms due to its influence on photosynthesis, heating, radiations and vision. The majority of Intertidal organisms are dependent on oxygen. The solubility of oxygen increases as both the temperature and salinity falls on the Intertidal zone. At 35 ppt salinity, the oxygen content of saturated seawater decreases as temperature increases. Shallow coastal waters typically contain high levels of oxygen. However, if plant life is limited in tide pools, the inhabiting animals may utilize the oxygen faster than it can diffuse in, creating a net deficit. Tide pools with abundant plant life may experience low oxygen levels during the night, when photosynthesis is at its lowest rate.

The coastal environment is being altered at ever-increasing rates, often without looking ahead at future consequences. This is due to a multitude of human activities. Human activities, both directly and indirectly, responsible for current high rates of biodiversity loss are habitat loss; fragmentation and degradation due to agricultural activities; extraction (including mining, fishing, logging and harvesting); and development (human settlements, industry and associated infrastructure). Habitat loss and fragmentation leads to the formation of isolated, small and scattered populations. In the last few decades, there has been increasing pressure on coastal ecosystem due to unplanned anthropogenic activities, rapidly industrial development and erratic changes of coastal process. Coastal areas are vital to the prosperity of the country and are biologically most productive areas, supporting a wealth of living marine resources. The rapid industrial development and urbanization along the coast has resulted in degradation of coastal ecosystems have also deteriorated due to over exploitation of resources, population influx and inadequate infrastructures. Direct physical alteration and destruction of habitats is now viewed as the most important threat to the coastal environment**.** It is estimated that 80 percent of the pollutant load in the oceans originates from land-based activities. The major threats to the health, productivity and biodiversity of the marine environment result from human activities in coastal areas as well as in the hinterland. The following are considered the most serious problems affecting the quality and uses of the marine and coastal environment (GESAMP, 2001).

The coastal zone receives a vast quantity of sewage waste, dredge spoils, industrial effluents and river runoff. These markedly affect the composition and quality of coastal environment, causing marine pollution. The productivity potential of coastal waters depends on the amount nutrients (nitrite, nitrate, phosphate, total phosphate, ammonia, silicate and total nitrogen) present in it. Their concentration varies monthly, seasonally and annually depending on various environmental factors. In the ocean, the physical, chemical, and biological processes are linked in an intimate manner (Pyle, et al., 2002). Change in shoreline due to sea-level fluctuations, erosion, sedimentation and tectonic activities, is a well-known phenomenon in any part of the World. Any change in the coastline directly affects human habitation of the coastal area, which can play a vital role in understanding the shoreline behavior in the past (Gaur, 2007). In recent years, maximum small and large scale industries producing toxic and non-toxic wastes have come up in coastal areas which disturb the natural ecological balance. The coastal ecosystem of India has been endangered by several kinds of anthropogenic causes such as over fishing, shipping, tourism, siltation, domestic sewage, industrial waste and oil pollution along the coast.

The impact of the fishing gear (trawls and dredges) on the sea bed changes the habitat by increasing sedimentation and breaking up structures within the sediment such as polychaete tubes (Tuck, et al., 1998). Secondary effects include an increase in organic input created by the decaying bodies of dead and damaged organisms. Several community changes caused by fishing have been documented and are thought to depend on the duration and intensity of the disturbance (Underwood, 1989). Changes include a reduction in biomass and production of macrofauna (Schratzberger, et al., 2000), a reduction in abundance (Kaiser, et al., 1998; Hansson, et al., 2000), especially of fragile organisms and an increase in opportunistic species. This is thought to occur due to changes in competitive interactions and altered food availability (Frid, et al., 2000). Lindegarth and Hoskin (2001) also found increased spatial and temporal variability of the impacted benthic communities due to fishing disturbance.

An important activity that can have significant effect on marine environment is the construction and operation of ports and harbours. While there are some natural harbours, in many places artificial harbours have been constructed because of the demand by trade. Harbours and ports are constructed which are require to be dredged from time to time for entry of ship into shallow seashore. The debris generated by dredging operation to maintain navigational channels is dumped into the open sea causing pollution. Plastic pollution due to merchant ship adversely effects on sea bird life. Antifouling paint coated on the ship harm the coastal creatures even at some distance from ship. Waste from the periodic maintenance of ship by bottom scraping and sandblasting leave toxic material into the coastal environment. Increasingly larger vessels, oil tankers and the growing cruise ship scenario has resulted in a demand for ports that can berth large vessels and facilities to support associated activities (mechanized loading/unloading, storage of different kinds of materials). Consequently, extensive construction is required both on the shore and offshore.

The other activities on the coast include industries and settlements. With the thrust on industrialization in almost all countries, the coast has been a preferential location for industries for many reasons such as the proximity to cheap transport systems which can bring in raw materials and take finished products (shipping), established trade centers (many major towns and cities on the coast were established for this reason), disposal of wastes (into the sea), access to coolant water (for power plants etc.) and a relatively milder climate regime. In India, promotion for tourism is given more and more emphasis, which has resulted in many large hotels along the beaches. These hotels and resorts dump their solid waste and sewage into the sea. Aquatic life is harmed by fishing for fun and increasing turbidly resulting from the stirring action of motor and speedboats. Recreational activities such as snorkeling spear fishing, shell collection and coral walking by tourist and repeated anchoring of boats in reef area cause significance damage to the corals.

One of the most serious problems confronting the modern World today is the problem of water pollution, which has assumed global dimension. Widespread water pollution has been regarded as the most probable stress responsible for recent biodiversity related regional or global problems like the appearance of phytoplankton blooms, declining or alteration of other marine organisms, etc. Now a days it becomes relevant, also important, to understand the effect of pollution on marine biodiversity, on the basis of vigorous surveying of information obtained from the affected areas and from available research findings, in order to become alert before biodiversity loss (Agarwal and Agarwal, 2000)

Gujarat, situated on the western coast of India, has the longest coastline of (1,650 km i.e. 21% of the total coastline of India) among all the maritime states of the country, which makes it strategically serving as natural gateway to India. The Gulf of Kachchh and the Gulf of Khambhat are the two Gulfs in Gujarat out of the three Gulfs in the country. Extent of the inter-tidal and high tidal mudflats in the Gulf of Kachchh, the Gulf of Khambhat is exceptionally large. Mudflats, mangroves, marsh vegetation, coral reefs and saltpans cover a major part of the coastal wetland. Geo-morphological and climatic variation is very high on the Gujarat Coast. About 549 villages with the total population of about one million are situated along the Gujarat coast. The longest coastline dotted with 41 ports caters to demand and supply of cargo from the nearest maritime countries like Africa, Middle East and Europe. Besides this, the entire northern India and some parts of the central India also serve as hinterland to the ports.

The coastal stretches of Gujarat have several industries, which are based on salt as raw material. The saltpan activities not only provide livelihood for large number of unskilled workers but also provides raw material for several such chemical industries. Various industries on the Gujarat coastline like the Birla factory in Porbandar, GHL in Sutrapara, LNT and Cement factory in Kodinar, Bhavnagar and Jafrabad and various other Gujarat chemical industries on the Saurashtra-Kachchh coastline have been dumping millions of liters of industrial effluents and toxic wastes into the coastal waters every day, as they have no treatment plants. For example, there are four soda ash industries in Saurashtra producing more than 60 percent of the country‘s total production. One factory or another at one time releases effluents with more ammonia than maximum permissible limits. Veraval is one of the important port city located the western coast of Gujarat. In addition to this, load of pollution generated from the operation of boats and vessels, the domestic wastewater generated from the Veraval town is being discharged into the fishing harbour area without collection/treatment and also the effluent generated from the 45 fish processing industries located in the nearby GIDC also being discharged in to this fishing harbour area. All these sources of pollution from different spheres are contributing the load of pollution in fishing harbour area and subsequently contaminating the nearby coastal waters. An additional, about 14 fish processing industries are also located in Mangrol and Dwarka.

The present study was undertaken to set up an innovative trend of monitoring of the human-nature interaction and its effect on the natural system to set up the openings of the future study on this tract at this area. In this context, a detailed study on the Saurashtra coast line, one of the biggest one in India desired a detailed monitoring to work out the present status of the ecosystem, the threats mounting and impending, natural resistance and adaptation in response to the pressure and a possible negotiation to the neutralize the harsh condition to offer a better tomorrow. The present study deals with the biodiversity and man-made pressure on the coastal health as well wealth of the rocky intertidal macrofauna in four different stations along the Saurashtra coastline. With a view to assess the status of the intertidal macrofauna, the physico-chemical characteristic of the coast and the interaction between the fauna and anthropogenic activities were investigated. The Western coastal belt of India, these days is considerably being exploited heavily by various kinds of Industries. This study revealed how this is affecting the ecosystem of this area.

AIMS, OBJECTIVES & HYPOTHESES

Aims:

The aims of the present investigation were to study the spatial and temporal variations of the seawater quality and to evaluate the influence of seawater quality to the intertidal assemblages and the diversity of intertidal macrofauna around the selected shores along South Saurashtra coastline off Arabian Sea.

Objectives:

Keeping in mind the aforementioned aims of the study, the following objectives had been set forth:

- To study the identified shores for their coast characteristics.
- To identify and demark the sampling sites on the coastline.
- To monitor the general water quality parameters, for the coastal area, as prescribed by Ministry of Environment and Forests, in the sampling sites over a time scale.
- To study the selected shores for their macrofaunal and algal diversity.
- To identify the type and degree of anthropogenic activities those involve the coastal water.

Hypotheses set to be tested:

The hypotheses to be tested in this study are set in null form and are as follows:

- There will be no significant spatial variations in the general water quality parameters.
- There will be no significant variations in the general water quality parameters over the time scale.
- The water quality parameters are not influenced by anthropogenic activities in this shoreline.
- The macrofaunal diversity (and coastal assemblages) is not influenced either by water quality or by anthropogenic activities.

Chapter 2 REVIEW OF LITERATURE

The biodiversity of the Indian Ocean region, like most of the Word's marine domain, is poorly known (John and Tennille, 2005). About 80 % of all marine species occur in the coastal zone (Ray, et al., 1999; Arjunan, et al., 2010) and this figure is properly conservative (Reaka-Kudla, 1997). Currently the World's biodiversity is estimated at 1.75 million species, excluding microbial species (Heywood and Watson, 1996), but Reaka-Kudla (1997) estimates a range from 5 to 120 million. Approximately 300000 marine species are known (Reaka-Kudla, 1997; Gray, 1997).

Growing awareness of biodiversity issues has brought the need for comparable and meaningful measures of diversity at many scales into sharp focus (Gray, 1997; McCann, 2000). In particular, factors controlling the biodiversity of an area, and thus ecosystem function, are central to biodiversity research (Tilman, 2000). Diversity is high in benthic coastal areas (Gray, 1997). These habitats have important conservation and intrinsic values that make them worthy of study. They also play important roles in providing food for humans, fish and birds, and influence carbon and geochemical cycling. Intertidal and shallow subtidal soft-sediment habitats are subject to a wide array of human impacts and, consequently, macrobenthic communities have become one of the most common indicators of environmental effects (Gray, 1981).

In the face of uncertain knowledge about the magnitude and location of biodiversity, scientists look for trends or gradients in species richness and patterns of endemism (having a relatively narrow distribution) to determine what areas are most in need of protection. They hope that by focusing conservation efforts on species-rich areas or areas with many threatened and endemic species (hot spots), they can protect much of the flora and fauna that are yet to be discovered. Because only about 7 percent of the oceans have been sampled, the current state of knowledge regarding species distribution and hot spots is poor (Culotta, 1994). The highest overall diversity occurs in the tropical Indo-Western Pacific, a region that includes waters off the coasts of Asia, East Africa, northern Australia and the Pacific Islands (Reid and Miller, 1989). Within this region, some of the highest levels of marine species richness are found off the coasts of the Philippines, Indonesia and New Guinea. Waters surrounding

Polynesia, portions of the Indian Ocean and the Red Sea, and the Caribbean contain areas with high levels of reef fish diversity. Coral reef fish make up one quarter of all known marine fish species (Bryant, et al., 1998). Little is known about the extent of global biodiversity, and even less is known about what species exist in the World's Seas. Of the 1.7 million species cataloged to date, about 250,000 are from marine environments (Roberts, et al., 2002). Although marine ecosystems are probably less diverse than terrestrial environments in terms of total numbers of species, marine ecosystems harbour more varied life forms. Scientists measure this variation in "body architecture" by comparing the range of phyla (major kinds of organisms) found on land and in the sea (Franca, et al., 2009).

Biodiversity and faunal abundance are directly related to the complexity of marine and brackish habitats (e.g. Jones, et al., 1994; Atrill, et al., 1996; Yakovis, et al., 2004, 2008). For example Atrill et al. (1996, 1999) recorded the number of supralittoral species in the brackish environment of the Thames Estuary to be positively correlated with habitat complexity. Sandy–muddy sediments with a larger number of plant species, particles such as stones, shells, decayed wood and clay provided additional niches leading to much higher biodiversity than in locations lacking these complex features (Atrill, et al., 1996, 1999). In the areas with relatively low diversity (e.g. estuaries and brackish seas) the heterogeneity of the substrate seems to be of prime importance for the sustainability of local ecosystems (Atrill, et al., 1996, 1999). Therefore, documenting ecological patterns of such diversity hot spots is of special need in the light of proper ecosystem management and protection (Atrill, et al., 1996, 1999). Boulder fields assemblages have been the focus of many studies (e.g. Chapman and Underwood, 1996; Chapman, 2002 a, b; Cruz Motta, et al., 2003; Le Hir and Hily, 2005). With their spatial and temporal variations they constitute heterogeneous habitats conducive to high biodiversity (Chapman, 2002a). Smaller rocks are usually at constant state of recolonization following disturbance caused by overturning. Larger rocks being heavier are harder to overturn and thus offer much more stable substrate and usually support a more abundant biota (Osman, 1977; Wilson, 1987). Together with their sessile inhabitants, boulders can create complex three dimensional structures and provide additional niches for other organisms. The biotic part of such structures is often composed of animals (‗ecosystem engineers') like corals, mussels or algae (Yakovis, et al., 2008). Such species influence the diversity and abundance of organisms living in these three-dimensional structures and while they may not be involved in direct trophic interactions they can modulate the availability of resources to other species by creating physical complexity (Jones, et al., 1994). Even when such three dimensional structures are separated by only a few meters, they can harbour rather different faunal assemblages due to differences in their complexity (Katarzyna and Kuklinski, 2010).

A detailed descriptive and quantitative approach to intertidal communities is useful to estimate parameters such as productivity and community structure. Ecological studies are frequently based on abundance, diversity or biomass values of the biota (Anderlini and Wear, 1992; Underwood and Chapman, 1996) and may contribute to detect microscale relationships among their units and influences of environmental variables. Furthermore, multivariate analyses allow for an analysis of changes in community structure following the method proposed by Clarke (1993) based on Field et al. (1982). As human activities have an increasing effect on intertidal environments Worldwide (Tegner, et al., 1996), strategies are needed to protect these areas and ensure adequate handling of potential ecological problems. However, most protected areas in the World are terrestrial, and the strategies developed in these areas are often based on distributions of particular protected species and cannot be directly applied to the marine environment (Agardy, 1994). In fact, the biogeographical boundaries of marine species are poorly defined (Suchanek, 1994), and knowledge of species richness is more limited for marine than terrestrial habitats (Gray, 1997).

Even though the relationship between the diversity of species assemblages and the complexity and heterogeneity of the habitat is well known, ecologists have difficulty understanding the real underlying processes (Beck, 2000). For instance, numerous studies of the effects of habitat structure on species assemblages have not indicated that complexity or heterogeneity clearly enhances diversity, as might be expected theoretically (Guichard and Bourget, 1998). These ambiguous or even contradictory results have been attributed to such factors as the choice of a single observed taxonomic group, premature successional age of the studied assemblages, or an inappropriate observation scale (Chittaro, 2002). The scale of observation is very important, as suggested by Bishop et al. (2002). Another complication is the different meanings given to the same term in the literature relative to the effects of habitat structure on species assemblages (Beck, 2000).

The latitudinal gradient in species richness is frequently cited in comparative diversity discussions (Hawkins et al, 2000). In general, the negative relationship with increasing latitude holds true (Hillebrand, 2004), but causation remains a matter of debate (Levin, et al., 2001; Willig, et al., 2003). Further, there are many exceptions, and conflicting results exist for the marine macrobenthos (Gray, 2001). Thorson (1957) showed that the species richness of several infaunal groups remained constant between different climatic areas, while that of the epifauna increased in the tropics. Comparative studies of shallow tropical and temperate muds have lent support to the first, revealing little difference in diversity and community structure (Warwick and Ruswahyuni, 1987; Kendall and Aschan, 1993). Frouin and Hutchings (2001) reported on the macrobenthos of organically enriched sands in a Tahitian lagoon. Their species richness estimates were again no higher than those found in temperate shelf environments.

Coastal areas harbour a wide variety of habitats that support high species diversity, such as coastal sedimentary habitats (Gray, 1994), intertidal rock walls, and coral reefs (Sheppard, 1980; Huston, 1985). Unfortunately, biodiversity is most threatened in these coastal zones, most usually resulting from anthropogenic affects (Gray, 1997). In order to develop conservation strategies for the protection of biodiversity in these coastal ecosystems, more research on basic marine biodiversity patterns and community structure should be conducted (Olsgard, et al., 2003). Molluscan communities are effective indicators of overall ecosystem health and species diversity (Rittschof and McClellan-Green, 2005), making them ideal study organisms of conservation and biodiversity studies.

Measures of ecological diversity and species richness require adequate species recognition but the taxonomic tools available for the Western Indian Ocean are virtually non-existent and the taxonomic literature is widely dispersed. This taxonomic impediment (Kendall, et al., 2004) has forced this study to focus on those groups familiar to the authors, namely the Mollusca and Polychaeta. Studies of the molluscs of the Seychelles date back to the early nineteenth century (Dufo, 1840) and continue with faunal lists such as Melvill (1909) and Winckworth (1940). The single identification guide available (Jarrett, 2000) covers only the larger molluscs. Current data from other regions in the Western Indian Ocean; Red Sea (Dekker and Orlin, 2000), Arabian Sea (Dance, et al., 1995), R´eunion Island (Andrew, et al., 2005) suggest that a molluscan fauna in excess of 2000 species is likely for the Seychelles.

Study of marine fauna in India has drawn greater attention from the 18th century onwards. However, in India major studies have been conducted only on the commercially important organisms such as crustaceans, molluscs, holothurians and higher vertebrates. Focus of studies was not made on many minor phyla, which are not important for commercial purposes (Venkataraman and Wafar, 2005).

There are about as many procedures as the number of biologists working in the field of marine biodiversity to assess the quality of seawaters, many biotic indices based on macro-invertebrates have been proposed (Ghetti and Ravera, 1994). Washington (1984) illustrated 19 indices among those most commonly used. The biotic indices, developed for easily degradable organic matter pollution (sewage), are based on the different sensitivity of some taxa of macroinvertebrates. The measure of the diversity is another biological method used by several authors for monitoring the pollution level of the environment (Guerold, 2000).

Two measurements commonly used in studies of marine benthic fauna are density and species diversity. Density can be expressed as the number of individuals per unit area or volume whereas, species diversity is usually held to encompass the number of species present in a sample and the abundance of individuals within each of the species. It is maximal when each individual represents a separate species and minimal when all individuals belong to the same species (Gray, 1974). There is much controversy in the literature regarding the definition of species diversity, how to measure it, and what any differences in absolute values may indicate. However, in two recent exhaustive reviews by Gray (1974) and Peet (1974), it was suggested that certain species diversity indices, if used properly, could be of value in evaluating community structure. Communities and community changes over time due to disturbances can be analyzed and characterized in different ways. One of the most common methods is by looking at community diversity which is a measure of complexity of the community (Laetz, 1998). Diversity consists of two components, the variety and relative abundance of species. Therefore, diversity measures take into accounts two factors; species richness, that is number of species, and evenness or equitability, that is how equally abundant the species are (John and Tennille, 2005). Species diversity may thus be defined as a measure of species composition in terms of both the number of species and their relative abundances. Diversity indices characterize species composition at a given site and time. Providing a sound basis for the examination of species diversity, species abundance models describe the distribution of species abundance and give a better picture of the relationship between species richness and evenness. Several theoretical distributions such as geometric series of Motomura (1932), log series of Fisher et al, (1943), log normal of Preston (1948) and broken stick of MacArthur (1957) have been proposed to describe the abundances of species in communities. Of these models, log series and log normal distributions are most often being used in the field. In addition, it has been documented that the use of multivariate statistics is a much more precise way of detecting changes in benthic assemblages in space and time than the use of diversity indices (Gray, 2000).

Diversity measures are comprised of two components, richness and evenness, and various indices emphasize one or the other component differently. The number of species (species richness) has been the traditional measure of biodiversity in ecological and conservation studies, but the abstract concept of biodiversity as the ‗variety of life' (Gaston, 1996) cannot be encapsulated by a single measure (Warwick and Clarke, 1995). Ellingsen (2001, 2002) evaluated different measures of marine biodiversity, and suggested that, in addition to species richness, distributions of species and community differences should be taken into account. Marine species richness may only total 4% of global diversity (Ellingsen, 2002), life began in the sea, and much of deep diversity is still primarily or exclusively marine. For example, 35 animal phyla are found in the sea, 14 of which are exclusively marine, whereas only 11 are terrestrial and only one exclusively so (Gray, 1997). Our understanding of major changes in marine diversity over deep time is comparatively good, thanks to the excellent fossil record left by many marine organisms, although considerable sampling problems limit the potential for accurate fine grained analyses (Newman, 2000). In contrast, our knowledge of marine diversity in the present is poor compared to our knowledge for terrestrial organisms, and an appreciation for the dramatic changes in marine ecosystems that have occurred in historic times is only just beginning to emerge (Pandolfi, et al., 2003).

Species richness, Shannon information, and Simpson diversity are the three most commonly used nonparametric measures of species diversity. The bias in species richness and Shannon information depend on unknown parameters of the species abundance distribution. The proportion of the total diversity found within communities provides a natural measure of similarity among multiple communities. The expected similarity among multiple random samples from the same community depends on the number of samples and on the underlying measure of diversity (Lande, 1996). Measures of species diversity play a central role in ecology and conservation biology (Noss and Cooperrider, 1994). The most commonly employed measures of species diversity are species richness (number of species present in a community), and those based on species frequencies involving Shannon information (H).

Species diversity is well-known for its peak in the tropics. Recognizing that global diversity is the result of a multitude of factors, there is still much potential to discover emergent patterns because new methods and approaches can examine diversity in three dimensional space and time (Lomolino and Heaney, 2004). In addition, there has previously been a tendency to focus on species diversity in one dimension (latitude) using a single parameter (species richness), (Gaston, 2000). Two examples of approaches that are improving our description and understanding of diversity are macrophysiology and trait approaches. Macrophysiology describes how physiological traits are distributed in space (Chown, et al., 2004). Morphological traits have been used to explore selection pressures between assemblages of differing diversity (McGill, et al., 2006).

The similarity indices measure the similarity level of two communities. According to Washington (1984) this method, which could be a very useful tool in monitoring water bodies, requires a non-polluted reference environment. The different aims of chemical and biological monitoring and the advantages and disadvantages of biotic and diversity indices have been discussed by De Pauw and Hawkes, 1993 and Ravera, 1998. There is a very rich literature on biotic and diversity indices, but relatively few comparisons of these methods have been made (Cao, 1996).

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). Studies on benthos along the shelf region of the northwestern India are limited to the studies of Neyman (1969) who studied the benthos of the shelves in the northern part of Indian Ocean. Other works in the northwest coast of India include that of Parulekar and Wagh (1975), Parulekar et al., (1976), Harkantra et al., (1980), Joydas and Damodaran (2001) and Joydas (2002). Moreover, Parulelkar et al., (1982) studied the benthos of the Indian Seas. However no work has been done to elucidate the community structure of the shelf waters and the relationship between the benthos and environmental properties except that of Varshney et al., (1988) who studied the macrobenthos of very near shore depths (5-20m) off Versova, west coast of India. Rocky shores, the most extensive littoral habitats on eroding wave exposed coasts throughout the coastlines of the World‘s oceans, are ecologically very important (Crowe, et al., 2000). Most remarkably, rocky intertidal shores encompass a gradient of environmental conditions from fully marine below low tidal levels to fully terrestrial where splash and spray reach to the highest level above high tide (Underwood, 2000). Being a heterogeneous environment, intertidal rocky coastlines provide a multiple range of habitats that support a great variety of living forms (Terlizzi, et al., 2002).

Measures of species diversity play a central role in ecology and conservation biology (Whittaker, 1972; Pielou, 1975; Magurran, 1988). The diversity and seasonal variations of macrobenthic organisms and associated environmental factors influencing the benthic community in the west coast of India and Bay of Bengal were extensively studied (Harkantra and Rodrigues, 2004; Jayaraj, et al., 2007; Kundu, et al., 2009). Similar works in the northwest coast of India include that of Parulekar and Wagh (1975); Harkantra et al. (1980); Sajan et al. (2010); Vaghela et al. (2010). However, diversity and ecology of intertidal macrofauna in the western coast of India off Arabian Sea was reported by Parulelkar et al. (1982); Raghunathan, et al. (2003, 2004); Misra and Kundu (2005).

In rocky littoral communities, high nutrient levels are generally considered to stimulate the growth rate of photosynthetic organisms and to increase the primary production of the ecosystem. An increased production will, however, not only be visible as an increased growth rate of the existing algae, but also as a replacement of slow-growing species by faster-growing species (Bowers, 1999).

The studies on the ecology of the intertidal zones have attracted the attention of most of the ecologists all over the World, and it has been well recognized that the study of interactions and interrelationships between the living organisms and their environment is an extremely active and dynamic discipline of science (Reid, et al., 2001). A gradient of environmental conditions extends across the intertidal zone, due mainly to the different durations of submergence at each tidal level and therefore sea shore experiences wide and largely unpredictable variations in temperature, salinity and water loss (Newell, 1970) which call for a broad spectrum, physiological, behavioral adaptations. The habitats are diverse but compressed into a small area of intertidal zone where upper limits of distribution are usually determined by physical conditions and lower limits by biological interaction (Menge and Branch, 2001).

The amount of literature concerning distribution patterns of rocky shore organisms is vast. Classical descriptive works include the universal scheme of zonation proposed by Stephenson and Stephenson (1949, 1972), the extensive study of zonation pattern on the British Isles by Lewis (1961, 1964), and the similar approach for the Mediterranean by Peres and Picard (1964). Simultaneously with the descriptions of pattern of distribution (Lewis, 1964; Brattstrom, 1980; Norton, 1985; Russell, 1991) marine ecologists started to investigate the influence of physical and biological factors on marine intertidal communities (Ballantine, 1961; Connell, 1972; Underwood, 1981; McQuaid and Branch, 1984; Hawkins and Hartnoll, 1985; Southward, 1991). Experimental approaches to understand the functioning of rocky shores encompassed disturbance and succession, competition, grazing, predation and recruitment fluctuations (Jenkins, et al., 1999, 2000). An extensive literature has recently been synthesized by Littler and Kitching (1996), Raffaelli and Hawkins (1996) and Paine (2002).

The macrofauna community is mainly composed of filter-feeders (mussels, barnacles, serpulid polychaets, and bryozoans) herbivores and detrivores (gastropods, amphipods, isopods, sea-urchins) and carnivores (polychaets, crabs, starfish and fish). As for the herbivores, which depend on the algal growth, the filter-feeders and detrivores in benthic algal communities are also dependent on the organic particles produced by the benthic algae (Hopkins and Robertson, 2002; Airoldi, 2003), in addition to the particles of planktonic origin. Thus the major components of the fauna are expected to be dependent on the development of the algal community and to respond to nutrient addition subsequently to responses within plant communities.

Benthic macro fauna are those organisms that live on or inside the deposit at the bottom of a water body (Idowu and Ugwumba, 2005). In the marine water ecosystem, they include several species of organisms, which cut across different phyla including annelids, coelenterates, molluscs, arthropods and chordates. These organisms play a vital role in the circulation and recirculation of nutrients in aquatic ecosystems. They constitute the link between the unavailable nutrients in detritus and useful protein materials in fish and shellfish. Most benthic organisms feed on debris that settle on the bottom of the water and in turn serve as food for a wide range of fishes (George, et al., 2010). They also accelerate the breakdown of decaying organic matter into simpler inorganic forms such as phosphates and nitrates (Gallep, et al., 1978). All forms of aquatic plants, which are the first link of several food chains existing in aquatic environment, can utilize the nutrients. These organisms therefore form a major link in the food chain as most estuarine and marine fishes, birds and mammals depend directly or indirectly on the benthos for their food supply (Barnes and Hughes, 1988).

Benthic communities play a critical role in trophic relationships by providing major sources of energy to economically and ecologically important demersal fishes. Their diverse morphology and ability to adapt to various habitats make them important as food for large benthic organisms (McIntyre, 1977; Gerlach, 1978) and in recirculation of nutrients (Tamaki and Ingole, 1993). The distribution of estuarine benthos varies both temporally and spatially (Rainer, 1981) owing to the patchiness of their occurrence. Parulekar et al. (1980) and Ansari et al. (1986) have studied the distribution of macrobenthos in the Mandovi and Zuari estuaries; Parulekar et al. (1982)

investigated the association of macrobenthos with the demersal fishery of the estuary. The macrofauna in these waters has been empirically defined as animals retained by 0.5mm screens. Many organisms can thus be seen only on close inspection, while other may weigh several grams while fresh. Benthic macrofauna are good indicators of estuarine conditions because they are relatively sedentary at the sediment–water interface and within deeper sediments (Dauer and Conner, 1980). The abundance of benthic animals in an area is closely related to its environment and reflects the characteristics of an ecological niche (Ansari, et al., 2003).

Sediment grain size, organic content, current dynamics, and other habitat parameters may strongly affect large-scale faunal distributions, although they may be less important over smaller scales (Thrush, 1991). In addition to the broad distribution limits set by environmental constraints, biological interactions, such as predation, competition and amensalistic interactions will regulate local patterns of benthic community composition (Olafsson, et al., 1994). Although biological interactions are thought to operate within the constraints imposed by large-scale physical factors, the interaction of both physical and biological factors should be investigated when assessing benthic community patterns (Wilson, 1991). Primary productivity and hydrodynamics are often important in influencing macrobenthic communities over a variety of space and time scales (Pearson and Rosenberg, 1976; Hall, 1999), and in muddier, more cohesive sediments geochemical gradients down the sediment column become increasingly important (Rhoads, 1963; Aller, 1982). The influence of water currents on benthic communities has been well documented (Snelgrove and Butman, 1994), and recent research has also emphasized the importance of waves (Thrush, et al., 1996).

Marine benthic organisms are valuable as they are ecologically important, numerically abundant, often sessile life style and they also function as integrators of ecological processes and disturbances over long time scales (Beuchel, et al., 2006). Benthic assemblages are a direct measure of habitat condition. (Pearson and Rosenberg, 1976) noted that benthic communities, dominated by deposit-feeding polychaete worms, have been characterized by low species diversity and increased abundances close to sources of organic input. In India, indicator species from the benthic realm of estuarine and marine environments have been reported (Saraladevi and Venugopal, 1989; Kumar and Antony, 1994). Temporal and spatial changes in marine benthic assemblages have usually been explained in terms of local environmental changes, either anthropogenic or natural. However, recently it has been suggested that more global (oceanic) influences may have been underestimated, and these have been involved to explain sudden abrupt changes observed in the North Sea and elsewhere (Lindeboom, et al., 1995, Reid, et al., 2001).

Intertidal communities are plastic systems as they change continuously in composition and abundance of organisms at several spatial and temporal scales (Dye, 1998; Menconi, et al., 1999). The exceptionally spatial and temporal variability in rocky shore communities arises from a combination of abiotic and biotic factors (Menge and Sutherland, 1987). Many studies have shown that intertidal communities are structured along gradients of abiotic factors, such as exposure to wave action and vertical tide level (Lewis, 1978). To elucidate biotic influences, particularly manipulative experiments have led to an appreciation of the importance of species interactions, such as grazing, predation and competition, in spatial structuring of rocky shore communities (Dayton, 1971; Leonard, et al., 1999). Some studies have also shown that spatial and temporal variability in settlement and recruitment is important in establishing the mosaics associated with such communities (Jenkins, et al., 2001). Although short-term, i.e. interannual to intra-decadal studies are indispensable to understand rocky shore community interactions, they mainly reflect the natural variability of parameters relevant to population dynamics. However, long-term investigations spanning several decades, are a prerequisite to analyze anthropogenic impacts on communities, and to differentiate these from short-term as well as long-term natural fluctuations in populations or communities at a specific site (Chiappone and Sullivan, 1994). For example, changes in the abundance of macrobenthic species were related to predicted effects of recent climate warming (Sagarin, et al., 1999). Furthermore, changes in the European littoral communities appear to coincide with the anthropogenic introduction of the Pacific oyster *Crassostrea gigas* during recent decades (Wolff and Reise, 2002).

Intertidal invertebrates and algae are ectotherms that evolutionarily are of marine origin but must regularly contend with the terrestrial environment during each low tide. As such they provide a unique perspective on the relationships between both aquatic and terrestrial climatic regimes and organismal physiology and ecology. Indeed, largely because of the steep gradient in thermal and desiccation stresses that occurs during low tide, the rocky intertidal zone has long served as a natural laboratory for examining relationships between abiotic stresses, biotic interactions, and ecological patterns in nature (Wethey, 1985). The upper limits of zonation of many intertidal organisms (i.e., their upward extent from the low-tide level) can be set directly by thermal and desiccation stresses (Connell, 1972; Somero, 2002; Rawlinson et al., 2005). Biotic interactions and behavior can also play an important role (Underwood and Jernakoff, 1981), but such processes ultimately are dictated by the underlying environmental gradient (Raffaelli and Hawkins, 1996). Many intertidal organisms are therefore expected to display strong responses to changes in terrestrial climatic conditions (Somero, 2002).

Species can therefore be eliminated altogether from an intertidal region by changes in water temperature, upwelling regimes or oxygen levels (Luis and Kawamura, 2002 a, b). Many of the early biogeographic studies correlated species distributions with temperature (Hutchins, 1947; Andrewartha and Birch, 1954) and still form the basis of ecological principles today. Hutchins (1947) argued that isotherms of sea surface temperature were correlated with the Worldwide distribution of mussels (*Mytilus edulis*) and barnacles (*Semibalanus balanoides*), and he used these correlations to develop a general model to explain the role of thermal tolerance in setting range boundaries in coastal species.

Differences in physical and biological processes are the main cause of variation in intertidal communities, both in time and space (Paine and Levin, 1981; Sousa, 1984 a, b). Physical processes can include disturbances such as wave action, temperature, irradiance or salinity, whilst biological processes may include settlement, recruitment, predation and competition (Terlizzi, et al., 2002). Abiotic environmental variables affecting rocky intertidal species are hard to quantify (Taylor, 1971). A useful approach is to scale them by biological indicators, i.e. dominant or prominent key species and their associations (Lewis, 1964). This approach underlies the universal intertidal zonation scheme (Stephenson and Stephenson, 1972) which serves to describe the organism- environment interactions along the intertidal zone in many parts of the World and was used in comparing them within and between shores.

The assessments of the ecological status will combine physico-chemical, hydrodynamic and morphological characteristics as well as different biological components of the ecosystem (e.g. plankton, benthos, fish). Among these components the benthic fauna is of major importance, because on the one hand it plays a vital role in nutrient cycling, detrital decomposition and as food source for higher trophic levels and on the other hand benthic species are sensitive indicators of changes in the marine environment. Effects of anthropogenic disturbances on the benthos include changes in diversity, biomass, abundance of stress tolerant and sensitive benthic species, and the trophic or functional structure of the benthic community (Kaiser, et al., 2000; Grall and Chauvaud, 2002). A variety of indices are available, which indicate the status of ecological condition and trends in succession of marine benthic systems (reviewed in e.g. Diaz, et al., 2004; Pinto, et al., 2009). Univariate diversity indices such as the Shannon-Wiener Index were the most commonly used index in the past. In more recent studies more complex biotic and multimetric indices were developed to get a more sensible tool for the assessment of ecological quality in a benthic ecosystem. Consequently, the effects of a variety of anthropogenic pressures on the performance of indices were extensively tested and described (Simboura, et al., 2007). Univariate as well as multimetric indices may respond to any disturbance, man-induced or natural (Wilson and Jeffrey, 1994) and particularly information on the natural variability of indices is very meager. Nevertheless, the knowledge about the natural dynamics of indices is essential for the continuous monitoring and assessment of ecological quality status and for defining reference and baseline conditions. Especially long-term background data are needed, if the management objective is to re-establish the structure of benthic communities in the past.

Marine systems are among the World‘s most productive and diverse ecosystems, but they are also subject to intense human pressures; approximately 40% of the World‘s population lives within 100 km of the coast (Cohen, et al., 1997) and a significant proportion of these inhabitants depend on the ocean for food, economic prosperity and well-being. As in many terrestrial systems, a multitude of direct and indirect human influences have significantly altered the composition and diversity of marine communities at almost every trophic level (Pauly, et al., 1998). This has led to concern over the functional consequences of biodiversity loss, which are especially relevant given the high levels of extinction already witnessed and the anticipated future influence of anthropogenic forcing (Sala, et al., 2000).

Most of the threats to biodiversity in coastal zone are the demographic trends of increased human population densities in coastal areas (Gray, 1997). Intertidal zones are extraordinarily important both for people and wildlife. The natural productivity of the zone provides food, not only for humans, but also for important wildlife populations including marine species and migrating birds. Furthermore, intertidal regions form part of many landscapes that appeal to visitors, allowing the formation of important recreational and tourist economics (Bowers, 1999). These attract humans towards the intertidal area and provoke disturbance of its habitats, intensive exploitation and usage of its resources, thus creating an extraordinary pressure on the existing communities. Due to fact that many rocky intertidal communities, globally and locally, are subjected to a variety of stresses caused by human activities such as exploitation, trampling, research, educational field trips, seaside strolling, overturning rocks, photographing and fishing (Lasiak, 1998). Though biological communities of rocky shores may have the capacity to withstand or rebound from impacts generated by natural disturbances, large increase in the level of human disturbances inevitably alter the pattern of natural variability at various scales of organization within the community. This is because anthropogenic stresses are superimposed on stresses caused by natural environmental factors (Raffaelli and Hawkins, 1996). Strong linkages often exist among species (Paine, 1980) and therefore, rocky shore communities are sensitive to human induced disturbances that may play an important role in the shaping of species diversity through indirect influences on species abundances (Milazzo, et al., 2002; Daniela et al., 2006). Through the years, humans have substantially affected intertidal zones across the globe and this scenario has been proven by human exclusion experiments in rocky shore communities (Hockey, 1994), although this approach is difficult to implement in most places.

A majority of these studies have investigated the impacts of human activities, such as trampling or food harvesting, which have been shown to be detrimental to a large number of species including seaweeds (e.g. Bally and Griffiths, 1989; Keough and Quinn, 1998; Schiel and Taylor, 1999; Kristin et al., 2007), seagrasses (Zedler, 1978; Ambrose and Smith, 2005), barnacles (Zedler, 1978; Ghazanshahi, et al., 1983), limpets (Pombo and Escofet, 1996; Kido and Murray, 2003; Roy et al., 2003), sea stars (Ghazanshahi, et al., 1983; Ambrose and Smith, 2005), octopuses (Ghazanshahi, et al., 1983), snails (Roy, et al., 2003), crabs (Murray, et al., 1999), and bivalves (Brosnan and Crumrine, 1994; Smith, 2002; Murray, et al., 2002).

Concerning ever-increasing pressure created by human activities, marine ecosystem management has developed over the past 30 years as an approach for comprehensively managing marine resources. In reality, marine ecosystem management does not manage natural resources, but the human interactions with these resources (Larkin, 1996). Anthropogenic stress is the response of biological entity (individual, population, community etc.) to an anthropogenic disturbance or stressor. Stress at one level of organization (e.g. individual, population) may also have an impact on other level, for example, causing alterations in community structure. However, it is sometimes difficult to detect the effects of anthropogenic stress at the level of individual organisms and impacts, therefore, are more often investigated at a population or community level (Crowe, et al., 2000).

Marine invertebrates are affected directly through harvesting (species removal) and indirectly by fishing (predator removal and competition). Jones and Kaly, 1996 suggested that invertebrates can act as indicator species and can be monitored to assess whether their populations are experiencing ecological change as a result of the anthropogenic actions such as over fishing and harvesting. Macrobenthic invertebrates are useful bio-indicators providing a more accurate understanding of changing aquatic conditions than chemical and microbiological data, which at least give short-term fluctuations (Ravera, 1998, 2000; Ikomi et al., 2005). Odiete (1999) stated that the most popular biological method in assessment of freshwater bodies receiving domestic and industrial wastewaters is the use of benthic macro-invertebrates. Their composition, abundance and distribution can be influenced by water quality (Haslam, 1990; APHA, 1995; Odiete, 1999). They all stated that variations in the distribution of macro-benthic organisms could be as a result of differences in the local environmental conditions (George, et al., 2010).

Human influences are reflected as both acute and chronic effects over various temporal and spatial scales and can ultimately lead to broad-scale loss of productive habitats and altered or impaired community structure and function. Gray (1997) provides an excellent review of threats to coastal systems, which include habitat loss, global climate change, effects of fishing, pollution, species introductions and invasions, water shed and physical alterations of coasts, tourism and marine litter. In some cases the impacts of fishing activities are restricted to changes in target species size and abundance, either with no observable change in community diversity or species richness (Watson, et al., 1996), or with no change in richness but changes, including increases, in diversity due largely to changes in evenness (ICES, 1996; Bianchi, et al., 2000; Rice, 2000). In other cases fishing activities have led to declines in richness and diversity through extirpation of target species (Randall and Heemstra, 1991; Jennings, et al., 1995; Jennings and Polunin, 1997; Jennings and Kaiser, 1998; Hall, 1999; Gislason, et al., 2000). The structural complexity of a habitat has often been invoked as an important factor influencing the diversity of associated communities (e.g. Huston, 1994), a more complex habitat providing a wider range of niches and thus a higher number of species that can potentially occupy that habitat within a given area (MacArthur, 1965; May, 1972).

Wilson (2009) studied gastropod communities around motu Tiahura coast French Polynesia that currently under various stresses, both natural and anthropogenic. Pister (2007) investigates the ecological role of riprap using rocky intertidal communities along the west coast of North America. Riprap is simply the rocky rubble used to construct jetties, breakwaters and armored shorelines. Riprap structures are designed to reduce wave energy, protect shorelines from erosion, and alter currents and sedimentation processes. These anthropogenic structures have become a ubiquitous form of coastal modification throughout the World. Along the Greenlan coast, Arctic Ocean, Sejr, et al., (2010) quantify species richness, diversity, biomass and abundance of macrobenthic species, describe changes in species composition and attempt to establish relationships between biological and environmental variables. Kundu et al.,

(2009) worked with the diversity and seasonal variations of macro-benthic infauna and associated environmental factors influencing the benthic community in the inshore waters of Pazhayar, Parangipettai and Cuddalore southern Indian coast, Bay of Bengal.

Diversity, distribution and abundance of seaweeds are known to be influenced by both physical and biological factors (Lobban and Harrison, 1994; Nybakken, 2001). The role of algae in the economic life of humans and ecosystems is relatively well known. The use of algae as food, animal fodder, fertilizers, as raw materials in the production of industrial phycocolloids, and as natural feeds for economically important aquaculture species has received much attention in in many countries around the World (Aungtonya and Liao, 2002). As part of the human diet, seaweeds provide protein, vitamins, and minerals especially iodine from kelp. In addition, commercially important phycocolloids-agars, carrageenans, and alginated-alginates are extracted from red and brown algae. Agars obtained from *Gelidium* are used extensively in microbiology and tissue culture for solidifying growth media, and more recently in electrophoresis gels. The agar from *Gracilaria* is used mainly in foods. Carragenans chiefly from *Eucheuma* and *Chondrus* are widely used as thickeners in dairy products. Alginates, from *Macrocystis* and *Laminaria*, are also used as thickeners in a multitude of products ranging from salad dressing to oil-drilling fluids to the coatings in paper manufacture (Chapman and Chapman, 1980; Waaland, 1981; Lobban and Harrison, 1994).

Estuaries are transitional environments between rivers and the sea, and are characterized by largely varying and often unpredictable hydrological, morphological and chemical conditions (Costanza, et al., 1993). In most of the World's estuaries, this natural stress is intensified by human activities. Land reclamation, drainage of waste from domestic, industrial and agricultural activities, shipping and dredging are mainly responsible for the direct and indirect loss of the estuarine environment (Gray, 1997). This may have important negative effects on the biota and thus on the ecological structure of the system. Estuarine ecosystems are not only ecosystems with unique biodiversity characteristics, but they are also highly productive systems. They perform several vital functions, e.g. as nursery areas for fish and shrimp, feeding areas for migrating and wintering water birds, migration routes for anadromous and catadromous fish, etc. (Odum, 1983; Day, et al., 1989; McLusky, 1989; McLusky, et al., 1993).

Dumping and discharging of pollutants into the sea, oil spills, nutrient and silt-laden runoff from land and rivers, fallout of chemicals carried by the wind from land-based sources and noise from ships and other machinery (which disrupts communication among whales and other species) are some of the major contaminants affecting marine species and ecosystems (Zann, 2000). Air pollution and runoff and point discharges from the land (and rivers) account for some three fourths of the pollutants entering marine ecosystems. Contaminants affect marine biodiversity in a number of ways. Untreated sewage, oil, heavy metals, and other wastes may be directly toxic to some marine organisms. Their effects may be instantaneous or cumulative. For example, oil has lethal and almost immediate effects on a wide range of marine life from algae to seabirds resulting in death through asphyxiation, poisoning, and, among mammals and birds, loss of the insulating functions of feathers and fur, causing hypothermia. Eggs and larvae are particularly sensitive to the toxic effects of pollutants, as are organisms living at the ocean surface and on the seabed, where wastes tend to accumulate. Other contaminants such as radioactive waste, pesticides, and other chemicals have cumulative effects, building up within individuals over time, especially within species high on the food chain. Moreover, various contaminants and physical degradation can act together in a cumulative or synergistic fashion.

With the sudden increase of population and rapid economic development in littoral area, coastal water has received large amounts of pollution from a variety of sources such as recreation, fish culture and the assimilation and transport of pollution effluents (Bowen and Depledge, 2006; Kuppusamy and Giridhar, 2006). The coastal water faces many ecological problems, such as eutrophication and environmental pollution (Huang, et al., 2003). It is therefore essential and urgent to prevent and control marine water pollution, and regularly implement monitoring programs which help to understand the spatial and temporal variations in coastal water quality. Coastal water quality is largely determined by a number of factors, such as climatic conditions, interaction between land and ocean and anthropogenic activities. Water quality monitoring programs have generated huge databases describing spatial and temporal variations of water quality. The large and complicated data sets consisting of water quality parameters are often difficult to analyze for meaningful interpretation and require data reduction methods to simplify the data structure, in order to extract useful and interpretable information which could explain the spatial and temporal variation patterns of water quality (Dong, 2009).

An anthropogenic change of biogeochemical element fluxes from land to sea has emerged as one of the leading environmental issues of our time (Howarth, et al., 2000). River loads of nitrogen (N) and phosphorus (P) have increased worldwide more than fourfold due to anthropogenic activities in the river catchments, which have resulted in considerable eutrophication in many coastal seas. The increased N and P discharges have led to elevated organic production and widespread oxygen deficiency in bottom waters and sediments of the coastal seas. Negative effects of hypoxia such as a change in the structure and stock of benthic communities and large-scale fish kills are now global phenomena.

Runoff of sewage from cities and of fertilizers from agricultural areas elevates the levels of nutrients within near shore waters. Certain algal species capitalize on these conditions, undergoing massive population explosions (known as blooms), which, by lowering water clarity and oxygen content, effectively crowd out other taxa in the community (Burrows and Hawkins, 1998). He also reported that the algal blooms block the light reaching algae living within corals and other photosynthesizing bottom-dwelling organisms, killing them; then, the decomposition of the bloom algae deoxygenates the water. Many bloom species produce toxins so-called killer blooms have been linked to die-offs of fish, shellfish, and other species that consume or come into contact with toxic algae or that ingest other consumers of those algae. Human health can also be at risk. A 1987 toxic bloom occurring off the Guatemalan coast, for example, indirectly resulted in the death of 26 people and produced serious illness in 200 other individuals who consumed poisoned seafood (Burrows and Hawkins, 1998). Although small-scale blooms (both toxic and nontoxic) are a naturally occurring phenomenon in most regions, the frequency, magnitude, and toxicity of such events appear to have increased dramatically in recent years (Wilkinson and Buddemeier, 1994). Nontoxic solid wastes and marine debris cause significant mortality among marine species. For example, plastic bags, fishing lines, and other debris can entangle seals, seabirds, and other organisms, causing slow but sure deaths. Sea turtles and other species, often with fatal consequences, regularly ingest bits of plastic and other man-made materials. Abandoned fishing nets, lobster pots, and other equipment continue to catch fish and other marine creature‘s years after the gear is discarded or lost (Maragos and Payri, 1997).

Worldwide, coastal systems have undergone dramatic changes in recent decades, in particular due to eutrophication, climate change and introduced species (Valiela, 2006; Philippart, et al., 2007). Indian coast is continuously being threatened by effluent discharges from metropolis and industrial towns. This gives rise to immense environmental problems leading to deterioration of water quality. The extent of damage caused by indiscriminate discharges of wastes could be perceived from some of the published reports. Zingde and Govindan (2000) indicated that the coastal waters of Mumbai receives industrial discharges up to 230 million liters per day and domestic wastes of around 2,200 MLD of which, 1800 million liters per day are untreated. This has affected the water and sediment quality, with consequent effect on aquatic communities. Similarly rapid industrial growth of the Gujarat State, has given rise to waste discharges in some major rivers such as Kolak, Damanganga, Amba and others, which is responsible to degrade the estuarine and coastal waters (Zingde and Desai, 1987). In the east coast, increased metal concentration in the coastal waters of Pondichery as reported by Govindasamy and Azariah (1999) was as a result of the effluent discharges of nearly 16 major and minor industries. Similarly Cheevaporn and Menasveta (2003) reported BOD loads of 659 to 34,376 tons/year from municipal and industrial waters in Gulf of the Thailand which was responsible to starve aquatic life and alter the ecosystem structure of the region. In the gulf of Trieste (Italy) Hg mining is responsible to discharge about 1.5 tons of Hg / year which have increased the levels in marine organisms exceeding 0.5 mg/kg (Sirca and Rajar, 1997).

Change in shoreline due to sea-level fluctuations, erosion, sedimentation and tectonic activities, is a well-known phenomenon in any part of the World. Any change in the coastline directly affects human habitation of the coastal area, which can play a vital role in understanding the shoreline behavior in the past. Gujarat coast has been the focal point of human activities since the earliest time and has provided ample opportunities to understand natural phenomena that occurred in the past (Gaur, 2007). Human activities produce different pressures that interact with abiotic and biotic factors in shaping the structure and variation of communities. Dissecting the natural from the human induced sources of uncertainty can be extremely difficult (Clarke, 2000).

The information about the ocean water and its nutrients and circulation dynamics along the coast has paramount importance in understanding the numerous ocean processes. In the ocean, the physical, chemical, and biological processes are linked in an intimate manner (Tang, et al., 2002). Certain chemicals, for instance, make some animals more sensitive to heat or become more toxic at higher temperatures (e.g. Patra, et al., 2007; Schiedek, et al., 2007; Sokolova and Lannig, 2008) clearly those pollutants would be important to target in areas expected to see an increase in maximum temperatures. Changes in rainfall patterns are expected to increase the nutrient loads in some coastal areas.

In seawater conductivity is the property caused by their presence of various ionic species and regarded as less common variable as far as the coastal water quality is concern (EMECS, 2007). The DO concentration of the coastal water is lower than that of the rivers and lakes due to its high salinity. The COD level was also found to be low. COD is used as an organic pollution index including phytoplankton growth. If the concentration exceeds 3mg/l and concentration of DO is less than 5mg/l fish growth is affected (EMECS, 2007). Total suspended solids are an important component in the marine environment because they transport absorbed toxic substances, provide habitat for benthic and microorganisms, limit light availability and photosynthesis, and add deposits to ports and waterways that require dredging regularly (Park, 2007).

Seawater temperature is an important factor controlling the distribution of marine flora and fauna in the Northern Arabian Sea and Gulf of Oman (IOSEA, 2006). The pH of seawater has already decreased by 0.1 pH units, and is expected to decrease by an additional 0.3 – 0.5 units by 2100 (Caldeira and Wickett, 2005). These changes in the physical and chemical environment will have massive impacts on aquatic ecosystems (see Harley, et al., 2006). Seasonal growth of intertidal algae during the monsoon has also been described in parts of India (Misra, 1960), the Philippines (Kraft, 1970) and Kenya (Moorjani, 1979, 1982). Generally, seasonal periodicity in benthic algal growth in the tropics has been linked to increased light and temperature levels (Taylor and

Bernatowicz, 1969, Croley and Dawes, 1970), to water movement (Santelices, 1977) or to altered levels of herbivory (McClanahan, 1988).

In the deeper part of the Bay of Bengal and the Arabian Sea, the chlorophyll concentration shows very little variations, both spatially and temporally (0.1–0.5 mg/m^3) (Dey and Singh, 2003). The seasonal variations are very prominent in the Arabian Sea. The northern Arabian Sea is characterized by offshore and onshore chlorophyll blooms during the northeast monsoon period (Tang and Kawamura, 2001). In the Arabian Sea, most of the primary production occurred below the surface during the northeast monsoon and just after the monsoon, the vertical mixing brings them at the surface (Dey and Singh, 2003).

It was observed that water quality studies in the Gulf of Kachchh and South Saurashtra coastline are surprisingly scanty (Nair, 2002). The physical parameters in the coastal area depend normally on the weather condition and up to certain extents, the local activities. The baseline study conducted by WWF India in 1991, reported the normal DO level of some portion of the Gulf of Kachchh ranged between 4 to 9 mg/l. It is reported that with increasing salinity, the DO level decreases. The DO is also directly correlated with the depth of water (Pillai, et. al., 1979). The COD level normally remains low in the rocky shores and showed elevation in the muddy areas of the upper littoral zones where due to stagnation of water, desiccation and high temperature, the rate of decomposition of organic matter is high and the DO level is low (Sarvaiya, 1977). Reports are scanty on COD levels of the Gulf of Kachchh; however, more than 5mg/l COD level is believed to severely affect the growth and development of fish in the coastal areas (EMECS, 2007). In other parameters like sulphide, phenols and PHC were not in noticeable range. In case of biological parameters both primary productivity and zooplankton were reported less, this may be due to the high turbidity and low salinity of the water during the monsoon to immediate post monsoon season. Nine genera of phytoplankton were mostly reported and were predominantly diatoms (Bhaskaran and Gopalkrishnan, 1971; Gopalkrishnan, 1972).

The waters upwelled during the summer in the western Arabian Sea are marked by relatively low salinities (Schott, et al., 2002). According to Metcalf and Eddy (2004), the actual quantity of oxygen that can be present in solution is governed by four ways; solubility of the gas, gas partial pressure in the atmosphere, temperature and finally, the concentration of the impurities in the water such as salinity and suspended solid. Warmer water has a lower saturation point for DO than cooler water. In the summer months, a DO level is tending to be more critical because the rate of biochemical reaction that uses oxygen increases with increasing temperature. In waste water system, DO is desirable because it can eliminate the formation of noxious odours (Metcalf and Eddy, 2004). Levels of DO must be high enough to support the health and well-being of aquatic organisms or species may become stressed or disappear from a stream (Smith, 2004). Dissolve oxygen is not using only for determining water quality solely, the value of DO in water bodies will act as indicator for what kind of fish will survive and to what extent the aquatic life may live in the water bodies. Effluent discharging directly into water bodies will decline DO concentration.

Chemical oxygen demand (COD), which is defined as the amount of oxygen needed to oxidize the dissolved and particulate matter in water under certain conditions, is widely used in municipal and industrial laboratories as a practical indicator to the concentration of organic matter and water quality(GAO Xuelu, et al., 2007). Positively, spatial and temporal variations in COD concentration were affected by many other factors in addition to the mixing process of fresh water with seawater, and phytoplanktonic photosynthesis (GAO Xuelu et al., 2007).

The continuous and unlimited increase of the concentration of plant nutrients can have environmental impact, such as reduction of oxygen concentration, change of marine biodiversity (Justic, 1987; Gray, 1992), poor water quality, turbidity and increase of organic matter concentrations (Willemsen, 1980; Harris, 1995; Slinn, et al., 1995). Macroalgae, especially green macroalgae, are common on intertidal flats around the World (Fletcher, 1996; Raffaelli, et al., 1998). Their abundance is mainly regulated by combinations of 3 main factors: combined nitrogen (nitrate and ammonia), phosphorus and changes in the hydrography of the area (e.g. Reise and Siebert, 1994; Flindt, et al., 1997; Martins, et al., 2001). However, other factors can also be limiting, such as temperature, sub-optimal light and grazer conditions (Raffaelli, et al., 1998). One of the highest primary productions among the World oceans occurs in the Arabian Sea due to a variety of physical processes introduced by the semiannual reversal of monsoon winds (Qasim, 1982; Banse, 1987). During the summer monsoon, offshore divergence of the alongshore wind stress component leads to coastal upwelling and sea surface temperature cooling (Shetye, et al., 1985; Muraleedharan and Kumar, 1996; Naidu, et al., 1999; Luis and Kawamura, 2002 a, b). Strong summer monsoon winds enhance evaporative cooling in the central AS (McCreary and Kundu, 1989).

In coastal zones these finer particles are a food source for filter feeders which are part of the food chain, leading to biomagnification of chemical pollutants in fish and ultimately, in humans (Park, 2007). Also, wind induced resuspension of sediment could greatly impact the food web organization in marine ecosystem (Afri and Bouvy, 1995). Resuspension of sediment and increased turbidity significantly influences the marine ecosystem in terms of water quality and biological processes; e.g. nutrient release into overlying water column (Park and Park, 2000; Reddy, et al., 1996), increased chlorophyll by resuspension of benthic diatoms (Demers and Therriault, 1987), and organics input as a food source (Berkmann, et al., 1986). In seawater several of the heavy metals are considerably under saturated with respect to any likely solid phase, and many researchers have shown experimentally that adsorption on suspended solids is probably responsible for reducing the concentration levels of metals (McIlroy, et al., 1986; Radovanovic and Koelmans, 1998) and their toxicity (Cary, et al., 1987; Pyle, et al., 2002).

Seawater resources are considered to be one of the major components of environmental resources that are under threat either from over exploitation or pollution, caused by human activities (Efe, 2001). Coastal area is the most dynamic and productive ecosystems and are also foci of human settlements, industry and tourism (Xiaojun, 2008). Thus, the water quality plays very important role in well-being of human, animals and plants inhabiting the area (Dixon and Chiswell, 1996). The quality of surface water within a region is influenced by both natural processes and anthropogenic activities (Pejman, et al., 2009). Marine water quality has become a matter of serious concern because of its effects on human health and aquatic ecosystems including marine life (Gupta, et al., 2009). Physico-chemical characteristics are indeed vital water quality parameters for monitoring due to their instability (Efe, et al., 2005), where significant variations in physico-chemical parameters affect the quality of water resources (Vaghela, et al., 2010).

The proper and meaningful monitoring should include examination of spatial and temporal patterns of surface water quality, identification of chemical species related to hydrological conditions and assessment of environmental quality indicators (Perkins and Underwood, 2000; Voutsa et al., 2001; Bengraine and Marhaba, 2003; Ouyang, 2005; Ouyang et al., 2006). The nature and distribution of the flora and fauna in the aquatic system are mainly controlled by the fluctuations in the physical and chemical characteristics of the water body (Sundaramanickam, et al., 2008). The Arabian Sea is considered as one of the most productive zones in the World oceans (Qasim, 1977; De Sousa, et al., 1996). Coastal regions between Okha and Bhavnagar is now a hot-spot for mega industries like refineries, cement, chemicals, soda ash, Rayon, power plant, fertilizer and other supportive industries. This coastline is known for its rich marine life especially intertidal biota in its extended intertidal and subtidal areas (Shukla and Misra, 1977).

Chapter 3 MATERIALS AND METHODS

3.1. Study area

India has a coastline of 7517 km (total 4700 mile), which is bounded by the Indian Ocean on the south, the Arabian Sea on the west and the Bay of Bengal on the east. Among that, Gujarat is situated on the north-western part of peninsular India. It has about 1,650 km longest coastline; that accounts for 22 % of the total coastline available to the country, with a continental shelf of 164,200 km^2 (35.3% of the country) and an Exclusive Economic Zone (EEZ) of 214,000 km^2 (9.9% of the country). Gujarat coastline consist 28 % sandy beach, 21 % rocky coast, 29 % muddy flats, 22 % marshy coast. Further, the coastal zone of Gujarat state can broadly be divided into three major geographical parts, two major gulfs namely Gulf of Khambhat and Gulf of Kachchh and the Saurashtra coastline, each one with its own distinctive characteristic and diverse geo-environmental features, which embrace diverse coastal habitats as well as biota of ecological significance.

Saurashtra is a region located south-western part of Gujarat which occupies a total coastal stretch of 865 km. Saurashtra is a part of an arid peninsula called as Kathiawar. On an average, it receives 500 mm rainfall annually. The south coast of Saurashtra from Dwarka-Kodinar segment stretches for about 250 km. with smooth and straight sandy of rocky-sandy beaches. The beaches are usually calcareous and dominated by bio-clasts, the consolidated ancient equivalent of these biogenic sands are famous milliolite rocks. The milliolite underline the beach sands and occur as cliffs, wave cut platforms and submerged dunes, all along the shoreline indicating quaternary sea level fluctuations (Stanley, 2004).

People living in the coastal zone of India are considered to generate 1.11 × 1010 m^3 of sewage annually; a considerable fraction enters the coastal water (Zingde, 1999). There is a high concentration of large to medium industries within the narrow coastal belt of 25 km both the east and west coast of India. The west coast of India is more industrialized than east coast, with the state of Gujarat having the largest concentration of industries (Rejomon, et al., 2008).

The development of the Saurashtra region was driven solely by the trading possibilities offered by its long coastline and ports. It would appear that today the problems consequent to the high degree of industrialization along the Saurashtra coastline are being addressed with even more industrialization. There are two developed fishing harbours with allied at Veraval and Mangrol, which face 62 % fish production out of the total fish production. The industrial groups that have grater dominance are cement; food industry and the existing port with facilitate import or export of fish and fishery products, fertilizers, salt, cement, soda ash and lime stone etc.

The whole of south Saurashtra coast was surveyed extensively from physical and biological point of view for their coast characteristics. The main reason behind the selection of the Saurashtra coastline was the difference exists between the four sampling sites which different level of interferences with the human community. It would give a clear indication of the impact of different anthropogenic pressure on marine ecosystem keeping all the physico-chemical parameters constant. The other point of view for selection of this region was differences between locations, in terms of slop, substratum type and the length of the intertidal zone. The Saurashtra shoreline is straight and conspicuously rocky platform backed by sandy beaches.

3.2. Sampling sites

Before the selection of study sites, locations of the sampling sites were selected according to a preliminary survey of the coastline in view of different anthropogenic pressure on coastal area. Now a day‘s especially Saurashtra coast is being hot-spot for various mega industries, fishery related opportunities and further, more tourism is also one of the related problems on the coastal zone of Saurashtra peninsula. For spatial analysis Saurashtra coastline divided in to four sampling site, viz. Dwarka, Mangrol, Veraval and Kodinar (Plate-1). These shores were selected on the basis of their strategic locations, existing industries, infrastructural facilities for the likelihood of being developed as industrial zones, different anthropogenic activities along the entire coastal area of Saurashtra peninsula. The Saurashtra coastline is basically rocky-sandy, being rockier in the east and west, sandier in the central part and more rocky-muddy in the far eastern part. It is remarkable by having milliolite limestone formation along the coastline.

Sampling site: Dwarka

Dwarka (22^0 13' N, 68^0 58' E) is situated on the west coast of India and a major pilgrim town owing to that it is also be a tourist place on the coastal area. It is nearest about Okha port, which is well known as entry point of the Gulf of Kachchh (GoK) and to western India, and around 175 km west of Veraval and around the northernmost corner of the Kathiawar peninsula. There are small scales fishing industries also available. The local community mainly depends on the tourism and fishing related opportunities. The total length of the sampling site was about 1.5 km.

Sampling site: Mangrol

On the other hand, Mangrol (21^0 07' N, 70^0 07' E) is a small hamlet and important harbour around 50 km west of Veraval with predominantly fisherman population. There are many small scale fisheries industries located along the coastline and it exports the fishery related products to many other countries. The Mangrol port is having a small but proper landing place inclusive of all infrastructure facilities such as storage of catch, ice factories, repairing of boats and engines etc. The total length of the shoreline of this area is about 2 km. The local communities which live nearest about the coastline mainly depend on the fishing related opportunities and changes from time to time.

Sampling site: Veraval

Veraval (21^0 35' N, 69^0 36' E) is one of the largest fish landing site of India situated around 35 km east of Mangrol, surrounded by a large chemical factory, a medium scale cement factory, number of small to medium scale industries and fish processing units. It involves port activities like transport, boat manufacture and receive waste from different sources. In addition to that, the area, being one of the most developed spot from industrialization point of view is a hot spot for both heavy and small scale chemical industries. The area favors the fish processing industries too due to its proximity to the landing center and easy supply of the raw materials. The total length of the shore area is about 3 km.

Sampling site: Kodinar

Kodinar (20^0 41‘ N, 70^0 46‘ E) is a small town, situating southeastern part of Junagadh district, on the southern coastal region of Saurashtra peninsula. Tourists find ample places to visit in Kodinar and its nearby region. Very near to the costline, the Gujarat Ambuja Cement Group has established its flagship cement factory and the company have also developed the port of Muldwarka. It is also well-known for the sugar factory, which is situated near about the coastline and also minute level of fish catching unit located near the selected site. Total length of the selected coastal stretch of the sampling site is about 1.5 km. The coastal area between Kodinar and Veraval is fast emerging as an industrial hot-spot and few mega industries are already in operation.

3.3. Coastal characteristics

The selected locations are situated at South Saurashtra coastline off Arabian Sea, which are significantly rocky with irregular patches of sand or mud. The rocky portion is generally formed of rocks of miliolite and laterite stone. Extensive limestone deposits are seen to occur in the coastal areas of Gujarat. The intertidal rocks of Saurashtra shoreline are calcareous sand stone. The selected shoreline of Dwarka and Mangrol experiences wave actions to a heavy extent. The intertidal zone of Saurashtra coasts is not very wide, generally dynamic wave action due to this reason. The selected locations of Saurashtra coastline is rocky with hard substratum having many big cuphols and crevices, whereas, the upper intertidal zone is highly elevated with broad and deep caves because of heavy wave action. The substratum type is varies at the Saurashtra coastline. The intertidal belt is interspersed with many tide pools, puddles, crevices and small channels. The upper portion of the intertidal belt is generally covered with an admixture of silt and sand mixed with pieces of broken shells. The intertidal belt is intersected by many tide pools. Since the pools are natural ones, the shape and size are not precisely same. The upper intertidal pools have light accumulation of sand settled over the rocky base.

3.4. Zonation

Intertidal zones are transitional coastal regions. The cycling of the tides influences these regions. These littoral areas are located between the high and low tide marks.

Zonal classification is applied to the intertidal area except that it is customary to use a different set of terms for habitats. The intertidal zone has a vertical zonation pattern. These zones are based on height and tidal influence. The rocky intertidal region can be divided into four vertical zones. These four zones include from the highest to the lowest; the splash zone, the high intertidal zone, the mid-intertidal zone and the low intertidal zone; according to their nature and termed as site respectively. Ecologically, the intertidal zone is a diverse community where organisms are divided by the vertical zonation of the tidal zones. Intertidal organisms convey zonation in relation to moving further up the intertidal, and therefore, into more exposed environments. Due to the different zonation patterns, it can harbour different types of organisms. It was the nature of the intertidal zone, which was mainly responsible for exclusion of the idea of studying zone wise distribution patterns of the animals.

3.5. Study Period

The study of the seawater quality was conducted during November 2007 to October 2008, after that, till October 2009 the study was made to the all sites at monthly interval with a purpose of obtained data that matched with the previous year. The quantitative assessment of intertidal macrofauna and flora were done from November 2007 to October 2009, while for the qualitative study of intertidal macrofauna were done from November 2008 to October 2009 at regular monthly intervals. The collected data were presented seasonally as the weather condition of this part of the peninsular India typically represents the periods of winter (December to February), summer (March to May), monsoon (June to August) and post-monsoon (September to November). During this study various anthropogenic disturbance on the coastal area were also note down simultaneously.

3.6. Methodological Approach and Study Groups

Study was intended to conduct the spatial as well as temporal variations of rocky intertidal macrofauna, seawater quality and anthropogenic impact along the Saurashtra coastline. In this regards, four study sites; from Saurashtra coastline were considered as various anthropogenic impacts with different magnitude of human disturbances as seawater quality. Community stress, if any, discriminated by population ecology, community structure and various statistical methods to the recognized anthropogenic disturbances on intertidal macro-invertebrate assemblages and water quality from Saurashtra coastline, Arabian Sea.

The study focused on intertidal macrofaunal groups existing on rocky intertidal shores of selected locations. The study examined the differences in density, abundance, diversity, richness and evenness of all macro-invertebrate groups between four study localities. For the study of community structure and distribution of various macrofaunal groups on intertidal belt, six groups such as porifera, coelenterata, annelida, arthropoda, mollusca and echinodermata were recognized. These groups are significant on the coastal belt for the detailed study of coastal biodiversity. This investigation was undertaken due to the different anthropogenic pressures affects the intertidal community, which experienced by the coastal ecosystem.

3.7. Sampling Method for Macrofaunal Diversity

For Quantitative analysis

The intertidal zone of each sampling sites were surveyed regularly on monthly basis and all the macrofauna and flora encountered were recorded. Extensive photography was employed for the identification of the animal species with the identification keys, literature available in the form of books, journals, reports and with extensive use of internet. The complete study was conducted in a non-destructive manner in which the organisms were not at all disturbed and in some cases if disturbed, it was limited to the bare minimum, let alone killing any. Once the organisms were identified, during the successive surveys just the record of the encounter was made. However, few algal samples were collected and stored immediately in 10 % formaldehyde. They were then brought to the laboratory and washed in running tap water, and then it was subjected for temporary herbarium preparation. During the study, all sampling sites were frequently surveyed at regular intervals during the lowest tides. All intertidal macrofauna and algae observed were recorded properly and later classified systematically. Thus animals under various phyla were recorded and checklist was prepared.

For Qualitative analysis

The structural attributes of the intertidal fauna were studies by transect method (Misra, 1968). Belt and Foot transect methods in were used for generating the data on the selected belt and criss-cross direction was followed to cover the maximum exposed area on the intertidal belt. The surveys were made at the lowest tides of the months. Sampling used to be started with the start of the low tide and attempts were made to finish two sites within the stipulated duration of about 4 hours. Quadrates of 0.25 m^2 were laid while following an oblique direction covering maximum area at almost regular occurrence. At least 10 quadrates were laid vertically across the complete intertidal area from upper littoral to lower littoral zone for recording the attributes.

3.8. Sampling Methods for Seawater

Seawater samples were collected at monthly intervals from all the selected sampling sites for the estimation of various physical, chemical and biological parameters, at least six samples of surface seawater during time of high tide were collected from different locations of the same coast. However, the locations for the collection of samples in a particular coast were fixed, which were fixed using global positioning system (GPS) model ―Germin GPS-12". Seawater samples were directly collected from surface into the clean acid-washed polyethylene bottles. Samples for dissolved oxygen and biochemical oxygen demand were collected in glass BOD bottles (300 ml capacity). The sample bottles of DO and BOD were kept in dark. Seawater samples for other selected physical and chemical parameters were stored in sterile polyethylene bottles. Seawater samples for biological parameters such as chlorophyll and phaeophytin were collected separately in dark bottles. The samples were transported to the laboratory in an ice box. In the laboratory, the samples were stored at 4^0C until analysis. To avoid possible contamination, all glassware and equipment used were acid-washed.

3.9. Methods for Seawater Analysis

The selected seawater quality parameters were analyzed according to standard methods of Trivedi and Goel (1986) APHA (1995), and Grasshoff et al. (1999). The seawater quality parameters taken, their unit of expression and methods are given below.

Temperature, pH and conductivity were measure immediately after collection of water sample with the help of the electronic thermometer, portable digital pH meter and conductivity meter respectively from surface and note down the final reading. pH is the scale of acidity and alkalinity which defines the medium of samples. Portable pH meter was calibrated using standard pH buffer. On the other hand water is consists of various types of ions, these ions helps in passing the electric current through water. Conductivity is defined as the measure of ability of aqueous medium to carry on electric current. Conductivity is totally dependent upon concentration of ions. The unit of measurement for temperature and conductivity are Celsius degrees (^0C) and milisiemens/centimeter (ms/cm) respectively. Total solids and total dissolved solids were determined by the gravimetric method. Total solids represents a portion of water sample that are not lost even after evaporation of the unfiltered known volume of sample water, while total dissolved solids are residue left after evaporating the filtered sample through standard filter. Expression unit used for the solids is gram/liter. Nephelometer was used for the determination of turbidity into the seawater. Turbidity is a measure of water clarity. Turbidity measures the amount of light that is scattered or absorbed. The unit of expression is Nephelometric turbidity unit (NTU).

Salinity is formally define as the total amount of the dissolved inorganic solids in seawater, expressed as parts per thousand (ppt, ‰) by weight. Salinity in seawater was determined by titrimetric method, where in the chlorosity was first observed by titration of sample with silver nitrate solution.

Dissolved Oxygen (DO) content of the water samples were analyzed by Winkler's method. The precipitate of manganese (II) hydroxide is dissolved by acidification, liberating the manganese (III) ions, which reacts with iodine ions, previously added to water sample together with potassium hydroxide. The iodine ions were titrated against sodium thiosulphate. The end point of the titration (blue → colorless) is indicated by using starch as an indicator.

Biochemical Oxygen Demand (BOD) was determined by the same procedure (Winkler's method) as that for DO, after 5 days of incubation at 25^0C in a BOD incubator. The difference in the amount of oxygen on the 1^{st} and 5^{th} day gave the measure of Biochemical oxygen demand.

Chemical Oxygen Demand (COD) was determined by the open reflux method. The sample was refluxed with $K_2Cr_2O_7$ and H_2SO_4 in presence of mercuric sulphate to neutralize the effect of chlorides and silver sulphate (catalyst). The excess of potassium dichromate was titrated against ferrous ammonium sulphate using ferroin as an indicator. The amount of $K_2Cr_2O_7$ used was proportional to the oxidizable organic matter present in sample.

Iodometric method was used for determination of sulphide. Sulphides are stripped from the acidified sample with an inert gas and collected in zink acetate solution. Excess iodine to solution added to the zink sulphide suspension reacts with the sulphide under acidic condition. Thiosulphate is used to measure unreacted iodine to indicate the quantity of iodine consumed by sulphide. The unit of expression for dissolved oxygen, biochemical oxygen demand, chemical oxygen demand and sulphide is milligram per liter (mg/l).

Sulphate was analyzed by turbidimetric method. Sulphate ion was precipitated in the form of barium sulphate by adding barium chloride in hydrochloric acid medium. The concentration of the sulphate can be determined from the absorbance of light at 420 nm by barium sulphate and then comparing it with a standard curve. It is represented in gram per liter.

Phosphate content in seawater was estimated by spectrophotometric method. It is represented in milligram per liter. The phosphates in water react with ammonium molybdate and form complex heteropoly acid, which gets reduced to a complex of blue color in the presence of $SnCl_2$. The absorption of light by this blue color can be measured at 690nm to calculate the concentration of phosphates compare with standard curve.

Titration method was used for the estimation of the ammonia, expressed by milligram per liter. Ammonia ion after distillation is dissolved in boric acid + mixed indictor and can be titrated with HCl. Boric acid is so weak an acid that it does not interfere with acidimetric titration.

For the analysis of calcium and magnesium in seawater titration method was followed. Indicator such as ammonium purpurate forms a complex with only calcium at high pH. As EDTA is having a higher affinity towards calcium; the former complex is broken down and a new complex of purple color is formed. Magnesium forms a complex of wine red colour with Eriochrome Black T at pH 10.0. The EDTA has got a stronger affinity for Ca^{++} and Mg^{++}; the former complex is broken down and a new complex of blue colour is formed. The value of Mg^{++} can be obtained by subtracting the value of calcium from the total of Ca^{++} + Mg^{++}. Calcium and magnesium concentration in sample water is expressed through gram per liter.

Chlorophyll and phaeophytin were estimated by spectrophotometric method, expressed by milligram per cubic meter (mg/m^3). For estimation, 500 ml of water sample was filtered through glassfibre whatmann filter paper and extracted using 10 ml of 90% acetone overnight. The spectrophotometric determination of chlorophyll involves filtration, disruption of the cells, and extraction of the chlorophyll, followed by absorbance measurements. The optical density values were converted to chlorophyll *a* and phaeophytin using the formulae and appropriate calibration factor.

3.10. Method for Anthropogenic Impact Analysis

This study was highlighted the major environmental factors and the importance of biological interactions in structuring shore communities. However, quantitative estimation of anthropogenic impact is remained a non-conclusive controversial one. Thus, in the present study the various anthropogenic influences on exposed shores and the structural role of macro-invertebrate on the shores were qualitatively demonstrated by field experiments.

Extensive field study was regularly carried out along the entire coastal zone of Saurashtra region. The study sites were identified and make a note of the type of various anthropogenic activities such as tourism, fisheries, port activity, industry, sewage and disposal waste and later than classify it‘s to the degree of these activities which is actually more affected on the coastal area. Including these specific activities furthermore all the stations are also focus point of human settlement very near about the coastal area. For the prediction of likely nature and impact of anthropogenic stress, various environmental indicators were selected subject to the relevance to the study area. Further, direct, indirect, cumulative and unavoidable impacts were examined to assess the predictive impact. Anthropogenic stress is the response of biological entity (individual, population, community etc.) to an anthropogenic disturbance. Stress at one level of organization (e.g. individual, population) may also have an impact on other level, for example, causing alterations in community structure. The coastal area is mainly polluted by the water pollution; it is directly or indirectly created by human and industrial settlement near the coastal area as well as natural procedure, which is tremendously, affected the intertidal community. In the present study seawater quality parameters were used for describe the coastal pollution and its effects on the intertidal community.

3.11. Data Analysis

Biodiversity Indices

As diversity indices are increasingly used to assess the health of the habitats, presently index of similarity (S), Shannon index of general diversity (H‘), species richness indices (d), evenness indices (J‘), measures were used to estimate the ecological status of the intertidal area of selected stations.

Sorensen‘s index of similarity (Sorensen, 1948) has been used to compare the similarity in species composition of the benthic communities between sampling sites. It was calculated using following equation.

QS = 2C / A + B

Where, A and B are the species numbers in samples A and B, respectively, and C is the number of species shared by the two samples.

The most widely used measure of species diversity is the information theory indices. Shannon and Wiener (1963) independently derived functions, known as Shannon index of diversity. The Shannon-Wiener diversity index H‘ combines both equitability and species richness by using the proportion of the total count of individuals (p) for each (or the i^{th}) species.

$H' = -\sum (Ni/N) \log_e (Ni/N)$,

Where, the H' = diversity index, Ni = total number of individual species I, N = total number of individuals of all species in stand.

Species richness (d) refers simply to the number of species in a community. Species richness index d is based on the number of species present in a community (S) and incorporates the total number of individuals in the community (N). It is a measure of the number of species present for a given number of individuals. The species richness was calculated using Menhinick (1964).

$d = S / \sqrt{N}$

Where, S = number of species, N = number of individual.

The evenness was calculated using Pielou's measure. Pielou (1966) describes equitability or the evenness of the distribution of the numbers of individuals among species.

$J' = H' / \ln S$

Where, H'= Shannon index, S = number of species.

Population Ecology

Among the ecological attributes, seasonal variations in the population density and abundance of major phylum in each sampling stations were calculated (Misra, 1968). The collected data of ecological attributes were calculated by below formula were treated as raw data from which the total density and total abundance values were calculated.

$$\text{Density} = \frac{\text{Total number of individuals recorded from the sample plot}}{\text{Total number of sample plot studied}}$$

$$\text{Abundance} = \frac{\text{Total number of individuals recorded}}{\text{Total number of sample plot where the individuals occurred}}$$

Statistical Analyses

The collected monthly data were presented as seasonally for the seasonal approach like winter, summer, monsoon and post-monsoon. The obtained data were initially subjected to various descriptive statistical analyses like mean and standard deviation. The obtained data were further subjected to different statistical analyses for their cumulative acceptability (Sokal and Rohlf, 1969). Significance of spatial and temporal variations was compared by using single factor ANOVA. More advanced analyses like Regression and Correlation Coefficients analyses were also performed to find out relationship between various water quality parameters within a sampling site and to assess the influence of seawater quality parameters on the macrofaunal community structure (Southwood, 1978).

Chapter 4 RESULTS

4.1. Coast Characteristics

The Saurashtra coastline has mostly steeply declined tidal flat that makes it difficult to access the lower littoral zone. The sand portion of the coastline mainly consists of lime and shells. Substratum of the selected sampling sites contains many pools and cut by numerous creeks allowing the limpets to settle down at their habitat scars. This coastline shows a distinctive feature that is quite different from the Gulf of Kachchh. The intertidal belt is totally rocky formed of milliolite rocks except some interruption of sand patches where ever the so called spray zone is sandy. The upper littoral zone is formed of smooth rocks with many narrow creeks and pools facilitating its dwellers to move along with the upcoming tidal water. The middle and the lower zones share almost one and the same features from the point of view of the types of substratum and prevailing biotic composition. The faunal composition at the middle and the lower littoral zones do not vary so much with the seasons as the two zones remains submerged for most of the time and contain a very good number of pools and puddles, thus holding water for longer duration. The lower littoral zone suddenly ends to the subtidal zone, thus making the migration of the animals from the subtidal to intertidal zone almost impossible.

The selected intertidal zone of Dwarka is on the north-east of the town. The available intertidal area is rocky with hard substratum having many big cup-holes and clavicles, whereas, the outer intertidal zone is highly elevated with broad and deep caves because of heavy wave action (Plate-2). The rocky surface is very much sharp edged with abundant pools and puddles. Selected sites are sandy, stony and calcareous eruptions. The available intertidal zone of Mangrol lying south-east of the town is a hard flat rocky littoral area having small sized depressions in interspersed with many rocky pools and puddles (Plate-3). The spray zone is covered by sand; however a very horizontal rocky area is found exposed in the spray zone. The intertidal zone gets exposed up to 70-80 m during spring tides. This site is patches of sand and calcareous eruptions. The upper littoral part is rocky-sandy and middle and lower littoral zone are grooved rocky. The intertidal zone of Veraval covers a distance of about 50-60 m during spring tides. The substratum of the intertidal zone is mostly rocky which gets covers with sand (Plate-4). The underlying rock is lime stone with depressions, slightly covers deposits of silt or sand mixed with species of shells. The shore gently slopes towards the sea forming the intertidal belt which is interrupted by many small tide pools and gullies. The existing intertidal zone is flat and calcareous with sandy zone at Kodinar (Plate-5). The intertidal area is mostly rocky substratum with many small tide pools and small depressions, whereas the hard rocky area having substratum covered with sand. The rocky intertidal zone is smooth to irregular surface with sandy pools.

4.2. Zonation

The intertidal portion of selected locations off the Arabian Sea does not show any significant slope while exposed during the lower tides. The splash zone or spray zone is the highest and driest area. This zone is never submerged and only receives ocean water due to the splash from crashing waves. The upper littoral zone is only submerged briefly during the highest tides. Few organisms can withstand the extreme fluctuations in moisture, temperature and salinity found in this zone. The gastropod *Cellana radiata* and *Turbo coronetus* are the most common forms in the upper littoral zone of the shore. *Siphoneria siphoneria* was also observed at this zone. The upper zone is dominated by green algae *Ulva fasciata* and *Ulva lactuca* particularly. The middle and the lower littoral zones at most of the sampling sites harboured similar type of biota. The pools at the middle littoral zone were too deep, the bottom part of these pools were open to the sea, so regular thrust of upcoming tidal water. The middle littoral zone was dominated by a variety of algae and macrofaunal species. This is the portion which gets exposed during regular low tide. Most of the space of this zone was occupied by sessile organisms such as barnacles (*Balanus amphitrite*), *Zoanthus sp.* and sea anemone. The barnacle was also dominated on the upper littoral and upper part of middle littoral zone and usually in patches. The lower littoral zone ended up with sharp decline to the sub tidal zone and that is too irregular. Some species of echinodermata were occurred in this zone such as *Strongylocentrorus sp.* and other gastropods like *Octopus vulgaris* was also found mainly at the lower littoral zone. Inter-faunal competition is quite high because available habitable spaces at the different zones are very less. The intertidal belt is mostly harboured by hard shelled molluscs and hermit crabs which comprised in all three littoral zones.

4.3. Intertidal Macrofaunal Diversity

The selected sampling locations along the South Saurashtra coastline off Arabian Sea are predominantly rocky with some patches of sand which is represented various macrofauna and flora species. All the sampling stations have been surveyed regularly and all the species of macrofauna that occurring along the entire intertidal area has been recorded and checklist was prepared. The organisms observed at the four different sites of the present study are listed in table 1. In this present study, a total of 120 intertidal macrofaunal species represented by seven diverse phyla such as porifera, coelenterata, platyhelminthes, annelida, arthropoda, mollusca and echinodermata were recorded, of which mollusca, coelenterata and arthropoda was most prominent groups for the major macrofaunal population of selected intertidal zone.

Phylum porifera represents six species of sponges throughout the study period (Table 1). Some species such as *Halichondria panacea, Microciona sp., Oscareila lobularis* and *Tethya sp.* were recorded at all the selected sites (Plate-6), while *Leucosolenia punctata* and *Grantia sp.* were observed only at Dwarka and Mangrol respectively. Sponge population was relatively high at Dwarka than the other sapling sites. Mostly sponge population found in middle and lower littoral zones during the study. Sponge diversity was relatively less during summer season at all the sampling sites. Some species such as *Halichondria panacea* were common and highly diverse along the intertidal zone of all the selected sampling sites.

A total of 17 species were recorded in the phylum coelenterata, in case of six coral species were observed from intertidal region at four sampling site. Among them, three species *Goniastraea pectinata, Hydnophora exesa* and *Montipora folisa* were observed at all the sampling sites (Plate-6, 7), while *Favia favulus* and *Goniopora sp.* were recorded at Dwarka and Mangrol respectively. However, coral species have a patchy distribution along the rocky intertidal coast of the selected locations. Corals were totally absent in upper littoral zone but it has been found that the variation in species diversity was maximum in lower littoral zone and minimum in middle littoral zone. The corals are generally occurred in large numbers as colonies of individual polyps. There were observed another 11 species of other than corals in phylum coelenterata, in that *Zoanthus sociatus* and *Metridium sp.* were very common species in the intertidal zone of selected area throughout the study (Plate-7, 8), it has been found mainly in the middle and lower littoral zone and occasionally in the upper littoral region also. Among all the species of coelenterata *Zoanthus sp.* was highly occurred and covered most of the area of the intertidal region during most of the time at all the sampling sites. The patches of *Zoanthus sp.* was also present in upper littoral zone next to middle and lower littoral zone. *Metridium sp.* is ordinary species of the middle littoral zone.

In the phylum platyhelminthes three species were identified such as *Pseudoceros indicus, Pseudoceros stellae* and *Pseudoceros susanae* were observed (Plate-9). Among this species *Pseudoceros susanae* was recorded at all the sampling sites while *Pseudoceros stellae* observed at Dwarka and Veraval. *Pseudoceros indicus* was found only at Dwarka sampling site during post-monsoon season. These species of phylum platyhelminthes were mostly observed in the middle and lower littoral zone.

The animals of annelids phylum were present all time at the intertidal area of selected sites, it represents eight species during the study period. *Nereis pelagica* and *Baseodicus hemprichii* were observed almost throughout the study period (Plate-9, 10). *Serpula vermicularis* was recorded in the middle and lower littoral zone during study time at the sampling site Dwarka. *Baseodicus hemprichii* was recorded maximum time at Dwarka; however, it found mostly in middle littoral zone at all the sampling site. On the other hand, *Eulalia viridis* was observed mostly at Kodinar during the study. *Nereis pelagica* and *Hetronereis sp.* was present almost throughout the study and preferred mainly sandy portion like such pools and puddles of the rocky intertidal area and found in middle littoral zone next to upper littoral zone. The annelids were mainly seen in middle and lower littoral zone but rarely showed in upper littoral zone during the study. *Sabella pavonica* and *Chetopterus chetopterus* are the tube worm, recorded during most of the time of study at mostly in middle and lower littoral zone (Plate-9, 10). *Serpula vermicularis* was found to be attached with rock and observed only at Dwarka through the study period.

The phylum arthropoda was well represented in all the sampling sites throughout the study. A total of 15 species with the *Balanas amphitrite, Atergatis sanguinolentus* and various species of hermit crabs like *Clibanarius zebra* and *Clibanarius nathi* as dominant at the intertidal region of selected locations (Plate-11). Arthropoda covers all three littoral zone of the intertidal area. *Pilumnus hirtellus, Balanas amphitrite* and *Carcinus means* was recorded commonly at the entire littoral zone of all the sampling sites throughout the study. *Clibanarius zebra* and *Clibanarius nathi* were present in deserted shell of gastropod molluscs in all three zones. The species diversity showed more or less similar pattern at upper and middle littoral zones.

Phylum mollusca were highly occurred and most prominent group than any other phylum in the selected intertidal area of study. About 65 species of mollusca were recorded in the selected sites throughout the study period (Table 1). The most abundant species in all the sampling sites as mollusca the gastropods with the prominent species like *Turbo coronetus, Turbo intercostalis, Trochus radiatus, Nerita albicella, Cellena radiata, Rhinoclavis sinensis* and *Mancinella bufo* etc (Plate-12, 13,14). The vertical upper littoral was uniformly covered by small sized *Cellana radiata* and juveniles of *Cerithium scabridum*. *Chiton peregrinus* prefer the small pools of the upper and middle intertidal zone. *Turbo coronetus*, a dweller of the upper littoral zone occupies the plane substratum. *Cantharus spiralis* and *Cantharus undosus* were found in quite good number. The shell-fewer molluscs *Onchidium verruculatum* and *Berthellina citrina* were also present in the selected sites of the study area (Plate-13). *Berthellina citrina was* observed only at Dwarka during winter season. Among the entire animal recorded of phylum mollusca, many species were found in mostly upper littoral zone, while in middle littoral zone all species were present except *Octopus vulgaris* which were present mainly in lower littoral zone. Phylum mollusca generally feed on the marine algae and thus always associate with intertidal sea weeds.

At all the sampling site six species of phylum echinodermata have been recorded during study period. The members of this phylum were totally absent in upper littoral zone but abundantly occurred in middle and lower littoral zone. All six species were recorded at Dwarka, while three species at Mangrol and Veraval. *Ophioderma brevispinum* was found at all the sampling site during the study period (Plate-14). The species diversity of this phylum was comparatively less at all the selected intertidal region of the study area. Most of the species of this phylum were recorded during post-monsoon and winter season at the selected sampling sites.

Table 1. Checklist of the intertidal macrofauna recorded at various sampling sites during the study period (+ or – signs denote presence or absence).

Phylum: Porifera

Sr. No.	Name of species	Occurrence in the sampling sites			
		Dwarka	Mangrol	Veraval	Kodinar
1.	*Grantia sp.*	-	+	-	-
2.	*Halichondria panicea*	+	+	+	+
3.	*Leucosolenia punctata*	+	-	-	-
4.	*Microciona sp.*	+	+	+	+
5.	*Oscareila lobularis*	+	+	+	+
6.	*Tethya sp.*	+	+	+	+

Phylum: Coelenterata

Sr. No.	Name of species	Occurrence in the sampling sites			
		Dwarka	Mangrol	Veraval	Kodinar
	Corals				
1.	*Favia favulus*	+	-	-	-
2.	*Goniastraea pectinata*	+	+	+	+
3.	*Goniopora sp.*	-	+	-	-
4.	*Hydnophora exesa*	+	+	+	+
5.	*Montipora folisa*	+	+	+	+
6.	*Portis lutea*	+	+	+	-
	Other than Corals				
7.	*Anthopleura sp.*	+	+	+	+
8.	*Auralia aurita*	+	-	+	-
9.	*Isaurus tuberculata*	-	+	+	-
10.	*Metridium sp.*	+	+	+	+
11.	*Palythoa tuberculosa*	+	+	+	+
12.	*Physalia physalia*	+	+	+	+
13.	*Porpita porpita*	+	+	+	+
14.	*Protopalythoa vestitus*	+	+	+	+
15.	*Utricina sp.*	-	+	+	-
16.	*Vellella vellella*	+	-	-	-
17.	*Zoanthus sociatus*	+	+	+	+

Phylum: Platyhelminthes

Sr. No.	Name of species	Occurrence in the sampling sites			
		Dwarka	Mangrol	Veraval	Kodinar
1.	*Pseudoceros indicus*	+	-	-	-
2.	*Pseudoceros stellae*	+	-	+	-
3.	*Pseudoceros susanae*	+	+	+	+

Phylum: Annelida

Sr. No.	Name of species	Occurrence in the sampling sites			
		Dwarka	Mangrol	Veraval	Kodinar
1.	*Baseodicus hemprichii*	+	+	+	+
2.	*Chetopterus chetopterus*	+	+	+	+
3.	*Eulalia viridis*	+	+	+	+
4.	*Eurythoa complanata*	+	+	-	-
5.	*Hetronereis sp.*	+	+	+	+
6.	*Nereis pelagica*	+	+	+	+
7.	*Sabella pavonica*	+	+	+	+
8.	*Serpula vermicularis*	+	-	-	-

Phylum: Arthropoda

Sr. No.	Name of species	Occurrence in the sampling sites			
		Dwarka	Mangrol	Veraval	Kodinar
1.	*Atergatis sanguinolentus*	+	+	+	+
2.	*Balanus amphitrite*	+	+	+	+
3.	*Cancer pagurus*	+	-	+	+
4.	*Carcinus means*	+	+	+	+
5.	*Clibanarius nathi*	+	+	+	+
6.	*Clibanarius zebra*	+	+	+	+
7.	*Pachygrapsus crassipes*	+	+	+	+
8.	*Pagurus longicarpus*	+	+	+	+
9.	*Palaemon serratus*	+	+	+	+
10.	*Pilumnus hirtellus*	+	+	+	+
11.	*Pinaeus indicus*	+	-	+	+
12.	*Pinaeus monodon*	+	+	+	-
13.	*Portunus granulatus*	+	-	-	+
14.	*portunus pelagicius*	-	+	-	+
15.	*Squilla squilla*	-	+	-	-

Phylum: Mollusca

Sr. No.	Name of Mollusca	Occurrence in the sampling sites			
		Dwarka	Mangrol	Veraval	Kodinar
1.	*Aplysia oculifera*	+	+	+	+
2.	*Architectonica laevigata*	-	+	+	-
3.	*Austrea stellata*	+	+	+	+
4.	*Babylonia spirata*	+	-	+	-
5.	*Beguina variegata*	+	+	-	-
6.	*Berthellina citrina*	+	-	-	-
7.	*Brusa granularis*	+	+	+	+
8.	*Cantharus spirallis*	+	+	+	+
9.	*Cantharus undosus*	+	+	+	+
10.	*Cellana radiata*	+	+	+	+
11.	*Cerithium caeruleum*	+	+	+	+
12.	*Cerithium columna*	+	+	+	+
13.	*Cerithium morus*	-	-	+	-
14.	*Cerithium scabridum*	+	+	+	+
15.	*Chiton peregrinus*	+	+	+	+
16.	*Clavus clasa*	-	-	+	-
17.	*Conus miliaris*	+	+	+	+
18.	*Conus cumnigii*	+	-	+	+
19.	*Conus figulinus*	+	+	+	+
20.	*Cronia crontracta*	+	+	+	-
21.	*Cronia subnodulosa*	+	+	+	+
22.	*Cypraea isabella*	+	+	+	+
23.	*Cyprea lynx*	+	+	+	+
24.	*Cyprea ocellata*	-	+	-	+
25.	*Dosinia cretacea*	-	+	-	-
26.	*Engina zea*	+	+	+	+
27.	*Euchelus asper*	+	+	+	+
28.	*Hexaplex cichoreus*	-	+	-	-
29.	*Janthina globosa*	+	-	-	+
30.	*Mancinella bufo*	+	+	+	+
31.	*Mitra ambigua*	+	+	+	+
32.	*Mitra scutulata*	+	+	+	+
33.	*Monodonta australis*	+	+	+	+
34.	*Murex bruneus*	+	+	+	+
35.	*Murex ternispina*	+	+	+	+
36.	*Mytilus sp.*	+	-	-	-
37.	*Nassarius canaliculata*	+	-	+	-
38.	*Nassarius distortus*	+	+	+	-

39.	*Nassarius olivacea*	-	+	-	+
40.	*Nerita albicilla*	+	+	+	+
41.	*Nerita chamaeleon*	-	-	+	-
42.	*Octopus vulgaris*	+	+	+	+
43.	*Oliva globosa*	-	+	+	-
44.	*Oliva oliva*	+	+	+	+
45.	*Onchidium verruculatum*	+	+	+	+
46.	*Paphia ala-papilionis*	+	-	-	+
47.	*Perpura panama*	+	+	+	+
48.	*Pyrene flava*	-	-	+	+
49.	*Pyrene marquessa*	-	-	+	-
50.	*Pyrene terpsichore*	+	+	+	+
51.	*Rhinoclavis sinensis*	+	+	+	+
52.	*Siphoneria siphoneria*	+	+	+	+
53.	*Sunetta donacia*	+	+	+	+
54.	*Telescopium telescopium*	-	-	-	+
55.	*Thais lacera*	+	-	-	-
56.	*Thais rugosa*	+	+	+	+
57.	*Tibia insuladchorab*	+	+	+	+
58.	*Trachicardium flavum*	+	+	-	-
59.	*Trochus radiatus*	+	+	+	+
60.	*Turbo brunnes*	-	+	-	-
61.	*Turbo cornetus*	+	+	+	+
62.	*Turbo intercostalis*	+	+	+	+
63.	*Venerupis microphylla*	+	-	-	+
64.	*Venus reticulate*	+	+	+	+
65.	*Xancus pyrum*	-	+	-	-

Phylum: Echinodermata

Sr. No.	Name of species	Occurrence in the sampling sites			
		Dwarka	Mangrol	Veraval	Kodinar
1.	*Antedon sp.*	+	-	+	+
2.	*Asterina gibbosa*	+	-	-	-
3.	*Clymeaster sp.*	+	+	-	-
4.	*Echinus sp.*	+	-	+	-
5.	*Ophioderma brevispinum*	+	+	+	+
6.	*Strongylocentrorus sp.*	+	+	-	-

4.4. Spatial Variations in Macrofaunal Diversity

The total numbers of species in each phylum at the selected sampling sites are shown in Fig. 1. Among the total species of intertidal macrofauna occurred at different sampling sites, the number of species occurring at each sampling site was 100 species from Dwarka, 92 species from Mangrol, 91 species from Veraval and 82 species from Kodinar (Fig. 2). The total species observed mollusca was dominated phylum among all the sampling site, represented 65 species contributed about 54.2 % to the total number of individuals. 17 species of coelenterata contributed about 14.2 %, while the arthropoda 15 species comprised approximately 12.5 % to the total number of species recorded at all the sampling sites. The phylum annelid comprised 8 species about 6.7 %, whereas porifera and echinodermata contributed about 5.0 % and 5.7 % of total species respectively. Phylum platyhelminthes represented only 3 species contributed about 2.5 % to the total fauna recorded (Fig. 1).

The results showed that the number of macrofaunal species in each phylum recorded at Mangrol, Veraval and Kodinar was comparatively similar during the study period. The selected coastal belt of Dwarka comprised the highest number of species among each phylum during the study. The present study indicated the clear dominance of the mollusca in terms of number of species, it was also realized that the mollusca were more widely distributed macro invertebrates at all the selected sampling sites during the study. There were no great differences in the number of individuals at various sampling sites, while there were wide differences in the number of species in various groups at all the sampling sites (Fig. 2).

The significant variations observed between the sampling site Dwarka and Kodinar, while Mangrol and Kodinar showed relatively similar pattern in macrofaunal diversity. Phylum echinodermata comprises 6 species at sampling site Dwarka while at the Mangrol and Veraval 3 species were recorded throughout the study period. Similar distribution was observed in case of phylum annelids. 46 species of mollusca were observed at Kodinar, which was comparatively low than the other sampling site. It was observed that phylum echinodermata was highly occurred at Dwarka, while at the other sampling site the minimum distribution recorded during the study.

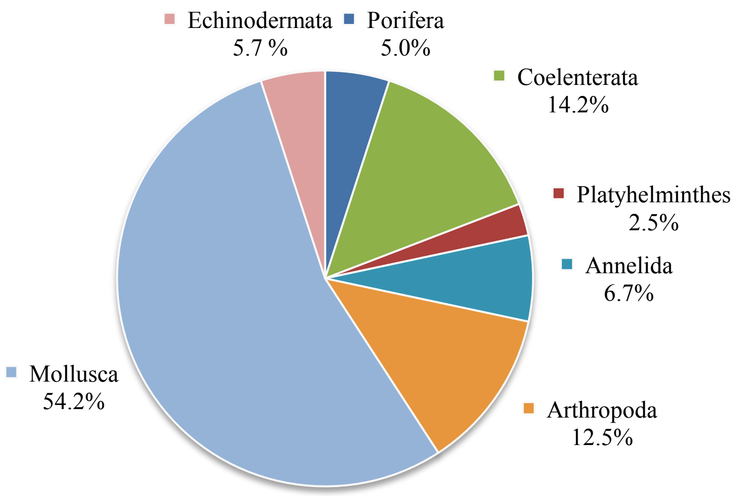

Figure 1. Group wise distribution of total intertidal macrofaunal diversity recorded from the all the selected sampling sites.

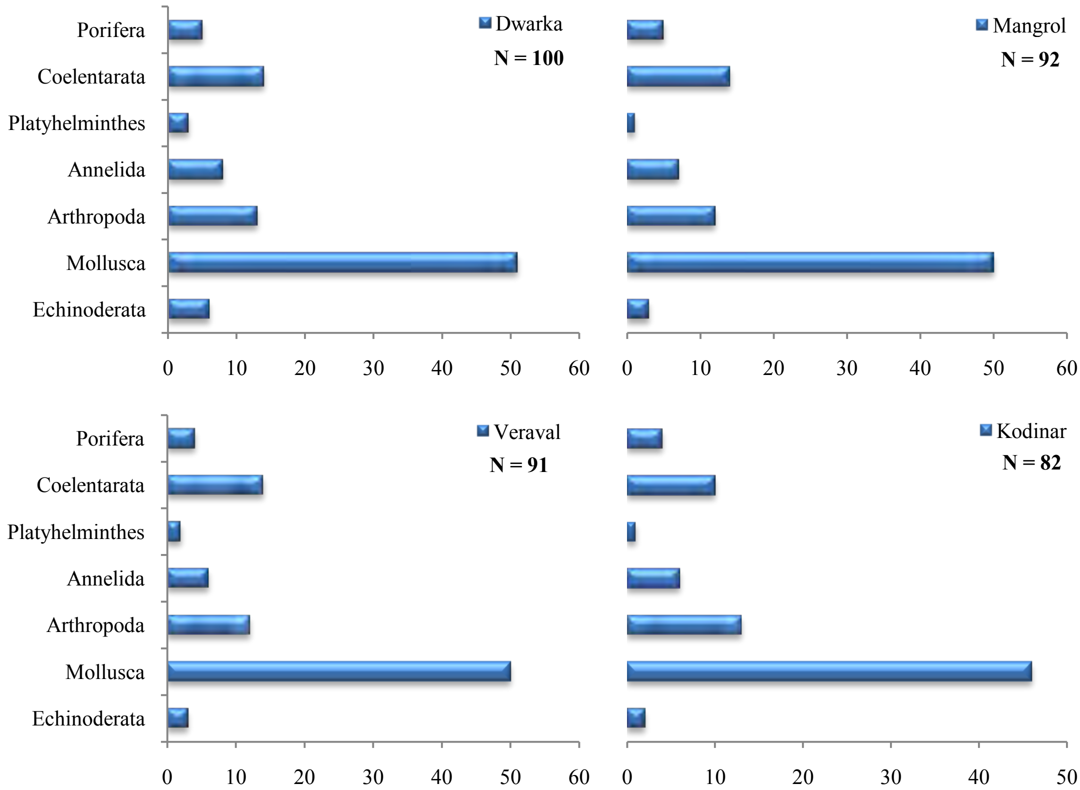

Figure 2. Community composition of sampled intertidal macrofauna at selected sampling sites. Numbers in plot indicate the number of species in each group. The total number of species found at each location is represented by N.

4.5. Similarity Index between Sampling Sites

The macrofaunal species occurrence was subjected to similar fauna of the intertidal belt found at various sampling sites. The Sorenson's index of similarity allowed to compares the species composition between sampling sites. The result showed values varied from 0.813 to 0.855 (Table 2). The similarity index of four sites indicates that Veraval and Kodinar (0.855) sites are more similar throughout the study period than Veraval and Dwarka (0.848), and Kodinar and Dwarka (0.846). However, during the study period similarity index of Mangrol and Kodinar (0.826) was closer to that of Mangrol and Veraval (0.831). The lowest value of similarity found between Mangrol and Dwarka (0.813), while between other sampling sites result suggest moderate standing macrofaunal species occurrence during the study. Each of these four sites, intertidal macrofaunal species showed high degree of similarity as all the indices values were above 0.80.

Table 2. Sorenson's index of similarity for occurrence of intertidal macrofauna at the four sampling sites.

	Dwarka	Mangrol	Veraval	Kodinar
Dwarka	1.000			
Mangrol	0.813	1.000		
Veraval	0.848	0.831	1.000	
Kodinar	0.846	0.826	0.855	1.000

4.6. Intertidal Seaweed (algae) Diversity

The selected sites of the Saurashtra coast were rich in algal population. The spatial distribution of marine algae in the selected area is depicted in table 3. As many as 51 intertidal seaweed species recorded during the study period. As a whole, 18 species of class Chlorophycea and Pheophyceae followed by 15 species of Rhodophyceae were found in the selected region all over the study time. The algal species belonging to class Chlorophycea like, *Ulva lactuca, Ulva fasciata, Caulerpa racemosa, Caulerpa scalpelliformis* were prominent at the intertidal region of all the selected sites (Plate-15). Large mashes of *Ulva lactuca* and other species like *Caulerpa racemosa* was found in each littoral zone at almost all the sampling locations. As far as the seasonal variation is concerned it is negligible during monsoon season, whereas optimum growth of algae had been observed during the post-monsoon season. *Caulerpa scalpelliformis, Halimeda tuna, Padina gymnospora, Turbinaria ornata, Gracilaria corticata* and *Laurencia papillosa* was the highly abundant species in to all the selected sampling sites. *Sargassum johnstonii* and *Sargassum swartzii* had the widest distribution, being able to colonize in lower littoral zone at all sampling sites. In contrast, some species were found only at specific sites, for example, *Hydroclathrus clathratus* and *Halymenia porfaroides* occurred only at Dwarka, while *Dityota atomaria* occurred only at Mangrol and *Halimeda macroloba* was found at Mangrol and Veraval throughout the study. Algal species of class Phaeophycea (Plate-16) and Rhodophycea (Plate-17) were mostly absent in upper littoral zone at the study sites.

Table 3. Checklist of the intertidal algae recorded at various sampling sites along the Saurashtra Coastline during the study period (+ or – signs denote presence or absence).

Class: Chlorophycea

Sr. No.	Name of species	Occurrence in the sampling sites			
		Dwarka	Mangrol	Veraval	Kodinar
1.	*Enteromorpha sp.*	+	+	+	+
2.	*Ulva fasciata*	+	+	+	+
3.	*Ulva lactuca*	+	+	+	+
4.	*Chaetomorpha antennina*	+	+	+	+
5.	*Cladophora glomerata*	+	-	+	-
6.	*Valonia aegagroplia*	+	+	-	-
7.	*Bryopsis plumose*	+	+	+	+
8.	*Caulerpa racemosa*	+	+	+	+
9.	*Caulerpa scalpelliformis*	+	+	+	+
10.	*Caulerpa taxifolia*	+	+	+	+
11.	*Codium dwarkense*	+	+	+	+
12.	*Halimeda tuna*	+	+	+	+
13.	*Halimeda cylindracea*	+	+	+	-
14.	*Halimeda cuneata*	+	+	-	-
15.	*Halimeda macroloba*	-	+	+	-
16.	*Udotea patiolata*	+	+	-	-
17.	*Boergesenia forbesii*	+	+	+	+
18.	*Galidiopsis intricata*	+	+	-	-

Class: Phaeophycea

Sr. No.	Name of species	Occurrence in the sampling sites			
		Dwarka	Mangrol	Veraval	Kodinar
1.	*Dictyota dichotoma*	+	+	+	+
2.	*Dityota atomaria*	-	+	-	-
3.	*Padina gymnospora*	+	+	+	+
4.	*Padina tetrastromatica*	+	-	+	+
5.	*Colpomenia sinuosa*	+	+	+	+
6.	*Cystoseria indica*	+	+	+	+
8.	*Sargassum johnstonii*	+	+	+	+
9.	*Sargassum swartzii*	+	+	+	+
11.	*Sargassum cinereum*	+	-	+	-
12.	*Turbinaria ornata*	+	+	-	-
13.	*Stoechospermum marginatum*	+	+	+	+
14.	*Spatoglossum asperum*	+	+	+	+
15.	*Colpomenia tuberculata*	+	+	+	+
16.	*Colpomenia sciniosa*	+	+	-	-
17.	*Etcocarpus sp.*	+	+	-	+
18.	*Hydroclathrus clathratus*	+	-	-	-

Class: Rhodophycea

Sr. No.	Name of species	Occurrence in the sampling sites			
		Dwarka	Mangrol	Veraval	Kodinar
1.	*Gracilaria corticata*	+	+	+	+
2.	*Ceramium truncatum*	+	-	+	-
3.	*Amphiroa anceps*	+	+	+	+
4.	*Grateloupia indica*	+	+	+	-
5.	*Champia compressa*	+	+	+	+
6.	*Champia indica*	+	+	+	+
8.	*Gelidiella acerosa*	+	+	+	+
9.	*Halymenia venusta*	+	+	-	-
11.	*Halymenia porfaroides*	+	-	-	-
12.	*Polysiphonia sp.*	+	+	+	+
13.	*Subdenia flabellata*	+	+	-	-
14.	*Laurencia papillosa*	+	+	+	+
15.	*Galaxaura oblongata*	+	+	+	+

4.7. Macrofaunal Community Structure

All the sampling sites along the Saurashtra coastline were frequently surveyed at regular intervals during the lowest tides for the present investigation. Intertidal macrofauna observed during these frequent surveys were recorded. Intended for the qualitative analysis, the whole invertebrate macrofauna found at the different sites considered as the phylum level. It was apparent that the intertidal macrofaunal species at all the sampling sites were represented by six phylum viz. porifera, coelenterata, annelida, arthropoda, mollusca and echinodermata. The sample analyses have revealed a total of 60 species living in the surveyed intertidal zones. The macrofaunal species numbering 60 (3 species of porifera, 8 species of coelenterata, 5 species of annelid, 6 species of arthropoda, 35 species of mollusca and 3 species of echinodermata) were studied during the study period. Therefore various diversity indices like Shannon-Wiener diversity index (H‘), richness index (d), evenness index (J‘), density and abundance for the ecological studies of each group were measured.

4.7.1. Shannon-Wieners Diversity Index

The utility of a diversity index increases with its capacity to highlight small differences between sites and, at the same station, differences over time. Shannon-Weiner diversity index was applied on the general pattern of seasonal variation of macrofaunal diversity. Pattern of faunal diversity (H‘) illustrated in table 4. In general, the species diversity varied from 0.015 to 2.089 throughout the study period. The results revealed that there was no specific pattern of diversity in between the sampling sites. High species diversity was observed during winter and monsoon at Veraval and Kodinar respectively, while it was observed slightly high value during summer season at Dwarka and Mangrol sampling site. The species diversity was found least values of phylum echinodermata and maximum was recorded in case of phylum mollusca throughout the study period at all the sites. The range of species diversity during monsoon was 0.019 to 1.898 and during the winter season it was around 0.015 to 1.1918 at all the sampling site (Table. 4). The diversity of porifera varied from 0.099 to 0.272 during summer and monsoon season at Dwarka and Kodinar respectively. It was also observed that any species of porifera group did not record during summer season at Veraval site. The diversity values were high during monsoon at all the sampling sites in case of porifera. *Halichondria panicea,* was commonly recorded and found to be well diverse species of phylum porifera. The results showed that maximum diversity values of porifera group observed during monsoon followed by post-monsoon season at the sampling site Mangrol and Kodinar. The diversity value of group coelenterata found maximum during post-monsoon (0.813) and lower (0.387) during monsoon season at Kodinar and Mangrol respectively, while at Veraval it was recorded high during winter season (0.776) and least value observed during monsoon season (0.592). It was found maximum diversity of *Zoanthus sp*. in phylum coelenterata especially during post-monsoon season at Dwarka, Mangrol and Kodinar, while at Veraval, where the highest diversity recorded during winter season. It was found high species diversity of coelenterata at Dwarka during post-monsoon after that slightly decreased during winter and minimum value observed during summer season. The diversity of annelids was relatively high during summer season at Mangrol compared to other sites. In that, *Nereis pelagica* was most prominent species in phylum annelids which was showed similar diverse pattern in the intertidal zone at all the sites throughout the study period. The diversity of annelida ranged between 0.143 at Dwarka to 0.272 at Mangrol during the summer season. In case of phylum arthropoda the maximum diversity (0.671) was observed during the post-monsoon season at Mangrol and minimum (0.412) was found during the summer season at sampling site Veraval. *Turbo coronetus, Turbo intercostalis* and *Trochus radiatus* were the greatly diverse species in phylum mollusca during each season at all the sampling sites. During winter season this phylum was showed high diversity at Veraval than the other sites, while during monsoon, diversity was maximum at Mangrol. Species diversity of phylum mollusca was ranged from 1.437 to 2.089 at all the sites throughout the study period. At the Kodinar sampling site diversity was high during monsoon season of the molluscan group, while in case of Dwarka it showed elevated during summer season. The results revealed that at Veraval species diversity was found high during winter followed by summer season. A diversity value of echinodermata was relatively low during study period, it was evident from sampling site Kodinar only one species, *Ophioderma* was found during the present investigation, whereas at other sites *Antedon rosacea* and S*trongylocentrotus sp.* was also recorded throughout the study. Spatial and temporal variations in case of coelenterates, arthropods and molluscan diversity were showed significant variations which confirmed by ANOVA ($p<0.05$) (Table 7).

Table 4. Shannon-Wiener Diversity of major intertidal groups present in the sampling sites during the study period. (Abbreviations used: W = winter, S = summer, M = monsoon and PM = post-monsoon).

	Porifera	Coelenterata	Annelida	Arthropoda	Mollusca	Echinodermata
Dwarka						
W	0.139	0.767	0.203	0.630	1.761	0.030
S	0.099	0.650	0.143	0.651	1.919	0.000
M	0.172	0.778	0.172	0.646	1.732	0.035
PM	0.108	0.871	0.163	0.623	1.646	0.044
Mangrol						
W	0.181	0.604	0.217	0.652	1.851	0.015
S	0.074	0.435	0.272	0.573	2.089	0.042
M	0.247	0.387	0.211	0.671	1.898	0.019
PM	0.212	0.686	0.232	0.559	1.722	0.034
Veraval						
W	0.141	0.776	0.211	0.476	1.918	0.033
S	0.000	0.654	0.195	0.412	1.843	0.000
M	0.207	0.592	0.139	0.455	1.810	0.043
PM	0.110	0.711	0.218	0.504	1.823	0.020
Kodinar						
W	0.201	0.665	0.246	0.567	1.530	0.021
S	0.115	0.632	0.249	0.617	1.501	0.000
M	0.272	0.467	0.227	0.565	1.558	0.000
PM	0.224	0.813	0.221	0.480	1.437	0.000

4.7.2. Species Richness

The species richness of major invertebrate phyla at all the sampling sites is shown in table 5. The species richness at four sites varied and did not show any clear trend of variation during the seasons. Species richness varied significantly throughout the study period, from a range of 0.270 in monsoon season to 2.914 in summer season. Results of the present investigation showed high species richness within all the groups in almost all the coastal areas. High species richness was observed in case of phylum Echinodermata during winter at the Dwarka. Amongst the animal groups studied phylum Mollusca showed the maximum species richness followed by annelids, sponges and arthropods in almost all sampling sites. The highest richness was found during the summer season of the phylum Mollusca (2.914) and the lowest richness was during monsoon season (0.265) of coelenterate. Although it was also observed in case of mollusca, lowest richness value (0.994) during post-monsoon season at Kodinar sampling site throughout the study period. The richness values of porifera ranged between 0.333 and 0.688 in post-monsoon and winter seasons respectively. Maximum richness of porifera group was recorded at the intertidal belt of Dwarka coast compared with the other sampling sites. Species richness of group porifera found comparatively low at Veraval and Kodinar sites and peaked at Mangrol during the study. Species richness varied constantly, with a tendency to increase from summer to post-monsoon at almost the sampling sites. The minimum values at Mangrol were observed during monsoon and maximum at 0.677 at Veraval in case of coelenterata group. Among the annelids group the richness at Mangrol was 0.873 to 1.336 which was maximum as compared to Dwarka and Veraval.

Table 5. Species Richness of major intertidal groups present in the sampling sites during the study period. (Abbreviations used, W = winter, S = summer, M = monsoon and PM = post-monsoon).

	Porifera	Coelenterata	Annelida	Arthropoda	Mollusca	Echinodermata
Dwarka						
W	0.688	0.535	0.981	0.552	2.232	1.154
S	0.667	0.609	0.832	0.521	2.539	0.000
M	0.655	0.598	0.943	0.588	2.170	1.155
PM	0.555	0.553	0.970	0.586	2.467	1.000
Mangrol						
W	0.671	0.603	0.873	0.659	2.315	1.000
S	0.447	0.412	1.213	0.722	2.843	1.414
M	0.655	0.265	1.336	0.739	2.540	1.000
PM	0.688	0.603	1.179	0.788	2.500	1.414
Veraval						
W	0.555	0.677	0.970	0.885	2.538	1.414
S	0.000	0.434	1.265	0.770	2.914	0.000
M	0.516	0.442	1.061	1.061	2.878	1.414
PM	0.333	0.536	1.336	0.937	2.446	1.000
Kodinar						
W	0.516	0.434	1.000	0.894	2.673	1.000
S	0.378	0.496	1.443	0.625	2.540	0.000
M	0.471	0.270	1.206	0.833	2.761	0.000
PM	0.516	0.643	1.155	1.078	0.994	0.000

4.7.3. Species Evenness

In the present study, in all the sampling sites the species evenness varied from 0.048 to 0.674 throughout the study period (Table 6). Species evenness did not show any distinct variation between sites and found to be more during monsoon period followed by post-monsoon and winter season. The results showed that molluscan group has highest evenness values followed by coelenterates and arthropods groups. While group echinodermata showed least evenness values during the study. The evenness values of phylum porifera ranged between 0.127 and 0.392 during winter and monsoon seasons at Dwarka and Kodinar respectively. It was also observed that in case of porifera group the evenness values was found maximum during monsoon season at all the sampling site. Annelid group showed similar distribution on the intertidal belt of selected shore, evenness values of this group did not show much seasonal variation throughout the study. Species evenness of phylum arthropoda showed significant variation throughout the study period. Similarly species evenness of arthropoda group did not show clear trend of variation. However, between the sampling locations evenness values showed clear trend of variation during the seasons. In case of seasonal variations in arthropods group, at Dwarka site attained the highest evenness (0.404) during summer season, when it compared monsoon (0.361) and winter (0.352). The maximum evenness values in case of group mollusca were observed at Mangrol (0.592) and lowest values (0.441) was found at sampling site Kodinar. At the sampling site Veraval maximum evenness value of group mollusca was recorded during winter, while minimum value was found during the monsoon season. In case of sampling site Dwarka and Mangrol, It was found the least value of evenness during post-monsoon compared to other seasons. The evenness values of group mollusca were increased from winter to monsoon at the sampling site Kodinar then it was decreased during post-monsoon season. From the results it is also showed that the relatively higher evenness in group echinodermata at Dwarka (0.063) during post-monsoon as compared to Veraval (0.062) during monsoon season. The minimum evenness was observed during winter in case of phylum echinodermata. The results of ANOVA showed significant variations between the four stations (Table 7). In the present study significant spatial variations in macrofaunal group annelids, arthropods and molluscan evenness were supported by ANOVA test.

Table 6. Species Evenness of major intertidal groups present in the sampling sites during the study period. (Abbreviations used, W = winter, S = summer, M = monsoon and PM = post-monsoon).

	Porifera	Coelenterata	Annelida	Arthropoda	Mollusca	Echinodermata
Dwarka						
W	0.127	0.394	0.126	0.352	0.495	0.043
S	0.143	0.363	0.130	0.404	0.540	0.000
M	0.157	0.400	0.124	0.361	0.504	0.050
PM	0.156	0.448	0.118	0.348	0.467	0.063
Mangrol						
W	0.165	0.337	0.157	0.364	0.534	0.000
S	0.000	0.396	0.169	0.356	0.592	0.061
M	0.225	0.558	0.131	0.374	0.553	0.000
PM	0.193	0.383	0.144	0.312	0.506	0.049
Veraval						
W	0.203	0.399	0.152	0.266	0.549	0.048
S	0.000	0.472	0.141	0.297	0.542	0.000
M	0.299	0.427	0.127	0.254	0.527	0.062
PM	0.000	0.442	0.135	0.281	0.547	0.000
Kodinar						
W	0.290	0.480	0.177	0.316	0.464	0.000
S	0.000	0.456	0.155	0.383	0.479	0.000
M	0.392	0.674	0.164	0.351	0.484	0.000
PM	0.323	0.454	0.159	0.268	0.441	0.000

Table 7. Results of ANOVA for diversity, richness and evenness of major macrofaunal groups in the selected sampling sites. Tabulated ‗f' value at p = 0.05 level is 3.4903. ('*' sign denotes significant)

Phylum	Diversity	Richness	Evenness
Porifera	1.4851	3.4466	0.8312
Coelenterata	2.8945	0.6714	1.8127
Annelida	5.8276*	2.2063	8.8955*
Arthropoda	12.1567*	7.3309*	6.0998*
Mollusca	11.5069*	2.8561	8.2687*
Echinodermata	1.8437	2.4773	1.5767

4.7.4. Population Ecology

Seasonal density and abundance values of macrofauna at four different sites are given in table 8. In general, the abundance of intertidal macrofauna was more during winter and low during summer season comparatively. Among those mollusca was dominated at all the sites followed by coelenterata and arthropoda. Dwarka and Mangrol recorded highest density during winter and monsoon. The population density at sampling site Veraval and Kodinar was found to be varied from 0.02 to 2.80, 0.02 to 1.68 no/ 0.25 m^2 respectively (Table 8).

The mean density of each phylum was significantly influenced by space and seasons. In the present study, the density value was low during most of the time at Kodinar, Veraval and Mangrol than the Dwarka comparatively. At Dwarka macrofaunal population showed a higher density as well as abundance values than the other sites during summer season. Density and abundance was found less at sampling site Kodinar during the most of season. At the sampling site Kodinar maximum density of porifera recorded was 0.30 no/0.25 m^2 and at Veraval, it was 0.25 no/0.25 m^2 during monsoon season. The abundance varied greatly among the sampling sites, the highest abundance was found in case of phylum mollusca at site Dwarka (35.75 no/0.25 m^2) during winter season, where large number of gastropods species found that time. Mean abundance value of annelids at Dwarka and Mangrol was 2.33 no/0.25m^2 followed by Kodinar (1.83 no/0.25m^2) during summer (Table 8).

In the intertidal zone of the selected sampling sites, the density and abundance values of the coelenterata showed no meaningful variations however decreased during summer season. Coelenterata was dominated at all the sampling sites followed by arthropoda. Annelid was represented highest density value (0.45 no/0.25m^2) at Dwarka during winter season. Echinodermata showed lowest density and abundance values during winter season with 0.02 and 0.17 no/0.25m^2 respectively (Table 8). The abundance value of mollusca at Veraval site ranged from 16.58 no/0.25m^2 to 25.67 no/0.25m^2 during summer and winter season respectively. The least value of density and abundance found during summer and maximum during winter season. In the present study significant spatial variations in coelenterata, arthropods and molluscan groups were well supported by ANOVA test (Table 9).

Table 8. Seasonal mean Density and Abundance values of various Groups in each sampling sites during the study period. (Abbreviations used, W = winter, S = summer, M = monsoon and PM = post-monsoon).

Macrofaunal group	Density				Abundance			
	W	S	M	PM	W	S	M	PM
Dwarka								
Porifera	0.32	0.15	0.35	0.30	3.17	1.50	3.50	3.00
Coelenterata	2.85	1.62	2.28	2.67	25.78	15.92	20.83	26.17
Annelida	0.45	0.23	0.30	0.28	3.83	2.33	2.58	2.67
Arthropoda	1.92	1.53	1.73	1.75	14.31	11.75	13.00	14.33
Mollusca	4.10	3.17	3.40	3.15	35.75	29.42	29.28	29.50
Echinodermata	0.05	0.00	0.05	0.07	0.50	0.00	0.50	0.50
Mangrol								
Porifera	0.33	0.08	0.35	0.32	3.33	0.83	3.50	3.17
Coelenterata	1.65	0.88	0.95	1.65	14.67	8.83	8.92	13.25
Annelida	0.35	0.28	0.23	0.30	2.42	2.33	1.83	2.83
Arthropoda	1.38	0.80	1.10	0.97	11.58	7.25	9.58	9.00
Mollusca	3.18	2.38	2.48	2.40	29.25	22.08	22.39	22.00
Echinodermata	0.02	0.03	0.02	0.03	0.17	0.33	0.17	0.33
Veraval								
Porifera	0.22	0.00	0.25	0.15	2.17	0.00	2.50	1.50
Coelenterata	1.78	1.03	1.23	1.45	16.28	9.75	10.33	13.67
Annelida	0.28	0.15	0.13	0.23	2.25	1.50	1.33	1.92
Arthropoda	0.77	0.37	0.52	0.67	6.75	3.50	4.75	6.50
Mollusca	2.80	1.75	1.93	2.07	25.67	16.58	18.92	19.00
Echinodermata	0.03	0.00	0.03	0.02	0.33	0.00	0.33	0.17
Kodinar								
Porifera	0.25	0.12	0.30	0.25	2.50	1.17	3.00	2.50
Coelenterata	1.42	1.08	0.92	1.45	13.47	10.42	8.92	14.25
Annelida	0.37	0.20	0.18	0.18	3.17	1.83	1.67	1.67
Arthropoda	0.73	0.68	0.60	0.52	6.33	5.92	5.42	4.67
Mollusca	1.68	1.33	1.37	1.33	16.25	12.75	13.08	12.92
Echinodermata	0.02	0.00	0.00	0.00	0.17	0.00	0.00	0.00

Table 9. Results of ANOVA for density and abundance of major macrofaunal groups in the selected sampling sites. Tabulated ‗f' value at p = 0.05 level is 3.4903. ('*' sign denotes significant)

Phylum	Density	Abundance
Porifera	1.2396	1.2396
Coelenterata	7.0755*	8.8941*
Annelida	1.8958	2.6520
Arthropoda	36.3633*	29.8796*
Mollusca	19.7270*	20.4185*
Echinodermata	3.0370	2.9111

4.8. Seawater Quality

4.8.1. Rational of Sampling

The locations for the collection of seawater samples from the selected sampling sites were fixed. At least six samples of surface seawater during time of high tide were collected from different locations of the same coast. These selected sampling locations were set on basis of the length of the sampling site. Seawater samples were collected at monthly intervals for the estimation of various seawater quality parameters.

4.8.2. Spatial and Temporal Variations

The chemical, physical and biological properties of water quality parameters are inter-related and must be considered together. Water quality is highly variable over time as well as space due to both natural and human factors. Various seawater quality parameters covered in this study did not show much spatial variations during each season throughout study period. Clearly visible seasonal changes in the concentration of the various seawater quality parameters were observed during the present study.

The seawater temperature showed obvious seasonal variation with minimum in winter, it ranged from 21.17 to 21.24^{0}C then after increased and showed maximum values during summer season, which was ranged from 25.63 to 25.83^{0}C, than it was decreased during monsoon after that again slightly increased throughout the post-monsoon season. In general, all four stations showed similar seasonal changes in case of seawater temperature (Fig. 3). The annual seawater temperature ranged from minimum 21.17^{0}C at Kodinar during winter season, to maximum 25.83^{0}C at Veraval during summer season, throughout the study period. In case of station Dwarka and Mangrol the seawater temperature ranged from 21.22 to 25.71^{0}C and 21.22 to 25.79^{0}C respectively.

The spatial and temporal distribution of pH values is shown in Fig. 4. Like seawater temperature the pH values also did not show much spatial variations (Table 10). The pH values, reveled slight variations ranged from 8.14 to 8.32. There was no conspicuous variation in the station-wise average value of pH. However, a marginal variations between seasons was observed, particularly the values were relatively low during the winter and monsoon period. The highest pH value (8.32) was observed during summer season of the seawater sample from Veraval station. It was also observed that the pH value was remained high during most of the season at Veraval compare to other stations during the study period.

The conductivity values showed slight variation in spatial as well as temporal distribution. The conductivity value was found high (17.58 ms/cm) into the seawater sample of Dwarka during post-monsoon and low (17.17 ms/cm) at Kodinar during summer season. It was also observed that seawater samples from Mangrol and Kodinar showed high conductivity value during post-monsoon, while in case of Veraval high conductivity value was recorded during monsoon season then it decreased in post-monsoon season throughout the study period (Fig. 5). Fluctuations in the conductivity of water at the study stations were similar with the spatial difference. Elevated values were recorded at Dwarka in post-monsoon season. In case of summer season conductivity values was much higher at Dwarka than other selected sampling sites. The conductivity values of seawater from the sampling sites showed statistically significant spatial and temporal variations (Table 10).

Total solids in seawater samples at all the sampling sites steadily increased from winter to monsoon and during this season maximum values were observed in case of the samples for total solids, while it was minimum during winter season during the study time (Fig. 6). It was slightly lower values observed during monsoon to post-monsoon season. It was found slightly high values in samples of Kodinar station during winter compare to other seasons. On the other hand it was also observed that during summer and monsoon seasons, values were high at Veraval than the other sampling stations. There did not show much variation between the sampling stations. Similar trend was observed in case of the total dissolved solids (Fig. 7). Erratic temporal and spatial variations in total solids and total dissolved solids were observed at the study stretch. Peak values were recorded during monsoon at the station Veraval. The minimum values of total dissolved solids found during winter at Mangrol, while maximum values were recorded at Veraval for the duration of monsoon season. The values of total solids and total dissolved solids ranged from 39.56 to 45.68 g/l and 39.03 to 44.82 g/l respectively.

Turbidity values showed irregular trend of spatial variation during the study period. Turbidity was constantly increased in the samples of the Mangrol from winter to post-monsoon season, while the values was slightly decreased through monsoon to post-monsoon season in case of other sampling stations. Turbidity values were relatively constant ranging from 4.20 NTU to 5.37 NTU. Seawater samples of Veraval showed maximum and minimum value of turbidity during monsoon and winter season. In case of Kodinar minimum values were observed during the monsoon and post-monsoon season compared to other stations (Fig. 8). Turbidity value of seawater samples did not showed any significant variations throughout the study period.

Salinity value of the seawater during the period of the present investigation is given in figure 9. The salinity value showed that all the stations revealed narrow variation in the level of salinity content. It was ranged from 32.26 ‰ to 35.58 ‰. High concentration of salinity in the seawater sample was observed in the summer season comparing with that found in the other seasons at all the stations. It was observed slightly high value during post-monsoon season at sampling station Kodinar and Mangrol than other stations. At the temporal scale maximum salinity values were recorded during almost season at the sample from Dwarka. During the post-monsoon season highest values of salinity were observed at Dwarka (35.29 ‰) and Veraval (35.30 ‰) in contrast to Mangrol and Kodinar respectively.

Dissolved oxygen content from seawater samples varied from 5.62 to 6.38 mg/l, the values were marginally higher in post-monsoon season in the water samples of Veraval and Kodinar, while at Dwarka and Mangrol, it was higher during the winter season throughout the study period. Temporal fluctuations were observed in the dissolved oxygen content at all the sampling sites throughout the study period. The seasonally average value showed a decrease in DO concentration from winter to summer, after which it increased gradually up to post-monsoon. No meaningful clear trend in DO content was observed with respect to the sampling sites (Fig. 10).

The variation of biochemical oxygen demand revealed that the highest concentration (0.95 mg/l) was recorded at Mangrol during monsoon and lowest value (0.48 mg/l) was observed at Kodinar during monsoon. The values of BOD was increased up to winter to monsoon and slightly decreased in post-monsoon, while in case of samples from Kodinar BOD values was decreased from winter to monsoon then it was increased during post-monsoon. But it was also observed at Veraval values were marginally decreased up to post-monsoon season (Fig. 11). The values of chemical oxygen demand did not show much variation seasonally as well as station wise. Slightly elevated values were observed in winter at all the sampling sites, but the values of COD were higher in Kodinar than Veraval throughout the study. The minimum concentration value of chemical oxygen demand was 0.86 mg/l recorded at Dwarka during summer, while maximum value was 1.07 mg/l detected in seawater samples from Kodinar during winter season. The values of COD from the samples of Mangrol did not showed any variations during the seasonal study (Fig. 12).

Some macro nutrients such as sulphate, sulphide, phosphate and ammonia were revealed less variations throughout the spatial pattern. The value of sulphide was high in post-monsoon season at Veraval and lowest values were observed during monsoon at Mangrol (Fig. 13). In case of sulphate, it was recorded high value during monsoon (3.69 g/l) at Veraval and lowest in Mangrol during summer season (2.56 g/l). It was also observed that in water samples of Dwarka sulphide and sulphate values was increased from winter to monsoon then it was slightly decreased throughout the study period (Fig. 14). There was observed reverse trend between Dwarka and Mangrol sampling sites in case of sulphide concentration in seawater samples, the values of sulphide was increased from winter to monsoon, while in case of water samples from Mangrol it was decreased up to monsoon. It was recorded that in seawater samples from Dwarka and Veraval lower concentration of sulphate observed in winter season 2.62 g/l and 2.75 g/l respectively; then it was increased and maximum concentration observed during monsoon season after that it was slightly decreased to post-monsoon. On the other hand Kodinar and Mangrol showed minimum values during summer and maximum during post-monsoon (3.37 g/l) and monsoon (3.22 g/l) respectively. In case of phosphate and ammonia similar trend was observed over the time scale and there did not show more variations throughout the spatial pattern. It was observed decline trend of phosphate and ammonia values from winter to summer there after increased from summer to monsoon then slightly decreased to post-monsoon season (Fig. 15, 16). The highest value of phosphate (0.075 mg/l) was recorded at Dwarka during monsoon season and minimum (0.055 mg/l) were recorded during summer at Kodinar. Similarly trend was observed in case of ammonia, maximum value 0.019 mg/l at Dwarka during monsoon and lowest during summer 0.013 mg/l at Kodinar.

Minerals such as calcium and magnesium showed more or less variations over the selected sampling sites. High values of calcium (0.45 g/l) and magnesium (1.35 g/l) recorded during monsoon at Mangrol, It was increased from winter to monsoon then showed decline trend to post monsoon season. In case of calcium lowest values were observed at Veraval (Fig. 17). Dwarka showed more or less similar values of calcium and magnesium throughout the study period, on the other hand slight variations in values observed in the water samples from Kodinar during study period (Fig. 17, 18). Magnesium did not showed any significant variation during study, while Calcium levels showed statistically significant spatial variations.

In biological parameters chlorophyll was high during winter season then it decline to summer and there after increased in monsoon and again slightly turns down during post-monsoon season. Similar trend observed in case of phaeophytin throughout the study period. There did not observe any fluctuations between sampling sites, but it was obviously recorded seasonal variations throughout the study period (Fig. 19, 20). Biological parameters chlorophyll and phaeophytin did not show statistically significant spatial and temporal variations (Table 10).

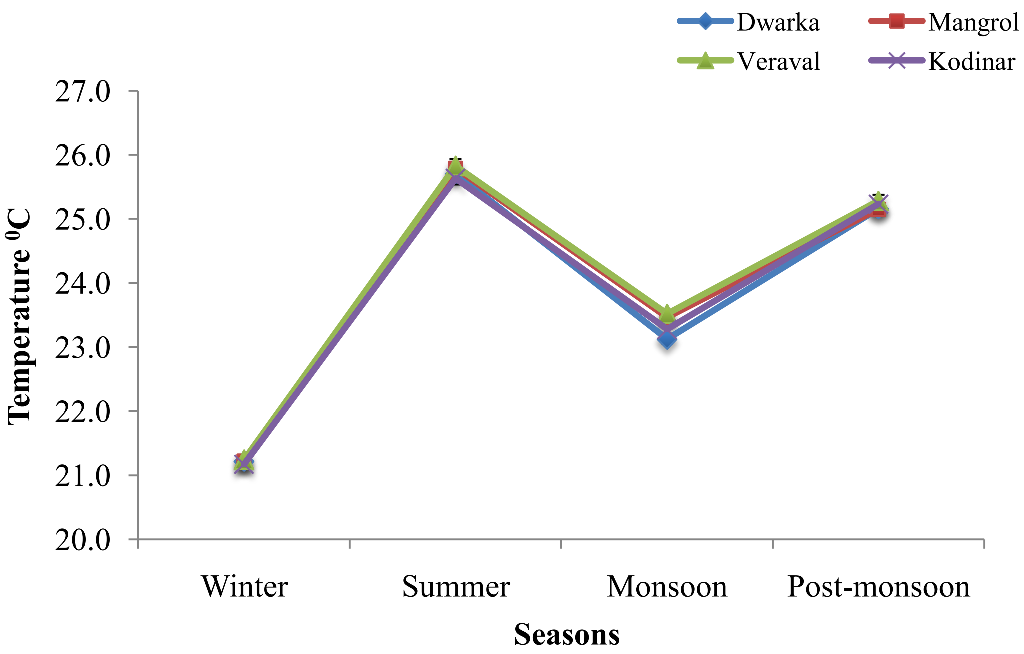

Figure 3. Season wise distribution of Temperature (^{0}C) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

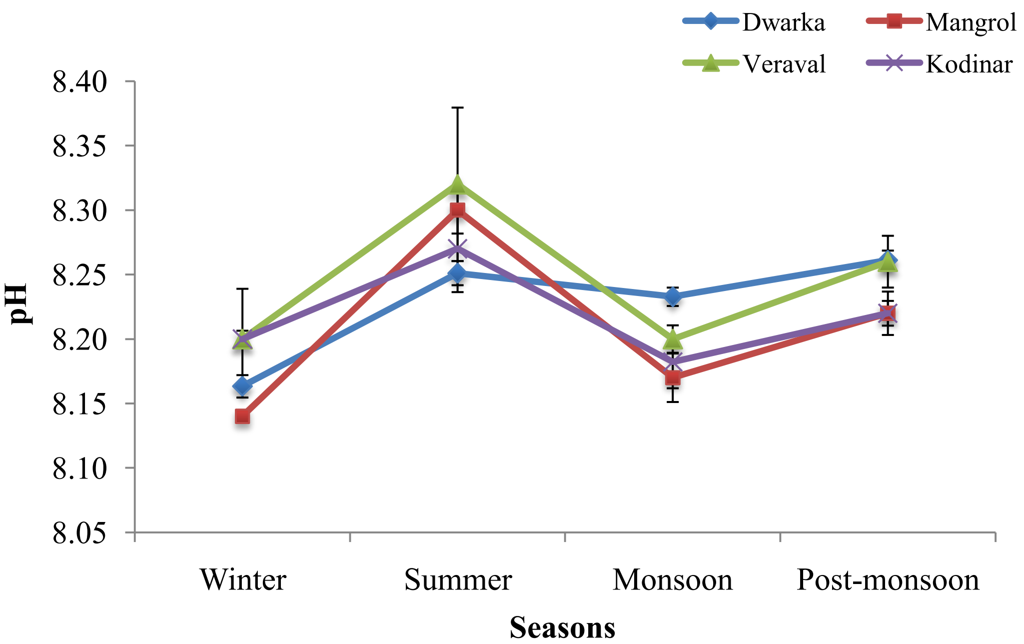

Figure 4. Season wise distribution of pH of the seawater samples of selected sampling sites. Values express are mean and vertical bar in each point represents standard deviation.

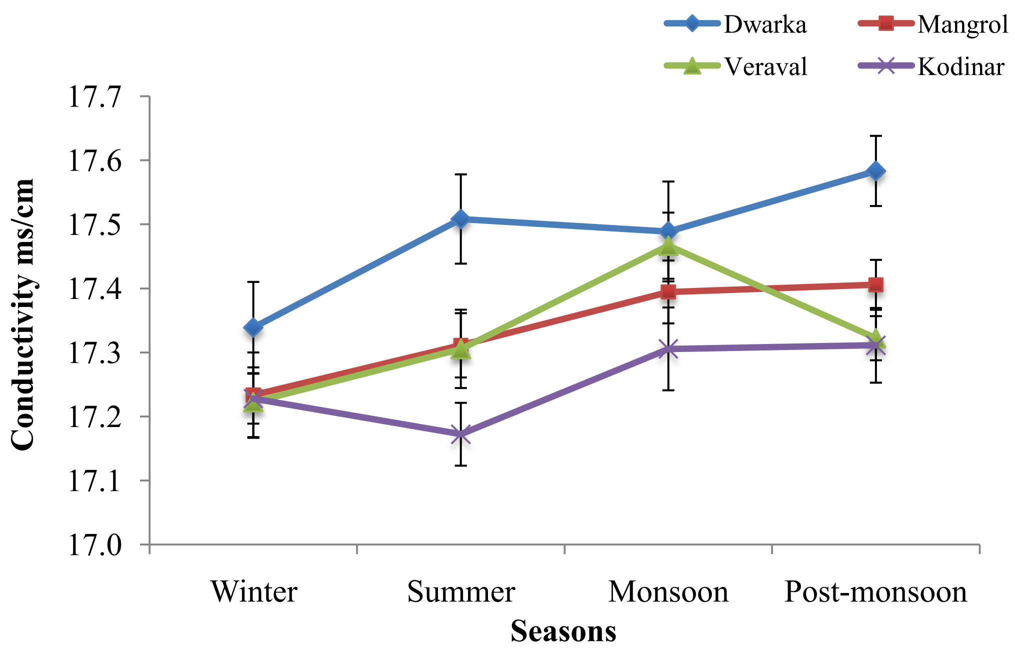

Figure 5. Season wise distribution of Conductivity (ms/cm) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

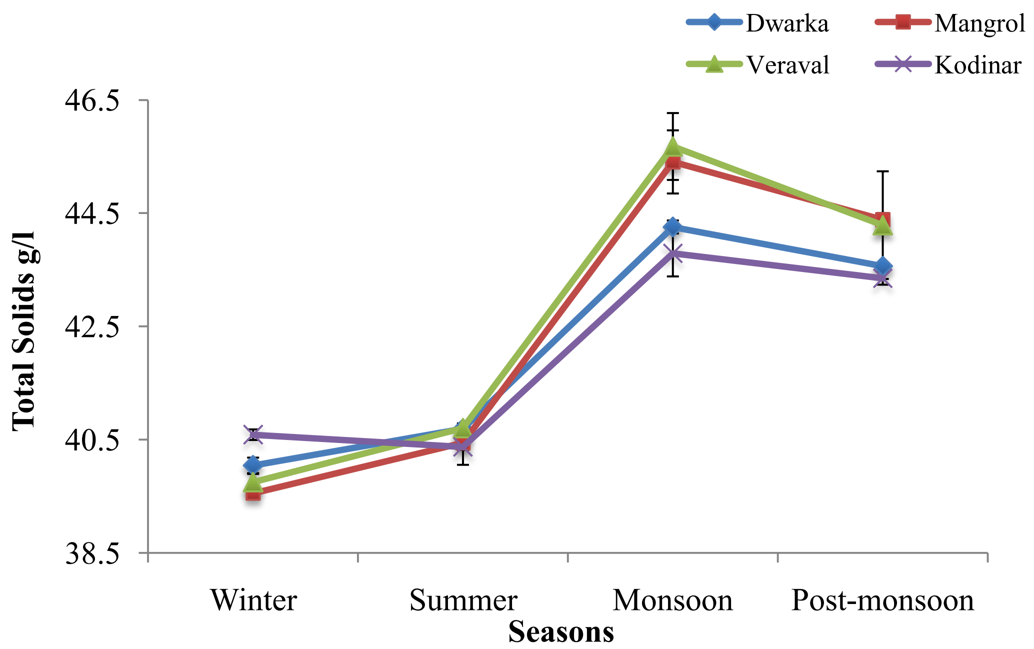

Figure 6. Season wise distribution of Total solids (g/l) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

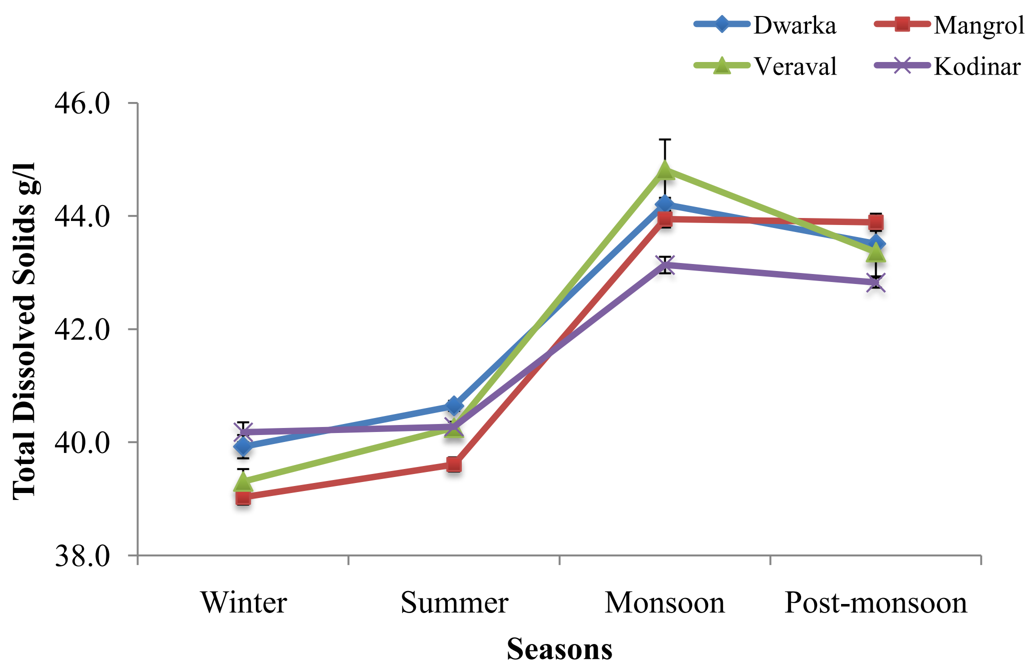

Figure 7. Season wise distribution of Total dissolved solids (g/l) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

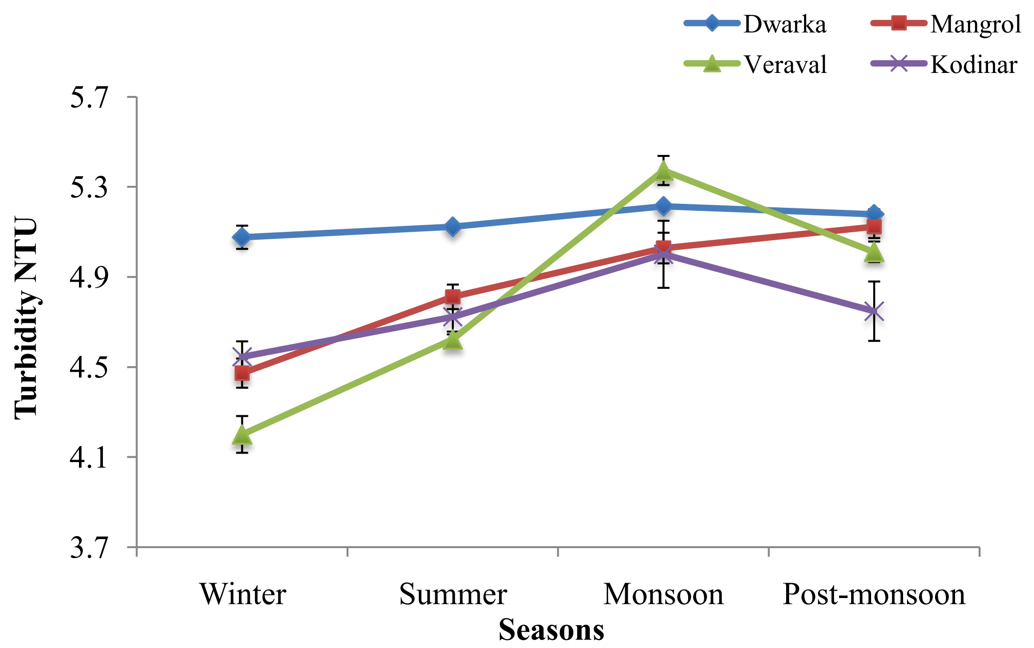

Figure 8. Season wise distribution of Turbidity (NTU) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

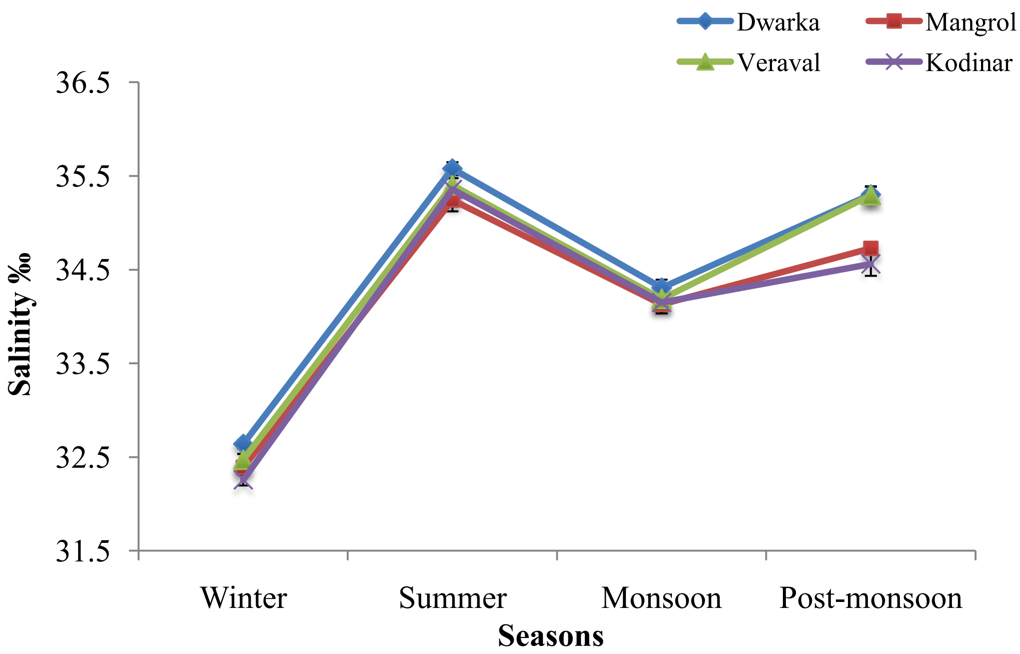

Figure 9. Season wise distribution of Salinity (‰) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

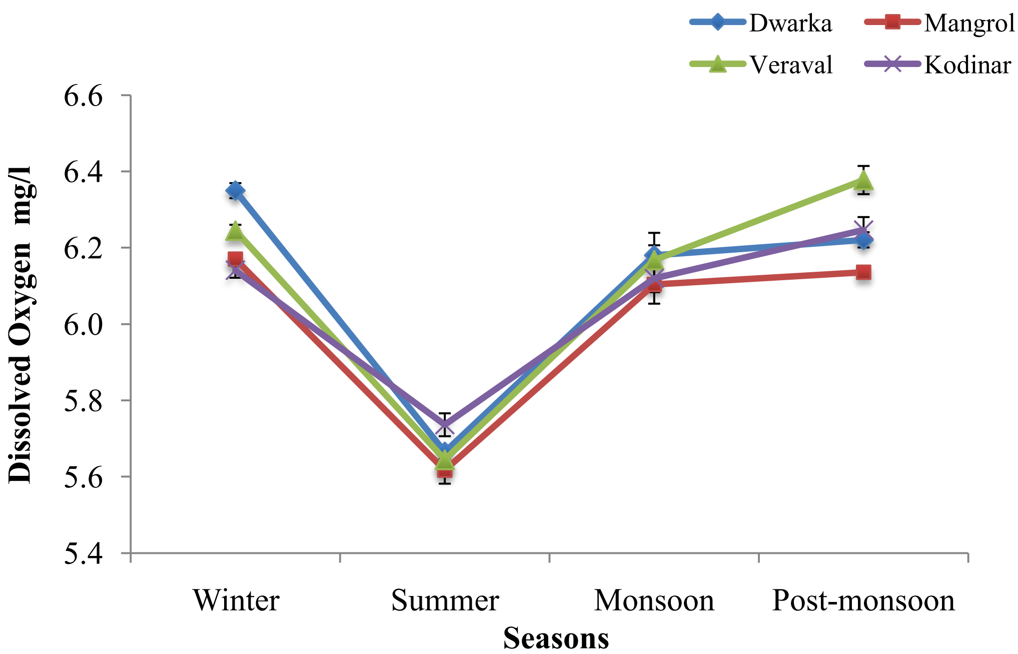

Figure 10. Season wise distribution of Dissolved Oxygen (mg/l) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

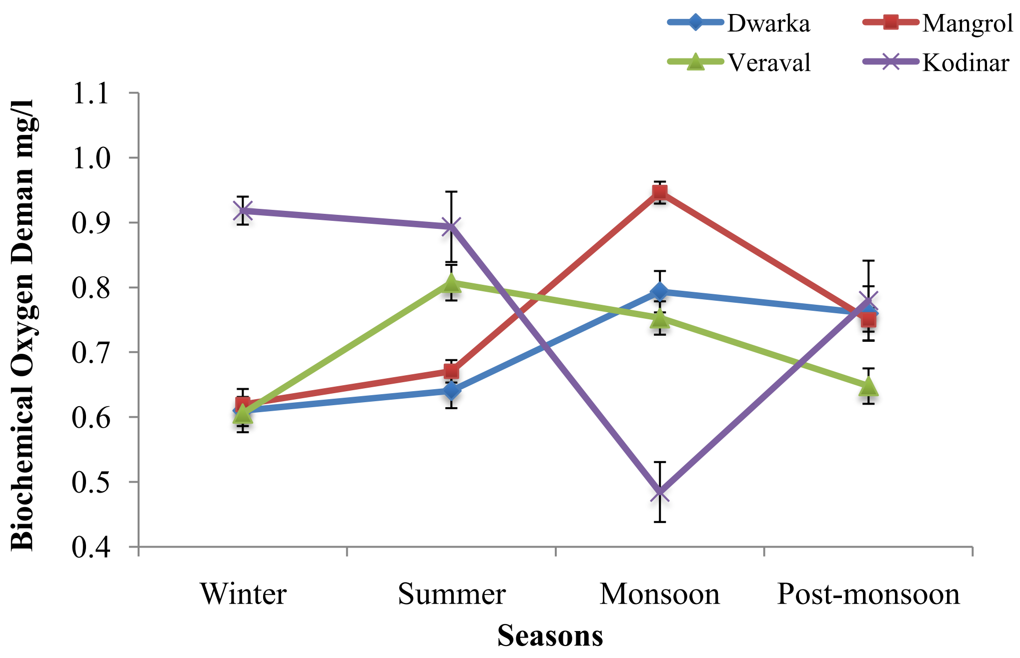

Figure 11. Season wise distribution of Biochemical Oxygen Demand (mg/l) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

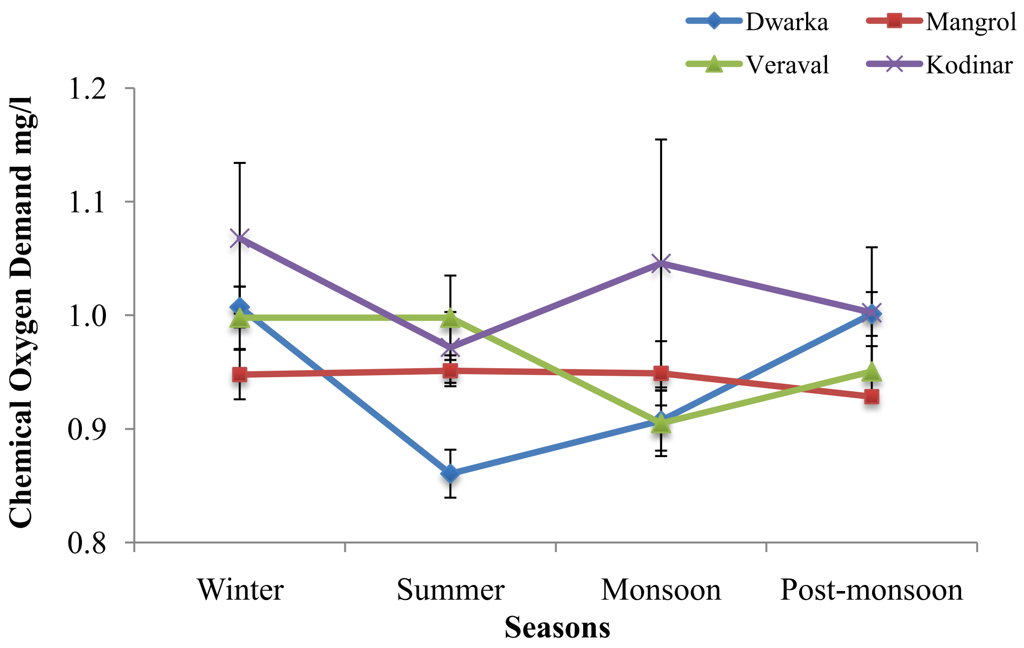

Figure 12. Season wise distribution of Chemical Oxygen Demand (mg/l) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

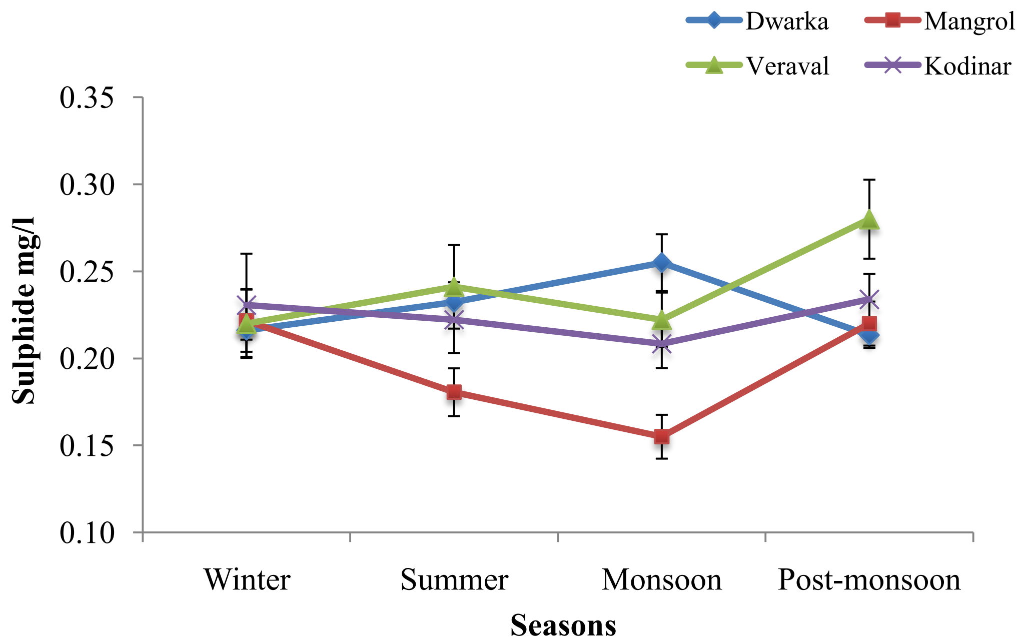

Figure 13. Season wise distribution of Sulphide (mg/l) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

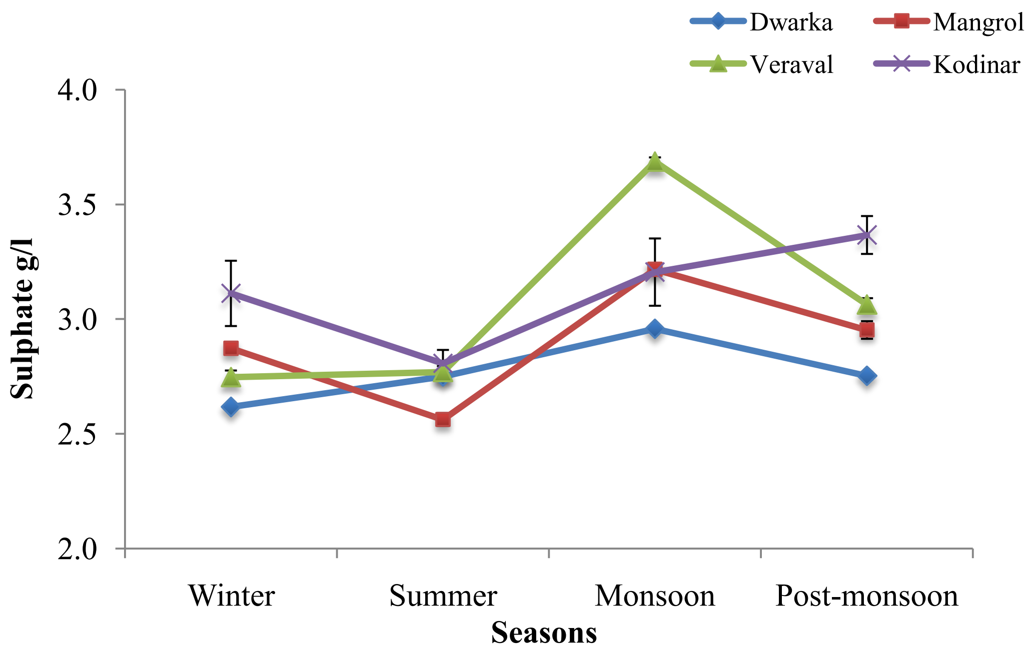

Figure 14. Season wise distribution of Sulphate (g/l) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

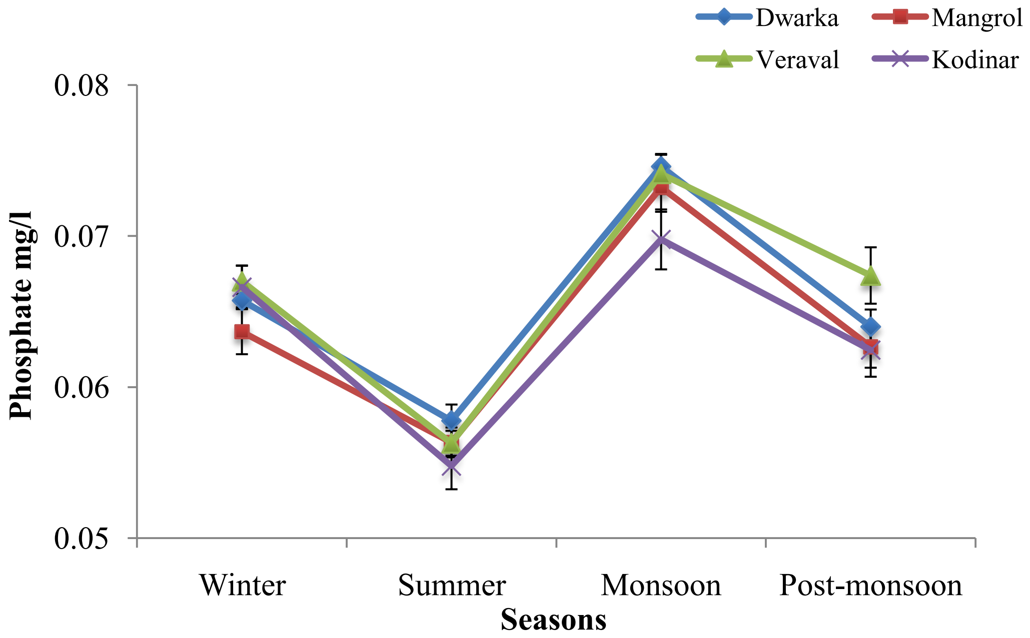

Figure 15. Season wise distribution of Phosphate (mg/l) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

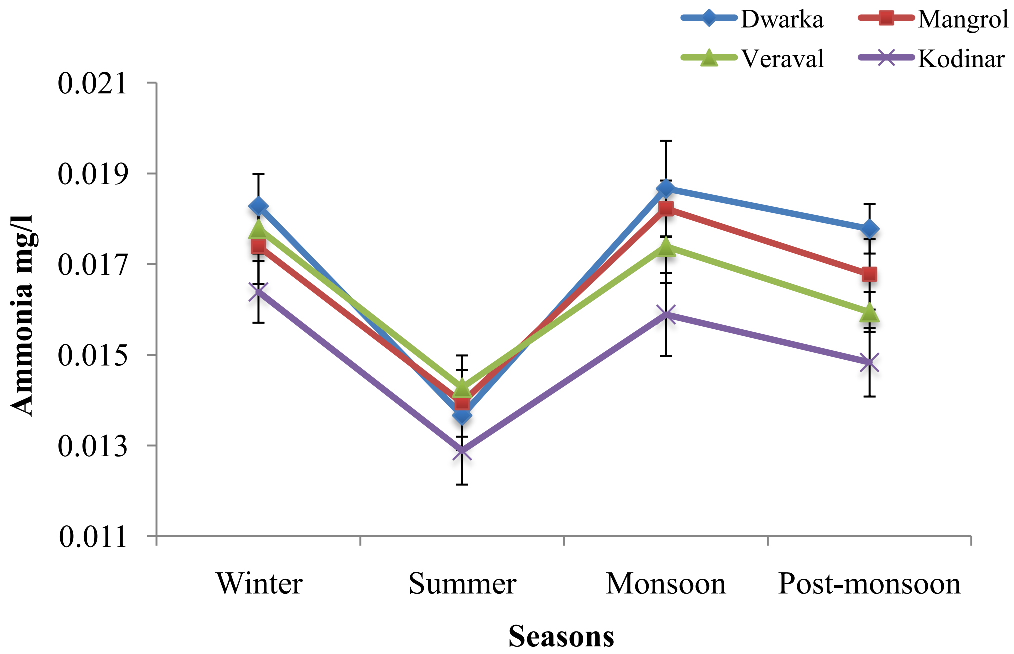

Figure 16. Season wise distribution of Ammonia (mg/l) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

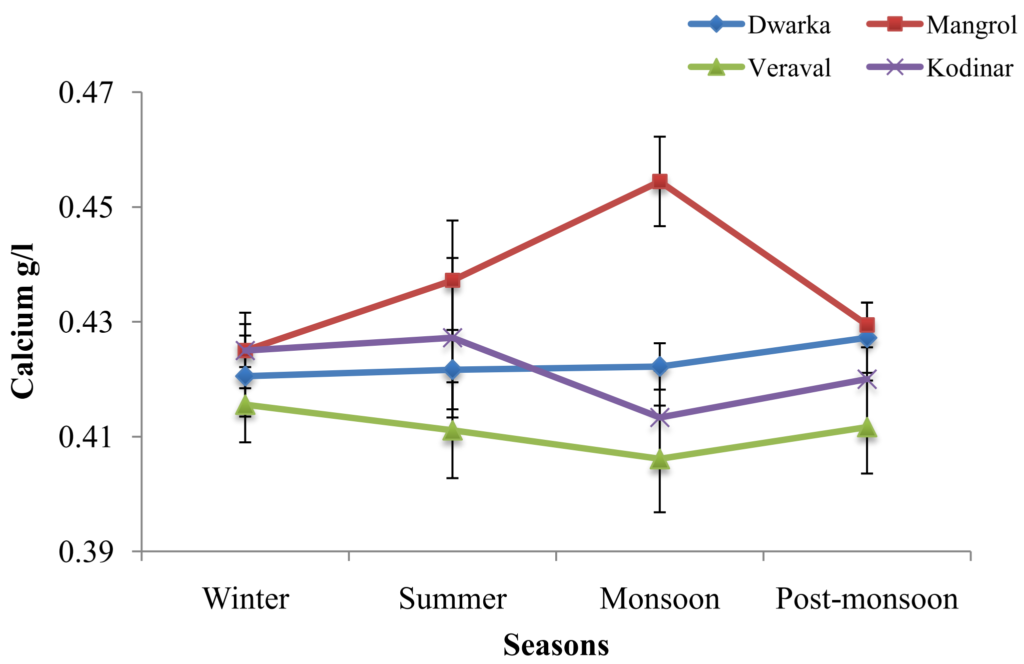

Figure 17. Season wise distribution of Calcium (g/l) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

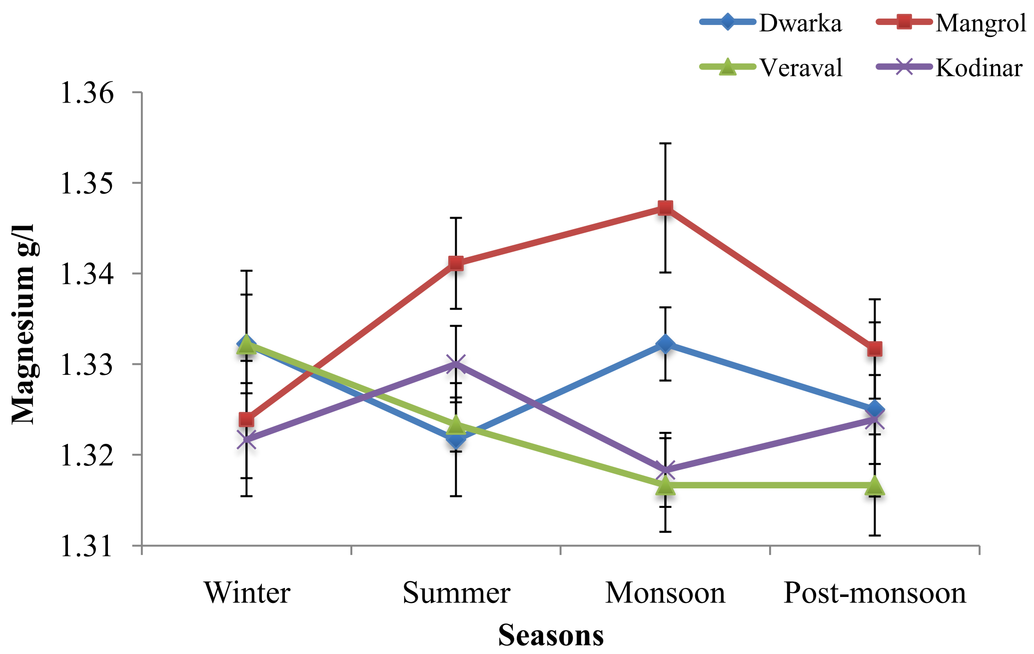

Figure 18. Season wise distribution of Magnesium (g/l) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

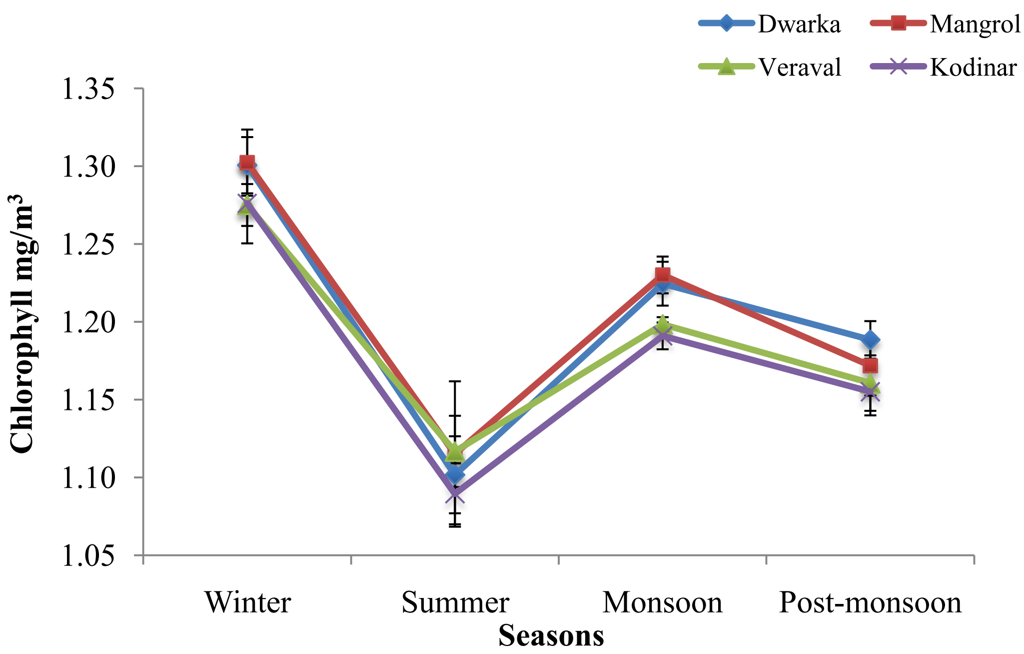

Figure 19. Season wise distribution of Chlorophyll (mg/m^3) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

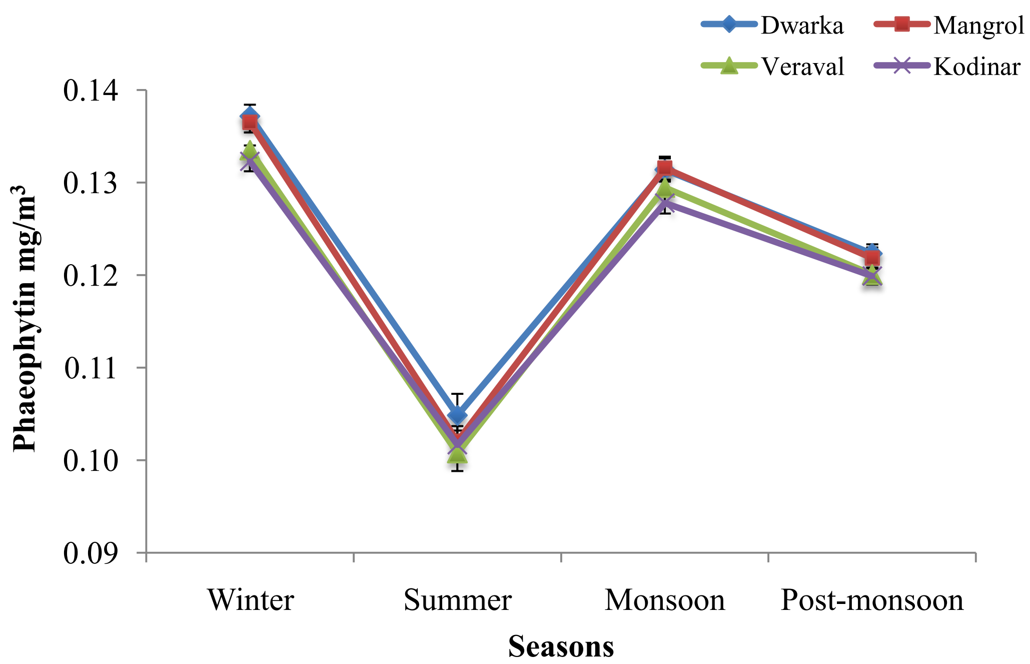

Figure 20. Season wise distribution of Phaeophytin (mg/m^3) of the seawater samples of selected sampling sites. Values expressed are mean and vertical bar in each point represents standard deviation.

Table 10. Results of ANOVA of the mean values of the seawater parameters sites for spatial variations. Tabulated ‗f' value at p = 0.05 level is 3.4903. ('*' sign denotes significant)

Parameters	Calculated F value
Temperature	0.0056
pH	0.3491
Conductivity	4.4865*
TS	0.0483
TDS	0.0419
Turbidity	1.3263
Salinity	0.0737
DO	0.1149
BOD	0.2319
COD	2.3757
Sulphide	2.7098
Sulphate	1.2177
Phosphate	0.1409
Ammonia	0.9322
Calcium	7.5849*
Magnesium	2.9078
Chlorophyll	0.1143
Phaeophytin	0.0539

4.9. Anthropogenic Impact Study

The present study was deal with identify the type and degree of various anthropogenic activities on the Saurashtra coastline, Arabian Sea. The results suggested that different types of anthropogenic activities exist and that was observed along the Saurashtra coastal area. Generally, it was identified that various kinds of medium to large scale industries situated near the coastline, sewage and waste disposal, fisheries and port activities as well as tourism are major influences on the coastal belt of selected region. There were also recognized that during the study the human population of these area settled very near to the coastline. Due to these activities, the coastal area especially the intertidal zone were affect direct or indirect way in terms of environmental contaminations.

Saurashtra region tops in the marine fish production in India. In Saurashtra, 42 fish processing industries are located in Veraval GIDC while about 5 fish processing industries in Mangrol and 4 fish processing industries in Dwarka. There are also small scales fishing available at almost all the sampling locations at Saurashtra peninsula. The harbour related activities at Veraval (Plate-20) and Mangrol (Plate-19) contribute deterioration of coastal water quality and its environment. In addition to this, load of pollution generated from the operation of boats and vessels, the domestic wastewater generated from the Veraval town is being discharged into the fishing harbour area without treatment (Plate-20). All these sources of pollution from different spheres are contributing the load of pollution in fishing harbour area and subsequently contaminating the nearby coastal waters.

Along with that various industries located on the Saurashtra coastline like the Century rayon in Veraval, GHL in Sutrapara, TATA chemicals in Okha. While, Kodinar has the major industrial sectors like large cement and sugar factory contributing to industrial waste sludge (Plate-21), which is toxic and hazardous in nature. On the other hand, Saurashtra coastal zone has extensive deposits of miliolite rocks, which are raw materials for soda ash and cement production. Mangrol has severe degree of current environmental pressure face from mining activities.

Among all the selected sites, Dwarka and Somnath are major Hindu pilgrim centers. Due to that these places are also large tourist places on the coastal area and another local tourist place Muldwarka, situated on the Kodinar coastline. Recreational activities like shell collection and walking on the intertidal area by tourists caused significant effect on coastal area. Tourist dumped plastic waste directly in the coastal area (Plate-18). In tourist center, promotion for tourism is given more and more emphasis, which has resulted in many large hotels and resorts along the beaches. These hotels and resorts dump their solid waste and sewage in to the sea. The other most serious land-based pollutants entering the sea through rivers and direct runoff are domestic sewage and dumpling plastic waste and garbage directly in to coastal area.

Chapter 5 DISCUSSION

5.1 General Discussion

The present study was undertaken to set up an innovative trend of monitoring of the human-nature interaction and its effect on the natural system to set up the openings of the future study on this tract at this area. In this context, a detailed study on the Saurashtra coast line, one of the biggest one in India desired a detailed monitoring to work out the present status of the ecosystem, the threats mounting and impending, natural resistance and adaptation in response to the pressure and a possible negotiation to the neutralize the harsh condition to offer a better tomorrow. The present study deals with the biodiversity and man-made pressure on the coastal health as well wealth of the rocky intertidal macrofauna in four different stations along the Saurashtra coastline. With a view to assess the status of the intertidal macrofauna, the physico-chemical characteristic of the coast and the interaction between the fauna and anthropogenic activities were investigated. The Western coastal belt of India, these days is considerably being exploited heavily by various kinds of Industries. This study revealed how this is affecting the ecosystem of this area.

5.2. Macrofaunal Diversity

The macro-invertebrates showed fluctuations among different sampling sites of Saurashtra coast. There has been a renaissance of taxonomy and related subjects such as abundance and distribution of species as biodiversity in the last two decades. This has resulted from growing awareness that ecological, economic and livelihood securities of mankind are inseparably linked with the maintenance of the diversity of the biological components in land, water and atmospheric environments.

For the variety of reasons, macrofauna are extremely important in the functioning of coastal system, from a logistic standpoint that they make a good study specimen, because they are abundant, readily surveyed and taxonomically rich. Macrofaunal groups like coelenterata (Patel, 1978, 1988; Pillai and Patel, 1988; Deshmukhe, et al., 2000) and mollusca (Misra and Kundu, 2005; Vaghela et al., 2010) were studied along the Saurashtra coast.

In the present study, amongst four sites, Dwarka showed more macrofaunal diversity on the intertidal belt than the other sites. Mollusca were the most dominant group and platyhelminthes was the least observed group. A clear dominance was observed between the sampling site of Veraval and Kodinar based on the macrofaunal diversity. In the present investigation, a total of 120 species were recorded from the four sampling sites in Saurashtra peninsula.

It was observed during the present study that in the case of macrofauna, the sponge population was less because sponge is very delicate and damaged by fishermen and other people. They were seen mainly in middle and lower littoral zone, somewhat present in upper littoral but not in dried area. Among the various intertidal faunal groups, porifera has an evolutionary history of about 570 million years and so far, 486 species have been described in India (Thomas, 1998). The Gulf of Kachchh has the highest diversity about 25 species of sponges (Venkataraman and Wafar, 2005).

It has been found in group coelenterata that the variation in species was high in lower littoral zone and minimum was in upper littoral zone. This may be due to the fact that lower littoral zone was least exposed zone and upper littoral zone was the maximum exposed one, providing the habitat for only some selected species of this sessile group. Among the corals from the intertidal region three species (*Goniastraea pectinata, Hydnophora exesa* and *Montipora folisa*) were recorded from all the sampling sites. However, all these coral species have a patchy distribution along the rocky intertidal coast (Raghunathan, et al., 2004). The occurrence of the corals in the intertidal zone is restricted between middle littoral and lower littoral zones. Species like *Portis lutea* and *Favia favulus* were recorded mostly in rock pools. The *Zoanthus* population is quite good here. In the pools of rocky beach, sea anemones were found. However, the lower zone consists of big boulders usually covered with *Zoanthus*.

Platyhelminthes group comprised three species, which was present in tide pools with the existence of water during low tide and associated with algae. In case of annelida, *Nereis pelagica* and *Heteronereis sp.* was present in sandy portion and under the rock in pools and due to its nature of burrowing, rarely came out in the open. *Chetopterus chetopterus, Serpula vermicularis* and *Sabella pavonica* were mostly found in lower littoral zone and attached with rocks. The arthropoda group is prefers to be in association with intertidal algae at upper and middle littoral zone, especially in the pools and puddles. Arthropoda feeds on the Algae as well as zooplankton, thus, vigorous tidal activity of the lower littoral zone might not be a suitable place for them.

Group Mollusca showed more or less similar trend in upper and middle littoral zones. This trend may be due to the fact that the mollusca mainly feed on the marine algae and thus, always associated with intertidal seaweeds. The intertidal areas with rocky and partly sand substrate provide the habitat preferred by the molluscs under study. Mollusca have been recorded 3379 species along the Indian coast from the marine habitat (Subba Rao, et al., 1991, 2004; Subba Rao and Mantri, 2006). Among that eight species of oysters, two species of mussels, 17 species of clams, six species of pearl oysters, four species of giant clams and other gastropods such as *Trochus, Turbo* as well as 15 species of cephalopods are exploited from the Indian marine region (Venkataraman and Wafar, 2005).

Particularly echinoderms were commonly observed hidden in crevices, small caves and between algal cover. Similarly, the gastropod was abundant and frequently counted between seaweeds and the important role of seaweeds as refuge and substrate for many invertebrates. In the case of echinodermata species number was less because *Asterina gibbosa* and *Ophioderma brevispinum* inhabiting deep water. But also present in intertidal zone. On the whole, it appears that in general, this area rich in macrofauna and algae. *Ophioderma brevispinum* was communally occurred and the distributed species in this group at almost all the sampling sites.

The results of present investigation suggested that higher dominance of intertidal invertebrate species in the middle and lower littoral zone, as compared to the upper littoral, due to organisms of intertidal zone preferred a healthier environment. Misra and Kundu, (2005) reported, the marine animals along the intertidal have to protect themselves against high salinity, desiccation and against the predators. This they achieve through taking shelter under the thick cover of the seaweeds which grow better on the middle and lower littoral zone. Seaweeds on the upper littoral zone get desiccated out during the period of emergence, and therefore the animals cannot get shelter much at upper littoral zone. Therefore, with the advent of the disappearances of seaweed along the upper and middle littoral, the animal migrates towards the lower littoral as a safer habitat (Misra, 2004; Ramoliya, et al., 2007; Vaghela, et al., 2010). The lower littoral zone of the entire Saurashtra coastline is quite different in nature from other coasts. The rough edge of the lower littoral zone creates very strong wave force, thus, generating strong tearing force. That's hampers the settlement of the algae and feeble footed molluscs. However, the zone seemed to be the best suited one for intertidal organisms.

The intertidal harbours many microhabitats like tide pools, small puddles, crevices, and small channels. Thus, the spore lings of seaweeds germinate, settle and grow at a particular microhabitat. However, all the earlier finding and the present study confirms one important point and that is, maximum seaweed growth occurs during the winter months of December and January when the seawater temperature shows a minimum couple with maximum dissolved oxygen content (Patel, 2002; Vaghela, et al., 2010).

It is clear that there was greater degree of similarity between the middle and lower littoral levels of the intertidal than upper and middle littoral levels with respect to their biota. During the period of emergence i.e., at low tides, the first part to get emerged is the upper littoral zone and the last emerged is the lower littoral zone. This results in a maximum exposure time of the upper littoral and minimum exposure time of the lower littoral. Different organisms adapted to these environments take shelter at a suitable tidal level. So far as the seaweeds are concerned, these inhabiting the upper littoral get dried out and die first. On the contrary, organisms inhabiting the lower littoral level are the least exposed to the ambient environment and they get here more stable habitat as compared to the upper and middle littoral levels.

Intertidal macrofaunal community is characterized by temporal and spatial changes in the population and the vertical zonation is the most obvious distribution pattern of hard substrate communities (Witman and Dayton, 2001). The macrofaunal invertebrate were found to have a linkage with vegetation through food web (Bell, 1979). The flora and fauna present on intertidal rock platforms currently show relatively little variation between locations, with seasonal fluctuations. Most sites were dominated by the molluscan group than the other groups.

Seasonal variations were moderately erratic at selected locations, maximum macrofaunal occurrence during winter and post-monsoon. In these four sites, among all the invertebrate macrofaunal groups, mollusca constituted highest number of species and seasonal occurrence. While most of the groups exhibited obviously discontinuous seasonal occurrence. Certain macrofauna groups like platyhelminthes and echinodermata were appeared only once or twice during the study.

The association of animals on the bases that the algae provided them protection from extreme high and low temperature and their dislodgement by wave action. Further reason for their algal association may be that they also feed on spores, filaments or detritus matter of these algae as evident by their food content (Misra, 2004). From the results of the association of different species of fauna with the flora on the upper littoral zone, it is apparent that *Cellana radiata* seldom associated with *Ulva lactuca, Chiton* with *Ulva lactuca* and *Chaetomorpha antennina.* On the other hand, it appears that the *Trochus hanleyanus* did not show any specific affinity to any seaweed species. Thus, it is discernible that this species does not have any specific choice with particular algae and may be using the assemblage as source of food (Dudhatra, 2004). At the middle littoral zone, *Conus miliris* showed affinity with *Ulva lactuca. Nereis* and *Eurythoa complanata* have affinity to association with algae. In this zone *Trochus radiatus* and *Turbo sp.* also present and associated with algae too for feeding and breeding reasons. At the lower littoral zone *Chiton peregrinus* associated with *Sargassum swartzii* and *Ulva lactuca, Cyprea sp.*with *Sargassum swartzii*, *Ulva lactuca* and *Gracilaria corticata.* While *Aplysia benedicti associated* with *Sargassum sp.*and *Ulva lactuca.* In general, it appears that, all the animal species were well associated with particularly two seaweed species *Ulva lactuca* and *Sargassum sp.* While, the gastropods *Trochus radiatus* and *Monodonta australis* associated with almost all species of algae.

In general, higher number of species composition and distribution of intertidal macrofauna and algae recorded at all the stations. This could be due to the favorable physico-chemical parameter and hard substratum with many pools and puddles (Rajkumar, et al., 2009).

5.3. Distribution and Community Structure

Coastal rocky intertidal communities were sampled along the Saurashtra coastline, Arabian Sea. Including the present study, a total of 60 species of intertidal macro-invertebrate designated for descriptive community structure on the rocky intertidal belt. Among that mollusca group comprised 35 species followed by coelenterata, arthropoda, annelida, porifera and echinodermata. Understanding of ecological processes in the rocky intertidal assemblages depends on the better perception of spatial and temporal variations (Underwood and Chapman, 1998; Misra and Kundu, 2005).

Overall in the macro-invertebrate of Saurashtra coastal belt was found dominant. Besides the rich algal abundant also provides the right substratum for the colonization of these macrofaunal groups. Above all, the basically vegetation and rocky substratum, nature coupled with adaptability to extreme environmental conditions might have helped the species to become dominant in the coastal belt. These groups can be effectively used for monitoring pollution in the coastline. In feeding trials, intertidal macrofauna consistently prefers smaller ephemeral seaweeds, such as *Enteromorpha* and *Ulva* (Lubchenco, 1978).

As diversity indices are increasingly used to assess the well-being health of the habitats (Ajamal Khan et al. 2004). Shannon-Weiner diversity index (H‘) was applied on the general pattern of seasonal variation of macrofaunal diversity. In a healthy environment, the Shannon diversity is higher and in the range of 2.5-3.5 (Ajamal Khan et al. 2004). However in the present study, in all the sampling sites the species diversity varied from 0.015 to 2.089 throughout the study period (Table 4). The results of Shannon diversity showed comparatively lesser value during the study period possibly due to fact that the species diversity is mainly controlled by the fluctuations in the environment that lead to less diversity (Sanders, 1968).

Species richness was high in almost all the selected locations at Saurashtra coastal area. However, the species evenness was found to be low during the study. However, low levels of species evenness possibly due to the flatness of the intertidal areas, which is exposed during low tide as supported by the Shannon-Weiner diversity index (Misra and Kundu, 2005). The results revealed the pattern of species diversity; lower diversity during summer and higher diversity values in winter recorded in the study area is in conformity with the earlier observation (Chandran 1987; Devi 1994). Maximum evenness and richness recorded during the winter season at almost all the study sites; it might be due to stable environmental factors, which play an important role in faunal distribution (Ansari, et al., 1986; Kumar, 2001; Raghunathan, et al., 2004; Vaghela, et al., 2010).

Amongst the animal groups studied, group mollusca showed the maximum species richness and evenness followed by annelids, sponges and arthropods in almost all sampling sites. It is apparent that being predominantly rocky shores the coasts studied harbours different species of this dominant groups and moderate to high level of species richness indicating the suitability of these coasts forming typical intertidal assemblage of that particular shoreline (Underwood, 2000, Vaghela, et al., 2010).

The lower diversity of phylum porifera found during summer and maximum during monsoon seasons at Mangrol and Kodinar respectively. Bakus and Ormsby, 1994 suggested that sponge species richness is typically high in the tropics regions and lower in temperate regions for various seasons. The maximum species diversity of porifera recorded at Mangrol. Other macrofaunal groups like coelenterata have been extensively studied at the Saurashtra coastline by several authors (Raghunathan, et al., 2004; Bhagirathan, et al., 2008). Corals are probably the best studied marine group with respect to pattern in biodiversity (Sheppard, 1998). It was observed that high density of the coelenterata group was due to the presence of genus *Zoanthus* on the rocks, forming large patches in the upper and middle littoral zones. Increasing siltation seemed to be the most probable limiting factor for the proliferation of this group in the intertidal zones (Bjork, et al., 1995). High species richness was observed during winter season in case of group echinodermata; however, its evenness was the lowest amongst all groups studied.

Group arthropoda showed maximum diversity during post-monsoon seasons. In the west coast, post-monsoon season was registered by high macrofaunal density in the study made by Ansari et al., (1986), Kumar and Antony, (1994), GUIDE, (2000) and Kumar, (2001). Availability of the dead gastropod shells determined the occurrence of this group as most of the arthropods found were different species hermit crabs and *Balanus Amphitrite* (Naik, et al., 1991). Gastropod molluscs are collected for food by coastal people of the Saurashtra peninsula (Misra and Kundu, 2005; Vaghela et al., 2010). Highest diversity of mollusca groups due to the gastropod species occur in the intertidal zone when the wave action is moderate to strong, which increases the recruitment and settlement of these animals; It was also reported earlier by Prasad and Mansuri, 1982, Misra and Kundu, 2005 and Vaghela, et al., 2010.

The results of ANOVA showed significant variations between the four stations. In the present study significant spatial variations in annelids, arthropods and molluscan diversity and evenness were supported by ANOVA test. Species richness of phylum arthropoda showed significant variation throughout the study period (Table 7). Among the entire sampling site along the Saurashtra peninsula are distinct characteristics in terms of rocky shores.

Population density and abundance values of macrofaunal groups at four different sites were significantly influenced by space and time. The mean density and abundance of each group in the present study was high during most of the time at Dwarka than the other sampling sites because of the selected sites are often greatly complicated by cracks and crevices, rocks pools and variations in slop and rock type. Cracks and crevices provide protection from waves and from desiccation and will increase species richness of a shores and abundance of some species.

The population density and abundance of intertidal macrofauna was more during winter and low during summer season. It has been observed that winter and post-monsoon seasons were most favorable for most of the animal groups while summer season was the least favorable condition for these free moving animals that probably migrate towards deeper areas of the intertidal to avoid exposure (Vaghela, et al., 2010). The density and abundance values were slightly decreased during monsoon to post-monsoon season then it was increased up to winter season in case of porifera group. It has been also observed that during summer season macrofaunal population was high at Dwarka followed by Mangrol and Veraval. At the sampling site Kodinar population density and abundance have been least values of macrofaunal group. Overall the least value of the population density and abundance found during summer and maximum during winter season. In the present study significant spatial variations in coelenterata, arthropoda and mollusca were supported by ANOVA test which may be due to the variations in general abiotic parameters and difference population of these species between the sampling sites. Other animal groups did not show significant spatial variation either in population density or abundance (Table 9).

5.4. Seawater Quality

Seawater quality monitoring study was done in four different sampling sites, which is anthropogenically influence shore along the Saurashtra coastline, Arabian Sea. The information about the coastal water and its nutrients and circulation dynamics along the coast has paramount importance in understanding the numerous coastal processes. In the coastal zone, the physical, chemical and biological processes area linked in an intimate manner (Tang, et al., 2002).

All the stations showed a similar trend in terms of seasonal changes. Generally, surface water temperature is influenced by the intensity of solar radiation, evaporation, freshwater influx and cooling. In the present study, summer peaks and monsoonal troughs in air and water temperature has been found to be similar to that reported for west coast of India (Arthur, 2000). Temperature is one of the most important factors in the coastal ecosystems, which influences the physico-chemical characters of coastal water (Sundaramanickam, et al., 2008). Since, the sampling sites were on the open sea coastline off Arabian Sea, were situated more than tens of kilometers away of each other but shared the common open coastline, spatial variations were not evident (Table. 9). The shores are open and continuous without any barrier and thus, normal tidal activities occurred all along this coastline. The seasonal variations in the seawater temperature showed similar pattern in all the sampling sites (Fig. 3). Seasonal fluctuations in the water temperature were typical of this area which was also supported from previous work on this area by Misra and Kundu, 2005.

The pH of water is important because many biological activities can occur only within narrow range (Shepherd and Bromage, 1992). Like temperature the pH values also did not show much spatial variations (Table. 10). However, slight fluctuations were observed which may be due to local environmental conditions. Veraval was recorded high pH values (Fig. 4), which may be due to high anthropogenic activities in this location. Veraval is a highly industrialized shore where human interference to the coastline is high throughout the year. Many other places on the coastal area of Saurashtra like, Dwarka is a seasonal tourist center where the human activity reaches to its maximum during winter months (Vaghela, et al., 2010). The pH was low during the peak monsoon season probably due to the influence of freshwater influx, dilution of saline water, reduction of salinity and temperature, and decomposition of organic matter (Zingde, et al., 1985).

The conductivity values of seawater from the sampling sites showed statistically significant spatial and temporal variations (Table. 10). This may be due to the varying degrees of suspended solids present in different locations. It was evident that at Dwarka, Mangrol and Veraval, conductivity was high compare to that of other station (Fig. 5). The tidal activity was found to be very high at the sampling site Dwarka and Mangrol due to their uneven rocky substratum and steep slope of subtidal shelf. The shores of these areas are calcareous, uneven, and full of small pools and puddles with occasional sandy and muddy patches. The rough tidal activity possibly increased the solid levels which probably been responsible for the variations in the conductivity values (Vaghela, et al., 2010). Conductivity value of each station was much higher in monsoon season due to facing strong wave action of Arabian Sea and effects of monsoon wind. Boyd (1981) suggested that the fluctuation in electric conductivity was due to fluctuation in total dissolved solids and salinity. Significant variation found in case of conductivity between sampling stations with positive correlation coefficient values among conductivity and total solids at Dwarka (0.658), Mangrol (0.942), Veraval (0.882) and Kodinar (0.947). The relation between total solid and electric conductivity is a function of the type and nature of the dissolved cations and anions in the water (Clair, et al., 1994). Other physical parameters like total solids, total dissolved solids and turbidity in the seawater however, did not show any statistically significant spatial and temporal variations between the coasts (Table. 10) but, high values were observed in Dwarka and Veraval (Fig. 8). The statistical analysis also revealed strong positive correlation between TS, TDS and turbidity. Maximum turbidity observed in monsoon and post-monsoon seasons possibly due to rainwater runoff during south-west monsoon season prevailing in this area (Misra and Kundu, 2005).

In the chemical parameters, salinity levels did not show any statistically significant spatial and temporal variations in any of the sampling sites (Table. 10). This may be due the fact the sampling sites are actually open shore where much fluctuations do not occur. The salinity of Mangrol and Kodinar (Fig. 9) was found to be lower possibly due to dilution of incoming seawater with freshwater rivulets near the sampling area. Similar trend was observed in case of DO, BOD and COD (Fig. 10, 11, 12). The observed DO was above 5 mg/l which is also reported earlier in the Arabian Sea (Raghunathan, et al., 2004) and in Gulf of Kachchh (Desa, et al., 2005). The DO was lower during summer when the temperature was high and maximum during post-monsoon and winter when the temperature was low and high tidal activity due to windy monsoon conditions (Faragallah, et al., 2009). With the DO level beyond 5 mg/l level the BOD and COD would be minimum (Paul and Mukhaerjee, 2006), which was reflected in the study. However, COD can indicate the level of water pollution by reductive pollutants is the main determinant used to assess organic pollution in aqueous systems and is one of the most important parameters in water monitoring (Himebaugh and Smith, 1979). The inverse relationship between temperature and DO (Sheathe and Kazama, 2007) and between salinity and DO (Pillai, et al., 1979) are a natural process.

The macro nutrients like sulphide and sulphate levels (Fig. 13, 14) showed slight variations from place to place depending on their locations, coast characteristics and population levels. Calcium levels showed statistically significant spatial variations (Table. 10) may be due to the characteristics of substratum and the level of intertidal population. However, levels of macro nutrients were found to be high in Veraval and Kodinar (Fig. 13, 14) where human interference to the coast is relatively high. Ascending degree of pollution from domestic sewage, industrial effluent and port and fishing activities might have enhanced levels of macro nutrients of these areas (Faragallah, et al., 2009) than the relatively undisturbed coasts of Mangrol and Dwarka.

Biological parameters chlorophyll and phaeophytin did not show statistically significant spatial and temporal variations (Table. 10). Higher values were observed in relatively less human interfered sampling sites like Mangrol and Dwarka, and low values were obtained from highly industrialized sampling sites Veraval and Kodinar (Fig. 19, 20). Higher chlorophyll concentration in the northern Arabian Sea is attributed with the winter cooling phenomena (Dey and Singh, 2003).

The results of correlation coefficient test showed relationship between the parameters studied. In case of Dwarka coast significant positive correlation was observed between temperature and pH (0.932), conductivity and salinity (0.916), whereas, significant negative correlation was observed between temperature and chlorophyll (-0.944) and phaeophytin (-0.896). The positive correlation of pH was with conductivity (0.978) and salinity (0.971). Salinity had a positive correlation with only conductivity (0.916) whereas; TS and TDS had strong positive correlation with turbidity (0.975 and 0.978) and sulphate (0.823 and 0.826) content (Table 11). Salinity had a significant negative correlation with chlorophyll (-0.931) and phaeophytin (-0.852) and chlorophyll showed very strong positive correlation with phaeophytin (0.975). As expected, the dissolved oxygen levels had very significant positive correlation with both chlorophyll (0.916) and phaeophytin (0.941). The results clearly indicate a healthy seawater condition at Dwarka. In case of Mangrol which is another relatively unaffected area showed similar correlation coefficient values like Dwarka. Mangrol is a small hamlet with rocky-sandy coastline showed healthy water quality parameters. This coastline is free from any higher degree of anthropogenic pressure which is reflected from its water quality parameters. Salinity had a significant negative correlation with chlorophyll (-0.969) and phaeophytin (-0.838). It was also observed strong negative correlation between temperature and chlorophyll (-0.984), pH and chlorophyll (-0.965), pH and phaeophytin (-0.997) (Table. 12). At Veraval similar results was observed like that of Dwarka in case of temperature. In case of pH however, negative correlation were occurred with chlorophyll (-0.887) and phaeophytin (-0.985). In this case no positive correlation coefficient was observed between pH and any other parameters. In case of Veraval, positive correlation between conductivity and TS (0.882), TDS (0.897), turbidity (0.947) and sulphate (0.948) clearly indicating slightly different water quality status than that of Dwarka (Table. 13). It may be due to the anthropogenic pressure created to this area in forms of municipal sewage disposal, release of industrial influents, port related activities and other human interferences. Veraval is one of the biggest fish landing sites of India and the water quality clearly reflects its not so healthy conditions like Dwarka. The physico-chemical parameters at Kodinar which is also affected by anthropogenic pressure in the form of industrial run off showed similar pattern like Veraval. The results also indicated that presence of sulphate which influenced the water quality parameters significantly. The results suggested moderately influenced water quality at Kodinar compared to that of Dwarka and Mangrol (Vaghela, et al., 2010). It was observed strong significant positive correlation between total solids and total dissolved solids (0.997). Significant negative correlation was observed between temperature and chlorophyll (-0.962), salinity and chlorophyll (-0.984), whereas, significant positive correlation was observed between chlorophyll and phaeophytin (0.930) in case of Kodinar coast (Table. 14).

5.5. Environmental Influence on Macrofaunal Community

Macro-invertebrate abundance, community structure and ecological function have long been used to characterize water quality in coastal ecosystem. Factors influencing the biodiversity and community ecology of intertidal zones are often investigated to test hypotheses on the generality of patterns that immersion and other physical and biological factors exert on assemblages (Connell, 1972; Paine, 1974; Underwood and Chapman, 1996, 1998; Benedetti-Cecchi and Cinelli, 1997; Menconi, et al., 1999; Menge and Branch, 2001). The present results are indicating that a natural variable such as temperature and salinity are the best correlating with species diversity indices. Due to the other environmental factors like substrate and anthropogenic pollution, contaminated the seawater thus the species diversity is more affected. Correlation analysis of seawater parameter with Shannon-Wiener diversity index proved, since most of the environment factors were significantly correlated with macrofauna and it also suggested that a combined effect of two or more factors involved in the variations in macrofaunal community (Jayaraj, et al., 2007).

Significant correlation was observed in case of temperature and diversity of echinodermata (0.938) at Mangrol and (0.865) at Kodinar (Table 15), while group annelida was also showed significant correlation with temperature (0.961) at Dwarka.

At the sampling site Veraval and Kodinar were strongly influenced by pH. Similarly other macrofaunal groups like porifera, annelida and echinodermata were also correlates with pH. It was found that diversity of all macrofaunal groups was influenced by dissolved oxygen content at all four locations studied (Table 16). The correlation coefficient analysis between richness and abiotic factors showed variations amongst different groups and within different parameters (Table 17, 18). However, significant variations observed in the species richness of annelids with salinity at Veraval and Kodinar (0.93 and 0.90 respectively), possibly due to influx of freshwater runoff in these coasts. Mollusca and sponges were found to be associated with variations in DO at Mangrol (0.934 and 0.993 respectively) and Kodinar (0.908 and 0.967 respectively) sampling sites. Variation in salinity, dissolved oxygen and turbidity are affected in differences in the physico-chemical characteristics of near shore environment (Gillanders and Kingsferd, 2002; Ingram and Lin, 2002; Incera, et al., 2003; Tanaka and Fosca, 2003; Baldo, et al., 2006). This environmental variation thus lead to presence of a diverse range of habitats in these waters, which are often characterized by distinct and diverse faunal assemblages (Teske and Wooldridge, 2003; Wildsmith, et al., 2005). Raghunathan et al. (2003) stated that species diversity directly correlates with the concentration of chlorophyll. In this study, group annelida were found to be associated with levels of chlorophyll at Dwarka, Veraval and Kodinar (0.86, 0.86 and 0.93 respectively). In case of species evenness, more groups were influenced by factors like pH and DO (Table 19, 20), possibly due to contamination of industrial effluents and sewage disposal, which might have influenced the pH level of the area under study. The results also indicate that the species richness and evenness were much influenced at the shores, where it was influenced by various anthropogenic activities (Misra and Kundu, 2005). Amongst the four coasts studied, Veraval and Kodinar shores were much influenced by industrial and sewage discharges, whereas, in Dwarka and Mangrol the human influence was minimum. The most important factors were temperature, salinity, dissolved oxygen and chlorophyll, and no single factor could be considered as an ecological master factor (Harkantra and Rodrigues, 2004).

Table 11. Correlation coefficients of different Physico-chemical and Biological parameters at Dwarka, Saurashtra Coastline. (Abbreviations : Temp. –Temperature, Cond. – Conductivity, TS – Total solids, TDS – Total suspended solids, Turb. – Turbidity, Sal. – Salinity, DO – Dissolved oxygen, BOD – Biochemical oxygen demand, Sulp. – Sulphate, Chlo. – Chlorophyll)

	Temp.	**pH**	**Cond.**	**TS**	**TDS**	**Turb.**	**Sal.**	**DO**	**BOD**	**COD**	**Sulp.**	**Chlo.**
pH	0.932											
Cond.	0.877	0.978										
TS	0.246	0.579	0.658									
TDS	0.258	0.588	0.666	1.000								
Turb.	0.359	0.670	0.705	0.975	0.978							
Sal.	0.989	0.971	0.916	0.370	0.381	0.488						
DO	-0.736	-0.547	-0.371	0.238	0.226	0.036	-0.709					
BOD	0.250	0.582	0.657	1.000	1.000	0.979	0.375	0.224				
COD	-0.497	-0.451	-0.258	-0.018	-0.029	-0.239	-0.539	0.860	-0.038			
Sulp.	0.240	0.526	0.485	0.823	0.826	0.911	0.381	-0.131	0.835	-0.523		
Chlo.	-0.944	-0.827	-0.708	-0.065	-0.077	-0.232	-0.931	0.916	-0.074	0.728	-0.249	
Phae.	-0.896	-0.704	-0.578	0.152	0.140	-0.010	-0.852	0.941	0.144	0.677	-0.038	0.975

Table 12. Correlation coefficients of different Physico-chemical and Biological parameters at Mangrol, Saurashtra Coastline. (Abbreviations : Temp. –Temperature, Cond. – Conductivity, TS – Total solids, TDS – Total suspended solids, Turb. – Turbidity, Sal. – Salinity, DO – Dissolved oxygen, BOD – Biochemical oxygen demand, Sulp. – Sulphate, Chlo. – Chlorophyll)

	Temp.	pH	Cond.	TS	TDS	Turb.	Sal.	DO	BOD	COD	Sulp.	Chlo.
pH	0.905											
Cond.	0.588	0.196										
TS	0.289	-0.127	0.942									
TDS	0.305	-0.125	0.948	0.990								
Turb.	0.680	0.308	0.992	0.892	0.905							
Sal.	0.988	0.875	0.642	0.368	0.365	0.723						
DO	-0.660	-0.896	0.120	0.375	0.421	0.026	-0.659					
BOD	0.130	-0.196	0.775	0.901	0.831	0.704	0.258	0.255				
COD	-0.284	0.011	-0.537	-0.450	-0.572	-0.558	-0.204	-0.447	-0.022			
Sulp.	-0.386	-0.719	0.513	0.770	0.745	0.403	-0.297	0.780	0.797	-0.208		
Chlo.	-0.984	-0.965	-0.444	-0.132	-0.138	-0.545	-0.969	0.781	-0.018	0.147	0.524	
Phae.	-0.868	-0.997	-0.121	0.197	0.200	-0.234	-0.838	0.926	0.241	-0.078	0.760	0.942

Table 13. Correlation coefficients of different Physico-chemical and Biological parameters at Veraval, Saurashtra Coastline. (Abbreviations : Temp. –Temperature, Cond. – Conductivity, TS – Total solids, TDS – Total suspended solids, Turb. – Turbidity, Sal. – Salinity, DO – Dissolved oxygen, BOD – Biochemical oxygen demand, Sulp. – Sulphate, Chlo. – Chlorophyll).

	Temp.	**pH**	**Cond.**	**TS**	**TDS**	**Turb.**	**Sal.**	**DO**	**BOD**	**COD**	**Sulp.**	**Chlo.**
pH	0.848											
Cond.	0.281	-0.186										
TS	0.290	-0.260	0.882									
TDS	0.288	-0.260	0.897	0.999								
Turb.	0.424	-0.103	0.947	0.972	0.977							
Sal.	0.994	0.788	0.356	0.386	0.384	0.509						
DO	-0.456	-0.715	0.027	0.413	0.391	0.188	-0.381					
BOD	0.633	0.571	0.537	0.178	0.202	0.404	0.613	-0.822				
COD	-0.074	0.452	-0.917	-0.965	-0.970	-0.934	-0.172	-0.424	-0.158			
Sulp.	0.013	-0.475	0.948	0.908	0.919	0.904	0.103	0.309	0.256	-0.982		
Chlo.	-0.986	-0.877	-0.294	-0.223	-0.227	-0.388	-0.971	0.591	-0.742	0.032	-0.001	
Phae.	-0.849	-0.985	0.069	0.219	0.213	0.033	-0.790	0.807	-0.702	-0.384	0.379	0.900

Table 14. Correlation coefficients of different Physico-chemical and Biological parameters at Kodinar, Saurashtra Coastline. (Abbreviations : Temp. –Temperature, Cond. – Conductivity, TS – Total solids, TDS – Total suspended solids, Turb. – Turbidity, Sal. – Salinity, DO – Dissolved oxygen, BOD – Biochemical oxygen demand, Sulp. – Sulphate, Chlo. – Chlorophyll).

	Temp.	**pH**	**Cond.**	**TS**	**TDS**	**Turb.**	**Sal.**	**DO**	**BOD**	**COD**	**Sulp.**	**Chlo.**
pH	0.705											
Cond.	-0.064	-0.728										
TS	0.156	-0.591	0.947									
TDS	0.230	-0.528	0.925	0.997								
Turb.	0.307	-0.314	0.544	0.771	0.790							
Sal.	0.963	0.652	-0.097	0.180	0.254	0.481						
DO	-0.415	-0.790	0.854	0.641	0.594	0.054	-0.529					
BOD	-0.001	0.618	-0.708	-0.847	-0.841	-0.941	-0.164	-0.324				
COD	-0.956	-0.882	0.349	0.141	0.066	-0.085	-0.915	0.614	-0.246			
Sulp.	-0.168	-0.698	0.942	0.794	0.763	0.233	-0.280	0.962	-0.439	0.411		
Chlo.	-0.962	-0.777	0.259	-0.005	-0.081	-0.329	-0.984	0.635	-0.006	0.965	0.407	
Phae.	-0.845	-0.946	0.583	0.361	0.289	-0.010	-0.850	0.815	-0.330	0.957	0.658	0.930

Table 15. Correlation coefficient *R* between seawater quality parameters and Shannon-Wiener Diversity of macrofaunal groups at selected stations. (Abbreviation used temp = temperature, cond = conductivity, tur = turbidity).

		Temp.	**pH**	**Cond.**	**TDS**	**Tur.**
Porifera	D	-0.691	-0.417	-0.398	0.397	0.370
	M	-0.420	-0.765	0.481	0.735	0.378
	V	-0.621	-0.941	0.479	0.571	0.432
	K	-0.401	-0.932	0.915	0.799	0.542
Coelenterata	D	-0.161	0.066	0.270	0.595	0.414
	M	-0.140	-0.219	-0.081	0.018	-0.059
	V	-0.471	-0.136	-0.917	-0.685	-0.813
	K	0.295	0.351	0.034	-0.116	-0.610
Annelida	D	-0.961	-0.902	-0.799	-0.242	-0.389
	M	0.743	0.955	-0.103	-0.411	0.014
	V	0.053	0.347	-0.877	-0.614	-0.678
	K	-0.226	0.501	-0.957	-0.961	-0.594
Arthropoda	D	0.243	0.205	0.004	-0.070	0.133
	M	-0.796	-0.782	-0.250	-0.019	-0.363
	V	-0.303	-0.514	-0.133	0.289	0.091
	K	-0.088	0.387	-0.806	-0.646	-0.047
Mollusca	D	0.235	-0.019	-0.219	-0.629	-0.452
	M	0.287	0.584	-0.331	-0.544	-0.283
	V	-0.721	-0.263	-0.844	-0.856	-0.932
	K	-0.622	-0.456	-0.143	-0.129	0.288
Echinodermata	D	-0.355	-0.086	0.109	0.612	0.434
	M	0.938	0.973	0.287	-0.017	0.403
	V	-0.721	-0.975	0.397	0.456	0.317
	K	-0.865	-0.317	-0.264	-0.595	-0.743

Table 16. Correlation coefficient *R* between seawater quality parameters and Shannon-Wiener Diversity of macrofaunal groups at selected stations. (Abbreviation used sal = salinity, phos = phosphate, ammo = ammonia, chlor = chlorophyll).

		Sal.	**DO**	**Phos.**	**Ammo.**	**Chlor.**
Porifera	D	-0.576	0.549	0.952	0.730	0.639
	M	-0.363	0.890	0.888	0.953	0.570
	V	-0.537	0.733	0.986	0.906	0.664
	K	-0.361	0.826	0.917	0.789	0.522
Coelenterata	D	-0.125	0.785	0.449	0.778	0.471
	M	-0.270	0.502	-0.280	0.136	0.206
	V	-0.511	0.373	-0.187	0.232	0.534
	K	0.027	0.278	-0.405	-0.198	-0.092
Annelida	D	-0.969	0.855	0.470	0.749	0.986
	M	0.692	-0.933	-0.863	-0.994	-0.845
	V	0.003	0.146	-0.509	-0.262	0.024
	K	-0.174	-0.726	-0.457	-0.296	0.018
Arthropoda	D	0.290	-0.740	-0.024	-0.565	-0.522
	M	-0.694	0.471	0.770	0.711	0.791
	V	-0.240	0.963	0.585	0.537	0.456
	K	0.097	-0.853	-0.326	-0.351	-0.185
Mollusca	D	0.186	-0.825	-0.552	-0.841	-0.530
	M	0.334	-0.879	-0.382	-0.680	-0.435
	V	-0.783	0.062	-0.210	0.352	0.693
	K	-0.390	-0.178	0.513	0.422	0.418
Echinodermata	D	-0.297	0.881	0.645	0.908	0.625
	M	0.886	-0.774	-0.733	-0.865	-0.968
	V	-0.646	0.694	0.952	0.948	0.749
	K	-0.925	0.239	0.330	0.598	0.842

Table 17. Correlation coefficient *R* between seawater quality parameters and richness of macrofaunal groups at selected stations. (Abbreviation used temp = temperature, cond = conductivity, tur = turbidity).

		Temp.	**pH**	**Cond.**	**TDS**	**Tur.**
Porifera	D	-0.546	-0.669	-0.809	-0.623	-0.533
	M	-0.568	-0.839	0.215	0.500	0.127
	V	-0.831	-0.990	0.121	0.257	0.081
	K	-0.561	-0.752	0.693	0.369	-0.184
Coelenterata	D	0.566	0.589	0.419	0.245	0.444
	M	-0.210	-0.145	-0.377	-0.307	-0.340
	V	-0.757	-0.500	-0.743	-0.536	-0.702
	K	0.523	0.541	-0.052	-0.106	-0.503
Annelida	D	-0.650	-0.462	-0.272	0.268	0.070
	M	0.677	0.433	0.837	0.693	0.840
	V	0.931	0.797	0.056	0.217	0.292
	K	0.800	0.763	-0.461	-0.096	0.348
Arthropoda	D	-0.194	0.146	0.301	0.849	0.728
	M	0.748	0.398	0.937	0.827	0.967
	V	-0.299	-0.757	0.722	0.827	0.723
	K	-0.171	-0.540	0.788	0.547	-0.074
Mollusca	D	0.861	0.636	0.592	-0.206	-0.141
	M	0.839	0.931	0.241	-0.068	0.326
	V	0.289	0.282	0.534	0.119	0.300
	K	-0.013	-0.608	0.954	0.825	0.311
Echinodermata	D	-0.704	-0.448	-0.285	0.406	0.239
	M	0.884	0.867	0.319	0.057	0.434
	V	-0.767	-0.976	0.178	0.345	0.165
	K	-0.865	-0.317	-0.264	-0.595	-0.743

Table 18. Correlation coefficient *R* between seawater quality parameters and richness of macrofaunal groups at selected stations. (Abbreviation used sal = salinity, phos = phosphate, ammo = ammonia, chlor = chlorophyll).

		Sal.	DO	Phos.	Ammo.	Chlor.
Porifera	D	-0.558	-0.164	0.054	-0.170	0.242
	M	-0.572	0.993	0.651	0.902	0.703
	V	-0.769	0.802	0.881	0.992	0.882
	K	-0.697	0.967	0.714	0.831	0.765
Coelenterata	D	0.631	-0.800	-0.041	-0.582	-0.746
	M	-0.353	0.323	-0.486	-0.055	0.217
	V	-0.774	0.560	0.152	0.583	0.814
	K	0.276	0.086	-0.593	-0.434	-0.344
Annelida	D	-0.627	0.992	0.579	0.936	0.863
	M	0.776	-0.311	0.314	-0.071	-0.610
	V	0.929	-0.201	-0.467	-0.812	-0.866
	K	0.902	-0.837	-0.743	-0.911	-0.934
Arthropoda	D	-0.092	0.705	0.783	0.842	0.430
	M	0.752	-0.003	0.080	-0.035	-0.616
	V	-0.200	0.669	0.972	0.695	0.354
	K	-0.353	0.943	0.485	0.558	0.433
Mollusca	D	0.776	-0.695	-0.886	-0.799	-0.820
	M	0.865	-0.934	-0.481	-0.812	-0.908
	V	0.269	-0.785	-0.218	-0.342	-0.431
	K	-0.125	0.908	0.557	0.502	0.258
Echinodermata	D	-0.643	0.971	0.792	0.998	0.872
	M	0.803	-0.576	-0.741	-0.760	-0.884
	V	-0.697	0.848	0.917	0.972	0.830
	K	-0.925	0.239	0.330	0.598	0.842

Table 19. Correlation coefficient *R* between seawater quality parameters and evenness of macrofaunal groups at selected stations. (Abbreviation used temp = temperature, cond = conductivity, tur = turbidity).

		Temp.	**pH**	**Cond.**	**TDS**	**Tur.**
Porifera	D	0.582	0.836	0.870	0.933	0.963
	M	-0.492	-0.816	0.397	0.668	0.293
	V	-0.740	-0.874	0.422	0.280	0.212
	K	-0.502	-0.949	0.895	0.704	0.351
Coelenterata	D	0.041	0.237	0.435	0.605	0.437
	M	0.119	-0.113	0.627	0.648	0.560
	V	0.953	0.925	0.201	0.086	0.262
	K	-0.286	-0.684	0.494	0.586	0.818
Annelida	D	-0.078	-0.296	-0.488	-0.677	-0.520
	M	0.194	0.572	-0.676	-0.863	-0.580
	V	-0.481	0.021	-0.962	-0.944	-0.992
	K	-0.976	-0.651	0.067	-0.273	-0.464
Arthropoda	D	0.556	0.343	0.147	-0.375	-0.179
	M	-0.499	-0.308	-0.421	-0.352	-0.485
	V	0.724	0.964	-0.430	-0.441	-0.318
	K	0.110	0.381	-0.655	-0.403	0.242
Mollusca	D	0.215	0.037	-0.174	-0.448	-0.252
	M	0.303	0.574	-0.264	-0.474	-0.222
	V	-0.077	0.262	-0.932	-0.693	-0.766
	K	-0.147	-0.001	-0.388	-0.187	0.423
Echinodermata	D	-0.355	-0.086	0.109	0.612	0.434
	M	0.894	0.926	0.245	-0.040	0.364
	V	-0.790	-0.889	0.350	0.215	0.139
	K	0.000	0.000	0.000	0.000	0.000

Table 20. Correlation coefficient *R* between seawater quality parameters and evenness of macrofaunal groups at selected stations. (Abbreviation used sal = salinity, phos = phosphate, ammo = ammonia, chlor = chlorophyll).

		Sal.	DO	Phos.	Ammo.	Chlor.
Porifera	D	0.686	-0.113	0.346	0.114	-0.428
	M	-0.449	0.939	0.849	0.966	0.638
	V	-0.694	0.314	0.762	0.842	0.694
	K	-0.508	0.917	0.928	0.868	0.649
Coelenterata	D	0.065	0.646	0.292	0.628	0.288
	M	0.264	0.059	0.762	0.402	-0.051
	V	0.922	-0.705	-0.667	-0.958	-0.987
	K	-0.070	0.202	0.711	0.461	0.211
Annelida	D	-0.114	-0.616	-0.337	-0.627	-0.248
	M	0.105	-0.700	-0.924	-0.849	-0.346
	V	-0.558	-0.064	-0.459	0.076	0.462
	K	-0.998	0.491	0.661	0.852	0.981
Arthropoda	D	0.525	-0.972	-0.592	-0.936	-0.795
	M	-0.393	-0.121	0.393	0.183	0.407
	V	0.653	-0.614	-0.930	-0.934	-0.736
	K	0.330	-0.866	-0.322	-0.446	-0.377
Mollusca	D	0.204	-0.814	-0.348	-0.754	-0.524
	M	0.362	-0.865	-0.314	-0.640	-0.442
	V	-0.132	0.152	-0.486	-0.170	0.144
	K	0.115	-0.608	0.063	-0.102	-0.110
Echinodermata	D	-0.297	0.881	0.645	0.908	0.625
	M	0.819	-0.689	-0.788	-0.844	-0.917
	V	-0.748	0.328	0.743	0.865	0.744
	K	0.000	0.000	0.000	0.000	0.000

Table 21. Correlation coefficient *R* between seawater quality parameters and population density of macrofaunal groups at selected stations. (Abbreviation used temp = temperature, cond = conductivity, tur = turbidity).

		Temp.	pH	Cond.	TDS	Tur.
Porifera	D	-0.666	-0.374	-0.227	0.510	0.363
	M	-0.648	-0.908	0.200	0.500	0.094
	V	-0.735	-0.981	0.301	0.424	0.261
	K	-0.555	-0.975	0.860	0.675	0.373
Coelenterata	D	-0.660	-0.542	-0.353	0.083	-0.123
	M	-0.437	-0.502	-0.211	-0.026	-0.224
	V	-0.797	-0.661	-0.567	-0.320	-0.512
	K	-0.174	0.022	0.069	-0.226	-0.773
Annelida	D	-0.936	-0.951	-0.864	-0.426	-0.564
	M	-0.463	-0.239	-0.742	-0.653	-0.716
	V	-0.562	-0.328	-0.795	-0.510	-0.675
	K	-0.833	-0.241	-0.348	-0.663	-0.774
Arthropoda	D	-0.862	-0.767	-0.618	-0.085	-0.267
	M	-0.988	-0.938	-0.519	-0.220	-0.611
	V	-0.703	-0.671	-0.455	-0.141	-0.347
	K	-0.548	0.162	-0.793	-0.883	-0.559
Mollusca	D	-0.946	-0.997	-0.959	-0.544	-0.640
	M	-0.926	-0.716	-0.814	-0.588	-0.867
	V	-0.885	-0.640	-0.636	-0.498	-0.661
	K	-0.907	-0.388	-0.221	-0.549	-0.678
Echinodermata	D	-0.410	-0.166	0.034	0.523	0.334
	M	0.884	0.867	0.319	0.057	0.434
	V	-0.848	-1.000	0.186	0.260	0.103
	K	-0.865	-0.317	-0.264	-0.595	-0.743

Table 22. Correlation coefficient *R* between seawater quality parameters and population density of macrofaunal groups at selected stations. (Abbreviation used sal = salinity, phos = phosphate, ammo = ammonia, chlor = chlorophyll).

		Sal.	**DO**	**Phos.**	**Ammo.**	**Chlor.**
Porifera	D	-0.584	0.921	0.877	0.996	0.818
	M	-0.620	0.983	0.793	0.977	0.774
	V	-0.660	0.792	0.951	0.965	0.786
	K	-0.537	0.878	0.960	0.892	0.678
Coelenterata	D	-0.669	0.967	0.412	0.849	0.866
	M	-0.547	0.694	-0.069	0.371	0.501
	V	-0.788	0.731	0.379	0.728	0.872
	K	-0.432	0.488	-0.068	0.210	0.366
Annelida	D	-0.972	0.761	0.294	0.609	0.934
	M	-0.590	0.217	-0.502	-0.093	0.405
	V	-0.578	0.581	0.048	0.415	0.647
	K	-0.890	0.155	0.256	0.529	0.794
Arthropoda	D	-0.869	0.950	0.477	0.838	0.975
	M	-0.988	0.756	0.461	0.724	0.994
	V	-0.676	0.854	0.483	0.728	0.807
	K	-0.471	-0.499	-0.114	0.052	0.343
Mollusca	D	-0.983	0.609	0.250	0.471	0.865
	M	-0.964	0.475	0.082	0.380	0.868
	V	-0.897	0.539	0.263	0.713	0.918
	K	-0.948	0.263	0.403	0.652	0.877
Echinodermata	D	-0.365	0.915	0.601	0.912	0.678
	M	0.803	-0.576	-0.741	-0.760	-0.884
	V	-0.788	0.715	0.880	0.995	0.877
	K	-0.925	0.239	0.330	0.598	0.842

Table 23. Correlation coefficient *R* between seawater quality parameters and population abundance of macrofaunal groups at selected stations. (Abbreviation used temp = temperature, cond = conductivity, tur = turbidity).

		Temp.	pH	Cond.	TDS	Tur.
Porifera	D	-0.666	-0.374	-0.227	0.510	0.363
	M	-0.648	-0.908	0.200	0.500	0.094
	V	-0.735	-0.981	0.301	0.424	0.261
	K	-0.555	-0.975	0.860	0.675	0.373
Coelenterata	D	-0.502	-0.394	-0.192	0.133	-0.078
	M	-0.558	-0.544	-0.399	-0.204	-0.414
	V	-0.682	-0.497	-0.694	-0.418	-0.600
	K	-0.123	0.021	0.121	-0.163	-0.729
Annelida	D	-0.875	-0.938	-0.851	-0.524	-0.664
	M	0.246	0.225	-0.030	-0.074	0.042
	V	-0.554	-0.280	-0.841	-0.578	-0.732
	K	-0.825	-0.223	-0.367	-0.678	-0.780
Arthropoda	D	-0.521	-0.416	-0.216	0.115	-0.096
	M	-0.959	-0.955	-0.435	-0.127	-0.528
	V	-0.575	-0.596	-0.420	-0.056	-0.263
	K	-0.587	0.098	-0.753	-0.841	-0.502
Mollusca	D	-0.827	-0.956	-0.907	-0.687	-0.796
	M	-0.896	-0.666	-0.846	-0.635	-0.891
	V	-0.932	-0.708	-0.560	-0.451	-0.612
	K	-0.900	-0.393	-0.197	-0.534	-0.691
Echinodermata	D	-0.620	-0.363	-0.185	0.452	0.274
	M	0.884	0.867	0.319	0.057	0.434
	V	-0.848	-1.000	0.186	0.260	0.103
	K	-0.865	-0.317	-0.264	-0.595	-0.743

Table 24. Correlation coefficient *R* between seawater quality parameters and population abundance of macrofaunal groups at selected stations. (Abbreviation used sal = salinity, phos = phosphate, ammo = ammonia, chlor = chlorophyll).

		Sal.	**DO**	**Phos.**	**Ammo.**	**Chlor.**
Porifera	D	-0.584	0.921	0.877	0.996	0.818
	M	-0.620	0.983	0.793	0.977	0.774
	V	-0.660	0.792	0.951	0.965	0.786
	K	-0.537	0.878	0.960	0.892	0.678
Coelenterata	D	-0.520	0.916	0.307	0.785	0.751
	M	-0.667	0.653	-0.108	0.342	0.590
	V	-0.686	0.673	0.216	0.576	0.766
	K	-0.386	0.514	-0.070	0.194	0.328
Annelida	D	-0.932	0.706	0.147	0.515	0.878
	M	0.102	0.092	-0.618	-0.287	-0.213
	V	-0.579	0.512	-0.024	0.371	0.629
	K	-0.881	0.136	0.239	0.513	0.782
Arthropoda	D	-0.539	0.920	0.307	0.786	0.764
	M	-0.967	0.829	0.481	0.769	0.986
	V	-0.541	0.895	0.474	0.648	0.699
	K	-0.493	-0.475	-0.047	0.103	0.376
Mollusca	D	-0.901	0.542	-0.002	0.331	0.774
	M	-0.942	0.428	0.010	0.317	0.830
	V	-0.939	0.537	0.331	0.775	0.955
	K	-0.952	0.295	0.405	0.660	0.882
Echinodermata	D	-0.563	0.971	0.743	0.988	0.824
	M	0.803	-0.576	-0.741	-0.760	-0.884
	V	-0.788	0.715	0.880	0.995	0.877
	K	-0.925	0.239	0.330	0.598	0.842

5.6. Anthropogenic Impact

Ecological diversity within this region can be very high, with species from many classes and genera often present. Vital ecological communities can also be found in the Intertidal regions, emphasizing the importance of the particular area of the shore as a habitat (Jenkins, et al., 2001; Raghunathan, 2003). The intertidal area is strongly influenced by the tides, which allow sea levels to fluctuate between high and low. Tidal variations affect the number of species immersed by the sea, therefore dictating the regions ecology (Littler and Kitching, 1996). The extent of stress experienced by the region is dependent on the intensity of various environmental factors, of which vary with latitude (Lewis, 1978). For many years humans have substantially affected Intertidal zones across the globe. Oil spills, Nutrient and pesticide pollution and the introduction of exotic species have all had very significant impacts on Intertidal communities (Crowe, et al., 2000). However, it is the impacts of recreational stresses on intertidal zones that have become a more important focus of Intertidal ecological research over the past decade (Brosnan and Crumrine, 1994). Coastal areas in Saurashtra peninsula are attractive to tourism, industries, fishing and many more activities. These activities in the coastal areas give rise to competition and therefore conflicts between human uses. Furthermore, these conflicts may occur between human activities and the intertidal zone biota. Dumping and discharging of pollutants into the sea, nutrient and runoff from land and rivers, fallout of chemicals carried by the wind from land-based sources are some of the major contaminants affecting marine ecosystems. Nontoxic solid wastes and marine debris cause significant mortality among marine species like plastic bags, fishing lines, and other debris causing slow.

Rich intertidal biodiversity is a main characteristic feature of the South Saurashtra coastline along the Arabian Sea. This coastline has a broad continental shelf thereby extremely rich in intertidal and subtidal flora and fauna, because of its high primary productivity. This area supports some of the rich fishing ground in India. Saurashtra coastline also contains numerous industrial belt and pilgrim tourist sites which produce human activities that interfere on the coastal ecosystem. Impacts of various human activities in the coastal zone are very complex and difficult to assess as there are no direct method to evaluate them quantitatively. The effects of various activities vary considerably from case to case or type to type not only due to the variety anthropogenic activities and sources but also due to the specificities of the receiving micro environmental and prevailing hydro morphological conditions (Vaghela, et al., 2010). Therefore, overall anthropogenic effects in terms of industrial pressure, domestic sewage, port activities and tourism on the coastal region are a mosaic type composed of different types of inputs and mechanisms (Misra, 2004).

The development of the Saurashtra region was driven solely by the trading possibilities offered by its long coastline and ports. It would appear that today the problems consequent to the high degree of industrialization along the Saurashtra coastline are being addressed with even more industrialization. There are two developed fishing harbours with allied at Veraval and Mangrol, which face 62 % fish production out of the total fish production. The industrial groups that have grater dominance are cement; food industry and the existing port with facilitate import or export of fish and fishery products, fertilizers, salt, cement, soda ash and lime stone etc. With respect to coastal Saurashtra, the minerals present include limestone, bauxite, lignite, chalk and bentonite amongst others. Saurashtra has a number of key minerals with significant economic potential. It is already exploiting its rich mineral resources. However, there are other key minerals present in the region that have significant potential present, namely, lignite and bentonite. Gujarat has a large mineral resource base and 4th largest producer of limestone in the country.

It was also observed the harvesting of marine algae for industrial and for the other at various parts of Saurashtra coast. As it appears, the harvesting of marine algae for the different industrial purposes was singular most important devastating tourism activity which seriously affects the marine life. Marine algae are relatively well known in the intertidal diversity and economic life of humans and ecosystems. The use of algae as food, animal fodder, fertilizers, as raw materials in the industrial product have been received much attention in Saurashtra coast. In addition, commercially important agars are extracted from red and brown algae. Agars obtained from *Gelidium sp.* are used extensively in microbiology and tissue culture. The agar from *Gracilaria sp.* is used mainly in foods.

Kodinar coastline is influenced by a cement factory and a sugar mill. The human activity near the coast is not much in terms of direct contact of the people to the coastline. However, dumping of waste from these industries was the main anthropogenic pressure. The Dwarka sampling site in notoriously use by the visiting human population which freely perform all kinds of notorious human activities in this coast. The most seriously consequent of this tourism related human activities are habitat destruction which adversely and more permanently affects the coastal ecosystem. In case of Mangrol which is relatively unaffected area. This coastline is free from any anthropogenic pressure which is evident from its water quality parameters.

The results of the water quality as a reference to the human interference clearly indicate a less human interference at Dwarka. In case of Mangrol which is another relatively unaffected area showed similar results like Dwarka. However, the sampling site Veraval clearly indicating anthropogenically affected water quality status. The physico-chemical parameters at Kodinar which is also affected by anthropogenic pressure in the form of industrial run off showed similar pattern like Veraval. The results suggested moderately influenced water quality at Kodinar compared to that of Dwarka and Mangrol. Cluster analysis was applied through a dendogram to find out the similarity groups between the sampling stations (Fig. 21), grouping all the four sampling stations into three statistically meaningful clusters. The two stations (Kodinar and Veraval) form cluster 1 which comprises relatively high anthropogenically influenced sites that receive waste from industries, domestic sewage and fisheries related activities. Cluster 2 includes cluster 1 and station Mangrol that was resemble to almost one another. Mangrol sampling site corresponds to moderately influenced sites.

In general, the present investigation revealed contrasting health of the coastline in terms of water quality at different shores studied. At Dwarka and Mangrol the water quality was almost near to the ideal conditions possibly due to absence of any significant anthropogenic impact on the coast. On the contrary, at Veraval and Kodinar, the water quality was indicative of high degree of anthropogenic impact. The condition of Kodinar coast however, was not as anthropogenically influenced as Veraval as indicated by correlation coefficient test.

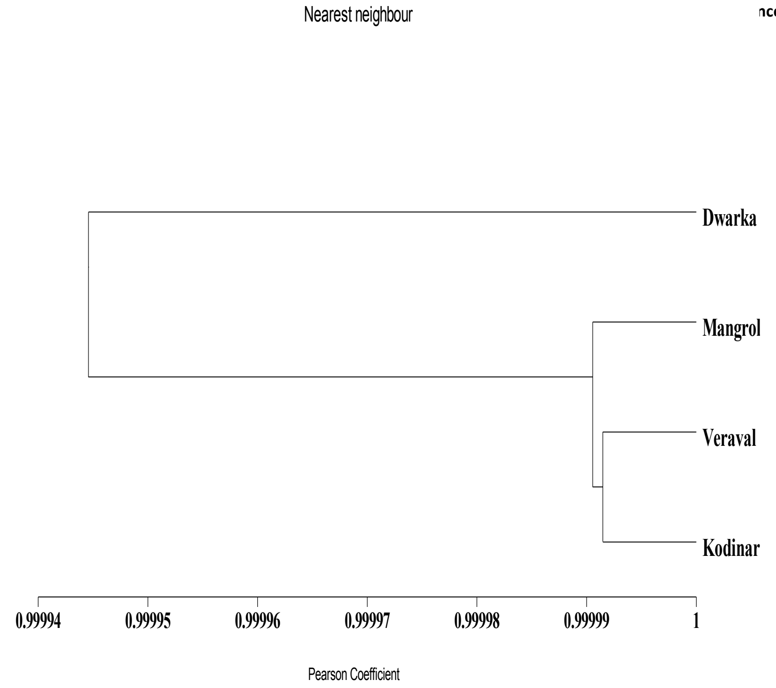

Figure 21. Dendogram showing clustering of similar groups between the sampling stations.

RESULTS OF HYPOTHESES TESTED

Hypotheses tested in this proposed work were made in Null form. The results of the present investigations ratified and tested these hypotheses which are as follows:

NO.	HYPOTHESIS TESTED	RESULT
1.	There will be no significant spatial variations in the general water quality parameters.	True
2.	There will be no significant variations in the general water quality parameters over the time scale.	True
3.	The water quality parameters are not influenced by anthropogenic activities in this shoreline.	False
4.	The macrofaunal diversity in the coastal assemblages is not influenced either by water quality or by anthropogenic activities.	False

Chapter 6 SUMMARY

1. The present study was undertaken to monitor the human- nature interaction and its effect on the natural system to set up the openings of the future study on this tract at this area. In this context, a detailed study on the Saurashtra coastline, one of the biggest one in India desired a detailed monitoring to work out the present status of the ecosystem, the threats mounting and impending, natural resistance and adaptation in response to the pressure and a possible negotiation to the neutralize the harsh condition to offer a better tomorrow. The present study deals with the biodiversity and man-made pressure on the coastal health as well wealth of the rocky intertidal macrofauna in four different stations along the Saurashtra coastline. With a view to assess the status of the intertidal macrofauna, the physico-chemical characteristic of the coast and the interaction between the fauna and anthropogenic activities were investigated. The Western coastal belt of India, these days is considerably being exploited heavily by various kinds of Industries. This study revealed how this is affecting the ecosystem of this area.

2. Sampling sites were selected according to a preliminary survey of the coastline in view of different anthropogenic pressure on coastal area. Saurashtra coast is now the hot-spot for various mega industries, fishery related opportunities. Added to these, more tourism is also one of the related problems for the coastal zones of Saurashtra peninsula. For spatial analysis Saurashtra coastline divided in to four sampling site, viz. Dwarka, Mangrol, Veraval and Kodinar. These shores were selected on the basis of their strategic locations, existing industries, infrastructural facilities for the likelihood of being developed as industrial zones, different anthropogenic activities along the entire coastal area of Saurashtra peninsula.

3. Study was intended to conduct the spatial as well as temporal variations of rocky intertidal macrofauna, seawater quality and anthropogenic impact along the Saurashtra coastline. In this regards, four study sites, Dwarka, Mangrol, Veraval and Kodinar from Saurashtra coastline were selected. These sites exhibit various anthropogenic impacts with different magnitude of human disturbances as seawater quality, community stress, if any, discriminated by population ecology, community

structure and various statistical methods to the recognized anthropogenic disturbances on intertidal macro-invertebrate assemblages and water quality from Saurashtra coastline off Arabian Sea.

4. The water quality monitoring study was conducted at a stretch from November 2007 to October 2009 to the all sites at monthly basis. The quantitative assessment of intertidal macrofauna and flora were done from November 2007 to October 2009, while for the qualitative study of intertidal macrofauna were done from November 2008 to October 2009 at regular monthly intervals. The collected data were presented seasonally as the weather condition of this part of the peninsular India typically represents the periods of winter (December to February), summer (March to May), monsoon (June to August) and post-monsoon (September to November). During this study various anthropogenic disturbance on the coastal area were also note down simultaneously.

5. The study examined the variations in population density and abundance, diversity, richness and evenness of all macro-invertebrate groups between four study localities. For the study of community structure and distribution of various macrofaunal groups on intertidal belt, such as porifera, coelenterata, annelida, arthropoda, mollusca and echinodermata were considered. This investigation was undertaken due to the different anthropogenic pressures affects the intertidal community, which experienced by the coastal ecosystem.

6. The intertidal zone of each sampling sites were surveyed regularly on monthly basis and all the macrofauna and flora encountered were recorded. Extensive photography was employed for the identification of the animal species with the identification keys, literature available in the form of books, journals, reports and with extensive use of internet. The complete study was conducted in a non-destructive manner in which the organisms were not at all disturbed and in some cases if disturbed, it was limited to the bare minimum, let alone killing any.

7. The structural attributes of the intertidal fauna were studies by transect method. Belt and Foot transect methods in were used for generating the data on the selected belt and criss-cross direction was followed to cover the maximum exposed area on

the intertidal belt. The surveys were made at the lowest tides of the months. Quadrates of 0.25 m^2 were laid while following an oblique direction covering maximum area at almost regular occurrence.

8. Sea water samples were collected at monthly intervals from all the selected sampling sites for the estimation of various physical, chemical and biological parameters. At least six samples of surface seawater during time of high tide were collected from different locations of the same coast. However, the locations for the collection of samples in a particular coast were fixed, which were fixed using global positioning system (GPS). The selected sea water quality parameters were analyzed according to standard methods.

9. Quantitative estimation of anthropogenic impact is remained a non-conclusive controversial one. Thus, in the present study the various anthropogenic influences on exposed shores and the structural role of macro-invertebrate on the shores were qualitatively demonstrated by field experiments. Extensive field study was regularly carried out along the entire coastal zone of Saurashtra region. The study sites were identified and make a note of the type of various anthropogenic activities such as tourism, fisheries, port activity, industry, sewage and disposal waste. In the present study sea water quality parameters were used for describe the coastal pollution and its effects on the intertidal community.

10. As diversity indices are increasingly used to assess the health of the habitats, presently index of similarity (S), Shannon index of general diversity (H‘), species richness indices (d), evenness indices (J‘), measures were used to estimate the ecological status of the intertidal area of selected stations. Among the ecological attributes, seasonal variations in the population density and abundance of major phylum in each sampling stations were calculated.

11. The collected monthly data were presented as seasonally for the seasonal approach like winter, summer, monsoon and post-monsoon. The obtained data were initially subjected to various descriptive statistical analyses like mean and standard deviation. The obtained data were further subjected to different statistical analyses for their cumulative acceptability.

12. In the present study, a total of 60 species of intertidal macro-invertebrate designated for descriptive community structure on the rocky intertidal belt. Among that mollusca group comprised 35 species followed by coelenterata, arthropoda, annelida, porifera and echinodermata. Species richness was high in almost all the selected locations at Saurashtra coastal area. However, the species evenness was found to be low during the study. However, low levels of species evenness possibly due to the flatness of the intertidal areas, which is exposed during low tide as supported by the Shannon-Weiner diversity index. The results revealed lower diversity during summer and higher diversity values in winter recorded in the study area is in conformity with the earlier observations. Maximum evenness and richness recorded during the winter season at almost all the study sites; it might be due to stable environmental factors, which play an important role in faunal distribution.

13. Amongst the animal groups, mollusca showed the maximum species richness and evenness followed by annelids, sponges and arthropods in almost all sampling sites. The lower diversity of phylum porifera found during summer and maximum during monsoon seasons at Mangrol and Kodinar respectively. It was observed that high density of the coelenterata group was due to the presence of genus *Zoanthus* on the rocks, forming large patches in the middle and lower littoral zones. Increasing siltation seemed to be the most probable limiting factor for the proliferation of this group in the intertidal zones. High species richness was observed during winter season in case of group echinodermata; however, its evenness was the lowest amongst all groups studied. Group arthropoda showed maximum diversity during post-monsoon seasons.

14. Population density and abundance values of macrofaunal groups at four different sites were significantly influenced by space and time. The mean density and abundance of each group in the present study was high during most of the time at Dwarka than the other sampling sites because of the selected sites are often greatly complicated by cracks and crevices, rocks pools and variations in slop and rock type. The population density and abundance of intertidal macrofauna was more during winter and low during summer season. It has been observed that winter and post-monsoon seasons were most favorable for most of the animal groups while

summer season was the least favorable condition for these free moving animals that probably migrate towards deeper areas of the intertidal to avoid exposure. It has been observed that during summer season macrofaunal population was high at Dwarka followed by Mangrol and Veraval. At the sampling site Kodinar population density and abundance have been the least.

15. Seawater quality monitoring study was done in four different sampling sites, which is anthropogenically influence shore along the Saurashtra coastline, Arabian Sea. All the stations showed a similar trend in terms of seasonal changes. The physical parameters did not show much spatial variations. However, slight fluctuations were observed which may be due to local environmental conditions. Veraval was recorded high pH values which may be due to high anthropogenic activities in this location. In the chemical parameters, salinity levels did not show any statistically significant spatial and temporal variations in any of the sampling sites. Biological parameters chlorophyll and phaeophytin did not show statistically significant spatial and temporal variations. Higher values were observed in relatively less human interfered sampling sites like Mangrol and Dwarka, and low values were obtained from highly industrialized sampling sites Veraval and Kodinar. The results clearly indicate a healthy sea water condition at Dwarka and Mangrol.

16. Results indicating less influence of parameters like temperature, pH and turbidity to the species richness of different groups. However, significant variations observed in the species richness of annelids with salinity at Veraval and Kodinar possibly due to influx of freshwater runoff in these coasts. Mollusca and sponges were found to be associated with variations in DO at Mangrol and Kodinar sampling sites. Variation in salinity, dissolved oxygen and turbidity are affected in differences in the physico-chemical characteristics of near shore environment. Annelida were found to be associated with levels of chlorophyll at Dwarka, Veraval and Kodinar. There was a significant positive correlation in the dissolved oxygen level and species richness of sponges at Mangrol, Kodinar and in case of arthropoda at Dwarka and Kodinar. In case of species evenness, more groups were influenced by factors like pH and DO. Significant correlation coefficient was observed in case of sponges at Veraval and Kodinar, possibly due to contamination of industrial effluents and sewage disposal,

which might have influenced the pH level of the area under study. Similar observations were evident in case of coelenterata at Veraval, for arthropoda at Veraval and for echinodermata at Mangrol.

17. The results of the correlation coefficient clearly indicate that the species richness and evenness were much influenced at the shores, where it was influenced by various anthropogenic activities. Amongst the four coasts studied, Veraval and Kodinar shores were much influenced by industrial and sewage discharges, whereas, in Dwarka and Mangrol the human influence was minimum. The most important factors were temperature, salinity, dissolved oxygen and chlorophyll, and no single factor could be considered as an ecological master factor.

18. The results clearly indicate a healthy sea water condition at Dwarka. In case of Mangrol which is another relatively unaffected area showed similar correlation coefficient values like Dwarka. Mangrol is a small hamlet with rocky-sandy coastline showed healthy water quality parameters. This coastline is free from any higher degree of anthropogenic pressure which is reflected from its water quality parameters. However, the sampling site Veraval clearly indicating anthropogenically affected water quality status. The physico-chemical parameters at Kodinar which is also affected by anthropogenic pressure in the form of industrial runoff showed similar pattern like Veraval. The results suggested moderately influenced water quality at Kodinar compared to that of Dwarka and Mangrol. Factors influencing the biodiversity and community ecology of intertidal zones are often investigated to test hypotheses on the generality of patterns that immersion and other physical and biological factors exert on assemblages.

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APPENDIX

Research papers presented

- “Diversity of intertidal macrofauna of a rocky shore off south Saurashtra coastline in view of climate change.” Presented in Science Excellence-2010, Department of Botany, Gujarat University, Ahmedabad on 9th January 2010.

- “Diversity of intertidal assemblage of a rocky shore off south Saurashtra coastline.” Presented in International Symposium on Environmental Pollution Ecology and Human Health, Department of Zoology, S. V. University, Tirupati on 25 – 27th July 2009.

- “Physical and Chemical characteristics of the seawater, around anthropogenically influenced shores.” Presented in XXII Gujarat Science Congress 2008, Bhavnagar University, Bhavnagar, Gujarat on 9th March 2008.

- “Community structure and distribution pattern of invertebrate macrofaunal groups in few rocky shores of Kathiawar Peninsula off Arabian Sea.” Presented in Symposium on Trends in Biological Sciences, Department of Biosciences, Saurashtra University, Rajkot on 16-17th September 2010.

PUBLICATIONS

- Vaghela A., **Bhadja P.**, Ramoliya J., Patel N., and Kundu R. (2010). Seasonal variations in the water quality, diversity and population ecology of intertidal macrofauna at an industrially influenced coast. Journal of Water Science and Technology, 61(6): 1505-1514. (IWA Publishing, US/UK). *IF-2009: 1.24*.

- **Bhadja P.** and Kundu R. Status of the seawater quality at few industrially important coasts of Gujarat (India) off Arabian Sea. Indian Journal of Marine Sciences. Communicated.

- **Bhadja P.** and Kundu R. Community structure and distribution pattern of intertidal macrofauna in few contrasting rocky shores of Kathiawar Peninsula (India) off Arabian Sea. Estuarine, Coastal and Shelf Science. Communicated.

- Other Two Papers are in different stages of communication.

Plate : 1. Map of the Study area.

Dwarka : 22^0 13' N, 68^0 58' E

Mangrol : 21^0 07' N, 70^0 07' E

Veraval : 21^0 35' N 69^0 36' E

Kodinar : 21^0 35' N, 69^0 36' E

Source : Google earth

Plate : 2

Intertidal portion of the Dwarka sampling site

Plate : 3

Intertidal portion of the Mangrol sampling site

Plate : 4

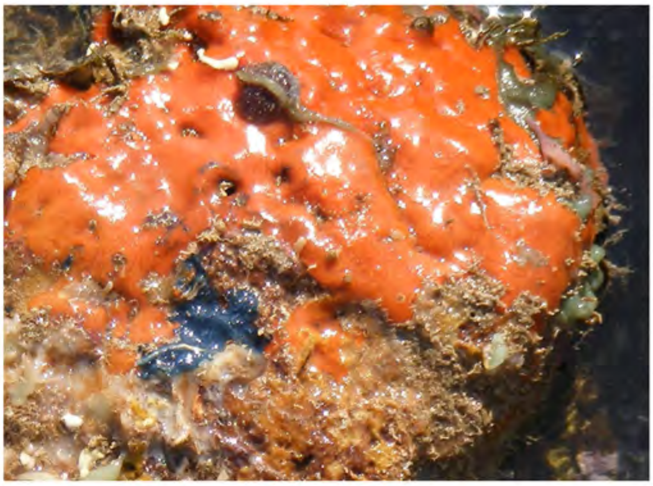
Intertidal portion of the Veraval sampling site

Plate : 5

Intertidal portion of the Kodinar sampling site

Plate : 6

Halichondria panicea



Microciona sp.

Tethya sp.

Goniastrea pectinata

Goniopora sp.

Hydnophora exesa

Plate : 7

Montipora folisa

Portis lutea

Anthopleura sp.

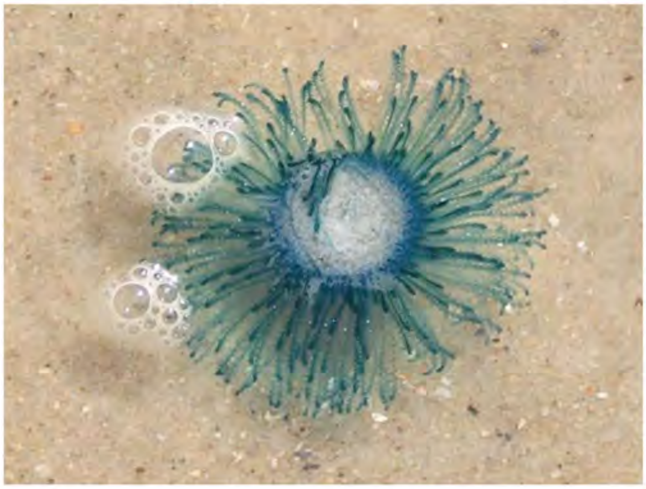
Auralia aurita

Isaurus tuberculosa

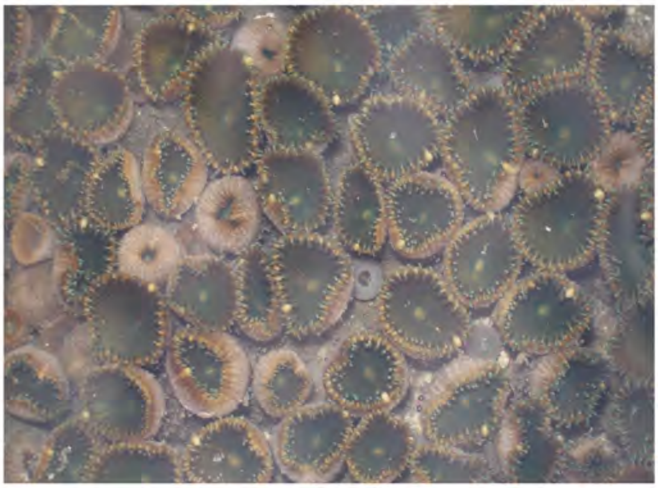
Metridium sp.

Plate : 8

Physalia physalia



Porpita porpita



Protopalythoa vestitus

Utricina sp.

Vellella velllella

Zoanthus sociatus

Plate : 9

Pseudoceros indicus

Pseudoceros stellae

Pseudoceros susanae

Baseodicus hemprichii

Chetopterus chetopterus

Eulalia viridis

Plate : 10

Eurythoa complanata

Nereis pelagica

Sabella pavonica

Serpula vermicularis

Atergatis sanguinolentus

Balanus amphitrite

Plate : 11

Cancer pagurus

Clibanarius nathi

Clibanarius zebra

Pachygrapsus crassipes

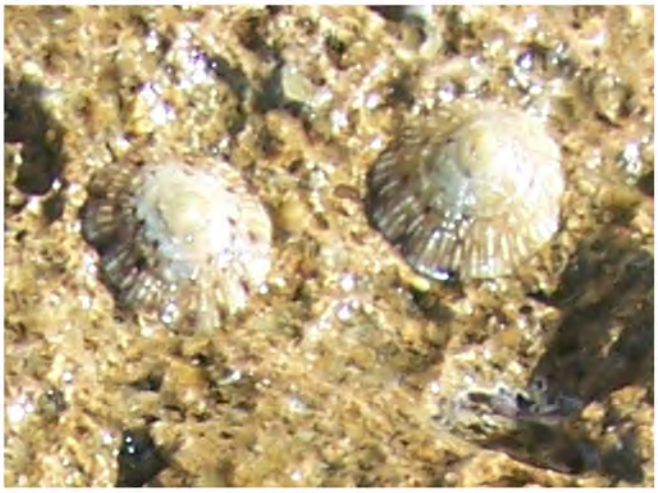
Pilumnus hirtellus

Portunus pelagicius

Plate : 12

Aplysia oculifera

Austrea stellata



Cellana radiata

Cerithium columna

Chiton peregrinus

Conus miliaris

Plate : 13

Cyprea lynx

Onchidium verruculatum

Perpura panama

Siphoneria siphoneria

Tibia insuladchorab

Trochus radiatus

Plate : 14

Turbo coronetus

Turbo intercostalis

Venus reticulate

Antedon sp.

Asterina gibbosa

Ophioderma brevispinum

Plate : 15

Boergesenia forbessi

Bryopsis plumose

Caulerpa racemosa

Caulerpa taxifolia

Udotea patiolata

Ulva lactuca

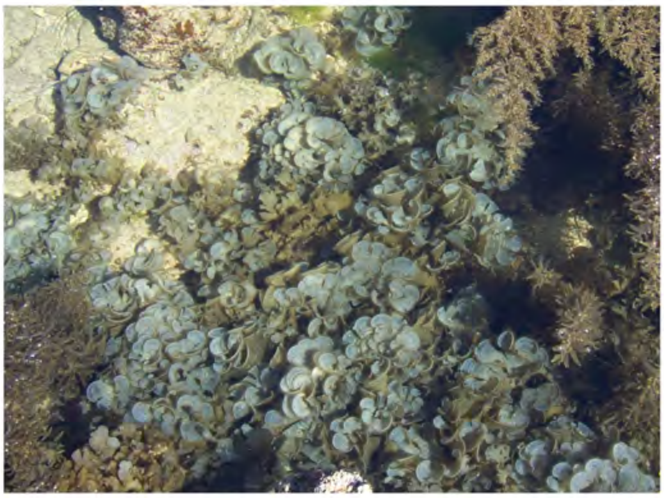
Plate : 16

Colpomenia sinuosa

Cystoseria indica

Sargassum swartzii

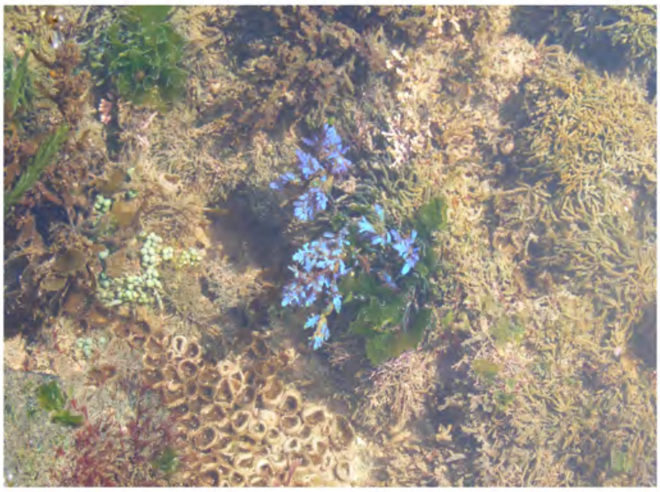
Hydroclathrus clathratus



Padina gymnospora

Stoechospermum marginatum

Plate : 17



Champia indica

Galaxaura oblongata

Gracilaria corticata

Grateloupia indica

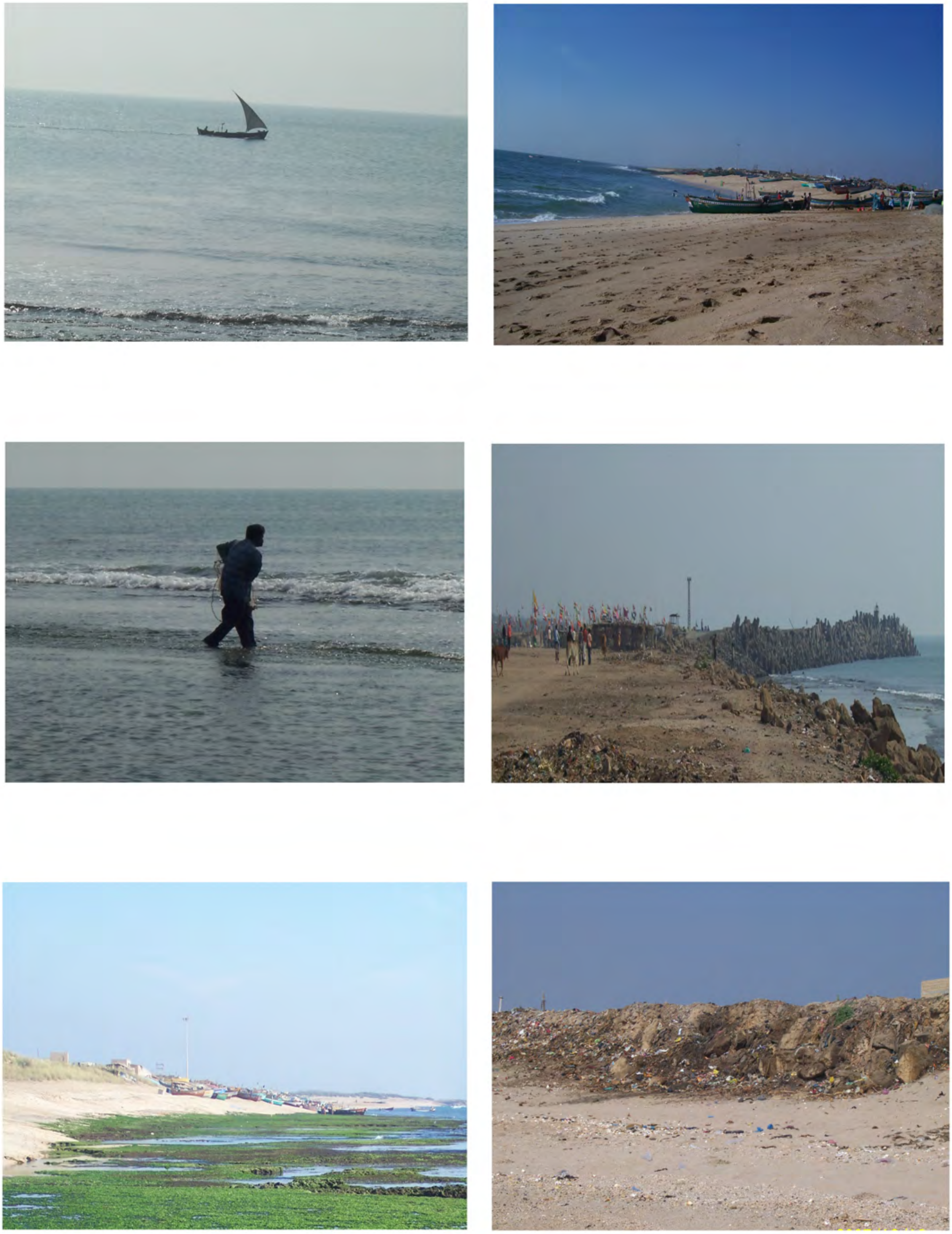
Halymenia venusta

Laurencia papillosa

Plate : 18

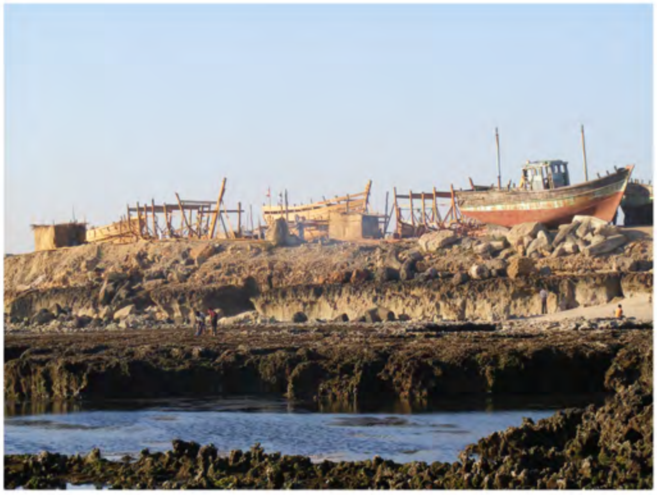
Different anthropogenic activities around Dwarka coast

Plate : 19



Different anthropogenic activities around Mangrol coast

Plate : 20



Different anthropogenic activities around Veraval coast

Plate : 21

Different anthropogenic activities around Kodinar coast