Chapter 1 Introduction

1.1 OVERVIEW

The coast is one of the most scenic, complex and dynamic part of earth's surface lying at the interface between land and sea. To a layman, the coast would be the place where land meets to sea but in scientific terms, the coastal zone is a broad transitional area in which terrestrial environments influence marine environments and in which marine environments influence terrestrial environments (Carter, 1988). The amalgamations of these two different environments have given rise to a unique landscape type, which supports high and fragile biological diversity and productivity (Turner *et al*., 1996). The coastal zone is characterized by various landforms such as sandy beaches, rocky shores, river mouths, estuaries, lagoons, inter-tidal flats, wetlands and barrier islands etc. These landforms are endowed with unique biological communities like mangroves, algae, sea grass and coral reefs. The combination of abiotic and biotic components of the coast and its adjoining inland environment form these unique types of habitats which are rich in natural resources, nutrients and biological diversity (WRI, 2000). Thus, the coast truly acts as a treasure of natural resources.

The dynamic nature of the coast is attributed to natural processes and anthropogenic activities that occur there. Natural processes include oceanographic and geomorphologic factors such as topography, waves, tides, winds, currents and sea level changes-among others which modify the coast continuously at different sites and time scales (Nicholls *et al*., 2007). Time scale is a very important factor. This can change the area in a span of a few minutes to a few years. For example, natural incidents of storms, cyclones or tsunamis modify the coast within a few seconds, minutes or hours depending on their intensity and severity. Compared to these, the phenomenon of sea level change, a natural process requires a decade or longer to show its impact. Another important factor, responsible for bringing changes in coastal areas is anthropogenic influence. This includes the development of concrete structures such as port, jetty, resorts and industries etc. along the coast. In addition to this, at many places, coastal areas becomes dumping sites for solid waste as well as for discharge of municipal and industrial waste. This pollution has not only deteriorated the beauty and quality of coast and its resources but has affected fishery and tourist industries (Clark, 1992). Today, this process of development and modification of the coast has increased to such an extent that no coast in this world is beyond the influence of human beings. This human force has become as powerful as natural forces of change and sometimes even dominates it (Nicholls *et al.*, 2007).

The process of modifying the coast is as old as humanity. The coast always had a great appeal and from the beginning of civilization, it has been one of the preferred places for all developmental activities. This utilization of coast has increased dramatically during the 20th century and a similar trend has continued in to the 21st century as well (Nicholls *et al.*, 2007). The scenic nature of the coast as well as the wealth of natural resources it support are the prime reasons for the attraction and subsequent migration of populations towards coastal areas (Bookman *et al.*, 1999; Anon, 2000; Anon, 2004a). According to Small and Nicholls (2003) about 23% of the world population lives within 100 km distance of coast and population densities in coastal region are about three times higher than the global average. This attraction has resulted in disproportionate expansion of settlements and economic activities such as development of industries, urban centers and tourist resorts. With an increase in population, their needs of food, space for shelter, water and fuel has also increased considerably over time. To fulfill these wants, humans have altered the landscape by indulging in activities such as deforestation, reclamation of wetlands, construction of dams, weirs, channels and jetties. These activities in turn have changed the sedimentary and nutrient cycles, the water circulation pattern and thereby altered the hydrology and land use pattern of an area (Nicholls *et al.*, 2007). All these modifications in the coastal systems may eventually result in complex and non-linear morphological responses (Dronkers, 2005).

A report by the United Nations in 2010 suggests that, the coastal population may increase from 220.7 million in 2009 to 301.7 million people by 2025 (Anon, 2010b). This would create an additional pressure and may cause a rapid decline in quality of the coastal zone. Further, climate change predictions in terms of rise in sea level and sea temperature as well as increase of storm intensity would significantly influence and degraded the coastal environment (McInnes *et al.*, 2003; Nicholls and Klein, 2005; Meehl *et al.*, 2007). In such circumstances, it would be essential to review decisions and developments undertaken on the coast from time to time in order to develop and utilize it and its resources in a sustainable way. Also, in order to preserve the natural habitat and manage human development activities in a balanced way a proper understanding of the interrelationships of the ecosystem's structure, function and its economic value would be needed (Barbier *et al.*, 2008). Thus, a primary understanding of two important components i.e. the land use and land cover and biodiversity would be required to carry out an environmental appraisal of any coastal area.

1.2 <u>LAND USE LAND COVER</u>

'Land' is a key finite natural resource where human beings carry out all their activities including agriculture, industry, forestry, energy production, settlement, recreation and water catchment and its storage. '***Land use***' refers to human activity or economic function associated with a specific piece of land (Lillesand *et al.*, 2007). It is a product of human control over the land resources in a relatively systematic manner. The concept of land use becomes even more significant when dealing with coastal areas. In the coastal area, land itself is a limiting factor and becomes multifunctional to accomplish all human needs (Brandão *et al.*, 2010). The issue of space allocation is even more essential in this zone because of the potential risk of damage from flood and erosion (Filatova and van der Veen, 2006).

The land use of an area is constrained by environmental factors such as soil characteristics, climate, topography and vegetation. Apart from this, the land use is also influenced by - use of land in adjacent areas, social values and norms, human needs and public interest. Thus, land use is basically the result of interactions between a society's cultural background, state and physical needs on one side and the natural potential of land on the other side (Balak and Kolarkar, 1993). Changes in land use reflect history and may also indicate the future of the area. Such changes are always linked with economic development, population growth, technology and environmental change. The relationships among these are much more complex. For example, the rates of land use changes are parallel to rates of population growth, however these rates generally decline locally with increased economic development (Houghton, 1994).

The term '***Land cover***' describes the physical appearance of the earth surface i.e. composition and characteristics of land surface elements (Cihlar, 2000). It provides important environmental inputs for policy making, scientific resource management as well as for a range of other human activities. Land cover differs greatly over temporal frequencies of days to millennia and even at the spatial scale from local to global (Cihlar, 2000).

Many regions of the world have undergone rapid changes in land cover due to human activities as well as natural processes. But among these two, human activity has been the prime reason for alteration of land cover recently (Meyer, 1995; Jensen, 2005). Land cover change is one of the most important parameter for environmental change and represents the largest threat to ecological systems (Foody, 2003). This change in land cover has affected biodiversity, water and radiation budgets, trace gas emissions and other processes that, cumulatively, affect the global climate and biosphere (Anon, 1999; Ayuyo and Leonard, 2014; Yesuf *et al.*, 2015). Thus, land cover has become a fundamental component in current strategies for managing natural resources and monitoring environmental changes (Brandon, 1998).

Land use and land cover are always linked with each other. A change in the former invariably leads to change in the later. Land use land cover change (LULCC) involves interaction of biophysical, ecological, social and human behavioral attributes over time and space (Turner and Gardner, 1991; Riebsame *et al.*, 1994). They have directly or indirectly affected the biotic diversity (Sala *et al.*, 2000), species richness (Kivinen *et al.*, 2007), primary productivity (Feng *et al.*, 2007), soil organic carbon (Yadav and Malanson, 2008), soil erosion (Ni and Li, 2003), hydrologic regimes (He *et al.*, 2007) and local as well as regional climates (Chase *et al.*, 1999). The study of land use and land cover change helps to identify and locate areas that are facing deterioration of natural resources and those that lag behind in economic development. All this information is very important for policymakers to devise methods to improve the economic condition of an area without further deteriorating the environment. Hence, information on the types and patterns of land use and land cover change across spatial and temporal scales is essential for sustainable environmental management and development (Turner *et al.*, 1994). The optimum utilization of land ecosystem resources requires essential knowledge on its topography, extent and location, its quality, productivity, suitability and constraint of various land uses. It is always important to maintain equilibrium of nature by maintaining all types of land use such as cultivable land, forestland, wasteland, wetland etc in a balanced way (Nagamani and Ramchandran, 2003).

1.3 COASTAL VEGETATION

The unique location of the coast allows it to support a high diversity of vegetation. This coastal vegetation comprises of sea grass, algae, mangroves, mangrove associates, salt marsh and strand vegetation (Chapman, 1976). Each of this type of vegetation is associated with a particular type of coastal landforms. For example the strand vegetation is mostly associated with a rocky or sandy coast where as mangrove vegetation is restricted to muddy coasts. In coastal areas, environmental factors like water and nutrient availability, wind intensity, solar radiation, type of substrate, periodic inundation, salinity and hydrology of area control the establishment and development of the different vegetation types (Carter, 1988; Lee, 1989; Costa *et al.*, 1996; Maun, 2004). These factors along with the geomorphology vary greatly and thereby give rise to zonation patterns in the vegetation. The coastal zone is dominated by a few species that have adapted to survive in that environment (Zahran, 1977), but further inland, plant communities show increasing community complexity in terms of species richness, cover, height, biomass etc (Araujo and Pereira, 2004).

Coastal vegetation is of immense value and plays an important role in many environmental processes and provides multiple services to the local human community. It acts as a sediment binder and there by reduces coastal erosion (Kathiresan, 2010). At the time of a tsunami, cyclone or storm surge, it acts as a barrier and forms a live "Green Wall" (Selvum *et al.*, 2005; Thuy *et al.*, 2012). Mangrove and salt marsh vegetation act as a sink for organic carbon and provide nutrients to oceanic ecosystems (Hazelden and Boorman, 1999). They are also able to trap heavy metals and some toxic material and thus act as filter for pollutants (Kathiresan, 2010). They act as a nursery ground for many of the fishes and crabs and provide shelter to a number of birds and animals. In addition to this, coastal vegetation provides food, fodder, medicine, wood, fuel (Bandaranayake, 1999; Kathiresan, 2010). Thus, it holds great ecological as well as economic value.

Despite their immense importance, coastal vegetation is under threat due to the ever increasing developmental activities in coastal areas. The increasing population, economic activities and natural calamities have resulted in an enormous strain on this zone. Changes in land use taking place in the coast, often lead to fragmentation of the landscape, removal and introduction of specific species and the alteration of nutrient and water pathways. Several of these changes are unplanned and mismanaged and ultimately alter the composition of plant communities (Ojima *et al*., 1994). This may lead to decrease or even extinctions of many vulnerable species of flora and fauna from the coastal area (Davenport and Davenport, 2006). Hence, for conserving natural vegetation in its natural state, an indepth study of coastal vegetation, including inventorying and mapping is necessary. Vegetation maps provide information on vegetation dynamics as well as habitat characteristics. They are thus an essential tool in the evaluation, planning and conservation of nature (Provoost *et al*., 2005).

The land use and the vegetation pattern have a close relationship with the geomorphology of an area. Geomorphology is the science of earth-forms and has important applications in the investigation, evaluation and classification of land as a resource (Tage, 2014). Geomorphological knowledge is very crucial for land utilization especially for human habitation, industrialization, agriculture, transport and communication, selection of dam sites etc. For any planning and management activity, knowledge of land use and geomorphology is very important (Tage, 2014). Physiographic formations, soil characteristics, water conditions along with the drainage, altitude, slope, climate etc. are very important parameters in directing the development of any region. Coastal vegetation is also closely related to geomorphology through its dependence on the micro topography and substrate composition of an area. Topography controls the frequency, duration and extent of tidal flooding where as substrate controls soil moisture and availability of nutrients required for the growth of vegetation. Together, these variables have a significant influence on soil salinity and water logging that directly affects the physiology (Chapman, 1974; Etherington, 1975) and distribution of plant species.

Therefore in the present study, different features of the coast such as coastal plant diversity, coastal geomorphology along with its sediment characteristics and coastal land use land cover have been analyzed for selected talukas of 'Bharuch', one of the coastal district of Gujarat state, India.

1.4 STUDY AREA

The state of Gujarat is situated on the western coast of India between 22° 07' N and 24° 43' N latitude and 68° 10' E and 74° 29' E longitude (Anon, 2011a). It has a coastline of about 1650 km (22 per cent of the coastline of India), land area of 196,024 sq. km. (6 per cent of India's land area) and population of 60,383,628 which accounts for approximately 5 percent of total population of India (Anon, 2011b). The state is located on the tropic of cancer and shows sub-tropical type of climate. Two out of the three gulfs of India are found in Gujarat. The Gulf of Kachchh and Gulf of Khambhat covers about 2/3rd (60%) of the total coastline of the state (Anon, 2011c). The coast in Gujarat is distinct from other coasts of the country on account of its shallow depth, wider continental shelf and vast stretches of saline and tidal mudflats.

Ecologically, Gujarat is gifted with a great diversity of natural ecosystem ranging from desert, semi-arid, mangroves, coral-reefs and forests with dry deciduous, moist deciduous and evergreen trees. Gujarat is known for its highly diverse kinds of wetlands which include mangroves, coral reefs, beaches, mudflats, tidal flats, flood plain systems and fresh water lakes and reservoirs. Coastal wetlands dominate the wetlands of the state and are located in the Gulf of Kachchh, Great rann of Kachchh, Little rann of Kachchh, the Gulf of Khambhat and the coast of South Gujarat. They extend over 28070.51 sq. km, contributing about 80.78 % of the total wetland area of the state (Anon, 2010a). In terms of the areal extent of mangrove (Anon, 2013b) and in fish production (Ganapathiraju, 2010) Gujarat stands second in the country which indicates the good wealth of the coastal resources in the state. The state has the presence of 41 ports of which one (Kandla) is a major, 11 are intermediate and 29 are minor (Anon, 2007a). The state witnessed development of several industries and a number of SEZs along the coastal area. The coastal region and its resources thus play a significant role in the economy of the state.

The Gulf of Khambhat (formerly known as Gulf of Cambay) is a south to north penetration of the Arabian Sea on the western shelf of India between the Saurashtra peninsula and mainland Gujarat. It is located between 21° 00' N and 22° 18' N latitude and 72º 15' E and 72º 45' E longitude and covers about 19189sq. km area (Anon, 2011c). Figure 1.1 depicts the location of the Gulf of Khambhat and its surroundings. The Gulf of Khambhat is unique in terms of geomorphology, hydrodynamics and high tidal amplitudes. At its northern end, the Gulf is barely 5-6 km wide and it opens out southwards like a funnel, reaching its maximum width of 200 km to the south of Gopnath point. Its north-south length is approximately 115 km. The water of the Gulf make up a volume of 62,400 million m^3 while the intertidal mudflats and shoals cover an area of about 3,120 km^2 (Anon, 2002). The depth ranges from 18 to 27 m and it decreases towards the coast. The Gulf is characterized by

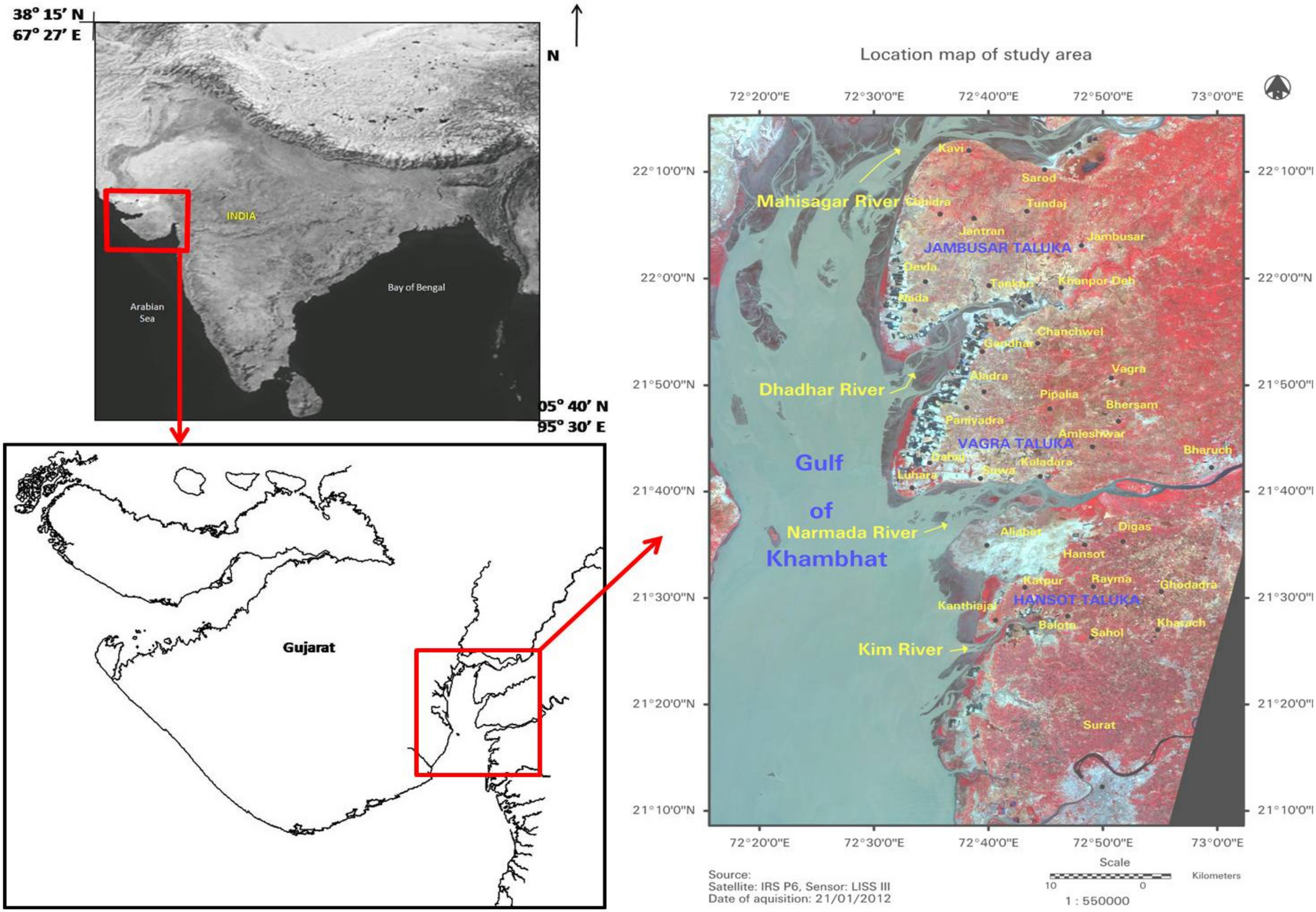

Figure 1.1 Location map of study area

mixed and semi diurnal type of tides with large diurnal inequality. It comprises an area of high tide (up to 11 m) which is the largest amplitude on the west coast and is exemplified by domination of strong tidal currents (Unnikrishnan *et al*., 1999). The gulf is intercepted by several inlets of sea and creeks formed by confluence of major rivers such as Narmada, Tapi, Mahi, Sabarmati and Shetrunji and several other minor rivers. All the major rivers form estuaries and their inflow carries a heavy load of suspended sediments which are responsible for high turbidity in the Gulf of Khambhat (Kunte, 2008). Gulf of Khambhat showed positive water balance, where the sum of rainfall and river run-off is higher compare to evaporation (Iyengar and Bandopadhyay, 2008). The gulf encompasses several ecosystem such as mangroves, salt marshs, estuaries, islands, creeks and vast inter tidal mud flats which supports rich biodiversity (Kunte, 2008).

The present study area is located in Bharuch distirct (formerly known as Broach) which is one of the four coastal districts of the Cambay Basin. It derives its name from "Bhrigukachcha", the residence of the great saint Bhrigu Rishi, which was later abridged to Bharuch (Anon, 1961). The district is located in south central Gujarat and is bound by Anand district on the northern side, Vadodara on the northern eastern side, Narmada on the eastern side and Surat on the southern side. On the western side it is delimited by the Arabian Sea. It is situated between 72° 45' E to 73° 15' E Longitudes and 21° 30' N to 22° 00' N Latitude and covers total area of 6527 sq. km. The population of the Bharuch district in 2011 was 1,550,822 with a population density is 238 per km (Anon, 2011b). The district consists of eight talukas namely Jambusar, Amod, Vagra, Bharuch, Jhagadia, Anklesvar, Hansot, and Valia with a total of 663 villages (Anon, 2001b). Jambusar, Vagra and Hansot are the coastal talukas of the district and have been taken up for detailed study.

1.4.1. PHYSIOGRAPHY

Physiographically, the study area falls under the division 'Main land Gujarat' and sub division, western alluvial plain. It comprises of a thick profile of consolidated sediments deposited by a combination of fluvial and aeolian agencies mainly during the Quaternary period. It occupies the central western half of mainland Gujarat and mainly includes the coastal plains. The altitude on its eastern edge ranges from 25 to 75 m with a gradual seaward slope (Merh, 1995). The eastern parts rise gradually towards hilly areas and provide a somewhat mixed landscape and through alluvium still predominates it gradually merges in to residual deposits. Figure 1.2 shows the physiography of the state.

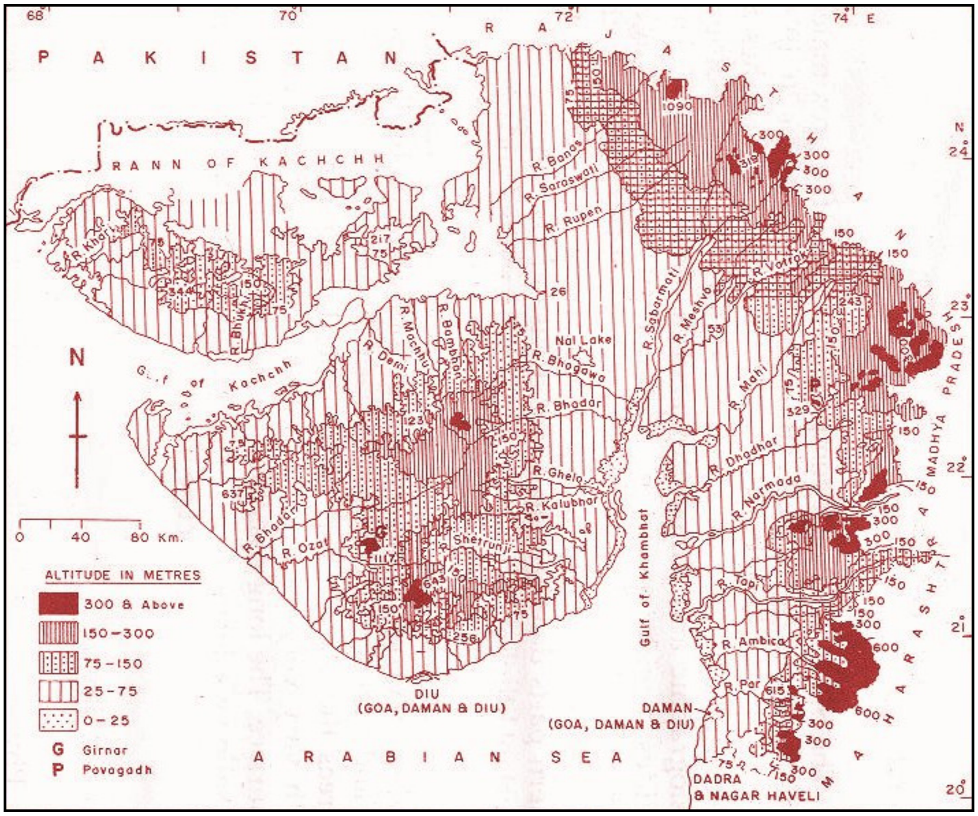

Figure 1.2 Physiography of Gujarat state (Source: After Merh, 1965)

1.4.2 GEOLOGY

Bharuch district is bounded to the north by the south-easterly flowing Mahi River, to the south by River Kim and to the west by Arabian Sea (Figure 1.3). Being made up of more or less deltaic and alluvial portions of land on the north, south-west and west, the configuration of area here is more or less flat with a gentle slope towards the sea i.e. the west.

The recent alluvial tract to the north and west of district consist of silt and sand of Narmada and Mahi Rivers and shore deposits forming sand hills fringing the coast. The thickness of this alluvium would aggregate to several hundred feet and covers rocks of tertiary age. This forms low ground together with banks of larger streams which are at some distance away from the sea and composed of fine, light coloured argillaceous loam, which is occasionally pebbly or gravelly. The Tertiary rocks are spread in gentle undulations over some portion of district from a little north-east of Jhagadia up to Tapti River south of Velachha. West of the tertiary outcrops the

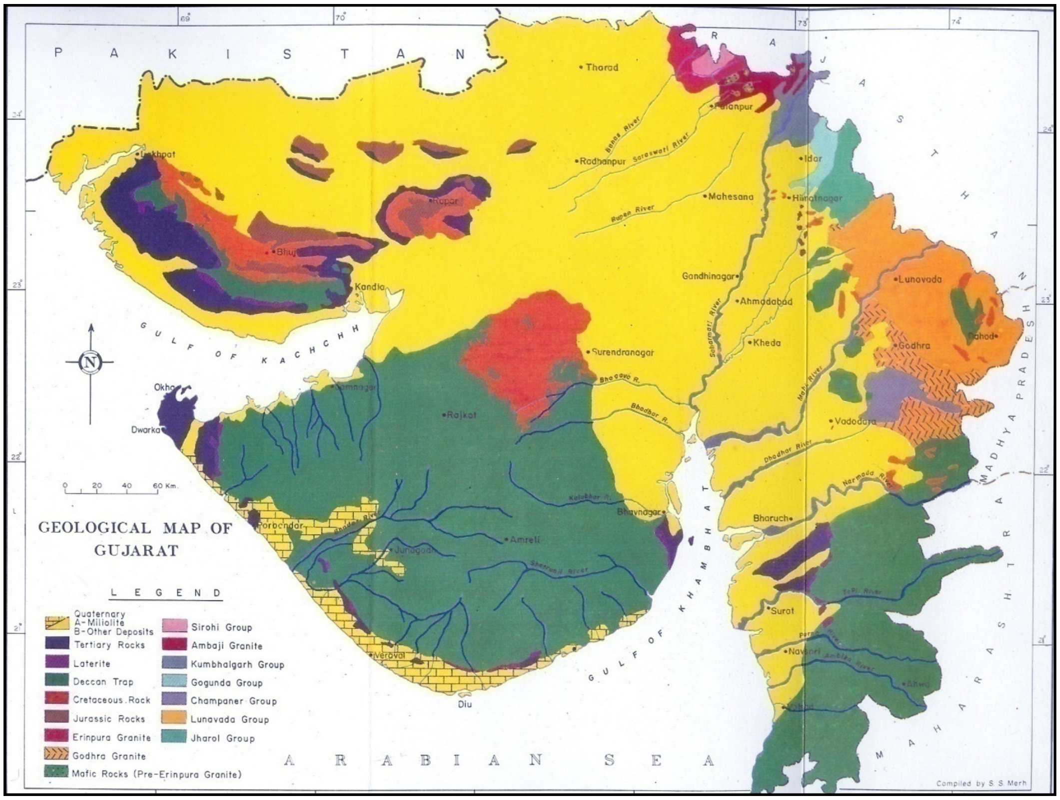

Figure 1.3 Geology of Gujarat state (Source: After Merh, 1995)

area is covered by Deccan lava flows of Eocene age. These lava flows cover the part of Jhagadia and Valia taluka (Anon, 1961).

The coastal segment between the rivers Mahi and Tapi, i.e. Bharuch and part of Surat districts are the main petroleum bearing Tertiary structure off the west coast in the state. Bharuch district comprises of the Jambusar-Broach Block (Block III) and the Narmada block (Block IV) of the Cambay Basin (Chandra and Chaudhary, 1969). The Jambusar block on the northern side is bounded by two basement faults, one along the river Mahi and the other extending NNW-SSE from Mahi (Cambay) to Narmada (Nareshwar), whereas on the southern side, it is lined by Narmada fault, next to which is the Narmada Block (Figure 1.4).

Seismologically, the district falls under zone- III which indicates moderate intensity zone with VII intensity scale. The River Narmada flows along ENE-WSW trending Narmada- Son lineament or fault, which is a well known seismo- tectonic feature (Gupta and Chakrapani, 2007) passing through the district (Figure 1.4).

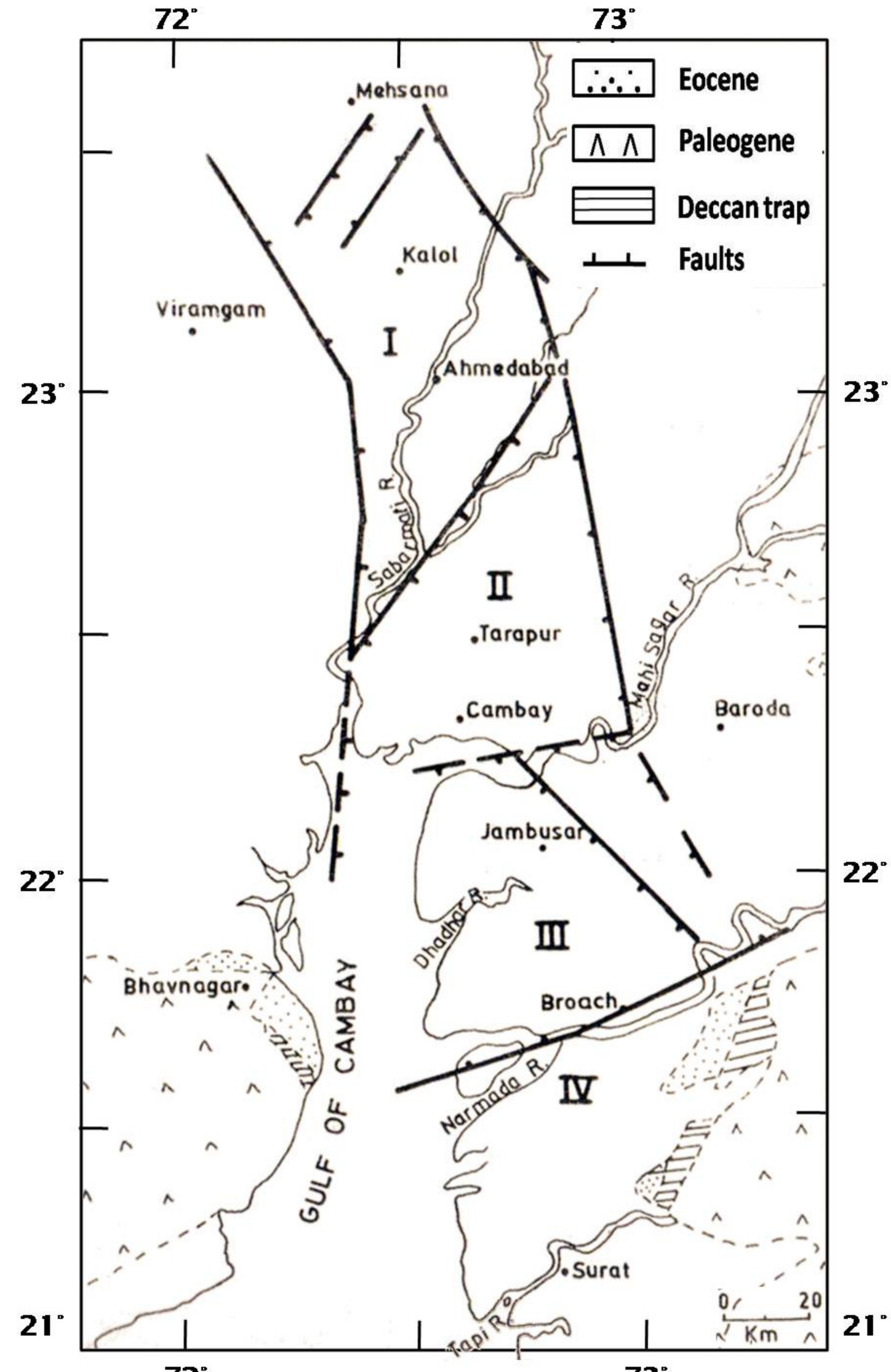

Figure 1.4 Coastal segment map of Cambay basin (Source: Adopted from Chandra and Chowdhary, 1969)

1.4.3 GEOMORPHOLOGY

Geomorphologically, the state is divided in to 3 main divisions namely, Kachchh, Saurashtra and Mainland Gujarat. Bharuch district falls under Main land Gujarat. The coast of main land Gujarat is further subdivided in to Khambhat-Dahej and Hansot-Umbergaon segments. The trend of the mainland coast is almost N-S and diverse landforms are present in both segments.

The northern part of the mainland coast faces the gulf and provides a good example of a drowned alluvial coast characterized by steep, cliffy river mouths. The cliffs rise abruptly to as much as 30 m above the tidal flats (Merh, 1995). The inter-tidal zone is about 3-4 km wide and is mainly composed of silty and muddy sediments. The major rivers Mahi, Dhadhar and Narmada that flow in to gulf show broad estuarine river mouths, mud-banks and mouth bars.

South of Narmada River, the coastal geomorphology changes abruptly. The coastline is sandy between Hansot and Umbergaon and shows estuarine river mouths, open mudflats, raised mudflats, alluvial plains and islands. The coastline differs greatly from the northern part in having inland sandy-ridges parallel to the coast. These ridges reflect the past high sea levels (Merh, 1995). The shoreline in this part is highly dissected and replete with small estuarine creeks along which tidal water spreads inland.

1.4.4 CLIMATE

The tropic of Cancer passes through the northern border of Gujarat due to which the state has an intensely hot or cold climate. Climate is dry in the northern districts and moist in the southern districts. Gujarat can be divided in to five climatic zones of which the Bharuch district comes under the sub humid and the moderately humid climatic zones (Merh, 1995).

1.4.4.1 Rainfall

The south-west monsoon is the major source of rainfall in Gujarat. The average rainfall varies from 330 to 1520 mm and as we move from North to South in the state, the rainfall increases gradually. The rainfall pattern of the state is thematically represented in the isohyte map of Gujarat State (Figure 1.5). The rainfall of Bharuch district for year 2013 was 1263.13 mm (Anon, 2014b).

1.4.4.2 Temperature

The temperature distribution in the state shows high variability and is characterized by a dry northwest along with, hot summers and cold winters. Summer begins in March and lasts till May during which temperature ranges from 27° - 42° C and is known to have temperature as high as 45°C. Winter is from November to February during which temperature ranges between 14° - 29°C. May is considered to be the hottest month where as January is considered to be the coldest month of the year. On account of the proximity of Bharuch district to the Gulf of Cambay in the west the severity of climatic extremes is moderated.

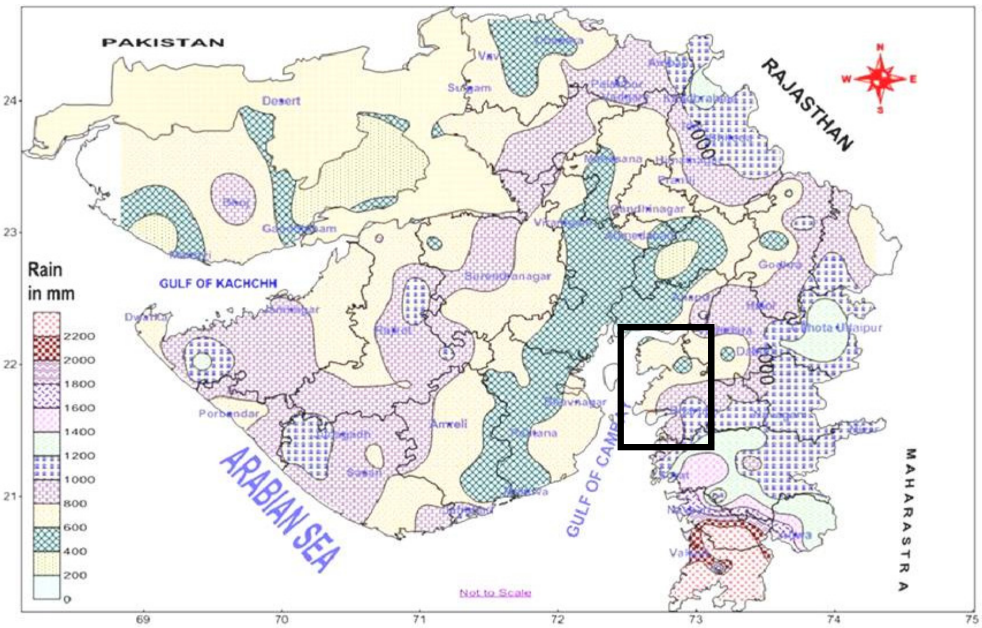

Figure 1.5 Isohytes of Gujarat state for year 2011 (Source: Anon., 2011f)

1.4.4.3 Wind Pattern

The wind pattern in this area is predominantly seasonal with rare cyclonic disturbances. Predominant wind directions in this area are west–south-westerly and north–north-easterly during the months June to September and December to March, respectively. Higher wind speeds are likely to occur during April to July (up to 7 to 8 m.p.h.) and lowest in November (2 to 3 m.p.h) (Anon, 1961).

1.4.4.4 Humidity

Bharuch, being a coastal district shows high humidity in comparison to the inland districts. However, humidity varies from season to season and even throughout the day. During monsoon humidity is very high which decreases in summer and winter. Relative humidity is high during early morning which varies from about 60% in winter and about 85-90% in monsoon months, whereas minimum value is recorded in the afternoon which is about 20-25% in winter with about 70% during monsoon periods (Anon, 1961).

1.4.5 TIDES AND CURRENTS

In the gulf, mixed semi-diurnal type of tide is observed which shows large diurnal inequality and varying amplitude that decreases from north to south. Because of its proximity to the tropic Cancer, Gujarat coast experiences very high tides; the highest anywhere along the Indian coast (Anon, 2002). Because of the funnel shape and semi-enclosed nature at head, tidal height increases tremendously in the upstream. Mean tidal elevation during spring is 4.7 m at Mahuva Bandar which rises to 6.5 m at Gopnath Point, 10.2 m at Bhavnagar, and 10 m at Bharuch. The maximum spring tide recorded at Bhavnagar is 12.5 m, which is the second highest tide recorded anywhere in the world (Anon, 2002). The average annual tidal level (from 2007-2009) at Bharuch (Dahej station) is depicted graphically in Figure 1.6 (Anon, 2011d). The Gulf has huge inter-tidal expanses of 1.5-5 km, which are perhaps the widest along the Indian coast and they get exposed during low-tide.

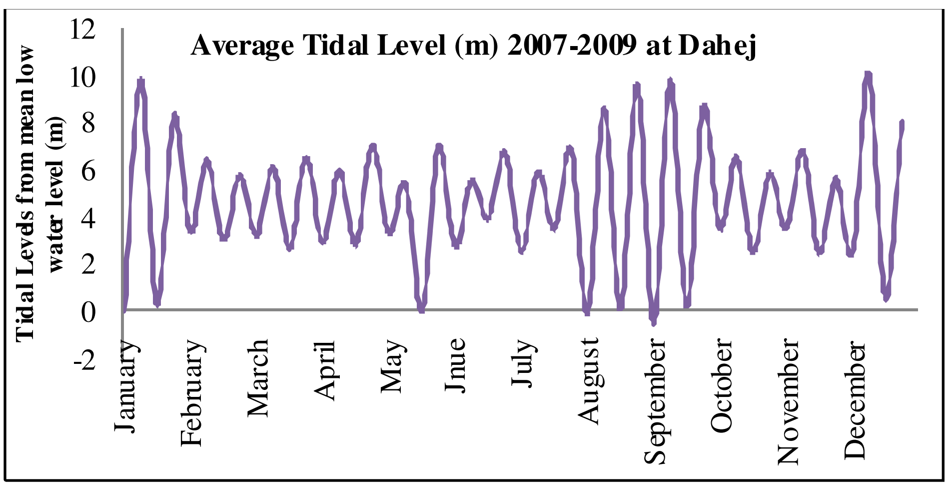

Figure 1.6 Average Tidal level at Dahej, Bharuch District (Source: Anon, 2011d)

Long-shore currents with low wave action dominate the open coasts along the Arabian Sea. However, due to exceptionally strong flood and ebb tides, powerful tidal currents with a speed of 3 to 4 knots dominate the flow. Maximum velocities of 6 knots associated with high wave energy occur during mid-tide. The currents in the Gulf are either tidal or monsoonal in origin and are dominated by barotropic tides (Unnikrishnan *et al.*, 1999). The flow adjusts its directional orientation with changing direction of wind which is in turn affected by changing seasons of the year. The direction of tidal current is from south to north during flood tide which reversed during ebb tide (north to south) (Figure 1.7). The turnover residence times are quite short because of its shallow depth, large tidal amplitude and strong tidal current (Anon, 2002).

1.4.6 DRAINAGE

Drainage is a reflection of terrain characteristic and is controlled by physiography, climate and tectonic framework (Merh, 1995). Rivers in different physiographic zones

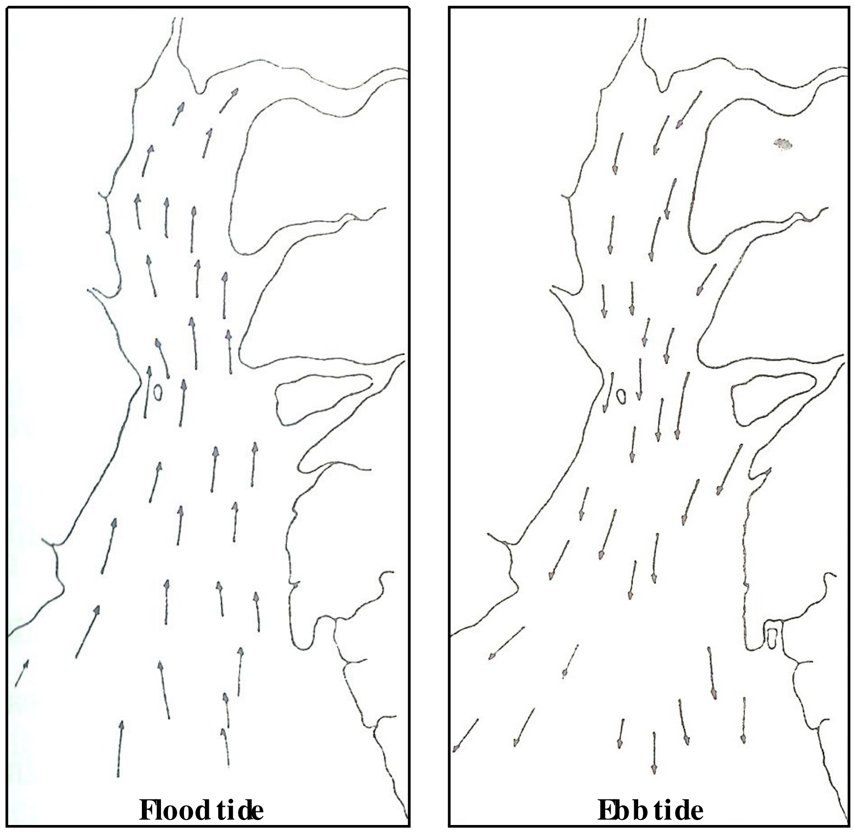

Figure 1.7 Current pattern in Gulf of Cambay (Source: After Nayak and Sahai, 1985)

behave differently and show striking diversity. Sabarmati, Mahi, Dhadhar and Narmada are major rivers that debouche into the Gulf of Cambay. Mahi marks the northern limits, Dhadhar is about 20 miles south of Mahi, Narmada in the centre while Kim is the southern limit of the district. Details of each of these rivers are given in Table 1.1. Drainage on the eastern side of Gulf is active while inverse is the case on the western side. The drainage pattern is highly dendritic forming a large number of tributaries. Figure 1.8 illustrates the drainage map of the state.

The principal rivers have a parallel flowing pattern and geologically they have developed the alluvial plain of South Gujarat of which Bharuch district is a part. The extensive depositional features are now marked with equally extensive erosional

Name of River	Origin	Latitude and Longitude	Catchment area	Tributaries	Length	Drainage area	Other details
Mahi	Vindhyachal Range, Dhar district, Madhya Pradesh	21° 46'N - 24° 30'N 72° 21'E - 75° 19'E	Madhya Pradesh, Rajasthan and Gujarat	Eru, Nori, Chap, Som, Jhakham, Moran, Anas, Gomti, Bhadar River	583 km	34,842 Sq. km	Third largest west-flowing peninsular river
Dhadhar	Pavagadh Hills, Gujarat	21° 45'N - 22° 45'N 72° 30'E - 73° 45'E	Gujarat	Vishwamitri, Jambuoa, Dev and Surya River	142 km	3423 Sq. km	Navigation is possible for short distance (from mouth till Tankari village)
Narmada	Satpura range, at Amarkantak, Anuppur district, Madhya Pradesh	21° 20'N - 23° 45'N 72° 32'E - 81° 45'E	Madhya Pradesh, Gujarat, Maharashtra and Chattisgarh	Barna, Ganjal, Chhota Tawa, Hiran,Jamtara, Kolar,Orsang, Sher and Tawa River	1312 km	98796 Sq. km	The Largest west-flowing river in the peninsula Navigation is confined to Gujarat part and possible from the mouth till Jhagadia (Big vessels) or Gora (small vessels)
Kim	Rajpipla hills in Narmada district, Gujarat	21° 19'N - 21° 38'N 72° 40'E - 73° 27'E	Gujarat	Tokari and Ghanta River	107 km	1286 Sq. km	Navigation is not possible Water is not used for irrigation

Table 1.1 Details of rivers draining in the Bharuch district (Source: Compiled from Anon, 1961; Singh, 2005 and Anon, 2006b)

features mainly due to change in sea level and resumption of erosive action of the streams (Anon, 1961). Thus, the large alluvial plain has been extremely dissected by gully erosion and deep cut channels (Anon, 1961). The rivers and their tributaries are often marked by a network of ravines formed by the force of their waters. This denudational action accounts for the intense soil erosion and the difficulties in bringing agricultural areas under irrigation. All the rivers of Gulf of Khambhat being

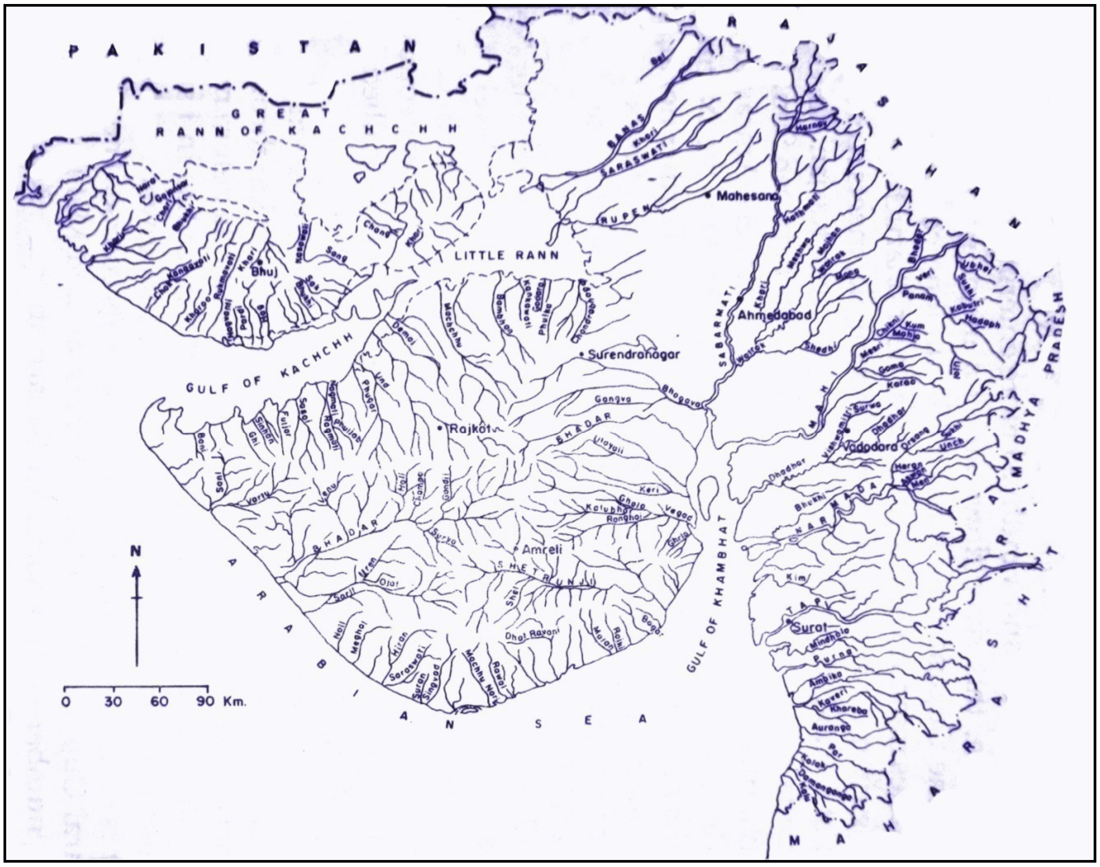

Figure 1.8 Drainage pattern of Gujarat State (Source: After Merh, 1995)

perennial in nature bring good amount of sediments which is responsible for the high degree of turbidity in the Gulf of Khambhat. Concentration of sediments observed at Dahej ranged from 211.6 to 1,174 miligrams per liter (mg/l) during ebb tides and 205.6 to 1,929 mg/l during flood tides (Anon, 2006a). The flow of water in most of rivers is now controlled by the construction of the dams, weirs or barriers on the main stream. The water is then used for irrigation as well as domestic purposes.

1.4.7 SOIL TYPE

The soils of Gujarat have been classified in to Entisols, Inceptisols, Vertisols, Aridisols and Alfisols. Of these, the study area mainly shows Vertisols type of soil.

Vertisols are mainly confined to uplands, piedmont plains, flood plains and intervening valleys. This type of soil is locally known as ‘Regur’ or black cotton soil. It is generally deep black in colour, but may show variation from dark brown to very dark grayish brown colours (Merh, 1995). Vertisols occur under semi-arid to sub-humid and humid climates with annual precipitation ranging from 500 to 2000 mm and mean annual temperature of 26 ° to 27 °C. The depth of the soil varies from 50 cm to as high as a few meters. This soil is neutral to alkaline in nature and classified as Chromustrts and Usterts (Merh, 1995). It is mainly clayey soil with monotmorillonitic mineralogy that has high shrink-swell property. Based on the agricultural crop type, the soil of Bharuch district is categorized in to five different types,

- Black Cotton (used for cultivation of jowar, paddy, wheat, gram, peas, sesamum and cotton)
- Gorat (for cultivation of paddy, pearl millet (bajri), Kodo millet (kodra), pigeon pea (tur), green gram (mug), kidney bean (math), sesamum, ground nut)
- Bhatha (crops like Jowar and Tobacco and vegetables - Bottle guard (Dudhi), bitter guard (kareli), tomatoes, Brinjal)
- Kyari (richest soil used for paddy, wheat and gram production)
- Stony soil (covered by forest cover).

1.4.8 FLORAL AND FAUNAL DIVERSITY

The unique geographical location of Bharuch district is one of the major reasons for the presence of diverse ecosystems. These include coastal area (coastal ecosystem) on the western side and hilly area (forest ecosystem) on the eastern side, making the district biologically highly diverse.

The district shows good plant diversity. The forests are mostly restricted to hilly region of the Jhagadia and Valia taluka and covers 5% of geographical area. These forests falls under, dry deciduous type which are further divided in to two sub types, dry teak forests and other dry mixed deciduous forest which merge in to one another imperceptibly. *Tectona grandis* (Teak) is a principle species followed by *Anogeissus latifolia* (Dhamodo), *Terminalia tomentosa* (Sadada), *Diospyrus melanoxylon* (Timru), *Acacia catechu* (Khair), *Dalbergia latifolia* (Shisham), *Cassia fistula* (Garmalo), *Eugenia zeylancia* (Jambudi), *Pterocarpus marsupium* (Bio), *Madhuca indica* (Moha) etc (Anon, 1961). The common plants of the district comprise of *Acacia nilotica*, *Azadirachta indica*, *Caesalpinia pulcherrima*, *Capparis decidua*, *Cassia auriculata*, *Clerodendrum multiflorum*, *Derris indica*, *Emblica officinalis*, *Ficus benghalensis*, *Grewia tenax*, *Gymnosporia montana*, *Jatropha curcas*, *Kirganelia reticulata*, *Mimosa cineraria*, *Peltophorum pterocarpum*, *Prosopis juliflora*, *Salvadora oleoides*, *Salvadora persica* and *Zizyphus jujuba* (Anon, 2011c). The coastal ecosystem shows the presence of mangrove vegetation (*Avicennia marina*), salt marsh vegetation (*Suaeda sp.*, *Sesuvium sp.*), mangrove associates (*Salvadora persica*, *Salvadora oleoides*), dune vegetation and other land vegetation.

In terms of fauna, about 31 mammals, 9 reptiles, more than 25 species of fishes and approximately 250 species of birds are recorded from Bharuch District (Anon, 1961). The common mammals include *Felis chaus* (Jungle Cat), *Hyaena striata* (Hyaena), *Herpestes mungo* (Indian mongoose), *Canis Lupus* (Indian wolf), *Vulpus bengalensis* (Indian Fox), *Canis aureus* (The Jackal), *Pteropus giganteus* (Bat), *Mus Booduga* (Field mouse), *Hystrix leucura* (Indian Porcupine), *Bosolphus tragocamelus* (Nilgai) etc. whereas, the common reptiles are Crocodile, Chameleon, Iguana, Tortoise, Snakes mainly- *Bungarus caeruleus* (Common Krait), *Vipera russelli* (Russell's viper) and *Echis carinatus* (Saw scaled viper) etc. Approximately 250 species of birds have been recorded in Bharuch which include *Columba livia* (blue rock pigeon), *Sypheotides aurital* (Lesser florican), *Pavo cristatus* (Pea fowl), duck, Sarus crane, the common crane, *Numenius arquatus* (the curlew), Spoon-bill, Storks, King-fisher, *Ploceus philippinus* (weaver birds), Indian parakeet, doves etc. Apart from these few birds other birds such as- *Anas poecilorhyncha* (spot-bill grey duck), *Dafila acuta* (the pin-tail), *Chaulelasmus streperus* (the gadwall), *Anas platyrhyncha* (the common wild-duck), *Spatula clypeate* (the shoveller) etc. are migratory birds found in the district. Fishes, based on their habitat, they are broadly divided in to 3 categories: marine, estuarine and fresh water. Bombay duck-*Harpodon nehereus* (Bumla), *Sciaena diacanthus* (Ghol), *Polynemus* sp. (Cheval), *Polynemus terrasactylus* (Ravas), *Lates calcarifer* (Gari), *Arius* sp. Large cat fish (Dharawa), Prawns (Cholla), *Clupea* sp. (Phansti), Skate (Varkhal), Crabs (Karachla), *Sciana* sp. (Dhagari), young pomfret (Pipad) etc. are the marine fishes whereas, *Hilsa toil* (Modar), *Bolcophthalamus* sp. (mud skeeper- levti), small cat fish (Tarolia), small coloured crab (Kamal Karachala), Stone crab, Sharks (Magara) are estuarine fishes and *Labeo rohita* (Rau/ Rohu), *Cirrhina mrigala* (Nagari), *Mystus seenghala*

(Shingala), *Palaemopn* sp. (large prawn (Sondiya)) are the fresh water fishes. Thus, Bharuch has a rich biological diversity in terms of both flora and fauna.

1.4.9 COASTAL POPULATION AND SOCIO ECONOMIC STRUCTURE

As per the Census data of 2011, the district population is 1,550,822 of which 66% is rural and 34% is urban. Of this, the coastal population contributes 20.31%. Bharuch has about 887 primary schools, 285 secondary and senior secondary schools and 15 colleges (Anon, 2013a). This progress in education sector has ranked the district at 8^{th} position in the state with a 83.03% literacy rate. The district has a number of primary health centers, sub health centers, dispensaries and civil and private hospitals. The availability of drinking water facilities, power supply, good road network and telephonic communication, facility of banks and commercials has resulted in a healthy socio-economic structure of the district. For transportation, state transport buses provide efficient service. Buses, taxies and three-wheeler auto-rickshaws ply on all the routes. Apart from this, all most all talukas of Bharuch are well connected with rail network and the main Bharuch town is connected by broad gauge to all the major stations of the state. Bharuch is a leading district in agriculture sector as a result of the fairly good rainfall and the development of a good canal network. The district and its surrounding area have the presence of a large number of tourist places such as Bhrigu Rishi temple, Garudeshwar, Nareshwar, Swaminarayan temple, Kabir-Vad, Shuklatirth, Stambheswar mahadev temple etc. which has developed good tourism in the district.

Bharuch also has a formidable industrial base in diverse sectors such as chemicals, petrochemical, textiles, drugs and pharmaceuticals, port and ship building. It has several industrial estates and special economic zones (SEZs). Apart from these, the passage of DMIC (Delhi Mumbai Industrial Corridor) is expected to fuel industrial and economic growth of district. The district also possesses good mineral wealth. The availability of minerals such as lignite (52% of the state's total), silica sand (92% is from the district itself), fuller's earth, agate (rarely occurring mineral and available only in Bharuch), limestone and calcite have resulted in the development of several mineral based industries in the district (Anon, 2013a). The port industry near Dahej provides excellent facilities and makes it an investment destination in port and ship building activities. Several private companies like Indo-Gulf, Gujarat Chemical Port Terminal Company Ltd. (GCPTCL) and Petronet LNG Ltd. have developed their facilities in and around Dahej port. It's ideal location in

Asia to serve north, west and central India and international destinations such as Middle East, Africa, Europe and North America has propeled the growth of port industry in Dahej. Thus in Bharuch, after Ankleshwar, Vagra taluka is expected to become the next industrial hub.

Bharuch, thus shows development in all the sectors including education, health, transportation, road networking, communication and industrial.

1.5 NEED OF STUDYING LAND USE LAND COVER AND COASTAL VEGETATION OF THE BHARUCH DISTRICT

The high rate of industrialization and developmental activities along the coast of Bharuch district has created an urgent need to monitor the coast. Unplanned and random development along the coast may cause serious damage to the coastal ecosystem by putting an additional pressure on the ecosystem in general and coastal resources in particular. Coastal vegetation plays an important role in the well being of coastal ecosystem as well as humans. Hence, there is an urgent need to continuously monitor it in order to protect the coast, human lives and their assets.

1.6 AIM AND OBJECTIVE

Keeping the significance of land use land cover and coastal vegetation in mind and the need to incorporate them in any sustainable development activity of the area so that there is minimal damage to the coastal environment, the present study was initiated. The main objectives of the present study were:

1. Mapping land use land cover changes of the coastal talukas of Bharuch District
2. Studying the diversity of coastal vegetation
3. Monitoring mangrove of the coastal talukas
4. Physico-chemical analysis of coastal sediments
5. Preparation of coastal geomorphological map
6. Identifying main drivers of the changes

1.7 BRIEF METHODOLOGY

Coasts are highly dynamic and become vulnerable with increase in coastal population, anthropogenic activities and natural calamities. Hence, it is essential to have scientific data on coastal wetlands, land use, land forms, shoreline and water quality at periodical intervals to ensure an environmentally effective coastal zone management. Data for this can be obtained by two different methods: 1) through conventional ground methods and 2) through use of geospatial tools. Conventional ground methods of mapping different land forms are labour intensive, time consuming and infrequent. Such generated maps soon become outdated with passage of time, especially in the rapidly changing coastal environment (Maiti and Bhattachrya, 2011).

Alternatively geospatial tools, including remote sensing and geographic Information System (GIS) can be used. Remote sensing technique because of its multispectral, synoptic and repetitive capabilities has increased its application in creating the baseline inventory of coastal wetlands, coral reef, mangroves, studying land use land cover changes, monitoring shoreline line changes and protected areas, estimating suspended sediments concentration (Nayak, 2004).

In present study both these methods have been used to bring out changes in land use land cover, to monitor mangrove and to study diversity of coastal vegetation. The methodology broadly, divided into three components:

1. Field surveys: For studying diversity of coastal vegetation, collection of mangrove sediments and accuracy assessment of maps
2. Lab analysis: Identification of plants, analysis of sediments
3. Geospatial analysis: Analysis of the satellite data, Mapping the land use land cover, change detection analysis

The detailed methodology used is discussed in the methodology chapter.