"ENVIRONMENTAL APPRAISAL OF MANGROVE WETLANDS BETWEEN MINDHOLA AND VAROLI ESTUARY (SOUTH GUJARAT) USING REMOTE SENSING"

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CHAPTER 1: INTRODUCTION

1. OVERVIEW

Coasts are often highly scenic and contain abundant natural resources. People have always been fascinated by the coast. The majority of the world's population lives close to sea. As many as 3 billion people (50% of the global total) live within 60 kms of the shoreline. The coast plays an important role in global transportation and is the destination of many of the world's tourist (Woodroffe, 2002).

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). It's a dynamic system, affected on a daily basis by marine and sedimentary processes and the related effects of changing weather systems.

Many species are adapted to these unstable habitats, having evolved strategies to either adapt or take advantage of changing substrates. Typically, such areas include a mosaic of habitats from bare sediment to stabilized and vegetated. One of the exceptional ecosystems which occupy this fringe habitat is the coastal ecosystem. It forms one of the most unique ecosystems as it is influenced by both terrestrial factors as well as marine factors.

The highly productive coastal ecosystems of the tropics play a crucial role in the economic and social development of the region (Nayak and

Bahuguna, 2001). The major vegetation types in this zone include seagrass, macro and micro algae, vegetation on sand patches, salt marshes and the highly productive mangroves. Mangrove ecosystems are important, both in terms of the aquatic food web they support and the nutrients they export to coastal waters and terrestrial wild life such as migratory birds. They also protect coasts, dampening wave activity and helping to disperse and filter water flows from inland. Mudflats, salt marshes and mangroves are significant for two reasons. First, they are productive ecosystems which contribute to the broader near-shore food web, a process termed as out-welling. They also provide habitats and perform a nursery role for a wide range of species that have a high rate of primary production. Second, they are areas of fine sediment build up and preserve a record of changing environments within their sediments (Woodroffe, 2002). They play a significant role in coastal stabilization and promoting land accretion, fixation of mud banks, dissipation of winds, wave and tidal energy. The importance of the mangrove vegetation can be gauged from the fact that nearly 80% of the fish catches are directly or indirectly dependent on mangrove and other coastal ecosystems worldwide (Kjerfve & Macintosh, 1997). Mangroves are unique because they are a gift of the tides along low-lying tropical and occasionally subtropical coastal areas, along the margins of estuaries, deltas, coastal lagoons, and brackish tidal waters in general. The species of mangroves, like those of other marginal ecosystems, can tolerate extreme environmental conditions which enable them to keep out

by competitive exclusion other species of plants and animals that do not tolerate such extremes (Vannucci, 2001).

Geomorphology is the study of landforms and coastal geomorphology is concerned primarily with different types of coastal landforms and understanding the factors that shape them. Explaining the geomorphological changes that are occurring on the coast is becoming increasingly important in order to manage coastal resources in a sustainable way. Physical processes, including both hydrodynamics and aerodynamics, are influenced by the substrate and the biota (plants and animals) growing on it. Geomorphological processes are also closely related to ecological processes. Sedimentation rate is likely to be spatially variable on muddy coasts, and coastal vegetations can cause more rapid deposition as a result of slowing down the velocity of the water flow. Vegetation can modify estuarine morphodynamics through its effects on sediment trapping and through its influence on the shear strength of channel banks (Woodroffe, 2002). Many workers (Woodroffe, 1992; Wolanski *et al.* 1992; Wolanski 1994, 1995; Furukawa *et al.* 1997; Kathiresan, 2003) hold the belief that the complex root systems of mangroves help in trapping the sediments and stabilizing the banks and the landforms they harbor.

To verify this, mapping of the coastal landforms was also undertaken in the present work, as many changes in the recent past has been observed in the coastal landforms of the study area, especially the formation of numerous channel and mouth bars in the rivers of the study area.

Thriving at an interface of land and water, which is to say in a complex habitat, mangroves however pose problems when it comes to study them. This is due to the fact that they occupy the muddy habitats of the coastal ecosystem and to that, their physical adaptations, i.e., their roots, grow in such a way that it becomes near impossible to traverse through a dense patch of mangrove. Studies employing remote sensing have proved to be very useful in such locations (Nayak *et al.*, 1992; Navalgund and Bahuguna; 1999; Green et al., 2000). A tool like remote sensing provides information about the subject from a distance, from an overhead perspective, without getting into direct contact. Habitat maps derived using remote sensing techniques are widely and increasingly being used to assess the status of coastal natural resources and as a basis for coastal planning and for the conservation, management, monitoring and valuation of these resources (Green et al., 2000). Remote sensing data has been very useful in mapping the mangroves density-wise (Nayak *et* al., 1992). Hence the use of satellite data for the present study was imperative, to generate thorough information on the mangrove habitats.

Here, the remote sensing technique was essentially employed to bring out the diversity (i.e. community zonation), for determining the areal extent and to detect the changes over the time in the mangrove wetlands.

1.2 MANGROVES

Mangroves are unique ecosystems. As a source of renewable resources, they are second to none in terms of its natural productivity and the wide range of goods and services they provide on a continuing basis.

Due to pressures from growing populations, which lead to changes in land use and over-utilization of the resources, mangroves are being rapidly depleted and degraded. A balance needs to be struck between meeting increasing present-day needs, on one hand, and conserving the environmental support system provided by the mangrove forests, on the other.

Growing awareness of the protective, productive and socio-economic functions of tropical mangrove ecosystems, and of the consequences of their deterioration, have highlighted the need for the conservation and sustainable, integrated management of these valuable resources. Mangroves have multiple-use potential, thus it is imperative that the management of mangrove based terrestrial and aquatic ecosystems be undertaken within the context of integrated coastal area management planning (FAO, 1994, 2007).

Mangroves dominate approximately 75% of the world's coastline between 25º N and 25º S latitudes (Wong and Tam, 1995). Mangroves occur in all coastal states and union territories of India to a larger or smaller extent. The mangroves in West Bengal represent the Indian part of the mangroves of the Sunderban, which are the largest single block of mangroves in the world. With a mangrove cover of 1046 sq km (Anon.,

2009), Gujarat stands second to West Bengal. The mangroves of Gujarat are distributed in three major regions, viz., the Indus delta, the Gulf of Kachchh and the Gulf of Khambhat. The mangroves of Gulf of Kachchh have received maximum attention till date, as they are considered to have the highest diversity of mangroves among the mangroves of Gujarat (Blasco 1975, Chavan 1985, Singh 2002, 2006 and Untawale, 1988). Nevertheless recently, a few research workers and research organizations have realized the presence and importance of the lesser known mangrove regions of Gujarat, especially the mangroves of south Gujarat.

1.3 INDUSTRIAL SET-UP

Ever since it's inception in 1960, Gujarat has followed a strategy focused on industrialization and urbanization with an open door policy. Economic reform measures introduced by the Central Government with an explicit emphasis on trade and industry have considerably benefited Gujarat, making its economic performance outstanding.

In the post - reforms period, Gujarat, in particular, has witnessed high growth in sectors like, chemicals and petrochemicals, engineering, agro and food processing. The specific instruments used by the State Government of Gujarat to promote economic growth through the private sector include tax and cost –related incentives, provision of infrastructure & input supplies, approvals and clearances for industries and land market reforms (Menon, 2008).

The Golden Corridor, a chemical industry belt set along the Western Express Highway between Vapi and Ahmedabad, a distance of over 200 kms, was created as a tax haven for the industry by the Gujarat government about 20 years ago. Financiers recovering from Bombay's textile strike quickly jumped onto the bandwagon and with a very limited understanding of the chemistry involved, set up units and factories to manufacture some of the most dangerous man-made chemicals. Today, even as individual units and factories are shutting down, the pollution of land, air and water by the release of chemical compounds over these many years has left a trail of ecological devastation (Yashwant S; www.infochangeindia.org).

The development of the Delhi-Mumbai Industrial Corridor (DMIC) is a key opportunity for attracting investments into Gujarat. The total length of the corridor is 1,483 km, of which Gujarat has a major share of 564 km (38 per cent). The DMIC influence area in Gujarat comprises 62 per cent of the total area (18 districts out of 25) and 74 per cent of the total population (37 million) (Anon., 2008).

With the numerous industries and the Special Economic Zone (SEZ) the industrial development in Gujarat is still at the threshold of the full-fledged development, it is to witness (Anon., 2009) (Figure – 1.1).

However, with so much development on the land, a limited commodity, the developmental activities are shifting the pressure on the coastal areas. This to a greater extend is also contributed to the vast coastline of Gujarat 1600 kms.

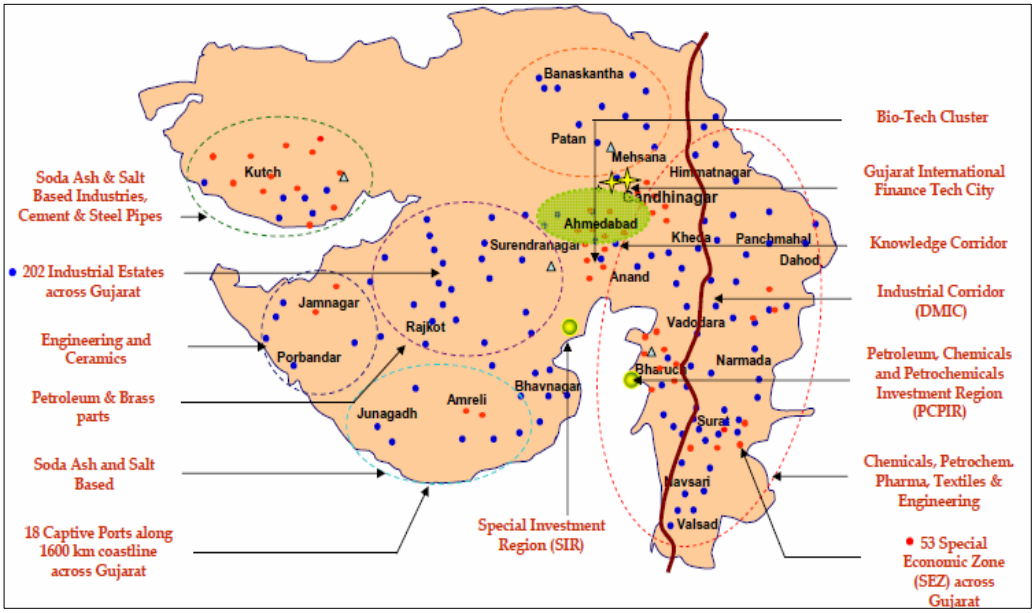

Figure 1.1 – Industrial zones of Gujarat (Source: Anon., 2009)

1.3.1 Ports development

Gujarat's coasts have always been India's global gateways for trade and commerce. The ports of Gujarat form a natural gateway for the land-locked north and north-central states of India, who's combined Gross State Domestic Product (GSDP) constitute almost 25 per cent of India's total GDP. The strategic position of Gujarat on the West Coast of India and its proximity to the Middle East countries helps it to service the vast North and Central Indian region. In order to avail of maximum advantage, the state has developed 41 ports including the major port at Kandla. Among the 185 minor and intermediate ports in India, 40 minor ports are based in Gujarat (Anon., 2011) (Figure – 1.2).

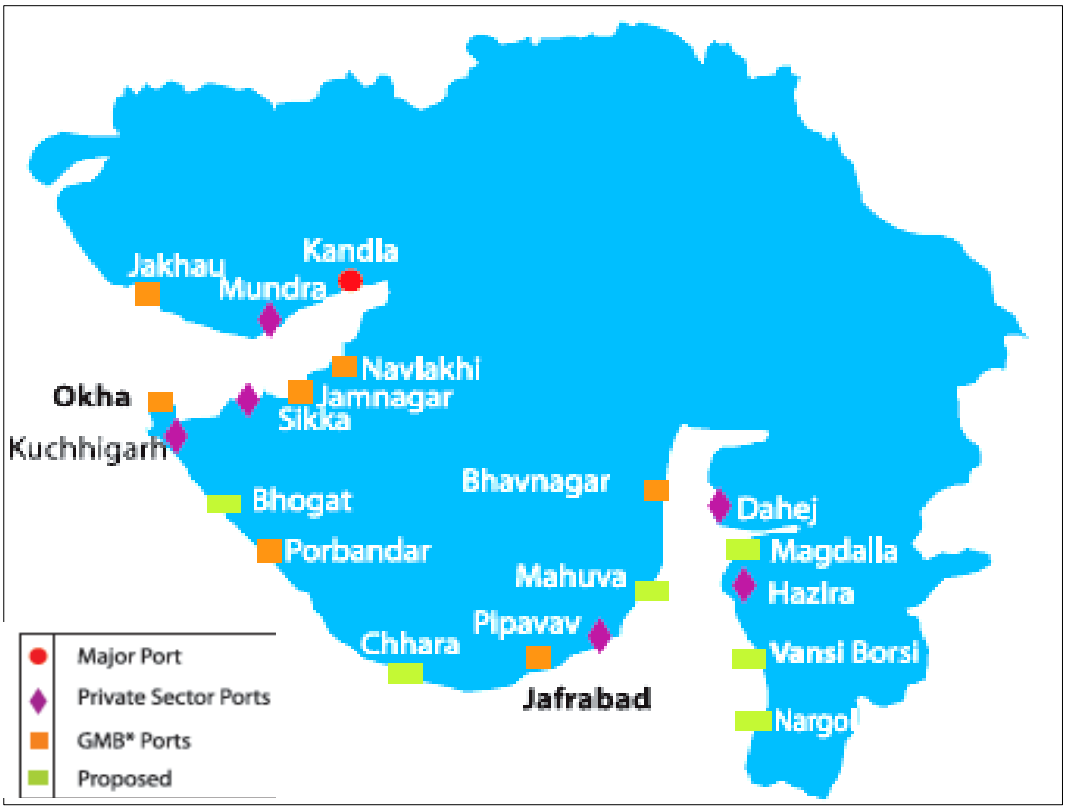

Figure 1.2 – Ports of Gujarat (Source: Anon., 2011)

1.4 STUDY AREA

Gujarat State is situated on the west coast of India between 20^0 07' to 24^0 43' N latitude and 68^0 10' to 74^0 29' E (Anon., 2009) longitude. The state shares its international boundary with the country of Pakistan on the North West side. It is bounded by the Arabian Sea in the west, by the state of Rajasthan in the north – north east, by Madhya Pradesh in the east and by Maharashtra in the south – south east and the Union territories of Diu, Daman, Dadra and Nagar Haveli in the south. The state also has the longest coastline in the country measuring about 1,600 kms along western parts of India, extending from Lakhpat in north to Valsad in South. The

climate of Gujarat in general is moderate with mean temperature 25^0 C to 27.5^0 C (Anon., 2009), with average annual rainfall between 800-1000 mm. Gujarat state has an area of 196, 022 sq. km. which makes for 5.96 % of land area of the country (Anon., 2009). The state is administratively divided into 25 districts and further it is divided into 226 sub-districts (or talukas) and has 18,539 villages (Anon., 2001). The recorded forest area for the state is 18,927 km^2, which is 9.66% of its geographic area. As per the Champion and Seth classification, the state has 23 forest types which belong to 4 forest groups' viz. Tropical moist deciduous, littoral and swamp forests, Tropical dry deciduous and Tropical thorn forests (Anon, 2009).

As regards to the developmental activities on the coastal land of the study area, Gujarat Maritime Board has identified **Vansi-Borsi as a green field site** for development of a direct berthing deep water port. The location is identified for handling petroleum and liquid chemical cargo for the immediate hinterland. The proposed site is 13 km away from nearest broad gauge railway link at Navsari and is 30 km south of the industrial town of Surat. The Government of Gujarat has also proposed development of a **modern fishing harbour at Dholai port (**Anon., 2008a**).**

1.5 PHYSIOGRAPHY

Physiographically, the state of Gujarat comprises of three distinct zones, Mainland Gujarat, Saurashtra and Kachchh. The mainland Gujarat is further divisible into two well-defined sub-zones; the eastern rocky

highlands and the western alluvial plains (Figure – 1.3). Each of these zones is marked by its own characteristic coastline (Merh, 1995).

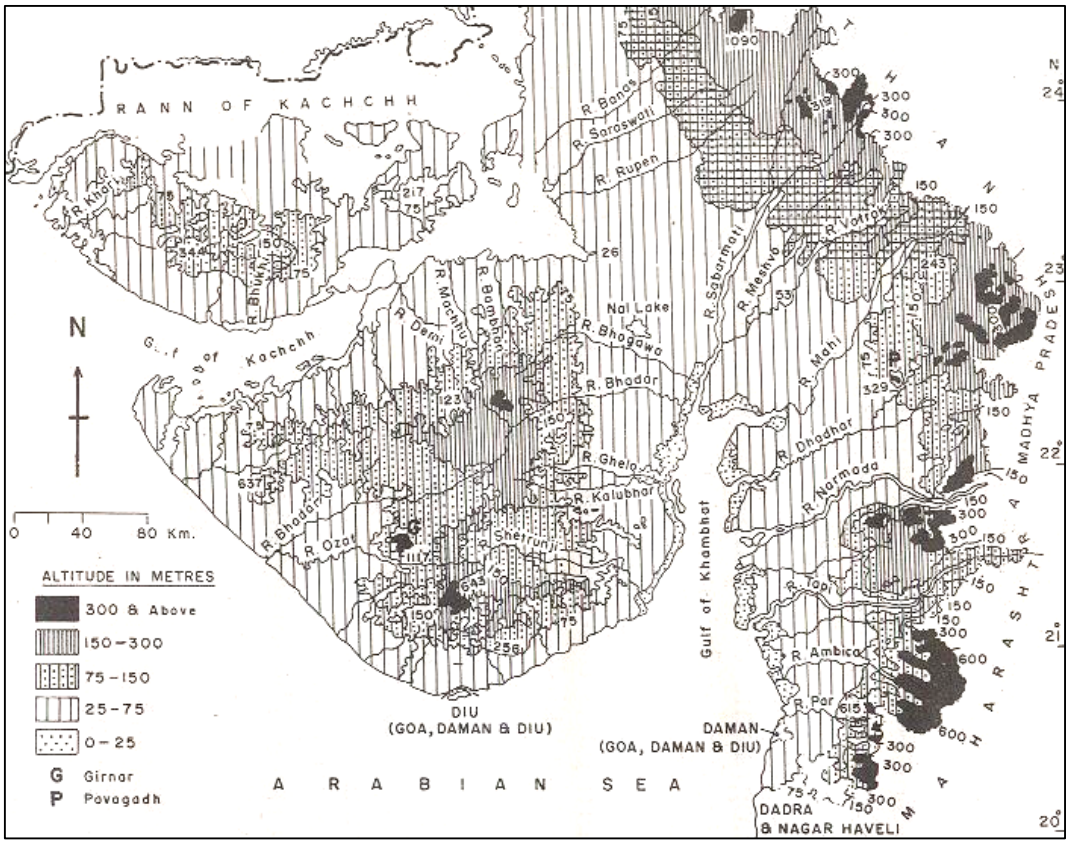

Figure 1.3 – Physiography map of Gujarat (Source: Merh, 1995)

The state is strategically placed and is important in terms of connectivity with the rest of the country. It is an upcoming state in the industrial sector and has the fastest growing economy in India. On account of increasing population and related settlements and industrial growths, there is an insufficiency of land required for new developments. This has led to reallocating the developmental activities on the coasts. The activities on the coast of Gujarat are more prominent because of the state's geographical feature, the most prominent being the longest coastline among all the coastal states of the country, measuring about 1600 kms and the two

of the three gulfs of the country; the Gulf of Khambhat or Cambay and the Gulf of Kachchh . The state has over two lakh sq. km of Exclusive Economic Zone (EEZ) and about 1.6 lakh sq. km of the continental shelf which provides an important resource for the overall development of the state. All these favorable setting has led to the phenomenal changes on the coastal area of Gujarat.

1.6 GEOLOGY

The geological evolution of Gujarat initiated sometime in the Triassic with the breaking up of the Gondwanaland and its subsequent geological history is related to the north-ward drift of the Indian sub-continent; the Mesozoic and Cenozoic tectonism related to the breaking up of the western continental margin and the subsequent drift have mainly controlled the geological evolution of Gujarat. The depositional history and the Deccan volcanism are part and parcel of this major tectonic phenomenon.

The rocks of Gujarat belong to the formations ranging in age from the oldest Precambrian to the recent. Stratigraphically however, the record is incomplete as the rocks of the Paleozoic Era are totally absent. The sedimentary and volcanic rocks rest over the southwesterly extended Proterozoic rocks of Rajasthan and post-Triassic. The major geological events of Gujarat are thus confined to the Mesozoic and the Cenozoic eras (Figure – 1.4).

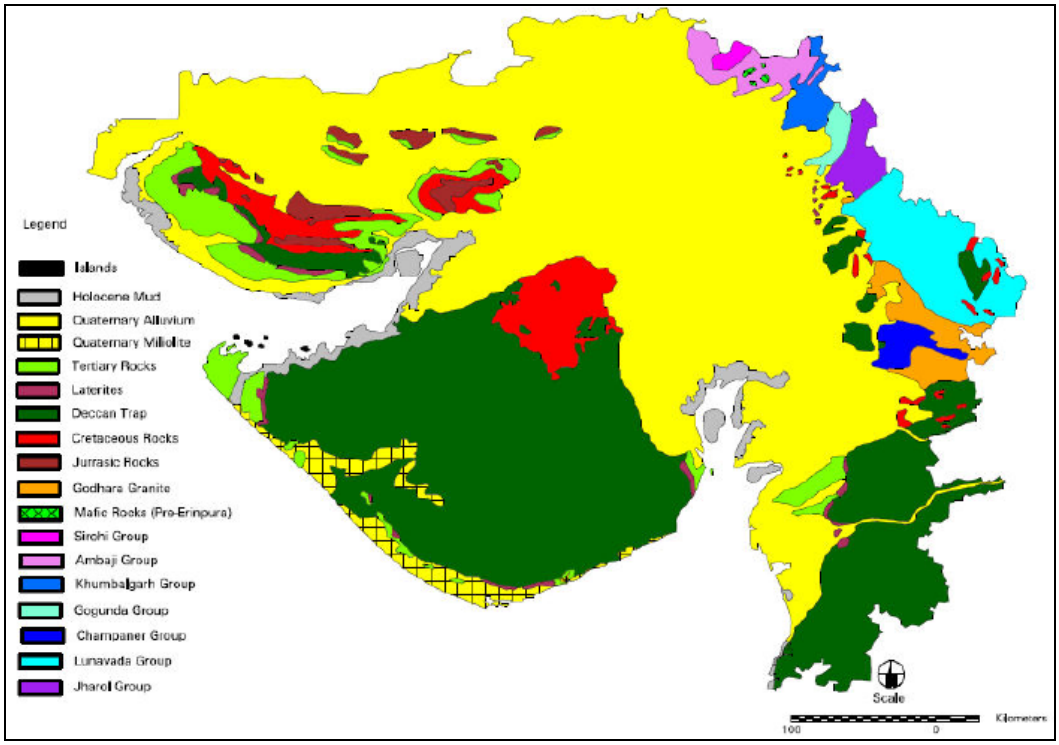

Figure 1.4– Geological map of Gujarat (modified after Merh S. S., 1995)

The geological diversity is reflected in the three major physiographic divisions, each characterised by diverse structure, stratigraphy and lithology. Each of the division also has its own evolutionary history. The geology of Gujarat comprises of a Precambrian basement over which the younger rocks commencing with the Jurassic, continuing through the Cretaceous, Tertiary and Quaternary have given rise to varying sequences in its different parts (Merh, 1995). The coastline of Mainland Gujarat provides an interesting geological site wherein the processes of eustasy, neotectonism and near-shore sedimentation have combined to produce motley of diverse landforms.

The study area stratigraphically represents formations of Cretaceo-Eocene and Quaternary periods and does not provide much geological

diversity. The Pleistocene and Holocene deposits are seen to rest over a trappean basement. The Quaternary sediments are formed by sub-aerial agencies, river action and marine processes derived from the erosion and denundation of the trap rocks. The stratigraphic sequence for the south Gujarat regions as worked out by Joottun et. al.(1982) is as below –

Shoreline Deposits: Beaches, barriers ridge complex, coastal dunes, Palaeo-bars and beach rock.		Holocene
Fluvio-Marine Deposits: River mouth bars and mudflats		
Fluvial Deposits: Recent alluvium, point bars, channel shoals and back swamps		
Residual Deposits: Colluvium and residual soils		
River Alluvium (older), Coastal gravel beds		Late Pleistocene

----------Unconformity----------

Basaltic and Dolertic dykes Basaltic lava flows	| |	Deccan trap	Upper Cretaceous to lower Eocene

Table – 1.1 Stratigraphic sequences for the south Gujarat regions (as worked by Joottun et. al.)

1.7 GEOMORPHOLOGY

The shoreline of the coastal area of Gujarat varies from being a smooth to moderately straight shoreline, from crenulate to indented and estuarine irregular shoreline. The coast of Gujarat, characterized by the

estuarine stretches is geologically classified to be of submergence type (Ahmed, 1972).

The study area's coastline, extending from the south of Tapi to Umargaon town is marked by estuaries having wide mudflats and the presence of sandy beaches. Geomorphologically it is a regime with extensive mudflats and rapidly changing shoreline geomorphology. Heavy influxes of sediments are received from the major perennial rivers of south Gujarat like Purna, Ambika, and Kolak etc. draining mainly from eastern highland into the Arabian Sea.

The present day landform assemblage and coastal features – both erosional and depositional, provides a sum of the geomorphic events of several generations co-existing together (Joottun et. al., 1982). However, the coast of south Gujarat characterizes the drowned alluvial coastline (Ahmed, 1972).

The wetlands of the study area comprise of intertidal mudflats, mangroves, salt marsh, sand beach, dunes, tidal creeks, etc. The lower most reaches of the river form extensive mudflats. The cross profile across the coast is made up of lower foreshore, upper foreshore, backshore/berm, paleoridge, coastal dunes resting over the ridge, tidal flats, raised mudflats, alluvial plain and hilly terrain (Joottun et. al., 1982). The river mouths support numerous small islands (Ahmed, 1972). Tidal waters reach the mudflats through a dense creek network. It experiences semi-diurnal tides, with two high and two low tides daily.

The coastline of the study area is sandy and shows development of inland sandy ridges parallel to the coast at places. These ridges reflect the past high sea-levels. The shoreline in this part is much dissected and replete with small estuarine creeks and lagoon, along which the tidal waters spread inland. The coast is more or less straight up to Umargaon with narrow sandy-ridge all along. The coast is rocky with narrow crescentic beaches separated by inward projecting headlands beyond Umargaon. The inter-tidal zone is made up of basaltic platform with a thin veneer or mud (Merh, 1995).

Sandy beaches consist of black sand from Purna estuary to Varoli and vary from 10 – 65 m in width. High tidal mudflats are present at the mudflats of almost all the estuaries. They are composed of clay, silt and have salt encrustations as well. Intertidal mudflats occur along the mouths of all the estuaries. These mudflats are cut through by numerous tidal channels and dense creek network. In the southern part of the study area, at many places along the coast, the Deccan Trap is exposed in the form of sheet rock. Such a rock coastline is observed south of Auranga and near Umargaon rocky (Anon., 1992).

1.8 CLIMATE

The Tropic of Cancer passes through the Gujarat. The state, thus, falls in the sub-tropical climatic zone and has a major part of it lying between the 35º C and 45º C isotherms. The climate varies drastically within the state of Gujarat. The climate of the area is influenced by Arabian

Sea and the hill range in South Gujarat. The coastal area along the sea has humid climate whereas area away from the coast has dry climate.

Rainfall

This area receives most of the rainfall from the south-west monsoon during June to September. The total rainfall received in the Navsari district is 2081 mm, whereas that received in the Valsad district is mm to 2448 mm in the year 2006 (Anon., 2007) (Figure – 1.5). The study area receives good rainfall as compared to the other parts of the state. This can be attributed to the fact that all the districts lie on the costal area and thus the Arabian Sea helps in fetching the monsoon and to the presence of the hills in the study area.

Temperature

The variation in the temperature in the state is also as extreme as in case of the rainfall. The climatological data of the Valsad and Surat Indian Meteorological Department (IMD) observatories which are situated in the vicinity of the river have been considered. The mean monthly temperature varies from 12.7 ^{o} C during December to 37.3 ^{o} C during April. The annual temperature for the year 2006 was found to be 11.1^{0}C minimum and 41.0^{0}C maximum for the Valsad district.

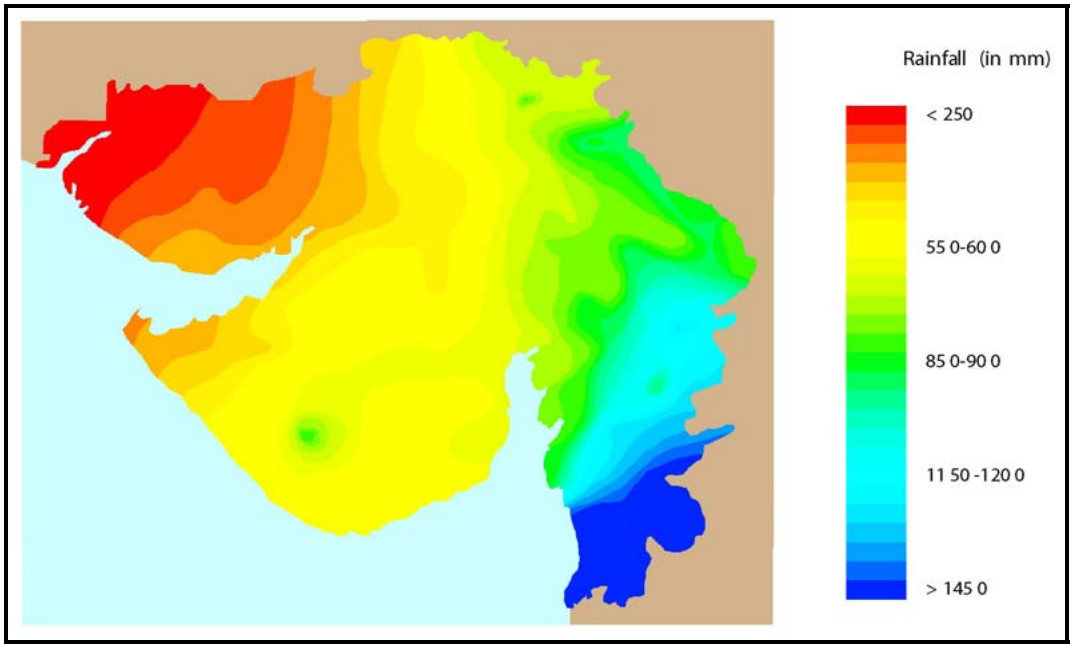

Figure 1.5 – Isohyte map of Gujarat (Source: Patel, 1997)

Humidity

The humidity during winter season is as low as 32 % in the month of February and increases with the onset of monsoon attains higher values up to 89 % in the month of August.

Wind

The winds are weak over Gujarat but coastal areas experience stronger winds during the monsoon period. Monsoonal winds are mostly south-westerly but during winter season, the winds are northerly or north-easterly. In summer, wind blows mainly from West and South-west.

Intensity of the wind effects along the coast varies in different coastal segments depending upon the trends of the coastline. The mean daily wind speed is maximum (12.33 km/hr) in the month of June and minimum (4.3 km/hr) in the month of December for the study area.

1.9 DRAINAGE

Drainage is the reflection of the terrain characteristics and being controlled by physiography, climate and tectonic framework, the rivers in the various physiographic zones behave differently and shows striking diversity (Figure – 1.6) (Merh, 1995).

The rivers draining the study area fall in to Arabian Sea. These rivers are smaller, compared to the other rivers of Gujarat. They rise within the boundaries of the state from the eastern trappean highlands and finally debouch in to the Arabian Sea.

The regional drainage pattern is dendritic to sub-dendritic in nature. The drainage is usually a function of the topography, which in itself related to the underlying lithology and structural features present in the area (Chow et al, 1988; Wisler and Brater, 1959).

Largely, drainage in the Deccan basalts show a dendritic to sub-dendritic pattern where it is largely controlled by slope and show some anomalies (non-dendritic patterns) where the influence of certain structure in the rocks (like fracture zones and dyke) influence the drainage geometry (Kulkarni, 1991; Pakhmode et al, 2003).

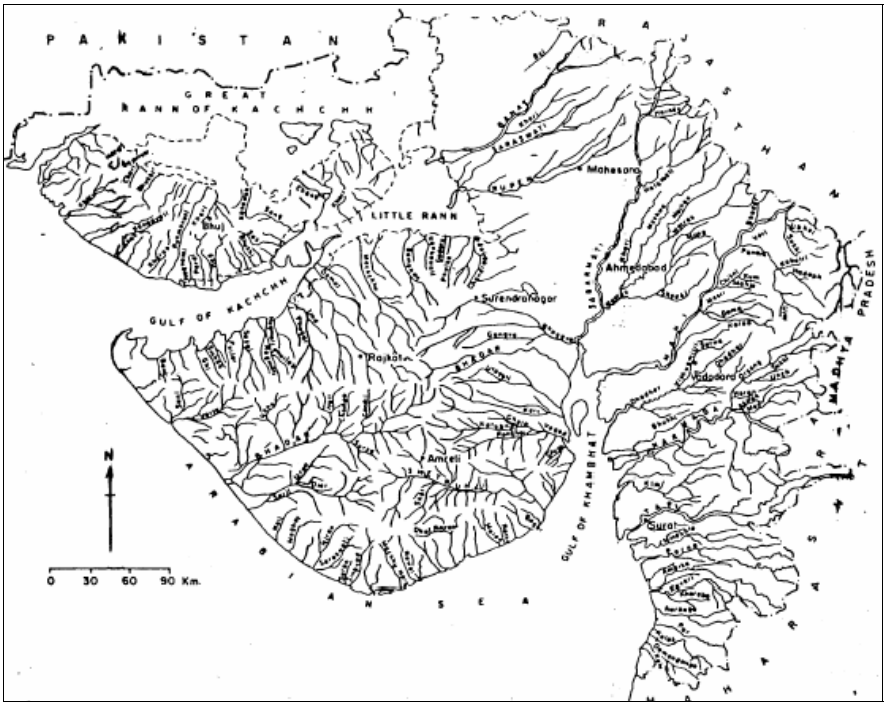

Figure 1.6 – Drainage Map of Gujarat (Source: Merh, 1995)

1.10 TIDES AND CURRENTS

Tides of the Gujarat coast are of mixed semi-diurnal type. The coast experiences very high tides. The tidal range increases tremendously form the mouth to upstream of the gulfs, due its unique funnel shape. In the Gulf, tidal currents are fairly strong and bimodal in nature having two dominant directions: upstream during flood and downstream during ebb. The low tides leave vast coastal area completely exposed, which get submerged during high tides.

The study area lies south to the Gulf of Cambay which experiences meso-tidal condition. South Gujarat coastline experiences semi-diurnal

tides, with two high and two low tides daily. The tidal amplitude of the meso-tidal range is of the range 6-10 mtrs, increasing upstream.

1.11 FLORAL AND FAUNAL DIVERSITY

Gujarat is rich in its store of flora and fauna. The state of Gujarat boasts in having a wide variety of flora and fauna which are spread throughout its length and breadth. It has varied landforms, ranging from dry deciduous forests to majestic grasslands, wetlands, marine ecosystems and rich moist deciduous forests. This has made the state suitable as the habitat of rare wildlife species. Asiatic Lion, Wild Ass, Black Buck, Four-horned Antelope and Great Indian Bustard are some of the rare species preserved by the various wildlife sanctuaries in Gujarat. These rare animals constitute the wildlife heritage of India.

In Gujarat, one can find as many as 500 varieties of mammals, more than 2000 species of birds, a wide range of insects, fishes, amphibians, reptiles, etc. Some of the important mammals found in Gujarat are the Asiatic lions, black bucks, nilgai, chital, wild boar, four horned antelope, hyenas, rusty spotted cats, etc. A large number of other animals like snakes, lizards, crocodiles, scorpions, bees, silkworm, Lac insect, etc., are found in the forest of Gujarat. as mosquitoes and locusts which are fatal both for mankind and animals. The fauna of Gujarat is incomplete without a reference to the birds. The state has any coastal and inland wetlands which provide shelter and nesting grounds to many kinds of birds. The commonly found birds here are peacock, parrots, pheasants, geese ducks,

cranes, etc. The state is also destination to many of the migratory birds like the flamingoes and houses conservation site for the bustards as well. The Marine National Park and Sanctuary is considered to be a birders paradise by the local and foreigners as well as.

Flora in Gujarat includes a wide variety of vegetation. The botanists of Gujarat have actively engaged in studying the flora of different parts of the state and considerable information is amassed. The wide variations in the climate and topography of the state have resulted in various types of forest growth ranging form moist deciduous to pure desert conditions. As per Champion and Seth classification, the forests of Gujarat have 23 types, belonging to 4 main types viz. Tropical moist deciduous, Littoral and swamp, Tropical dry deciduous and Tropical thorn forests (Chart – 1.1). The major concentrations of forests are found all along the eastern border of the stated and hilly portions of Saurashtra and some parts of north Gujarat. The plains are mostly devoid of forest cover. One can observe the different types of forests in Gujarat like the tropical moist deciduous forests, dry deciduous forests (dry teak and dry non-teak forests), scrub forests, mangrove forests (Shah, 1978).

In Gujarat, there is about 16,083 sq. km. of forest area (Anon., 2009). The flora in Gujarat include one of the largest dry deciduous forests in the western region of India, including trees like the teak, *Boswellia serrata, Anogeissus latifolia,. Diospyros*, etc. Owing to the arid climate, Gujarat also possesses a wide range of xerophytic vegetation. This includes *Acacia Arabica, Acacia leucophloea, Capparis ophylla, Zizyphus mauratiana,* etc.

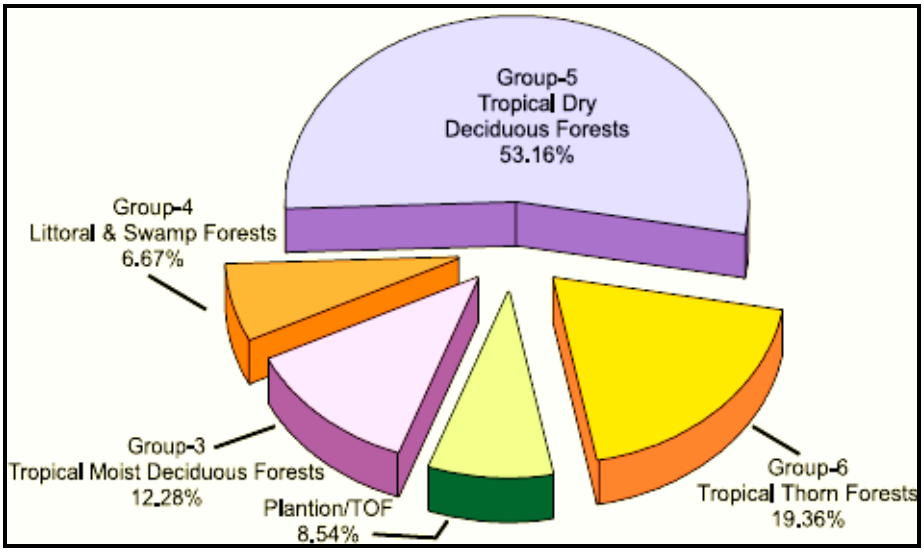

Chart – 1.1 Forest types of Gujarat (Source: Anon., 2009)

The south Gujarat region receives more rainfall as compared to the rest of the state. Hence, the forest cover here is also more as compared to the other region of Gujarat. The FSI, 2009 data clearly implies that through the percentage geographical coverage of forests in the districts of south Gujarat.

Coastal vegetation such has mangroves have not received attention as much as the land vegetation. In addition, much of the basic information needed for development and execution of management plans in mangrove forests, is presently not available (FAO, 1994, 2003). Such information is lacking at the regional level as well. Such data gap exists at the regional level in south Gujarat, where precise information on the mangroves is un-available. The literature survey and reconnaissance field surveys to the area did suggest presence of the mangroves on the coastal wetlands of south Gujarat.

Hence, to fill the gap existing for the mangroves of Gujarat, the current research work ***Environmental appraisal of mangrove wetlands between Mindhola and Varoli estuary (south Gujarat) using remote sensing*** was taken up, as it deals with the study of diversity and density of mangroves of south Gujarat region, with a remote sensing perspective while scrutinizing the environmental parameters of mangrove wetlands as well.

1.12 COASTAL WETLANDS OF THE STUDY AREA

The distinctive feature of the coastal area is that is marked with the unique interaction of saline water with freshwater bodies, which provides it the characteristics of an extended coastal wetland. Hence, they form the **transition zone**, which makes them so interesting. As they have both fresh water and marine characteristics, and, thus, they form a very unique environment, supporting diverse forms of flora and fauna. Of these, mangroves form one of the important components of the coastal wetlands. This is so because mangroves grow only along this transitional zone i.e., the coastal wetlands, making the plants exclusive to this area, thus creating a niche for themselves. The present study has been undertaken to study the mangroves of the coastal wetland systems of the rivers of South Gujarat.

The present study encompasses the coastal area south to the Gulf of Cambay region. It falls between the latitude 20^0 00' N to 21^0 15' N and the longitude 72^0 30' E to 73^0 00' E. The northern extent of the study area

extends to River Mindhola situated to the south of Surat City while to the south it extends to River Varoli, situated North of Umargaon which also constitutes the southern most extent of the coastline of Gujarat State. The study area comprises of the coastal wetlands of river Mindhola, Purna, Ambika, Auranga, Par, Kolak, Damanganga, Kalu/Kalai and that of Varoli, near Umargaon (Figure 1-.7). The length of the coastline of the study area extends to about 120 kms.

Administratively the study area falls within three coastal districts of Gujarat namely Surat, Navsari and Valsad in addition to the Union territory of Daman. The coastal wetland of Mindhola falls under the district of Surat. The coastal wetlands of Purna, Ambika, and Auranga fall in Navsari district whereas the Kolak and Varoli coastal wetlands fall in Valsad district. The coastal wetland of Damanganga forms part of the Union Territory of Daman and Diu. The northern part of the coastal wetland of Kalai falls into Damanganga jurisdiction whereas the southern part falls into Valsad district. However, keeping in view the continuity of the south Gujarat coastline the later two coastal wetlands has also been taken up for the present study. The following legend has been followed for all the coastal maps subsequently depicted.

Legend -

Mudflat Water Land

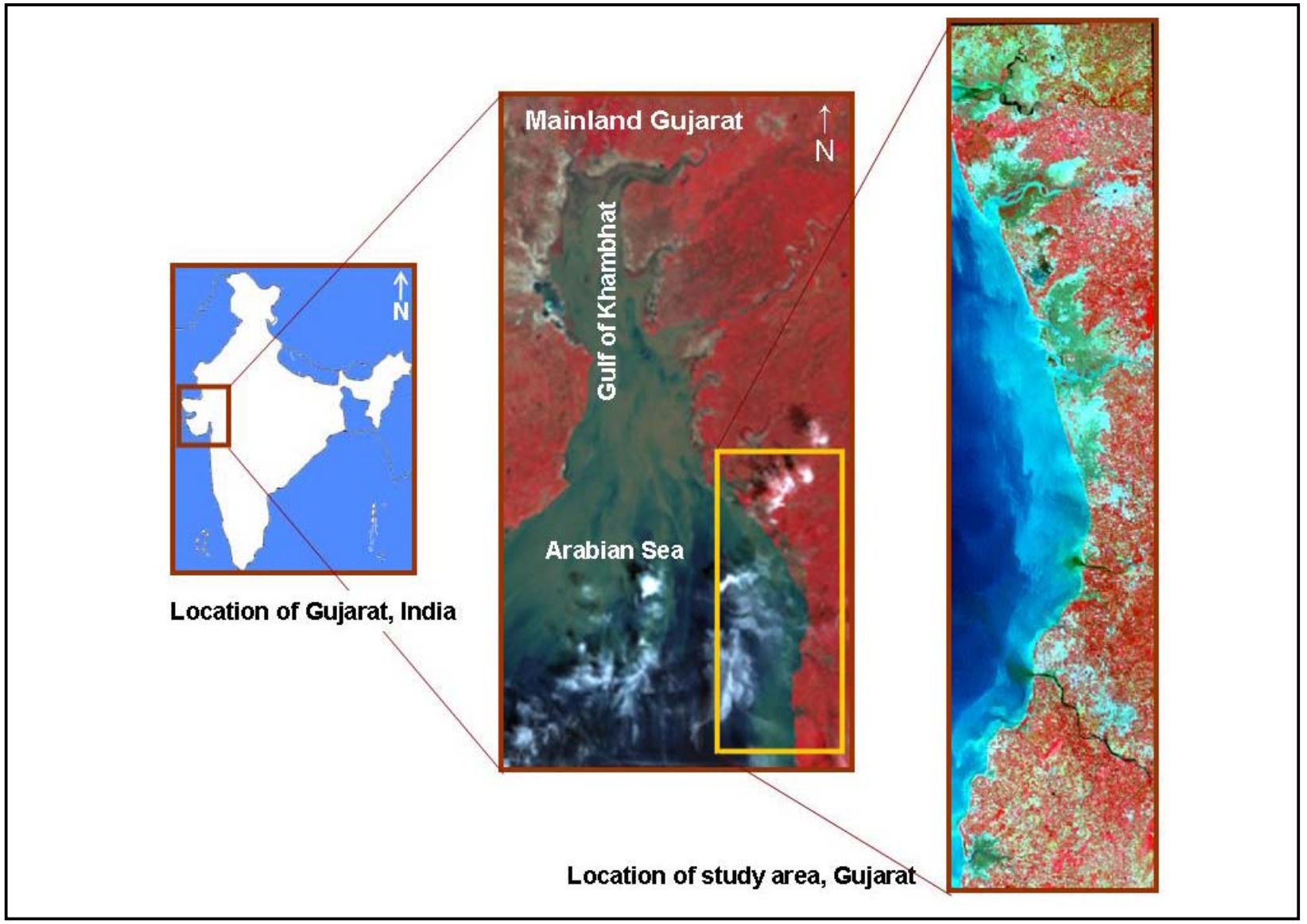

Figure – 1.7 Location map of the study area (ETM+, 2001)

1.12.1 Coastal wetland of Mindhola River

The coastal wetland of Mindhola River is located on the southern part of Gujarat state on the western coast of India. River Mindhola is a small west flowing river with its catchment lying entirely in Gujarat state. It debouches into the Arabian Sea near Navsari, south of Tapi. It extends between the latitude 21^0 01' 00 N to 21^0 07' 55 N and longitude 72^0 42' 00 E to 72^0 51' 45 E (Figure – 1.8). The study area is covered in the Survey of India (SOI) topographical maps 46C/ 12 & 46 C/ 16. It has a mouth span of approximately 3.6 km with the tidal influence up to 22.7 km upstream (as per the SOI topographical map, 1965).

During the field surveys, it has been observed that Mindhola has been extensively used as effluent output for different industries. The interaction with the local people gave an insight on how it was difficult to navigate through the river due to extreme acidic conditions, mostly leading in the corrosion and damage of their boats as well. This made field surveys difficult for the current work, as criss-crossing through the creeks became impossible.

1.12.2 Coastal wetland of Purna River

Purna is a perennial river of Navsari district in South Gujarat which originates from the Satpuras range and debouches into the Arabian Sea near Navsari. The coastal wetland of Purna River is located south to that of Mindhola's. It extends between the longitude 72^0 44' 00 E to 72^0 55' 00 E

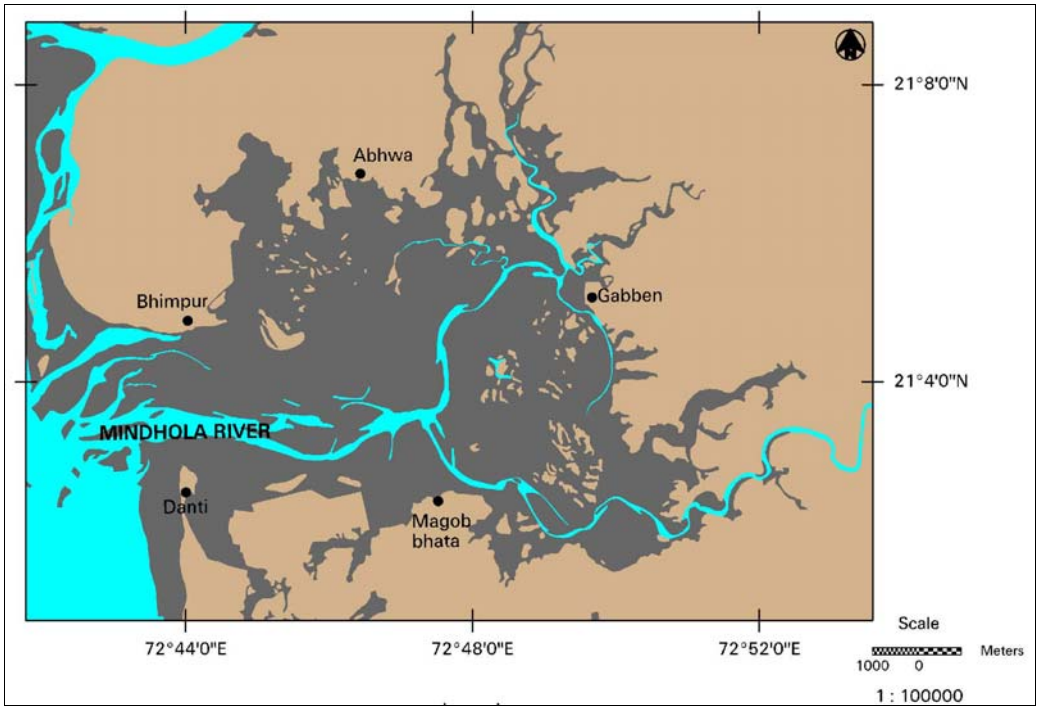

Figure – 1.8 Coastal wetland of Mindhola River

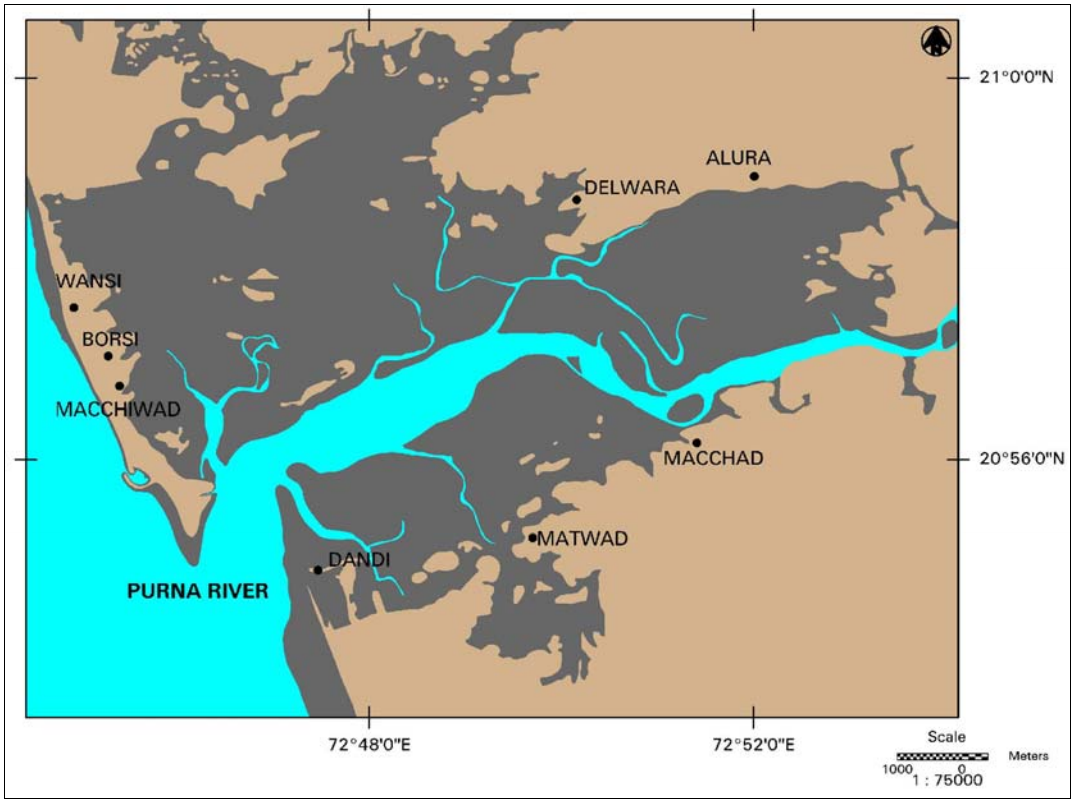

Figure – 1.9 Coastal wetland of Purna River

and latitude 20^0 53' 00 N to 21^0 01' 00 N (Figure – 1.9). The study area is covered in the Survey of India (SOI) topographical maps 46D/ 9 & 46 D/ 13. It has a mouth span of approximately 1.5 km with the tidal influence up to 26.2 km upstream (as per the SOI topographical map, 1965).

1.12.3 Coastal wetlands of Rivers Ambika & Auranga

River Ambika is a perennial river near Billimora district in South Gujarat, India, which originates from the Sahyadri's and debouches into the Arabian Sea near Billimora; whereas Auranga originates from the Sahyadris hills and debouches into the Arabian Sea near Valsad. The coastal wetland of Ambika River is located approximately between the longitudes 72^0 49' 00 E to 72^0 57' 00 E and latitude 20^0 52' 15 N to 20^0 42' 20 N. It forms the part of the SOI map 46D/ 13 & 46 D/ 14. Rivers Kaveri (North and South) and Kharera empty their water at the mouth of the estuary of Ambika. The intertidal area on the northern flank of Ambika River is extensive and is fed by a major creek, the Kavni (Kanai) creek. The southern part of coastal wetland coastal wetland of Ambika River almost merges with the northern part of the coastal wetland of Auranga River, making it difficult to demarcate the precise boundaries between the wetlands. For this reason, the wetlands of Ambika and Auranga will be treated as one unit for the present study (Figure – 1.10). Coastal wetland of Auranga River is located between 72^0 51' 30 E to 72^0 56' 00 E and 20^0 42' 20 N to 20^0 35' 45 N and falls in the SOI topographical map 46D/ 14. River Vanki, flowing through the southern region of Auranga wetland, empties its

water at Auranga River mouth. The extent of the coastal wetland on the northern flank of Auranga River is more extensive as compared to that on the southern flank.

River Ambika has a mouth span of approximately 1.6 kms with the tidal influence as far as up to 18 - 22 kms upstream (with 3 different channels feeding the wetland region - 1. Ambika River main, 2. North Kaveri and 3. south Kaveri) whereas the mouth span of River Auranga is very narrow being only about 0.5 kms wide and with tidal influence up to 14 kms upstream (as per the SOI topographical map, 1965).

1.12.4 Coastal wetland of Par River

Par is a perennial river of Valsad district in South Gujarat, India, which originates from the Sahyadri's and debouches into the Arabian Sea near Pardi. The coastal wetland of Par River is located approximately between the longitudes 72^0 52' 10 E to 72^0 55' 10 E and latitude 20^0 29' 10 N to 20^0 34' 00 N (Figure – 1.11). The coastal wetland area of Par forms the part of the SOI map 46D/ 14 & 46 D/ 15. The southern part of coastal wetland extends and reaches out almost till Udwada, a town famous for its Jewish connection. Par River has a mouth span of approximately 1.0 km with the tidal influence as far as up to 8 kms upstream (as per the SOI topographical map, 1965).

1.12.5 Coastal wetland of Kolak River

Kolak is a perennial river of Valsad district in South Gujarat, India, which originates from the Sahyadri's and debouches into the Arabian Sea south of Udwada. The coastal wetland of Kolak River is located approximately between the longitudes 72^0 50' 30 E to 72^0 53' 20 E and latitude 20^0 26' 55 N to 20^0 28' 22 N (Figure – 1.11). The coastal wetland of Kolak form part of the SOI topographical map 46D/ 15. River Kolak has a mouth span of approximately 2.5 km with the tidal influence as far as up to 6.2 kms upstream (as per the SOI topographical map, 1965).

1.12.6 Coastal wetland of Damanganga River

The Damanganga River falls under the Union territory of Daman and Diu jurisdiction. It also, like the other rivers of south Gujarat, originates from the Sahyadri's and debouches into the Arabian Sea. The coastal wetland of Damanganga River is located approximately between the longitudes 72^0 49' 25 E to 72^0 52' 23 E and latitude 20^0 25' 30 N to 20^0 22' 40 N (Figure – 1.13). The coastal wetland of Damanganga form part of the SOI topographical map 46D/ 15. River Damanganga has a mouth span of approximately 2.9 km with the tidal influence as far as up to 14.7 kms upstream (as per the SOI topographical map, 1965).

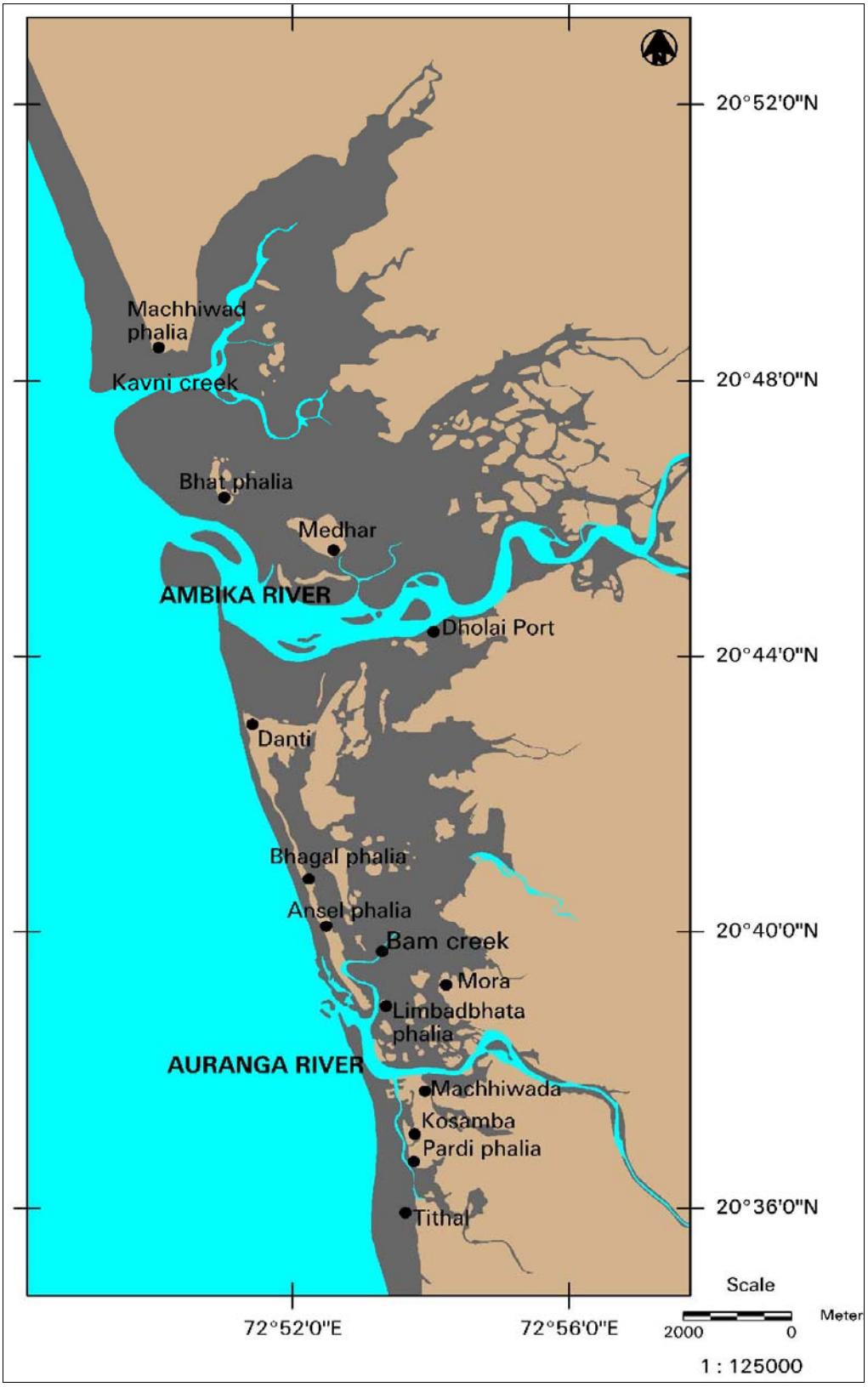

Figure – 1.10 Coastal wetland of Ambika - Auranga River

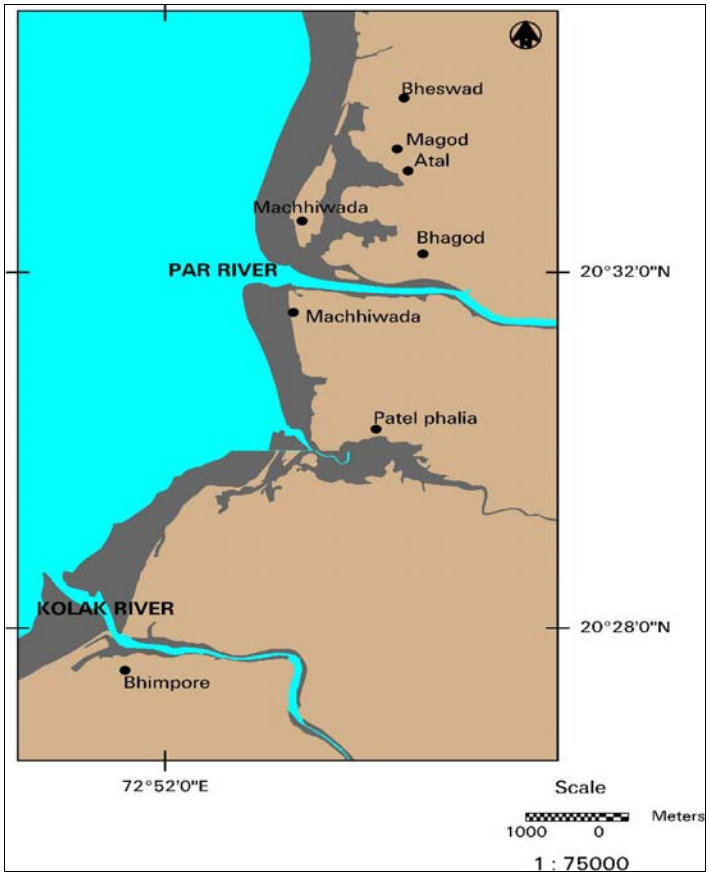

Figure – 1.11 Coastal wetland of Par – Kolak River

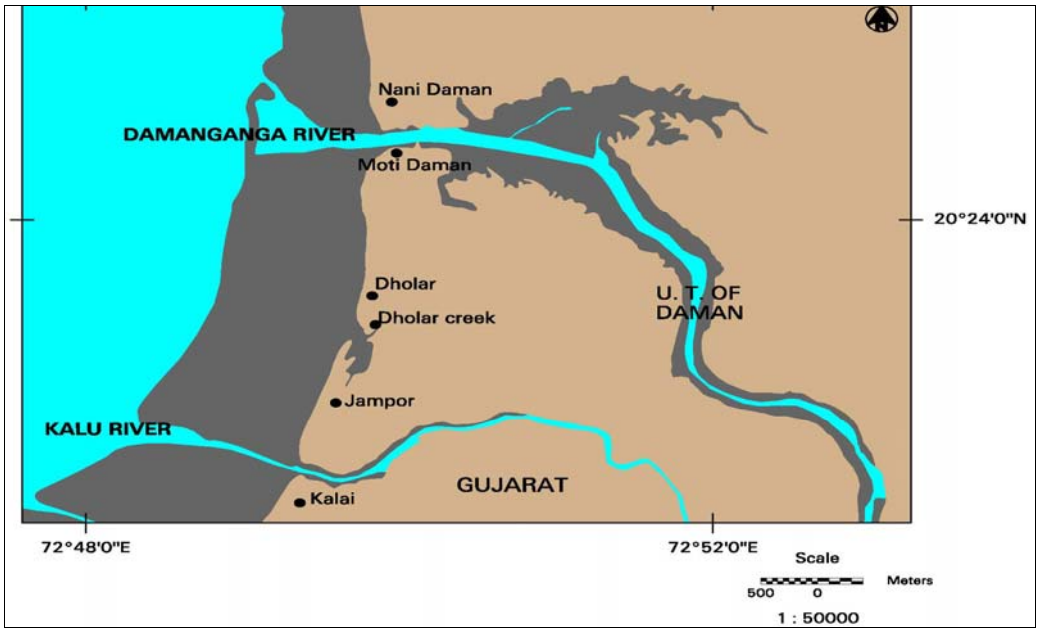

Figure – 1.12 Coastal wetland of Damanganga - Kalu River

1.12.7 Coastal wetland of Kalu/Kalai River

The northern part of Kalu River falls under the Union territory of Daman and Diu jurisdiction and the southern part falls under the Valsad district of Gujarat state. It originates from the hilly regions of the Gujarat and debouches into the Arabian Sea. The coastal wetland of Kalu River is located approximately between the longitudes 72^0 51' 30 E to 72^0 49' 05 E and latitude 20^0 21' 45 N to 20^0 22' 40 N. The coastal wetland of Kalu forms part of the SOI topographical map 46D/ 15. River Kalu has a mouth span of approximately 0.2 km with the tidal influence as far as up to 6.1 kms upstream (as per the SOI topographical map, 1965). It is smallest river of the study area.

1.12.8 Coastal wetland of Varoli River

The Varoli River originates from the Sahyadri's and debouches into the Arabian Sea. The coastal wetland of Varoli River is located to the north of Umargaon town and is placed approximately between the longitudes 72^0 44' 20 E to 72^0 48' 43 E and latitude 20^0 10' 43 N to 20^0 14' 30 N (Figure – 1.13). The coastal wetland of Varoli form part of the SOI topographical map 46D/ 16. River Varoli has a mouth span of approximately 0.3 km with the tidal influence as far as up to 10.2 kms upstream (as per the SOI topographical map, 1965).

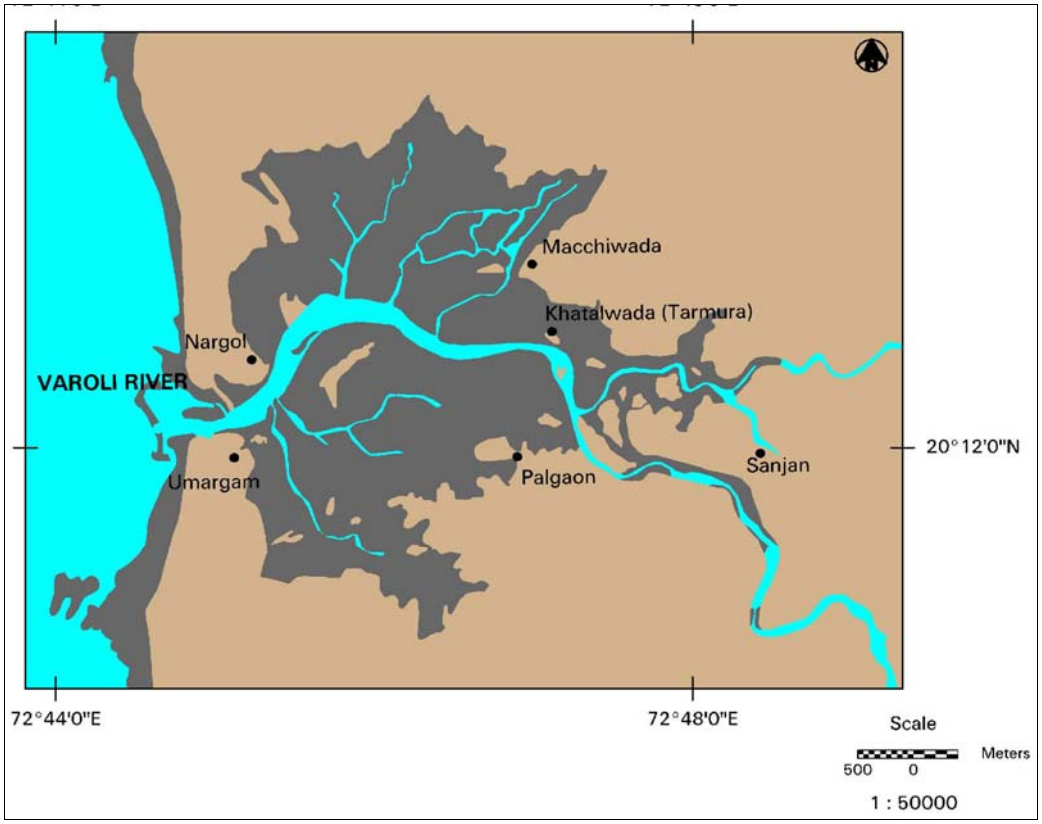

Figure – 1.13 Coastal wetland of Varoli River

Sr. No.	Coastal Wetland of	District	Nearest major city/town	Tidal Influence (upstream in approx. kms)	Mouth span (approx in kms.)	SOI Toposheet
1	Mindhola	Surat	Surat	22.7	3.6	46C/ 12 & 46 C/ 16
2	Purna	Navsari	Navsari	26	1.5	46D/ 09 & 46 D/ 13
3	Ambika	Valsad	Billimora	18 – 22	1.6	46D/ 13 & 46 D/ 14
4	Auranga	Valsad	Valsad	13.5	0.5	46D/ 13 & 46 D/ 14
5	Par	Valsad	Pardi	8	1.0	46D/ 14 & 46 D/ 15
6	Kolak	Valsad	Udwada	6.2	2.5	46D/ 15
7	Daman-Ganga	UT of Daman	Daman	14.7	2.9	46D/ 15
8	Kalu/Kalai	Valsad	Daman	6.1	0.2	46D/ 15
9	Varoli	Valsad	Umargaon	10.2	0.3	46D/ 16

Table 1.2 – Details of mangrove wetlands of the study area

1.13 AIMS AND OBJECTIVE OF THE THESIS

The present study thus focuses primarily on studying the lesser known mangroves of south Gujarat and the simultaneous geomorphological changes of the coastal wetlands of the rivers Mindhola, Purna, Ambika, Auranga, Par, Kolak, Kalu, Daman-Ganga and Varoli.

With a the aim to fill in the lacunae on the mangroves of Gujarat, study of mangroves of this area the present study was undertaken to fulfill the following objectives making use of remote sensing applications as the tool to study them

- Generating base line information for the mangroves of coastal wetlands of south Gujarat
- Mapping the mangrove habitats and area occupied by the mangroves
- Mapping the diversity and major mangrove communities
- Detecting change in the mangrove habitat during from the earliest date to the recent most available data for Purna and Ambika – Auranga's estuarine setup
- Mapping the geomorphological changes
- Physico-chemical influences on the mangrove *environs*

1.14 METHODOLOGY

This thesis aims to generate baseline information on the present-day status of mangroves of south Gujarat, while also evaluating their environmental condition on the basis of field data collection. The emphasis was thus to generate such information which can be useful for and by further studies and researchers.

Mangrove ecosystems are difficult to monitor *in situ* due to their dense understory and the difficult terrain of the wetland complex. For these reasons, extensive research of mangrove forest ecosystems has often been difficult. Therefore, the biological diversity and the extent of the mangroves are not well understood. Remote sensing data has been proved useful in study of such ecosystems (Nayak *et al*., 1992; Navalgund and Bahuguna, 1999; Green et al., 2000). As the information on the mangroves of the coastal wetlands of south Gujarat is scanty, the methodology was therefore so developed to not only map the mangroves but also to get an insight about the environmental condition of the mangrove ecosystems thriving in this location and that how they have changed over a period of time. In addition, the physico-chemical parameters were studied to know about the environment of the mangrove ecosystem of the study area.

The current work is thus divided into three broad divisions –

- **Field studies, data collection and analysis**
- **Laboratory analysis**
- **Remote sensing analysis**

CHAPTER 2: PREVIOUS WORK

Many studies have been carried out globally for the mangroves, stating their importance, the areal estimates and the number of mangrove species existing. In addition, the study of remote sensing technology in the works of mangroves is considered a great boon and this approach is of utmost importance to bring out the aerial extent of mangroves of any region. Major and important contributions have been cited in this chapter. The mangrove habitat expansion related geomorphological studies have not been carried out on a large scale till date. However, there are few workers and their observations have been discussed in this chapter. Mangroves studies are not limited to the areal extent and the species distribution but their environment is also significant and a great cause of concern. The significant references of work carried out in relevance to mangrove environment have been discussed below as well.

- Tomlinson (1986) gives a detailed description about the mangroves; their ecology, diversity and distribution, importance and a generic description. He has also set guidelines to recognize the mangroves and differentiate them from the mangrove associates.
- The work carried out by Spalding et al. (1997) is the most accepted one which gives the account of the distribution of mangroves globally, their mapping and the areal estimates of the mangrove vegetation. He has given regional account and details pertaining to the mangrove ecosystem of those regions. He also states the economic value of mangroves as they

form a ecosystem for the other organisms and help in increased fish-catch.

- Kathiresan and Bingham (2001) have given a detailed account on the mangroves by giving their historical account, evolutions and global distribution. They have also described the responses of mangroves to various environmental factors. The importance of mangroves form the ecological and economic retrospective has also been described by them.
- The morphological description leading to the identification of mangroves have been given in works by authors like Banerjee et al (1989), Rajendran & Sanjeevi (2004) and Shah (1978)
- Several classifications related to different setups of the mangrove ecosystems have been proposed. Singh (2002) defines them on the basis of the hydrological processes, tidal impact and composition of forest. Thom (1982) and Galloway (1982), classify on the basis of their substrate, tidal range and sedimentation. However, the most popular classification is devised by Lugo and Snedaker (1974). On basis of their work, Woodroffe (1992) has proposed a modified classification, which includes the influence of the physical processes on mangroves as well.
- The global diversity and areal extent of mangrove vegetation has been put forward by various authors over the past years. Globally, FAO and UNEP (1980-1981) initiated this for the work in the field of mangroves. A list by Chapman (1977) includes the major and the minor elements of mangroves. Duke (1992) gives a list of mangrove species belonging to 26 genera in 20 families. Saenger et. al., (1983) has reported species

exclusively from the tidal zone. Tomlinson (1986) on the basis of his criterions of true mangroves has enlisted them as well and Kathiresan and Bingham, (2001) have recognized mangrove species on the basis of the works of Tomlinson (1986) and Duke (1992).

- It was Van Rheede (1678), who gave the first scientific account of mangroves of India. Later on, Schimper (1891) also contributed to this by giving detailed information on the littoral flora of the Indo-Malayan coast.
- Blasco's (1975) work in the field of mangroves of India gave a head-start for the works to be carried out in future. In his work, he has reported species of mangroves and also given an estimate of the mangrove extent
- Untawale (1987) has worked on mangroves of India and in his work; he gives account of mangrove species from both the coasts, the West coast and the East coast. On the same line, Banerjee et al. (1989) has reported mangroves from the eastern coast (Tamil Nadu, Andhra Pradesh, Orissa, West Bengal and Andaman and Nicobar Islands) and the western coast (Kerala, Karnataka, Goa, Maharashtra and Gujarat) as well.
- The western coast of India has been extensively studied by Jagtap et al. (1993), concentrating majority of the work on the coastal areas of Maharashtra and Goa. Rajendran and Sanjeevi (2004) have prepared a list which includes the mangroves as well as the associates.
- The mangroves of Gujarat have been mainly studied by the authors like Singh (2002, 2006) and organizations like SAC (Nayak et. al., 1986,

1992). Their works clearly suggested that the importance was given to study the mangroves of Kachchh in Gujarat as no other areas were believed to have substantial mangrove patch.

- Chavan (1985) has studied the mangrove ecosystem of gulf of Kachchh extensively. Same has been done by Untawale and Wafar, 1988; Parulekar, 1988; Untawale and Ambiye; 1988, Singh, 2002; Thivakaran et. al., 2003; Shah et al., 2005; Singh, 2006.
- The recent studies of the mangroves on south Gujarat have been initiated on the basis of very few earlier works carried out for this area. Authors like Kothari & Rao (1991a) (1991b), Kothari & Singh (1998), Shah (1978) and Bhagwanani (1980) suggested the presence of mangroves on coast of Gujarat, which but remained uncertain till the present work was taken up.
- Of this Singh (2002, 2006) in his work mentioned the occurrence of largest single patch of mangroves in estuarine area of Purna and a report by SAC also describes the occurrence of salt marsh vegetation for the same location (Anon. 1992).
- An initiative was started off by the GoI in the 1987's which deals publication of the State of Art Report on Mangroves. This report continues to give the estimates every alternative year and gives an account of the density and area of the mangrove ecosystems of India (Anon., 1987, 1989, 1991, 1993, 1995, 1997, 1999, 2001, 2003, 2005 and 2009). Their latest reports give the estimates for the year 2009.

- These areal estimates of mangroves are essentially carried out with the help remote sensing technology.
- According to Campbell (2006) Applications of remote sensing studies on vegetation patterns, depend on knowledge of spectral properties of individual leaves and plants. Remote sensing often provides the only practical means of mapping and monitoring changes in major ecological regions that have great long-term significance for mankind.
- Jensen (2006) explains that it is the structure of the leaf and its interaction with electromagnetic energy which has a direct impact on how leaves and canopies appear spectrally when recorded using remote sensing instruments.
- Green et. al. (2000) demonstrated the importance of remote sensing in the vegetation such as mangrove ecosystems as it is a technique which provides information regarding the extent of the habitat and the type of habitat. Mapping of mangroves is only possible if the mangrove area can be accurately distinguished from the non- mangrove area and an remote sensing system offers different processing methods that gives accurate results for the study
- According to Hardisky et al. (1986), the studies employing remote sensing data provides a means to extend the knowledge of a small area *to* a larger region. Therefore, it turns out to be an important aide in the analysis of mangrove ecosystems.
- Jensen (2006) also stresses the importance of monitoring the vegetation through time to determine changes a system is undergoing. This is done

by the comparison of compatible remote sensing data and given an end result as *change detection*

- Untawale (1982) was probably the first worker who demonstrated the use of remote sensing based studies with the help of aerial photographs for the mangroves of Goa.
- Later on, many such works using remote sensing studies for mangroves were carried out by Nayak et. al. (1985, 1989, 1996, 1997 and 2001) mostly concentrated on the western coast of India. Most of the work was carried out making use of the Landsat series data and density classes could be differentiated on the basis of this data.
- Krishnamoorty et. al. (1993, 1996, and 2000) has also made extensive use of this technology and has mainly studied the mangroves of south India making use of Landsat and IRS data. His work was also focused to compare various sensors for classifications and on the study of the spectral radiances of mangroves.
- The mangroves of Maharashtra and Goa were also studied by Jagtap et. al (1994 and 2001). This work was focused on mapping the mangrove environments. The changes in the mangrove of Asia area were studied by Blasco et. al. (2001).
- Mangroves have also been attributed to influence the geomorphology by trapping the sediments with the help of their extensive root system. This is described best by Woodroffe (1992), Wolanski *et al.* (1992), Wolanski (1995) and Furukawa *et al.* (1997) and Bird & Barson (l977).

- Woodroffe (2002) states that plants play substantial roles in trapping or binding sediments on dunes, and upper intertidal areas of muddy coasts.
- Bird (1968) also supports these views, according to which, the geomorphological processes which act on the coastal landforms are influenced by a number factors; notably geological, climatic, biotic, tidal, and others. According to him, biota plays biomechanical and biochemical roles and have important effects on coastal geomorphology. These effects can be erosional, protective or constructional. Salt marsh and dune vegetation may stabilize the depositional landforms on the coasts or promote the accretion of sediment in such a way as to build new landforms.
- Thornbury (1985) has given the fundamental concepts of geomorphology
- Woodroffe (2002) has suggested the many forces act upon the coastal landforms apart from those mainly referred by many workers
- Johnson (1919) has proposed a classification scheme for coasts, which is largely based on the tectonic influence on the coastal area.
- Shepard (1973) has divided the coasts into primary (geological underpinning) and secondary (marine processes) types.

CHAPTER 3: MANGROVES

Mangrove trees and shrubs are a common sight on mudflats and banks of tropical and subtropical rivers and coastlines in many parts of the world (Spalding et. al., 1997). They are the trees or bushes growing between the level of high water of spring tide and the level close to slightly above the mean sea level. They occupy the intertidal area of coastal wetlands with significant adaptation for salt tolerance and a distinct morphology and phenology. Mangroves have immense ecological, economic and societal importance. This transitional habitat harbors varied life forms, making it one of the most productive ecosystems.

The term '***Mangrove'*** is considered a composite of the Portuguese word '*mangue'* and the English world '*grove'*. In French, it is known by the terms 'manglier' and 'paletuvier' (MacNae, 1968). The Spanish describe them by the term "*manglar" whereas* the Dutch make use of the word "*vloedbosschen*" to describe the mangrove community and restrict the term "*mangrove*" for the individual trees. The Germans follows the English. The word "*mangro*" is a common name for *Rhizophora* in Surinam (Chapman, 1976). It is believed that all these words originated from the Malaysian word, "*manggi-manggi*" meaning "above the soil." This word is no longer used in Malaysia, but is used in eastern Indonesia to refer to *Avicennia* species (Kathiresan and Bingham, 2001). Mangrove formations are best described as "Mangal", as proposed by

MacNae (1968) leaving the term 'mangrove' for the individual genera. The term "*mangrove"* is also used as an adjective, as in"mangrove tree" or "mangrove fauna." Mangrove forests are sometimes also known as "tidal forests", "coastal woodlands", or "oceanic rain forests" (Kathiresan and Bingham, 2001).

3.1 IMPORTANCE OF MANGROVES

"If there are no mangrove forests, then the sea will have no meaning. It is like having a tree with no roots, for the mangroves are the roots of the sea."

Fisherman on the coast of the Andaman Sea, Trang Province, Southern Thailand

"A town is saved, not more by the righteous men in it than the woods and swamps that surround it."

The wisdom of Henry Thoreau's

Probably understanding the underlying significance and implications of the above quotes, mangroves in recent times have received attention of many researchers across the world. Not only do they offer the scenic views, but the inimitable services provided by them have resulted in a renewed attention towards the conservation and effective management of this ecosystem.

3.1.1 ECONOMIC BENEFITS

The mangroves supply forestry products (firewood, charcoal, timber, honey *etc*.) as well as fishery products (fish, prawn, crab, mollusk *etc*.). Some of the mangrove species, especially *Avicennia* form cheap and nutritive feed for buffaloes, sheep, goats and camels. At many places, mangrove extracts are used in indigenous medicine. The mangrove ecosystems also provide seeds for aquaculture industries (Kathiresan, 2010). The aerial roots, trunks, leaves and branches host other group of organisms. They enrich coastal waters, yield commercial forest products and support coastal fisheries. The fishes, the avi-fauna birds, and the molluscans feed on the detritus of the mangroves (Spalding et. al., 1997).

Mangrove sediments generally support higher densities of benthic organisms than do adjacent non-vegetated sediments (Edgar, 1990; Sasekumar and Chong, 1998). This might be due to the fact that they are surrounded by loose sediments, and that the submerged roots, trunks and branches are islands of habitat that attract rich epi-faunal communities, including bacteria, fungi, macro-algae and invertebrates. In addition, it has been observed that the mangrove habitats and prawn/shrimp populations are closely linked. This can be explained by the fact that the organic detritus exported directly from the mangroves provides food and habitat for juvenile penaeids in offshore areas (Daniel and Robertson, 1990), which upon moving to the offshore enter the commercial fishery as they mature (Kathiresan and

Bingham, 2001). This hypothesis is strongly supported by surveys of larval, post-larval and juvenile penaeids in near-shore habitats (Vance *et al.*, 1990, 1996, 1997; Mohan *et al.*, 1997; Primavera, 1998; Rajendran and Kathiresan, 1999a).

Mangrove ecosystems are also important for the fish production. Mangroves harbor rich and diverse assemblage of fish, some with commercial value (Kathiresan and Bingham, 2001). They serve as nursery, feeding and breeding grounds for many fishes and shellfishes. Nearly 80% of the fish catches are directly or indirectly dependent on mangrove and other coastal ecosystems worldwide (Kjerfve & Macintosh, 1997)#. This is due to the large amounts of litter produced in the form of falling leaves, branches and other debris (Kathiresan and Bingham, 2001). Microorganisms found in the soil decompose the fallen parts. During this process, nutrients are released which enrich the surrounding waters. Detritus, an important product produced in the mangrove ecosystems as it is rich in protein and serves as a nutritious food for a variety of organisms. The organisms feed on detritus or filter the detritus particles from the water column. Such detritus–feeding fishes are preyed upon by larger carnivorous forms. The influx of nutrients generated by the mangroves supports other sensitive habitats like the coral reefs, seaweeds and seagrass beds (Kathiresan, 2010).

3.1.2 SOCIETAL IMPORTANCE & ECOLOGICAL SERVICES

Probably one of the most important attribute of the mangrove ecosystems is the influence it has in protecting the coast from the cyclones, floods, storm surges, wave action and coastal erosion.

Mangroves help in mitigating the effects of storm surges, cyclones, etc, by providing an effective barrier. Mangrove systems offer protection to the coastline against the flood, which are often caused by tidal waves or due to heavy rainfall associated with storms. The ability of mangroves in flood control is due to the response of their root system, which has a larger spread out, and in their roots capability to promote sedimentation (Kathiresan, 2010). In addition, they play an important role in preventing the erosion. The mere presence of mangroves in some places acts as a stabilizing factor for the river banks and coastline. The mangrove systems minimize the action of waves and thus prevent the coast from erosion. The deforestation of mangroves causes erosion problems, as has been noticed in the Gulf of Kachchh and other regions (Kathiresan, 2010).

One of the important functions of mangroves is trapping of sediment, and thus acting as sinks to the suspended sediments (Woodroffe, 1992; Wolanski *et al.,* 1992; Wolanski, 1995; Furukawa *et al.,* 1997). The mangrove trees catch sediments by their complex aerial root systems and thus function as land expanders. In numerous cases, there has been proof of annual sedimentation rate, ranging between 1 and 8 mm, in mangrove areas with

expansion of land (Bird & Barson, l977). The mangrove structures inhibit tidal flows, probably due to the friction force which the trees with their root system provide. The soil particles are carried in suspension into mangrove forests from seawater by the incoming tide, and the soil particles are left behind in the swamps and within the root system by the outgoing tides. Thus, the particles settle in the forests during the low tide, probably when the turbulence gets reduced and water velocity at low tide becomes sluggish and low to carry the particles back to the sea

The mangrove swamps apart from acting as traps for the sediments, are the sink for the nutrients as well. They also help in recycling of carbon, nitrogen and sulphur. It is perhaps the only biotic system, which recycles sulphur efficiently in nature, making it available in assimilable forms to other organisms. Mangrove sediments have a high capacity for absorbing and holding heavy metals thereby preventing the spread of metal pollution in coastal areas.

Mangrove ecosystems are receiving increasing attention, but we still lack much basic information about their structure and function (Kathiresan and Bingham, 2001). Many mangrove environs lack study on them especially the environmental parameters, the diversity and the density, etc.

3.2 THE MANGROVE ENVIRONMENT

The mangrove environment has some special characteristics of salinity, tidal currents, winds, high temperatures, and muddy anaerobic soil. Plants of the environment are able to adapt to themselves to practically all types of adverse conditions except perhaps frost, and hence they are distributed mostly in the tropical regions. Not only are they influenced by chemical and physical conditions of their environment, but they usually help to create those conditions. Based on this, their distribution is also diverse. They are found in a variety of tropical coastal settings like the deltas, estuarine areas with their own deltas, lagoons, and fringes of the coral reefs (Kathiresan, 2010).

Kathiresan (2010) has described the ecology and environment of the mangrove ecosystems. According to Kathiresan, three conditions favor mangrove formations and these are -

1. Open seashores where substratum is muddy and protected,
2. Protected banks of estuaries, and
3. Creeks which cut across the land mass.

Among these, the protected banks of estuaries are the best suited locations for the mangroves (Kathiresan, 2010).

Many classifications have been proposed by different workers, for the environmental setting of the mangrove ecosystem. Thom (1982) and Galloway

(1982), defines six main types of mangrove settings described on the basis of their substrate, tidal range and sedimentation. The classes are –

1. The large deltaic system
2. Tidal plains
3. Composite plains – under both tidal and alluvial influence
4. Fringing barriers and lagoon
5. Drowned bedrock valleys and
6. Coral coasts

Singh (2002), on the basis of the hydrological processes, tidal impact and composition of forest, divides the mangroves in the Gulf of Kachchh into following community types –

1. Fringe mangroves
2. Creek mangroves
3. Scrub mangroves

Most of the types of mangrove forests noted above get frequently affected by rapid changes in coastal geomorphology. Many ecological factors strongly influence the well being of mangroves and these include geographical latitudes, wave action, rainfall, freshwater runoff, erosion/sedimentation rates, aridity, salinity, nutrient inputs, and soil quality (Kjerfve *et al*., l999).

The most followed classification however is the one give by Lugo and Snedaker (1974) and Woodroffe (1992). According to them, there are normally

six functional types of mangrove forests. They are the fringe mangroves, riverine mangroves, basin mangroves, overwash mangroves, scrub mangroves (dwarf) and hammock mangrove forests. The last three types are the modified forms of the first three types. The six types can be summarized as follows (Figure 3.1):

1. Over-wash mangroves - These are small mangrove islands, frequently formed by tidal washings.
2. Fringing mangroves – These occur along the borders of protected shorelines and islands, influenced by daily tidal range. They are sensitive to erosion and long exposure to purely marine conditions with turbulent waves, and tides.
3. Riverine mangroves - These are luxuriant patches of mangroves existing along rivers and creeks, which get flooded daily by the tides. Such forests are influenced with the incursion of large amount of freshwater with fluvial nutrients and thus making the system highly productive with trees growing taller.
4. Basin mangroves - These are stunted mangroves located along the interior side of the swamps and in drainage depressions. Their positioning channels the terrestrial runoff to move towards the coast with a slow velocity of water flow.
5. Hammock mangroves - These are similar to the basin type except that they occur in more elevated sites than the four types given above

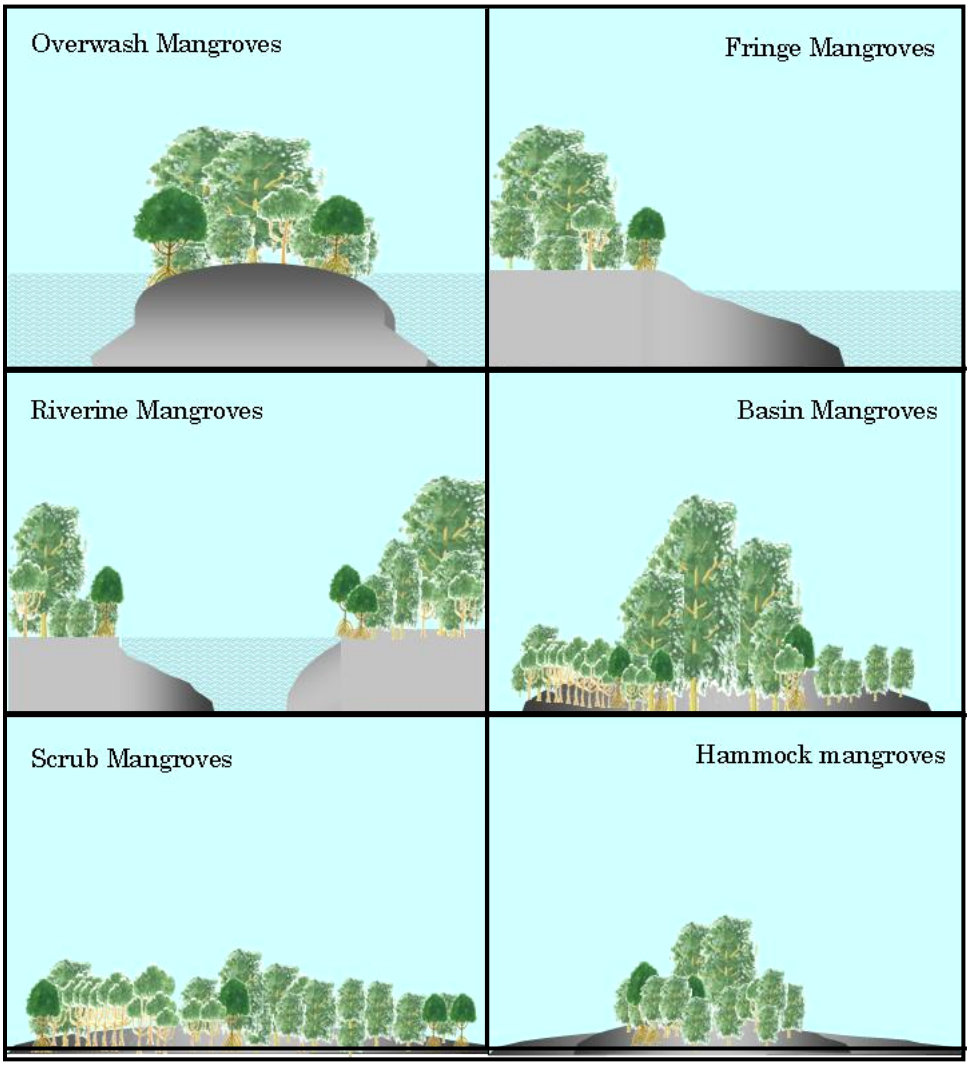

Figure 3.1 – Types of mangroves based on the environment setting

(Source: Adapted from Lugo and Snedaker 1974, Wharton, 1976)

6. Scrub mangroves - These form dwarf mangrove settings along flat coastal fringes.

This classification however has limitations in providing information on the physical processes that take place in all the types of forests. Therefore, a new classification has been suggested. This includes river dominated, tide dominated and interior mangrove forests (that have less influence of river/or

tides). The modified classification has been shown diagrammatically in figure 3.2 (Woodroffe, 1992, 2002).

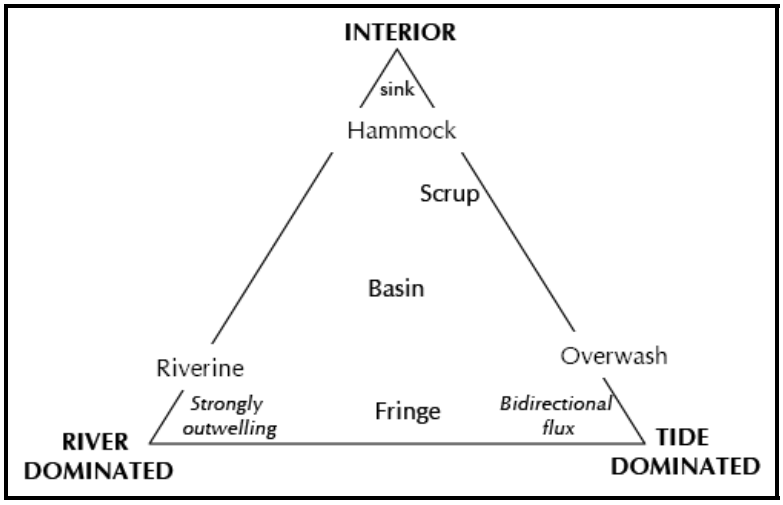

Figure 3.2 – Classification of mangrove environment
(Source: Woodroffe, 2002)
(based on domination of tide, river or delta)

3.3 MAJOR ENVIRONMENTAL PARAMETERS AFFECTING MANGROVES

Mangrove vegetation prefers a specific environment. Many factors influence this unique ecosystem. They are governed by local climate, salinity, geomorphology, waves and currents and tidal inundations to state major of them.

3.3.1 CLIMATE

Climatic factors such as temperature, humidity, precipitation, rainfall, etc., act as the major governing factors for proper growth of mangrove's and its development. Mangroves are tropical plants. Their maximum northern

and southern limit is up to 30^0. Beyond this, the environmental parameters do not permit proper growth and development of mangroves and hence salt marsh vegetation takes up the coastlines beyond tropics.

3.3.2 TEMPERATURE

Mangrove communities most commonly occur in areas where the average temperature of the coldest month is higher than 20°C and where the seasonal range does not exceed 10°C. Temperatures of around 5°C and frosts also limit mangrove distributions (Tomlinson, 1986). However, very high temperatures are not favourable as leaves of mangroves are sensitive to temperature and their photosynthetic capacity gets reduced, falling to zero at leaf temperatures of 38-40°C, as against the optimum leaf temperature for photosynthesis which is 28-32°C (Clough *et al*., l982; Andrews *et al*., l984).

Mangroves have been reported to grow in latitudes where average sea surface temperature is 24°C. Any further rise in temperature may lead to spreading of only some species in to higher latitudes, provided the direction of ocean currents facilitates the dispersal of their seeds. A small increase in temperature may not adversely affect the flowering, but may change their reproductive cycle and thus may alter the duration between flowering and the fall of ripe seeds (Kathiresan, 2010).

3.3.3 RAINFALL

The availability of freshwater is an important factor for the development and growth of mangrove forests. Freshwater supply has often

been indicated by the ratio of rainfall to evapo-transpiration. Under the humid conditions, where the ratio exceeds 1, the mangroves grow luxuriantly. In arid climates, on the other hand, where the ratio falls below 1, the mangroves get stunted. High rainfall in humid areas leaches out residual salts from the mangrove soil and thus encourages the growth of mangroves (Kathiresan, 2010)

Fresh water inputs plays an important role as it reduces the salinity from the soils, thus reducing the salinity stress. Areas, which have a great variety of mangrove species, are found along coasts that receive high rainfall, heavy run off and seepage into the intertidal zone from the hinterland. Such areas are commonly subject to extensive sedimentation, which provides a diverse range of substrate types and nutrient levels, which in turn are favourable for mangrove growth.

In the past, due to supply of water from the Indus River and relatively high rains the mangroves of the Kori creek were very diverse, with higher number of species then found today. Nevertheless, subsequent drought has affected the mangrove diversity and the number of species has reduced.

The influences of precipitation and temperature on mangrove distributions were analyzed by Blasco (1984). He reported four classification groupings: (1) warm humid areas where 90% of the world's mangroves are found (2) sub-humid areas where mangroves are occasionally found (3) semi-arid areas where mangroves are rarely found (4) arid areas where mangroves

are practically unknown, except where there are winter rains. In equatorial and tropical summer rainfall regions, mangroves are tall, dense and floristically diverse. In subtropical arid regions, mangroves are low, scattered and sporadic. Areas of higher coastal rainfall and high riverine inputs of freshwater tend to support more diverse communities of mangroves than areas of low coastal rainfall and limited runoff (Duke et. al. 1998).

3.3.4 TIDAL AMPLITUDE

Tidal amplitude may not be directly related to the physiological requirements of mangroves. However, they are very important in transporting the sediments and nutrients and in areas with high evaporation rates, they help in reducing the soil salinity, by washing off action. Tides also help in the dispersal of the propagules. Excess tidal amplitude on the hind side also deters the propagules' establishment and thus natural regeneration of the mangroves may be hampered.

In general, coasts with a greater tidal range can help in colonization of extensive mangrove forests. A greater tidal range increases the intertidal area and depending on the slope of the substrate, which if smooth encourages the growth of mangroves. The topography of a mangrove swamp is normally smooth and flat. However, any rise or fall of the land can greatly influence the direction and rate of flow of the water in the system, which changes the colonization of mangroves. Many species of mangroves respond differently to different tidal regimes (Kathiresan, 2010).

3.3.5 SALINITY

Salinity plays a vital role in the distribution of mangrove species, their productivity and the growth of mangrove forests (Chen & Twilley, 1998). Changes in salinity are normally controlled by climate, hydrology, rainfall, topography and tidal flooding. Mangroves generally tolerate higher salinity than do non-mangrove plants, but tolerance levels vary among the mangroves.

Experimental evidences indicate that at high salinity, mangroves spend more energy to maintain water balance and ion concentration compared to primary production and growth (Clough, l984). However, low salinity, associated with long periods of flooding, contributes to mangrove degradation through reduced cell turgidity and decreased respiration. Extremely high salt concentrations in the groundwater of tropical salt flats are also responsible for the complete absence of mangroves in such locations. There are often very sharp changes in the groundwater salt concentrations at the interface between salt flats and mangroves indicating that the mangroves are modifying the salinity of the groundwater (Ridd & Sam, 1996).

Mangroves are poor competitors under non-saline areas where freshwater marsh plants easily out-class them (Kathiresan, 2010), which is to say that a optimum level of salinity, varying from species to species, is necessary for the survival of mangrove forests.

The conservative water use by leaves enhance salt tolerance of mangrove species. However, this is at expense of growth rates, so that species with a broad range of salinity tolerance tend to grow more slowly than less tolerant species (Ball, 1996)

3.3.6 GEOMORPHOLOGY

Mangrove establishment requires protection from strong winds and wind generated waves, as wave action prevents seedling establishment. Consequently, mangrove communities tend to be located within sheltered coastal areas, surrounding highly indented estuaries, embayment and offshore islands protected by reefs and shoals (Mitsch and Gosselink, 1993).

3.4 GLOBAL DISTRIBUTION OF MANGROVES

Mangroves are distributed circumtropically, occurring in 112 countries and territories. There are two main centre of diversity for mangrove communities which have been termed the western and eastern groups (Tomlinson, 1986). The eastern group broadly corresponds with the Indo-Pacific and is bound to the east by the limits to natural mangrove occurrence in the west and central Pacific and to the west by the southern tip of Africa. The western group fringes the African and the American coasts of the Atlantic Ocean, the Caribbean Sea and the Gulf of Mexico, and includes the western (Pacific) coasts of the Americas (Spalding et al 1997). This is indicated in figure 3.3 below.

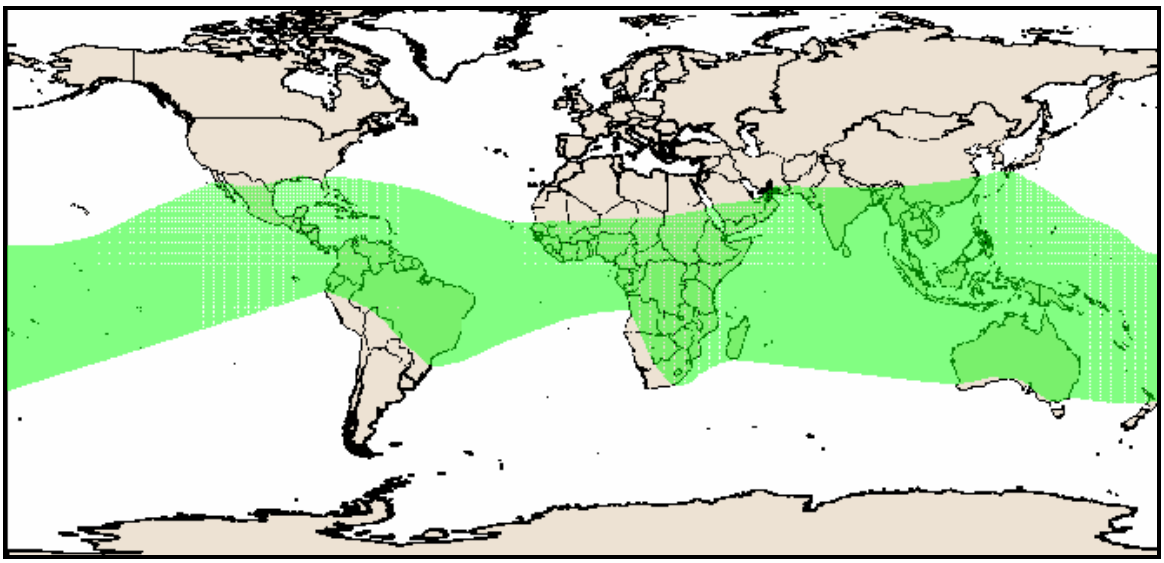

Figure 3.3 – World Distribution of Mangrove diversity

(Source: UNEP - WCMC, 2001)

These two regions have quite different floristic inventories. The eastern region has approximately five times the number of species than those found in the western region. Around 34 major and 20 minor mangrove species belonging to about 20 genera in over 11 families have been recorded globally (Tomlinson, 1986; Duke, 1992).

When it comes to listing the number of species of mangroves, there is variation in the number of true mangrove species. This may be due to the fact that many workers have identified different number of species, according to their individual studies, on the basis of their own definition or opinion. Tomlinson (1986) recognizes three groups of mangroves: major mangrove species, minor mangrove species and mangrove associates. The major species

are the strict or true mangroves, recognized by most or all of the following features:

1) they occur exclusively in mangal,
2) they play a major role in the structure of the community and have the ability to form pure stands,
3) they have morphological specializations - especially aerial roots and specialized mechanisms of gas exchange,
4) they have physiological mechanisms for salt exclusion and/or excretion,
5) they have viviparous reproduction, and
6) they are taxonomically isolated from terrestrial relatives. The strict mangroves are separated from their nearest relatives at least at the generic level, and often at the sub-family or family level.

On this basis, Tomlinson (1986) has recognized only 48 mangrove tree species. Whereas, Saenger et. al., (1983) has reported 60 species exclusively from the tidal zone, recognized as true mangroves in the list of IUCN. World-wide, Chapman (1976) has reported 90 species representing mangroves, Saenger et al. (1983) recorded 83 species, UNDP/UNESCO (1986) reported 65 species, and Tomlinson (1986) mentioned only 48 mangrove species, out of which 40 were considered true mangroves found in the Old world Tropics (Indo-West pacific region) and eight true mangroves from the New world Tropics (Mandal and Naskar, 2008) .

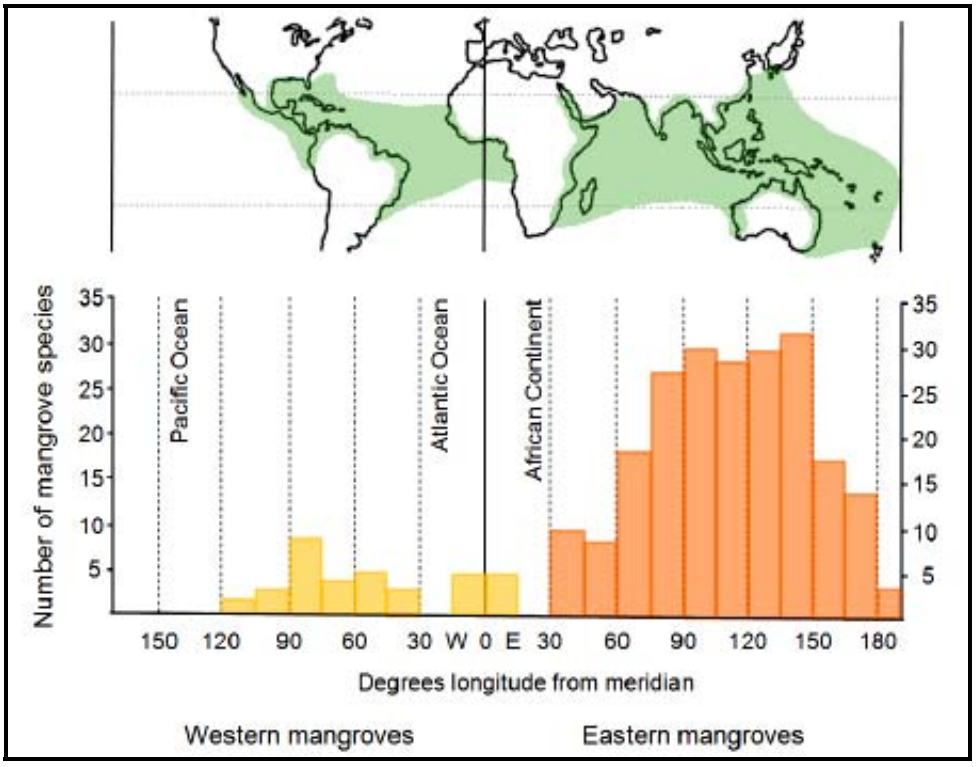

Figure 3.4 – Generalized global distribution of mangroves and the diversity of mangrove species per 15° of longitude

(Source: Tomlinson, 1986)

According to Tomlinson (1986), the major mangroves include 34 species in 9 genera and 5 families. The minor species contribute 20 species in 11 genera and 11 families. Thus, 54 mangrove species in 20 genera and 16 families are present globally. Their distribution has been indicated in figure 3.4. Duke (1992), on the other hand, identified 69 mangrove species belonging to 26 genera in 20 families. By reconciling common features from Tomlinson (1986) and Duke (1992), Kathiresan and Bingham, (2001) have recognized 65 mangrove species in 22 genera and 16 families (Kathiresan, 2010) (table 3.1).

Sr. no.	Family	Species present world over#	Presence in India
1	Avicenniaceae	*Avicennia alba*	+
2		*Avicennia balabophora*	-
3		*Avicennia bicolor*	-
4		*Avicennia eucalyptifolia*	-
5		*Avicennia germinans*	-
6		*Avicennia lanata*	-
7		*Avicennia marina*	+
8		*Avicennia officinalis*	+
9		*Avicennia schaueriana*	-
10		*Avicennia africana*	-
11	Acanthaceae	*Acanthus ilicifolius**	+
12		*Acanthus ebracteatus**	+
13		*Acanthus volubilis**	+
14	Bignoniaceae	*Dolichandrone spathaceae*	-
15	Bombacaceae	*Camptostemon philippinensis*	-
16		*Camptostemon schultzii*	-
17	Caesalpiniaceae	*Cynometra iripa*	-
18		*Cynometra ramiflor*	-
19	Combretaceae	*Conocarpus erectus*	-
20		*Laguncularia racemosa*	-
21		*Lumnitzera littorea*	+
22		*Lumnitzera racemosa*	+
23		*Lumnitzera x rosea*	-
24	Euphorbiaceae	*Excoecaria agallocha*	+
25		*Excoecaria indica*	-
26		*Excoecaria dallachyana*	-
27	Lythraceae	*Pemphis acidula*	+
28		*Pemphis madagascariensis*	-
29	Meliaceae	*Aglaia cucullata*	-
30		*Xylocarpus granatum*	+
31		*Xylocarpus mekongensis*	+
32		*Xylocarpus molluccensis*	-
33	Myrsinaceae	*Aegiceras corniculatum*	+
34		*Aegiceras floridum*	-
35	Myrtaceae	*Osbornia octodonta*	-
36	Palmae	*Nypa fruticans*`*	+
37		*Phoenix padulosa**	+
38	Pellicieraceae	*Pelliciera rhizophoreae*	-
39	Plumbaginaceae	*Aegialitis annulata*	-
40		*Aegialitistorundifolia*	-
41	Rhizophoraceae	*Bruguiera cylindrica*	+
42		*Bruguiera exaristata*	-
43		*Bruguiera gymnorrhiza*	+
44		*Bruguiera hainesii*	-
45		*Bruguiera parviflora*	+
46		*Bruguiera sexangula*	+
47		*Ceriops decandra*	+
48		*Ceriops tagal*	+
49		*Kandelia candel*	+
50		*Rhizophora apiculata*	+
51		*Rhizophora mangle*	-
52		*Rhizophora mucronata*	+
53		*Rhizophora racemosa*	-
54		*Rhizophora smoensis*	-
55		*Rhizophora stylosa*	+
56		*Rhizophora x lamarckii*	-
57		*Rhizophora x annamalayana*	+
58		*Rhizophora x setala*	-
59		*Rhizophora x harrisonii*	-
60	Rubiaceae	*Scyphiphota hydrophyllaceae*	+
61	Sonneratiacea	*Sonneratia alba*	-
62		*Sonneratia apetala*	+
63		*Sonneratia caseolaris*	+
64		*Sonneratia griffithii*	+
65		*Sonneratia lanceolata*	-
66		*Sonneratia ovata*	-
67		*Sonneratia x gulngai*	-
68	Sterculiaceae	*Heritiera fomes*	+
69		*Heritiera globosa*	-
70		*Heritiera littoralis*	+

TABLE – 3.1 Species recorded globally and in India
(Modified from Kathiresan and Bingham, 2001)

+ Recorded

- Missing

- includes the South east USA, Central/South America, Africa, South Asia, South east Asia, Malay archipelago, East Asia, Australia, South-west Pacific, West Pacific

* - not included in the list by Kathiresan and Bingham

TABLE – 3.1 Species recorded globally and in India

3.4.1 Global mangrove Extent

Global estimation of mangrove area was first attempted by the FAO / UNEP as a part of the Tropical Forest Resources Assessment in 1980. The first estimates gave the world total as 15.6 million hectares. More recent estimates range from 12 to 20 million ha (table 3.2). During these studies, countries with small areas of mangroves were excluded due to lack of information and also due to the fact that their combined area of mangroves would not significantly affect the world total. Later on, many studies were undertaken to study the mangroves of the world. The major works were carried out by FAO and UNEP (1980-1981), Saenger et. al., (1983), Aksornkoae et al., (1992), Spalding et al., 1997 Aizpuru et al (2000), FAO during 1994 and 2007. They have been summarized in table 3.2 (Chart 3.1) below. However, mangrove estimates given by Spalding et al (1997) are the most accepted.

Total global mangrove coverage is approximately 18 million which forms just about 0.45% of the world forests and woodlands. Mangroves are

largely restricted to the latitudes between 30^0 N and 30^0 S (Spalding, 1997). Mangroves of South and Southeast Asia form the worlds most extensive and diverse mangrove system comprising 41.4 % of global mangroves (Figure 3.5).

Reference	Reference year	No. of countries included	Estimated total area (ha)
FAO, UNEP, 1981	1980	51	15,642,673
Saenger *et al.*, 1983	1983	65	16,221,000
FAO, 1994	1980-1985	56	16,500,000
Groombridge, 1992	1992	87	19,847,861
ITTO/ISME, 1993	1993	54	12,429,115
Fisher and Spalding, 1993	1993	91	19,881,800
Spalding *et al.*, 1997	1997	112	18,100,077
Aizpuru *et al.*, 2000	2000	112	17,075,600

Table 3.2 - Estimates of global extent of mangroves by various workers (**Source:** FAO, 2003)

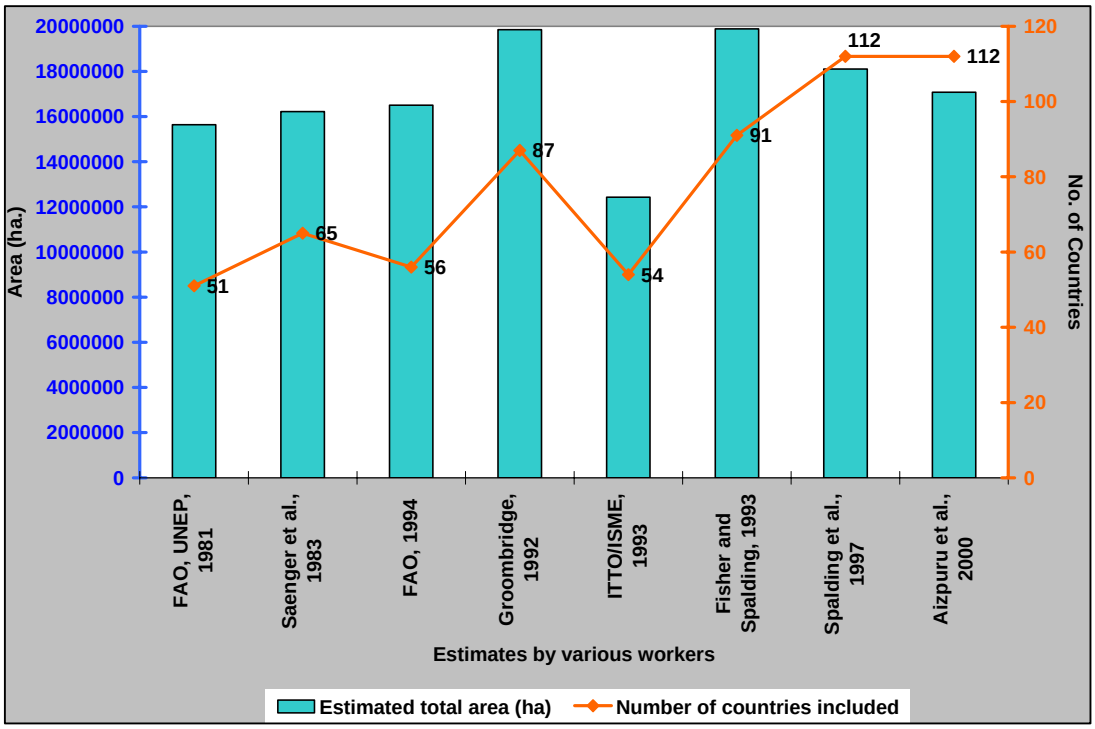

Chart 3.1 – Graphical area estimate of world mangroves by different workers

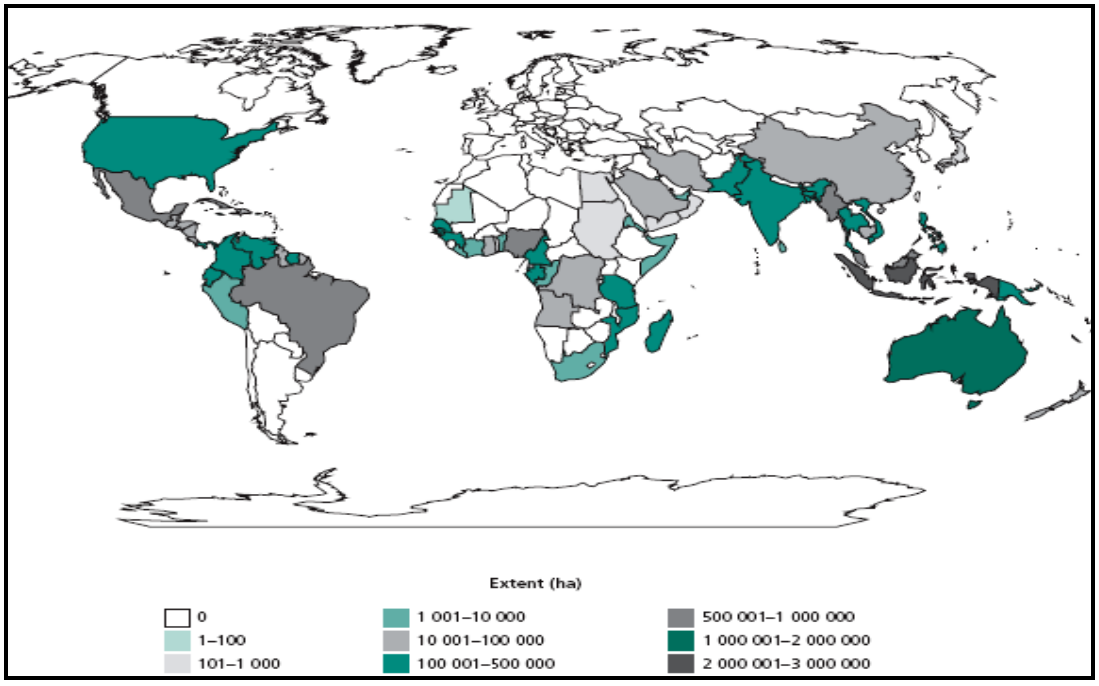

Figure 3.5 - Extent of mangrove world wide, 2005 (Source: FAO, 2007)

The Indo-West Pacific region is considered the cradle of the mangroves. The region between Pakistan in the west to China and Japan in the northeast, inclusive of the insular Southeast Asia to *Irian Jaya* (Indonesia) in the southeast comprises of the south and southeast mangrove stretches. This region has the highest diversity of mangrove species in the world. Many authors consider the Indo-Malayan region to be the major centre of origin for mangrove taxa, and that dispersal from here to other areas occurred particularly during the Tertiary and Quaternary (Spalding, 1997). Two competing hypotheses have been presented to explain this pattern. The center-of-origin hypothesis suggests that all mangrove taxa first appeared in the Indo-West Pacific and subsequently dispersed to other regions. The vicariance hypothesis, on the other hand, states that all mangroves originated around the Tethys Sea. Continental drift then isolated the flora in different regions of the earth where diversification created distinct faunas (Kathiresan and Bingham, 2001).

3.5 MANGROVES OF INDIA

India has a coastline of about 12,700 km, which can be divided into west and east coasts, with patchy mangrove distribution (Spalding, 1997). Mangroves in India are distributed along all the coastal states (figure 3.6, table 3.3). Greater part of the Indian mangroves are found in the east coast, where the coastal profile is typically less steeply shelving and the rivers and estuaries are better developed.

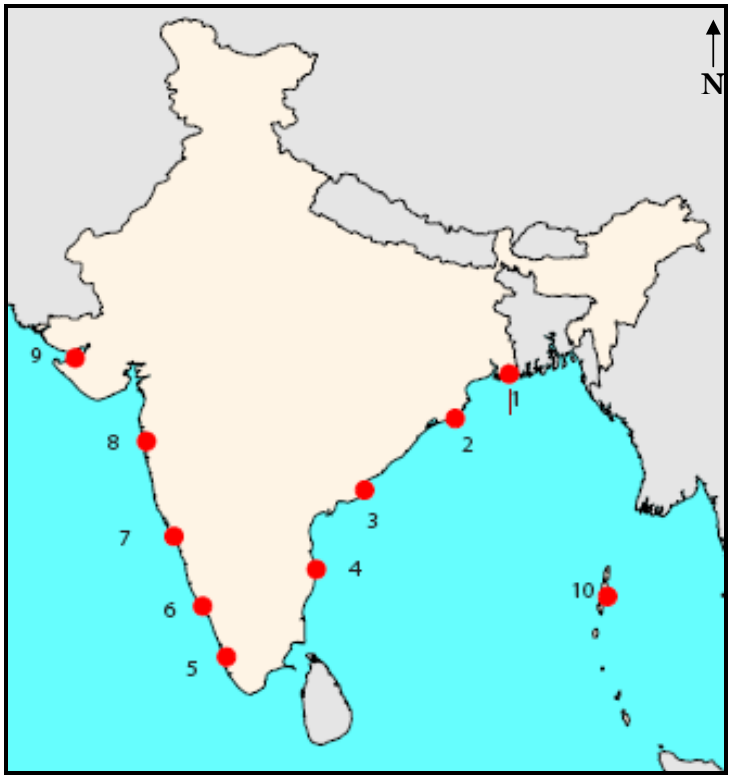

Figure 3.6 – Distribution of mangroves in India
(Source: Shah D. G., 2004)

Sr. no	State	Major mangrove areas
1	West Bengal:	Sundarbans, Subarnekha
2	Orissa	Bhitarkanika, Mahanadi delta
3	Andhra Pradesh	Godavari and Krishna delta
4	Tamil Nadu	Pichavaram
5	Kerala	Veli
6	Karnataka	Coondapoor
7	Goa	Charao Is., Mandovi & Zuary estuary
8	Maharasthra	Mumbai, Vijaydurg & Devgadh creeks
9	Gujarat	Gulf of Kachchh, Kori creek
10	Anadaman & Nicobar Islands	Mayabandar, Shoal bay, Porlob Jig

Table 3.3 – distribution of mangroves along the coastal states of India

The first scientific account of Indian mangroves was given by Van Rheede (1678) in his famous book *Hortus Malabaricus*. After about a span of two centuries Schimper (1891) gave detailed information on the littoral flora of the Indo-Malayan coast. The literature on mangroves has been scattered in local and regional floras and no directed effort was made to know the floristic components of the mangrove environments of the country till the 1970's. Blasco (1975) did some pioneering work in his report 'The Mangroves of India'. Detailed study on the all India composition of mangroves started in the 1987's with the compilation and publication of the State of Art Report on Mangroves report by the MoEF, GOI. This initiative led to successive work on mangroves in the years to come, especially in terms of mapping the density and the area of the mangrove ecosystems. It provided a benchmark for the further work as it was a comprehensive description on the nature, importance and distribution of mangroves in the different states of the country.

On the western coast of India, there are fringing mangroves along the estuaries of many small rivers, while there are important scrubby communities associated with the arid coast around the Gulf of Kachchh (Spalding, 1997). This is due to the regional geographical and the climatic variations. The eastern coast has many major perennial rivers which also form the deltaic environment, which also harbors the world's largest single mangrove block, the Sunderban mangroves (shared with Bangladesh). The west coast on the other hand lacks perennial rivers especially in the

northern most part, i.e. the state of Gujarat. In addition, the climate varies around the coastline (Spalding, 1997).

3.5.1 Mangrove extent in India

Mangrove cover in India accounts for about 3% of the world's mangrove (Chart 3.2) vegetation and is spread over an area of 4,639 km ^{2} in the coastal states and Union territories. This makes up for 0.14% of the country's total geographical area (Anon, 2009).

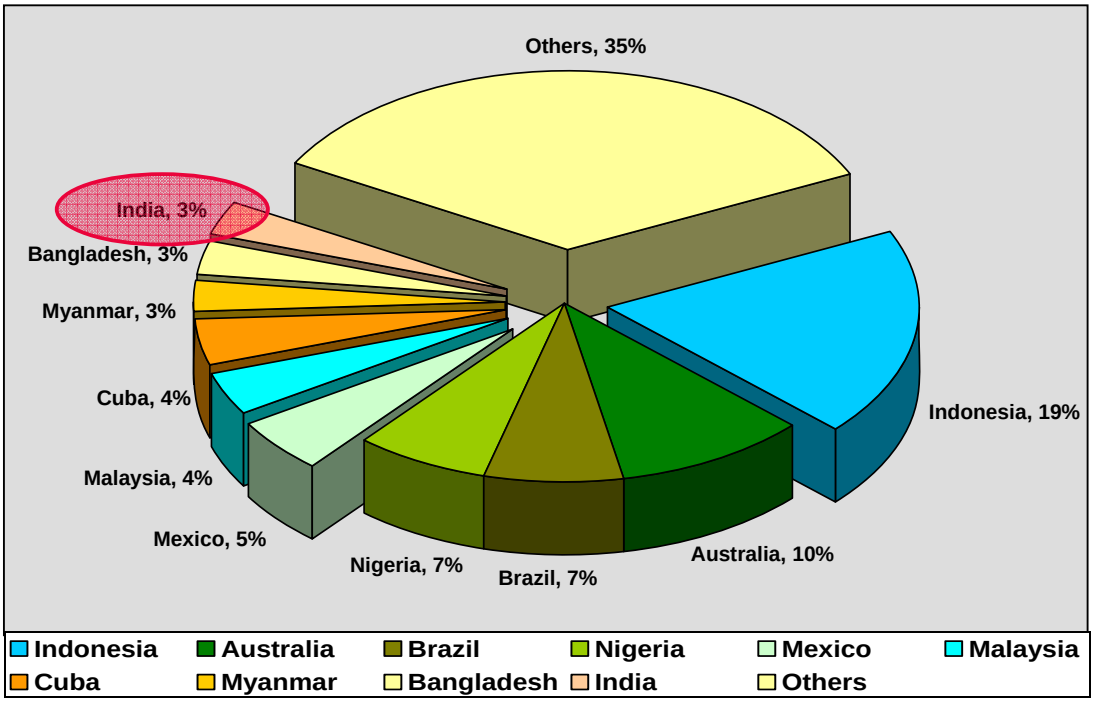

Chart 3.2 - Percentage of world mangrove area by country, 2005

(Source: FAO, 2007)

The mangrove cover in India has changed considerably over time (table 3.4). Blasco (1975) gave an estimate of about 52000 ha. of mangroves

in India. The state of the art report on mangroves in 1987 gave a first all India account of the actual mangrove cover in the country (chart 3.3). Since 1989, the Forest Survey of India has been mapping the mangroves of India and they have been giving the mangrove cover of the country every two years. The latest of their reports have come in 2009.

The latest assessment of the Forest Survey of India (FSI) shows that mangrove cover in the country is 4639 km^2, which is 0.14% of the country's total geographic area. The very dense mangroves comprises 1405 km^2 (30.29% of mangrove cover); moderately dense mangroves is 1659 km^2 (35.76%), while open mangrove covers an area of 1575 km^2 (33.95%) (Anon., 2009).

Several estimates for the mangrove extent in India have been given by different workers. They have been summarised in table 3.4.

3.6 THE FLORAL DIVERSITY OF MANGROVES OF INDIA

The usage of the term 'mangrove' and the number of mangrove species assigned on that basis vary remarkably among different workers. The species growing in the same region are designated differentially; some consider them as mangroves, but others do not (Mandal and Naskar, 2008). In India also, the reported number of mangrove species varies among researchers.

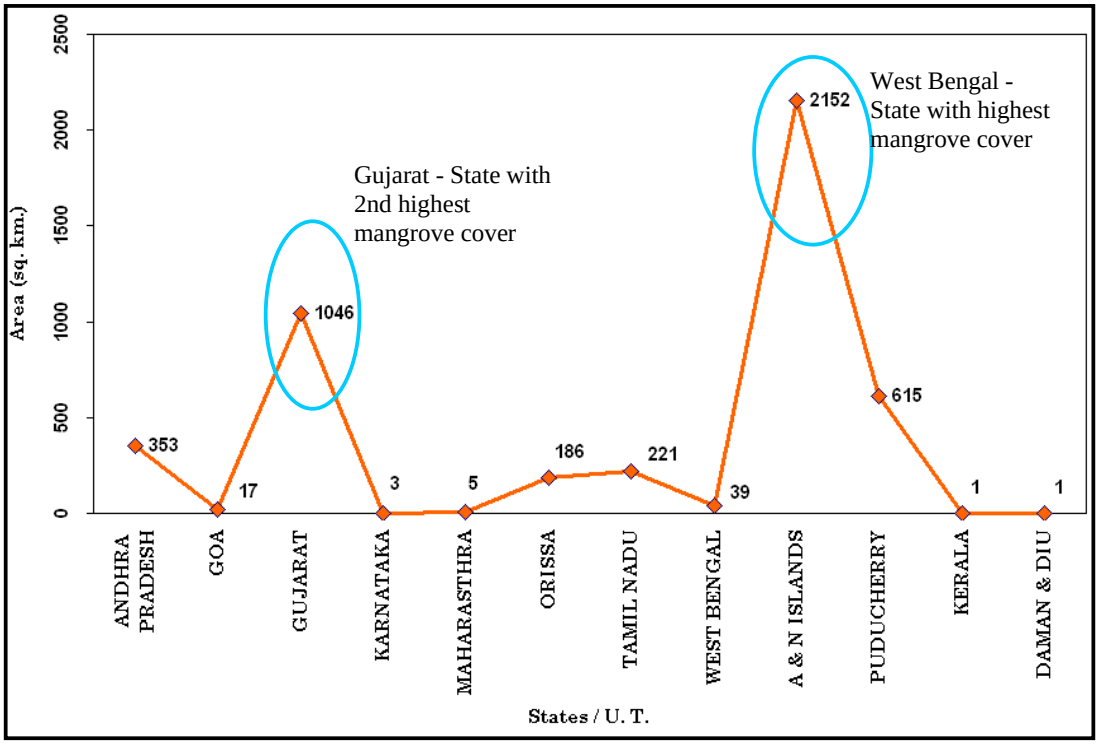

Chart 3.3 - Trend in mangrove area in the mangrove regions of India, for the year 2007 (Source: Anon, 2009)

Blasco et al. (1975) has reported about 50-60 species of mangroves whereas UNESCO (1986) accepts only 65 species of true mangroves occurring in the world. Untawale (1987), in his work on mangroves of India reports about 34 species from West coast and 48 species from East coast, accounting about 59 species in total. Of this 59 species and associated species of mangroves, some 25 species are restricted along the east coast, while eight species are restricted to the west coast. Naskar & Guha Bakshi (1987) record the presence of 35 true mangrove species, 28 mangrove associates and seven back mangals. However, Banerjee et al. (1989) reports 34 species on the eastern

Year	Area (ha)	Source	Methodology/Comments
1957	638818	Waheed Khan. 1957.	Cited in: Chaudhuri, A.B. and Choudhury, A. 1994. *Mangroves of the Sundarbans. Vol. 1. India.* The IUCN Wetlands Programme. Bangkok, Thailand, IUCN. This figure could include also water.
1957	571808	Mathauda, G.S. 1957. The mangrove of India. *In Proceedings of the Mangrove Symposium*. p. 66-97. Calcutta.	Cited in: Chaudhuri, A.B. and Choudhury, A. 1994. *Mangroves of the Sundarbans. Vol. 1. India.* The IUCN Wetlands Programme. The breakdown is provided.
1963	681976	Sidhu. 1963. *Studies on Mangrove*. National Accademy of Sciences.Vol 33b Part 1. p. 129-136.	Cited in: FAO. 1982. *Management and utilization of mangroves in Asia and the Pacific.* FAO Environment Paper 3. 160 pp. This extent includes also water.
1975	52000	Blasco, F. 1975. *The Mangroves of India.* Institut Francais de Pondichery. Pondichery.	Cited in: FAO. 1982. *Management and utilization of mangroves in Asia and the Pacific.* FAO Environment Paper 3. 160 pp.
1975	1400700	World Bank/WCMC/ABC. 1998 MacKinnon, J. *ed. Protected Areas Systems Review of the Indo-Malayan Realm*. World Conservation Monitoring Centre, Cambridge.	Digitized from general lines drawn on the 'Atlas of Forest Resources of India' at 1:2 000 000 in five map sheets (1975)
1980	91000	FAO, UNEP. 1981. *Tropical Forest Resourcess Assesment Project, Forest Resources of Tropical Asia.* FAO, UNEP, 475 pp.	Based on the information provided by Champion, H.G. and Seth, S.K. 1968. *A Revised Survey of the Forest Types of India.* Publication Division, Government of India - Delhi. Anon. 1976. *Atlas of Forest Resources of India.* National Atlas Organization. Calcutta. The area has been updated to year 1980 on the basis of annual deforestation rate.
1980	506702	FAO, 2002. Ibid	All the most reliable information available per province has been analysed and processed through the regression analysis. The 1980 figures obtained for each region have been used.
1982	404600	Forest Survey of India. 1987. *The state of Forest Report 1987*	Remote sensing.
1982	355000	Gopal B., Turner R.E., Wetzel RG and Whigham D.F. *eds.* 1982. *Wetlands ecology and management.* National Institute of Ecology and International Scientific Publications, New Delhi, India	Cited in: Spiers, A.G. 2001. *Review of international/continental wetland resources.* Environmental Research Institute of the Supervising Scientist

Year	Area (ha)	Source	Methodology/Comments
1983	96000	Wacharakitty, S. 1983. Mangrove Ecosystem in General. *In: ESCAP/UNESCO/NRCT Regional Remote Sensing Training Course of Mangrove Ecosystem*. P. 22-33. Bangkok, Nov. 28-Dec. 16 1983	Cited in: FAO. 1994. *Mangrove forest management guidelines*. FAO Forestry Paper 117. Rome, 319 pp.
1987	674000	Government of India. 1987. *Mangroves in India*. Government of India, Ministry of Environment & Forests, New Delhi. 150 pp.	Secondary reference, no primary source provided. The "Year" is the publication year.
1987	420000	Jagtap, T.G., Chavan, V.S. and Untawale, A.G. 1993. Mangrove Ecosystem of India: A need for Protection. *Ambio* 22 (4).	Remote sensing.
1988	424400	Forest Survey of India. 1991. *The State of Forest Report 1991*.	Remote sensing.
1991	303500	World Bank/WCMC/ABC. 1998 MacKinnon, J. *ed. Protected Areas Systems Review of the Indo-Malayan Realm*. World Conservation Monitoring Centre, Cambridge.	Data from The Conservation Atlas of Tropical Forests.
1993	447400	Nayak, S. 1993. *Role of Remote Sensing Application in the management of wetland ecosystems with special emphasis on Mangroves*. Lecture delivered at the UNESCO Curriculum Workshop on Management of mangrove Ecosystem and Coastal Ecosystem, Department of Marine Living Resource, Andhra University, Vishakhapatnam	Remote sensing.
1994	482700	Forest Survey of India. 1998. *The State of Forest Report 1997*	Remote sensing
1995	537900	Spalding, M.D., Blasco, F. and Field, C.D., eds. 1997. *World Mangrove Atlas*. The International Society for Mangrove Ecosystems, Okinawa, Japan. 178 pp.	Map analysis. Scale 1:1 000 000. According to the authors, the estimate by WWF-India personal communication (670 000 ha) is likely to be more accurate.
1996	400000	WRI, UNEP, UNDP, The World Bank. 1996. *World Resources 1996-1997*. New York and Oxford University Press 365 pp.	Secondary reference, no primary source provided. The "Year" is the publication year. It is probably an approximate figure.

Year	Area (ha)	Source	Methodology/Comments
1997	485000	Anon. 1997. *Status of forest cover*. Forest Survey of India, Dehra Dun.	Cited in: Singh, H.S. 2001. Mangroves in Gujarat on path of recovery - A success story. *Indian Forester*, April 2001.
1997	487100	Forest Survey of India. 1999. *The State of Forest Report 1999*.	Remote sensing
2000	670000	Aizpuru, M., Achard, F., and Blasco, F. 2000. Global Assessment of Cover Change of the Mangrove Forests using satellite imagery at medium to high resolution. *In EEC Research project n 15017-1999-05 FIED ISP FR* – Joint Research center, Ispra.	National level estimate based on extrapolation of a remote sensing case study for Ganges and literature review.
2000	448200	Forest Survey of India, 2001, State of Forest Report, 2001, Forest Survey of India, MoEF, GOI, India	Digital interpretation of 2000 IRS-1C/1D LISS II, resolution 23.5 m.; scale of interpretation 1:50000. Breakdown provided per state/union territory. This assessment is to be taken as the baseline information of mangroves cover for India. Not to be used to estimate increase or decrease from previous FSI assessments. Discrepancies may be caused due to change in methodology (visual to digital interpretation) & scale of interpretation (from 1:1 million to 1:50000)
2003	446100	Forest Survey of India, 2005, State of Forest Report, 2003, Forest Survey of India, MoEF, GOI, India	Digital interpretation of 2003 IRS-1C. Scale of interpretation 1:50000. Breakdown provided per state/union territory. The report provides information regarding the density classes as well (very dense, moderately dense & open)
2005	444500	Forest Survey of India, 2007, State of Forest Report, 2005, Forest Survey of India, MoEF, GOI, India	Digital interpretation of 2005 IRS-1C. Scale of interpretation 1:50000. Breakdown provided per state/U.T.(very dense, moderately dense & open)
2007	463900	Forest Survey of India, 2009, State of Forest Report, 2007, Forest Survey of India, MoEF, GOI, India	Digital interpretation of 2007 IRS-1C. Scale of interpretation 1:50000. Breakdown provided per state/ U.T. Provides information regarding density (very dense, moderately dense & open)

Table 3.4 - National level mangrove estimates
(Adapted from Mangroves of Asia 1980 – 2005, FAO, 2007; with necessary modifications)

coast (Tamil Nadu, Andhra Pradesh, Orissa, West Bengal and Andaman and Nicobar Islands) and 25 species on the west coast covering Kerala, Karnataka, Goa, Maharashtra and Gujarat. A census of mangrove species has identified 60 exclusive species distributed over 16 families confined to mangrove habitats only in the world and 23 non-exclusive species in mangrove and elsewhere observed. Jagtap et al. (1993) reports 50 species. Rajendran and Sanjeevi (2004) have prepared a list of 85 mangrove species in 53 genera and 34 families. However, this list includes the mangroves as well as the associates. Kathiresan and Bingham (2001) have prepared a list of 65 mangrove species in 22 genera and 16 families, which includes the major and minor species but not the associates. Keeping this in view, their classification/definition of mangroves is followed in the current study.

3.7 MANGROVES OF GUJARAT

Gujarat state is the western-most state of India. The Arabian Sea makes up the state's western coast. It has the longest coastline of the country, of about 1600 km, harboring approximately 1.046 sq. km of mangroves supporting the second largest block of tidal forests of India (Anon, 2009).

Mangroves in Gujarat are mostly confined to a) Indus deltaic region i.e. Kori creek and Sir Creek area, b) The Gulf of Kachchh, and c) The Gulf of Cambay. Major work on the mangroves in Gujarat had been carried out by agencies such as the State Forest Department, Space Applications Centre (SAC, Indian Space Research Organization, Ahmedabad), and

Gujarat Ecological Education and Research Foundation (Gandhinagar) (Anon., 1992; Singh, 2002; Shah D. G. et. al., 2005; Anon., 1991, 1993, 1995, 1997, 1999). Some of the more recent workers in this area are the Maharaja Sayajirao University, Gujarat Ecological Commission (GEC), and Gujarat Institute of Desert Ecology (GUIDE). However, most of the work has been restricted to the Gulf of Kachchh and to a small extent the other regions of Kachchh district, emphasizing mainly on the species diversity and their extent (Chavan, 1985; Untawale and Wafar, 1988; Parulekar, 1988; Untawale and Ambiye, 1988; Singh, 2002; Thivakaran G. A., 2003; Shah et al., 2005; Singh, 2006). It's only in the last decade where that the importance of mangroves have been recognized and hence several workers and organizations have began in-depth work on different aspects of mangroves in different parts of the state in difference to earlier works which were patchy. There has been a huge interest in mangrove resources and therefore, several organizations and workers are working on the mangroves of other areas of the state that had been studied so far in patches.

Gujarat state supports a diverse range of climatic conditions. Due to this difference in the regional climatic conditions, different areas have a distinct floral diversity (Anon., 1996). Mangrove vegetation occurring in these diverse regions also shows a difference in their diversity and structure. The mangroves of the Kori and Sir Creek grow in the open environment, i.e., on the islands, in the saline water of Arabian Sea, and lack fresh water, which was previously in abundance from the Indus. The

Gulf of Kachchh mangroves grow on the coastal mudflats, as well as on the islands of the Marine National park & Sanctuary. The mangroves are rarely fed by fresh water as the river discharge here is during rainy seasons only and the rainfall as such is scanty. The mangroves in Gulf of Cambay grow on the intertidal flats, and the tidal inlets.

The Gulf of Kachchh has an assemblage of different ecologically sensitive ecosystems, viz. coral reefs, mangroves, sea grasses, algae/seaweeds, etc. It is the largest inlet (approx. 7350 km²) of the Arabian Sea, about 60 km wide at its widest and 170 km long. Due to its rich diversity and fragile nature, the Govt. of Gujarat, in 1983 declared an area of about 457.92 sq km as the Marine Sanctuary and 162.89 sq km as Marine National Park. As the diversity and the areal extent of mangroves are found to be more in the Gulf of Kachchh region, the mangroves of this region are studied the most. It harbors the second largest mangrove patch in Gujarat. The southern part of this gulf is home to the Marine National Park and Sanctuary (MNP & S). Hence, much of the work on mangroves till date has been concentrated in this part of the state.

The Gulf is under severe threat due to natural as well as man-made conditions. The natural threats include cyclone, drought and earthquake. Gulf of Kachchh because of its strategic location is ideal for setting up of various industries, salt works, etc. There are already four petroleum industries, chemical factories, Fertilizer Company, thermal power plants, 11 major and minor ports, cement factories and about twenty-five salt

works in the area. A pipeline project is proposed right through the vital habitats of the coast.

Around 90% of the mangrove cover of Gujarat has been reported from the districts of Kachchh and Jamnagar. The mangroves of the marine national Park, in Jamnagar were considered as the most diverse patch in the state. In comparison to them, the Kori creek mangroves have less diversity. The southern Saurashtra coast harbors very less mangroves which are patchy as the coastline is rocky. This has also resulted in lower mangrove diversity. The Gulf of Cambay harbors mangroves along its mudflats and the tidal inlets of the rivers. The few reports on mangroves of the region indicate a low diversity here as well. The mangroves of south Gujarat are present along the tidal inlets of its river and here the diversity is relatively heterogeneous and mostly unexplored.

11 different species of mangroves have been reported from the state of Gujarat so far by different workers (Anon. 1987; Anon. 1992; Anon. 1998; Chavan 1985; Kothari & Rao 1991a 1991b; Kothari & Singh 1998; Rajendran & Sanjeevi 2004; Shah 1978; Shah et al 2005; Singh 2002; Singh 2006). They have been enlisted in table – 3.5. Out of these, three species (*Rhizophora apiculata, Bruguiera gymnorrhiza, Bruguiera cylindrica*) are considered to be extinct by some of the recent workers (Singh 2002; Singh 2006) leaving the mangrove diversity of Gujarat to be 8.

Sr. No.	Mangroves	Occurrence	
		Gujarat	GUK
	Family: Avicenniaceae		
1.	Avicennia alba Blume	P	P
2.	Avicennia marina (Forsk.) Vierh.	P	P
3.	Avicennia officinalis L.	P	-
	Family: Sonneratiaceae		
4.	Sonneratia apetala Buch. Ham.	P	-
	Family: Rhizophoraceae		
5.	Ceriops tagal (Perr.) C.B. Roinson	P	P
6.	Rhizophora mucronata Lam.	P	P
7.	Rhizophora apiculata Bl.	Extinct	-
8.	Bruguiera gymnorrhiza (L.) Lamk.	Extinct	-
9.	Bruguiera cylindrica (L.) Bl.	Extinct	-
	Family: Myrsinaceae		
10.	Aegiceras corniculatum (L.) Blanco	P	P
	Family: Acanthaceae		
11.	Acanthus ilicifolius L.	P	-

Table - 3.5 Diversity of mangroves of Gujarat
GUK = Gulf of Kachchh, P = Present

Acanthus ilicifolius

Aegiceras corniculatum

Plate 3.1 – Mangroves reported from Gujarat

Avicennia marina

Avicennia marina acutissima

Plate 3.2 – Mangroves reported from Gujarat

Avicennia officinalis

Ceriops tagal

Plate 3.3 – Mangroves reported from Gujarat

Rhizophora mucronata

Sonneratia apetala

Plate 3.4– Mangroves reported from Gujarat

3.7.1 Mangrove extent in Gujarat

As in India, so at the state level in Gujarat, the areal extent of mangroves has been fluctuating over the time (Chart - 3.4). An initial phase of decrease in the mangroves of Gujarat, owed mostly to less rainfall and the drought conditions. Mangroves were chopped by the locals of the vicinity to feed the cattle as well as for there own consumption as the fire-wood. Nevertheless, recent times have seen substantial improvement with constant increase in the mangrove area of the state. This chiefly is attributed to the various plantation activities carried out in the recent years by the Forest dept and the conservation practices being undertaken.

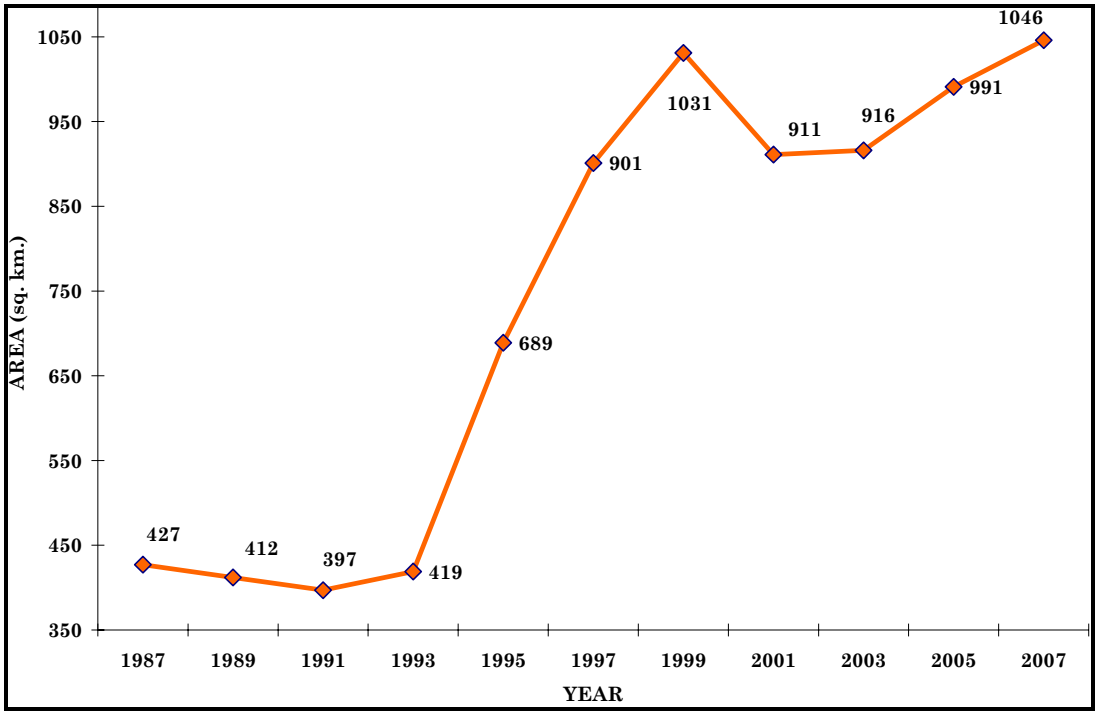

Chart – 3.4 Graph for changes in mangroves in Gujarat

(Source: FSI reports)

3.8 SOUTH GUJARAT – STUDY AREA

The south Gujarat coast is lined by a large number of perennial and seasonal rivers. Some of them have expansive mudflats while some have a large estuarine area.

The coastal wetlands of the study area were always believed to be devoid of mangroves or at times marked by presence of the salt marsh. Nevertheless, there were some periodic reports of mangroves being present at one of the wetlands. Earlier work (Kothari & Rao, 1991a, 1991b; Kothari & Singh, 1998; Shah, 1978; Bhagwanani, 1980) suggested that the coastal wetlands of south Gujarat harbor mangroves. The information was quite ambiguous, mentioning locations like Umargaon creek (Kothari & Rao, 1991a, 1991b; Kothari & Singh, 1998), sea coasts near Bulsar (now Valsad) (Shah, 1978) and Billimora, Valsad, Daman, Nargol and Umargaon creek (Bhagwanani, 1980). **However, observations (Singh, 2002) suggested that the coastal wetlands of south Gujarat** also harbor a rich diversity of mangroves.

Singh (2002) suggested that the estuaries of south Gujarat also harbor a rich diversity of mangroves. However, they have remained largely uninvestigated, except for areas of Umargaon creek (Kothari & Rao, 1991a, 1991b; Kothari & Singh, 1998) and Valsad (Shah, 1978). Precise information on mangrove distribution and diversity for any estuarine area in south Gujarat is lacking. Currently available information includes the

presence of *Sonneratia apetala* at river Tapi (Singh, 2002; Singh, 2006), *Bruguiera cylindrica* in the Umargaon creek (Kothari & Rao, 1991a, 1991b; Kothari & Singh, 1998), and *Rhizophora mucronata* at sea coasts near Bulsar (now Valsad) (Shah, 1978). In addition to this, the general occurrence of *Acanthus ilicifolius* in the estuarine area of South Gujarat has also been reported (Singh, 2002; Singh, 2006). GEER foundation in recent times reports to have observed *Excoecaria agallocha* (Newspaper Report, was confirmed during field work) No other mangrove species are reported to occur along the south Gujarat coast.

The coastal wetlands and the estuarine set up supports relatively high diversity as the mangrove vegetation here is governed by fresh as well as saline water input (Anon., 1998). Earlier works have mentioned the Purna River Estuary as the largest single patch of mangroves in South Gujarat (Singh 2002; Singh 2006) with the occurrence of salt marsh vegetation (Anon., 1992). However, information regarding mangrove species diversity, density as well as precise extent is lacking for the survey area. The Survey of India topographical maps from 1965 also showed no mangroves in our survey area. Also the Forest Survey of India (FSI) report of 2003 (Anon, 2005) reports a mangrove area of 100 ha for the entire Navsari district.

3.8.1 Mangrove extent in south Gujarat

Although the diversity of mangroves is reported to be low, the occurrence of mangroves along the south Gujarat region has been mapped by the Forest Survey of India since 1991.

Navsari district was separated from Valsad district at a later stage. So the initial years show combined area estimates of mangrove for Navsari and Valsad districts. Later on, after there separation, the areal estimates were also shown separately (Chart 3.5).

With a decline in area during 1995 – 2001, the mangrove area has then shown improvement in the area statistics. Major changes can be observed for the district of Surat owing to the plantation activities being carried out in the Surat and Hazira region by companies like SHELL, forest department and the Gujarat Ecological Commission (GEC).

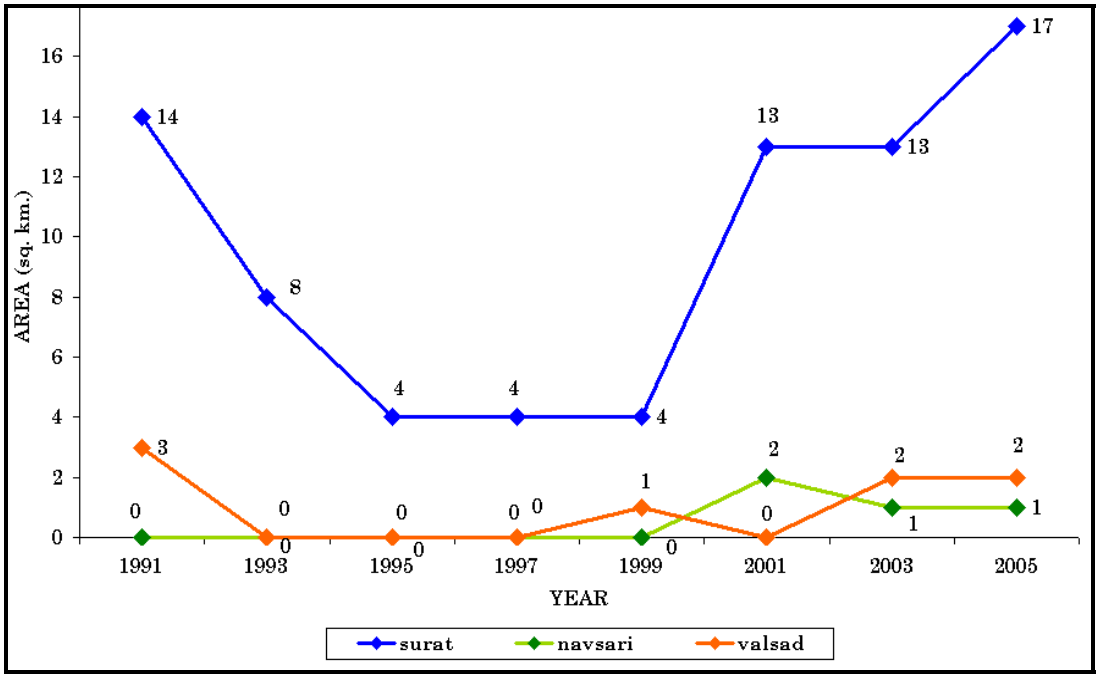

Chart - 3.5 Changes in mangrove area of the study area

(Source: FSI reports)

('0' = data not available.)

The current work is going to be thus an outcome of study of mangrove diversity of an un-explored estuarine area of rivers Mindhola, Purna, Ambika, Auranga, Par, Kolak, Damanganga, Kalu and Varoli; which have been investigated with emphasis on mangrove diversity, by systematic ground surveys, coupled with remote sensing studies to bring out the density and zonation of mangroves as well.

CHAPTER 4: ESTUARINE GEOMORPHOLOGY

This chapter provides the background of different components that make up estuarine geomorphology and describes the EXISTING geomorphological setup of the study area, the coastal wetlands of the study area, and the probable mechanisms controlling it.

Huge populations inhabit the coastal zone to take advantage of valuable resources offered and to participate in seaborne trade with other nations, thus reaping socio-economic benefits. Explaining the geomorphological changes that are occurring on the coast is thus becoming increasingly important to manage coastal resources in a sustainable way.

4.1 GEOMORPHOLOGY - DEFINITION

Geomorphology is a branch of geology developed in the late 19th century. The term Geomorphology is derived from the Greek word *Geo* meaning 'earth', *morfe* meaning 'form and *logos* meaning 'study (Chorley et al. 1984). Thus, geomorphology deals with the scientific study of the landscapes and the processes that shape them (Bloom, 1998).

Geomorphology deals with the scientific study of the landscapes and the processes that shape them. The science of geomorphology has two major goals. One is to organize and systematize the description of landscapes by intellectually schemes of classification. The other is to recognize in

landscapes evidence for changes in the processes that are shaping and have shaped them (Bloom, 1998).

4.2 FUNDAMENTAL CONCEPTS

Before understanding the processes which govern the geomorphological features, there are few fundamental concepts which one should consider in the interpretation of the landscapes and aid in the evaluation following it. Thornbury (1985) enumerates the following as the fundamental concepts.

1. The same physical processes and laws that operate today operated throughout the geologic time, although not necessarily always with the same intensity as now.
2. Geologic structure is a dominant control factor in the evolution of land forms and is reflected in them.
3. To a large degree, the earth's surface possesses relief because the geomorphic processes operate at different rates.
4. Geomorphic processes leave their distinctive imprint upon landforms and each geomorphic process develops its own characteristic assemblage of landforms.
5. As different erosional agents act upon the earth's surface, there is produced an orderly sequence of land forms.
6. Complexity of geomorphic evolution is more common than simplicity.

7. Little of the earth's topography is older than tertiary and most of it is no older than Pleistocene.
8. Proper interpretation of the present day landscapes is impossible without a full appreciation of the manifold influences of the geologic and climatic changes during the Pleistocene.
9. An appreciation of world climates is necessary to a proper understanding of the varying importance of the different geomorphic processes.
10. Geomorphology, although concerned primarily with present day landscapes, attains its maximum usefulness by historical extension.

The study of landform provides with an exciting challenge. The one landscape which almost everyone recognizes as undergoing continuous change is the coastline. The coastline changes not only over centuries or decades but in matter of hours or minutes. This rapid development applies both to the form of the coastline and to the coastal processes (Pethick, 1995)

4.3 COASTAL SYSTEMS

Coasts are among the most dynamic parts of the earth's surface. The land and the sea rarely meet at a constant boundary. The shoreline migrates daily with the tide; it can change seasonally, and varies over longer time scales as the coast erodes or deposits, or as sea level changes. Coastal sediment deposits are shaped and reshaped by the various processes, which in varies through time. The coastal geomorphology is

concerned with the way in which coastal landforms changes with time, both in terms of its present-day dynamics and its longer-term evolution. The techniques by which these morphological adjustments can be determined include monitoring landform changes as they take place, reconstructing past events by comparison of surveys (including maps and aerial photographs), and inferring changes from erosional landforms and depositional sedimentary sequences (Woodroffe, 2002).

Studying the coast as a system provides a framework within which inter-actions between many elements of the coastal geomorphology can be considered (Haslett, 2000). It enables the interrelationships between different components of complex landforms and the processes that shape them to be expressed, based on general systems theory (von Bertalanffy, 1952, 1968).

4.4 COASTAL GEOMORPHOLOGY

The majority of the world's population lives close to the sea. As many as 3 billion people (50% of the global total) live within 60 km of the shoreline. The coast plays an important role in global transportation, and is the destination of many of the world's tourists. Thus, explaining the geomorphological changes that are occurring on the coast is becoming increasingly important, in order to manage coastal resources in a sustainable way.

Geomorphology is the study of landforms and coastal geomorphology is concerned primarily with explaining the many different types of coastal

landforms and understanding the factors that shape them, their evolution, the processes at work on them, and the changes now taking place (Woodroffe, 2002; Bird, 1967).

The coast is a zone of varying width, including the shore and extending to the landward limit of penetration of marine influences; the crest of a cliff, the head of a tidal estuary or the solid ground that lies behind the coastal dunes, lagoons and swamps. The coastline is usually taken as the land margin in the backshore zone. It is useful to refer to the sea area adjoining the coast, comprising the near-shore and offshore zones, as coastal waters (Bird, 1967).

A coastal zone can be divided into relatively distinct landforms based on factors such as topography and lithology, or sediment texture and resistance. The coastal zone extends upstream as far as tidal influence is felt, which can vary over time in response to tidal or river flow characteristics. The most resistant are rocky coasts, characterised by cliffs. Sand and gravel are more mobile in the coastal zone and form coastal barriers on which there are beaches and associated landforms. Deltas or estuaries occur where rivers reach the sea. Muddy substrates occur in the more sheltered areas and can support coastal wetlands. Coastal zone include littoral zones, brackish water and estuarine regions, lagoons and coral reefs, and constitute (Anon, 1991) ~ 70% of total wetlands of the country (Jagtap et. al., 2001). The coastal zone is thus a broad transitional area in which terrestrial environments influence marine environments and

in which marine environments influence terrestrial environments (Carter, 1988).

4.5 COASTAL PROCESSES

A host of external processes contributes to produce a landscape. The rates of geomorphological processes vary enormously, from a few centimeters per thousand years for the surface weathering to 50 meters per second for an avalanche roaring down a mountain. Geomorphic processes also vary in intensity from one region to another, depending upon the climate, vegetation and altitude above or depth beneath the ocean (Bloom, 1998). The geomorphic processes are all those physical and chemical changes which effect a modification of the earth's surficial form. A geomorphic agent or agency is any natural medium which is capable of securing and transporting earth material (Thornbury, 2002).

Running water, including concentrated and un-concentrated runoff, groundwater, glaciers, wind and movements within bodies of standing waters including waves, currents, tides and tsunami are great geomorphic agencies. Most of the geomorphic agencies originate within the earth's atmosphere and are directed by force of the gravity. The processes performed by the origin from outside the earths crust are termed as exogenetic by Penk and the ones originating in the earth's crust are designated as endogenetic (Thornbury, 1985). The main endogenetic forms are neotectonic and volcanic forms whereas the main exogenetic forms are

denudational, karsts, fluvial, glacial, coastal, aeolian, and anthropogenic and various organic forms.

The processes shaping the coastal landforms are considered individually, although in practice a stretch of coast is likely to be influenced by several processes, acting simultaneously or in sequence. The coastline in today's scenario is the outcome of processes that operate today and those that have operated over time (Woodroffe, 2002). The geomorphological processes at work on coastal landforms are influenced by a number environmental factor; notably geological, climatic, biotic, tidal, and other oceanographic factors including salinity. These vary from one region of the coast to another, the variation being due to the change in terms climate and geological outcrops (Bird, 1967). Thornbury has suggested three main types of movement that carry on gradational work are waves, currents and tides and only rarely are tides of geomorphic significance. Woodroffe (2002) however suggests that there could be many other forces acting upon the coastal landforms apart from these three, and his approach of classifying and understand the coastal geomorphology has been followed in this work. Shepard's (1973) classification has integrated many of the earlier classification into one and he stresses the relative importance of the primary (geologic underpinning) and secondary (modern marine processes) agents.

The principal source of energy for most coastal systems comes from waves. Although incident waves (the waves arriving at a beach at the time of study) can be seen to move sediment, it has become clear that various

longer-period events also play a very significant role in shaping the coast, including - waves and extreme storms and other disturbances. On some coasts, tidal processes are significant. Tidal processes become particularly dominant in estuaries or other embayments. Other oceanographic processes are associated with ocean currents, sea ice, and ocean atmospheric circulation changes, such as the El Niño-Southern Oscillation phenomenon. The coast is also shaped by several sub-aerial processes that can supply sediment to the coast especially in delta environments. Wind can be important, particularly in generating waves, but also in moving dry sediment and building dunes. In the case of rocky or other bold coasts, hill-slope processes can also shape coastal landforms. Biological processes are important on many coasts. Organisms can have influences varying from minor roles that alter sediment properties or affect the surface of substrates, to boring and rasping, and in some cases secretion of sediment and construction of framework. Plants play substantial roles in trapping or binding sediments on dunes, and upper intertidal areas of muddy coasts (Woodroffe, 2002).

4.5.1 SEDIMENTARY PROCESSES

Coastal landforms are built through the erosion or deposition of sediment. Sediments are deposited when the flow decreases below the fall velocity; the larger grain sizes are deposited before the smaller grain sizes which continue to be transported. On the coast, rock fragments and sediment are generally transported in a fluid, usually water, although

occasionally also through air or ice. The rate at which these processes operate depends on the rock or sediment, including both the characteristics of individual grains and bulk properties (such as density, porosity, shape, size, sorting, fall velocity and angle of repose) and on the physical characteristics and fluid mechanics. Once sediment is entrained, its transport depends on several factors. Sediment grains may be moved in water by sliding or rolling along the seafloor; at greater velocities impact from grains settling can trigger a burst of new grains to be suspended into the water column, a process termed saltation. Which mode of transport occurs is a function of grain size.

4.5.2 WAVE PROCESSES

The principal source of energy in the coastal zone, both for erosion and deposition comes from waves. Aristotle recognized that wind created waves on the ocean. The wind transfers energy to waves, which appear to propagate because of pressure differences caused by the sheltering effect of successive crests (Jeffreys, 1925).

Waves are the superficial undulations of the water surface produced by the wind blowing over the sea (Bascom, 1959). Waves are undulations on the surface of a liquid that move across the liquid, transferring energy but generally not resulting in a net transfer of mass. The basics of deep-water wave theory have been understood for well over a century, but waves generally undergo significant transfoormations as they moved into shallow water. Most of the waves that can be seen on the surface of the ocean have been generated by wind. Deep water waves transform as they move into

shallower water. Wave speed decrease as the wave interacts with the seafloor in the shoaling zone, attenuating wave power as a result of transfer of energy into sediment mobilization (Woodroffe C. D., 2002).

It has been recognized that wave's action can be constructional on some coasts and destructive on others (Cornish, 1898 Lewis, 1931). Coasts that are exposed to ocean swell and stormy seas are known as high wave energy coasts. Those that are sheltered from strong wave action are termed as low wave energy coasts (Bird, 1967).

4.5.3 CURRENTS

Ocean currents have an effect on the global distribution of organisms and wave climates (Woodroffe, 2002). They are drifts of water in response to the prevailing wind patterns and are partly due to the variations in the oceans resulting from differences in salinity and temperature of water. True ocean currents are slow movements of water and are not important in coastal geomorphology, except where they bring in the warmer or colder water, which affects the ecological conditions near the coast and thereby influences the world distribution of such landforms as coral reefs and mangrove swamps.

Currents are generally more effective in shaping sea floor topography then developing coastal configuration. Currents generated by wind and the tides can be strong enough to move superficial sediment on the sea floor to prevent deposition and even to erode channels. Currents often play a role in removing material eroded by waves from the coasts or in supplying the sediments that is built into depositional forms by wave actions. In addition,

currents are also responsible for the development of various kinds of ripple patterns on foreshores and tidal flats, on the floors of estuaries and lagoons and on the sea bed (Bird, 1967).

4.5.4 TIDES AND TIDAL INFLUENCE

On almost all coasts, there is a rhythmic tidal rise and fall (flood and ebb) of water. Tides are movements of the oceans set up by the gravitational effects of the sun and the moon in relation to the earth. They are important in coastal geomorphology because they lead to regular changes in the level of the sea along the coasts (Bird, 1967). The tides are long waves; generally the period is 43, 000 s, or 12 hr 25 min (semidiurnal). The wave that constitutes the tide is driven by the gravitational pull of the moon, and to a lesser extent, that of the sun. Tidal range is increased and the velocity of the tidal wave is slowed over the shallow bathymetry of broad continental shelves.

Tides range in the mid-ocean is small, of an order of a ½ m but it increases when the tide invades the shallow coastal waters, particularly in the gulfs and the embayment (Bird, 1967). Coasts can be divided into micro-tidal where tidal range is <2 m, meso-tidal where it is 2-4 m, macrotidal where it is 4-6 m, and mega-tidal where it is >8 m Macro and mega-tidal ranges are common within gulfs and embayments where the volume of the tidal wave is constrained. Tidal range influences the broad distribution of coastal landforms (Davies, 1980). A large tide implies broad intertidal zone, leading often to the formation of extensive salt marshes. Where the tide range is small, wave energy is concentrated at a more consistent level,

facilitating cliff erosion and impending the development of costal marshlands (Bird, 1967). River deltas are well-developed in micro-tidal areas, as are barrier islands and spits (Hayes, 1975). There are many funnel-shaped estuaries in areas which experience a macrotidal regime, and these are generally flanked by extensive mudflats often with broad expanses of mangroves or salt marshes.

4.5.5 OTHER OCEANOGRAPHIC PROCESSES

Several other oceanographic processes are significant in terms of coastal geomorphology. Sea ice is a significant factor for some high latitude coast. Broad global circulation patterns, such as deep-water circulation and the El Niño and La Niña phenomena in the Pacific Ocean can result in long-term variations in geomorphological processes on coasts that are affected by these variations, and the role of extreme events such as storms and tsunami can be expressed in terms of coastal landforms.

Many other processes have an effect on the coast. Wind is significant, not only in relation to wave generation, but also in terms of dune building. In high latitudes, frost action can play a role in shattering rock. Rivers are important in terms of the water and the sediment that they bring to the coast.

4.5.6 WIND ACTION

Wind is an important factor responsible for the generation of waves. Although many coasts are influenced by swell, generated by waves associated with storms that are beyond the immediate influence of the coast, there are also significant locally generated wind waves which can

have important effects on the coast. Wind also plays a major role in the formation of dunes. Sand movement by winds blowing along a beach can also be significant (Bourman, 1986).

4.5.7 FROST ACTION

Freezing and thawing of rocks and sediments, called cryogenic processes, can affect high-latitude coast. On the shore, the upper intertidal zone can be frozen and inactive, whereas the lower intertidal zone can be unfrozen and still active.

4.5.8 FLUVIAL PROCESS

The role of rivers is particularly important in relation to estuaries and deltas. Rivers bring fresh water and sediment to the coast (Milliman, 2001) and estuaries can act as a sink for fluvial sediments and for near-shore sediments. River-borne clastic sediments can be an important addition to the littoral sediment budget, and their contribution can have important consequences for beach and dune systems.

4.5.9 WEATHERING AND HILL-SLOPE PROCESSES

In addition, other subaerial processes can be important in some coastal settings. Climatic factors have an influence on the rate of weathering which determines the resistance of the rock or sediment (Ollier, 1984). In the case of rocky coast, subaerial hillslope processes such as creep, slope-wash, rock-fall and mass movement can be significant.

Other subaerial processes include the weathering of rock that can occur on coasts that are subject to salt spray. Salt can influence the breakdown of rock.

4.5.10 BIOLOGICAL PROCESSES

Biota plays biomechanical and biochemical roles. Plants and animals can also have important effects on coastal geomorphology. The effects of the organisms can be erosional, protective or constructional. Some of the shore fauna could lead to the decomposition or dissolution of the coastal rock outcrops, especially on lime-stones. On other hand, salt marsh and dune vegetation may stabilize the depositional landforms on the coasts or promote the accretion of sediment in such a way as to build new landforms (Bird, 1967). The clearest example is the case of coral reefs, where entire landforms result from the constructional activities of organism. In addition, many organisms produce calcareous sediments. The nature of the organisms contributing to sands determines the skeletal components which influences the size characteristics of the sediment. For instance, coral breaks into distinctive sizes of shingle, and powders to a coral grit.

There are some plant forms also which form veneers and protect the landform surfaces. They bind sediments as in the case of algal mats. In the case of dunes, vegetation acts to bind sand, and on muddy coasts, the role of halophytic (salt-tolerant) vegetation in trapping fine-grained sediment is examined.

4.6 ESTUARINE GEOMORPHOLOGY

One such unique transitional environment is the estuarine system. A definition that is widely used, given by Cameron and Pritchard (1963) describes an estuary as 'a semi-enclosed coastal body of water having a free

connection with the open sea and within which sea water is measurably diluted with freshwater derived from land drainage' (Figure – 4.1). Estuaries are the tide-influenced lower parts of rivers and their valleys (Figure – 4.2). Estuarine morphology is influenced by geological settings and topography, and landforms are shaped by hydrodynamic processes. Riverine and coastal sediments are affected by both alluvial and marine influences, together with minor local processes, such as direct input of colluviums from hill-slopes, cliff retreat, wind redistribution of sediment, and chemical and biological action. Estuaries have adopted their present morphology on most coasts because of postglacial sea-level rise drowning river valleys - (Roy et. al., 1994).

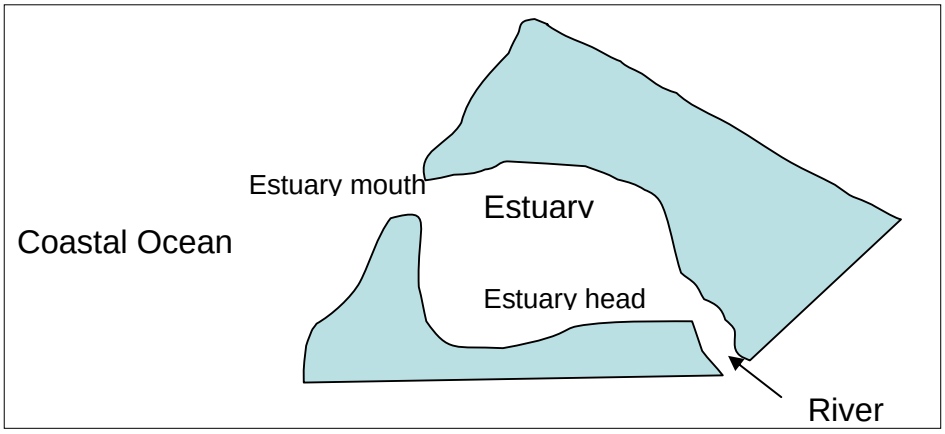

Figure 4.1 – An estuarine system
(Source: compiled from various sources)

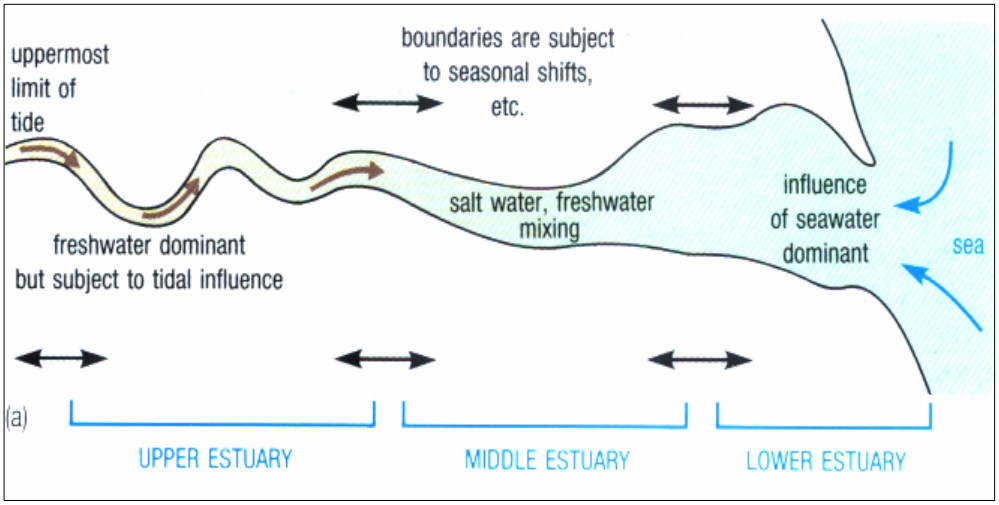

Figure 4.2 – Schematic diagram of a typical estuary

(Source: compiled from various sources)

Rivers play an important role in their geomorphology, but the significance of tide and wave processes has long been recognized. Where tide dominates, there is a progression from the tide-dominated deltas and tide-dominated estuaries, often with extensive tidal flats (Woodroffe, 2002).

4.6.1 ESTUARIES &THEIR GEOMORPHOLOGY

The term estuary, derived from the Latin 'aestus' meaning tide, refers to a tongue of the sea reaching inland. The upstream limit of an estuary can be defined in terms of the limit of saline water penetration, or the uppermost point at which tidal oscillation of water level discernible.

4.6.2 TYPES OF ESTUARIES

The term 'ria', which is Spanish for estuary, was used by von Richthofen (1886) to refer to mountainous-sided estuaries which have not been glaciated and which cut across the geological strike. It has been used more broadly to refer to an estuary in which there is control by bedrock (Cotton, 1956). Fjords are steep-sided valleys that have been glaciated, but

in which present riverine processes are generally limited; their origin was examined by Gregory (1913).

Coastal lagoons, some of which maybe periodically open to the sea, are considered estuarine environments because they show many similarities to other estuaries, such as barrier estuaries, in morphology and development. Large elongate coastal lagoons often develop segmentation, which has been the subject of debate in terms of relative role of wind, waves and vegetation in forming spits that separate discrete lagoons (#Zenkovich, 1959, Bird, 1967).

The geomorphology of estuaries was recognized as an important constraint on their ecology and functioning in several compilations of estuarine research in the 1960s (Fosberg, 1966, Lauff, 1967, Russell, 1967). There have been further refinements by Fairbridge, and recognition that some estuaries are only periodically, rather than permanently, open to the sea (Day, 1980). Fairbridge's classification of estuaries (Figure – 4.3), with some minor amendments (Perillo, 1995, Kench, 1999), recognizes:

1. Fjords (deep U-shaped valleys in areas which have had ice cover);
2. Rias (V-shaped river valleys drowned by sea-level rise, and generally with bedrock margins);
3. Coastal plain estuaries on sedimentary coasts
4. Delta-front estuaries (delta distributaries);
5. Bar-built estuaries;
6. Blind estuaries (blocked or periodically closed coastal lagoons); and

7. Structural or tectonic estuaries (which includes inlets that owe their origin to a range e of tectonic factors).

The study area shows presence of the coastal plain estuaries on sedimentary coasts.

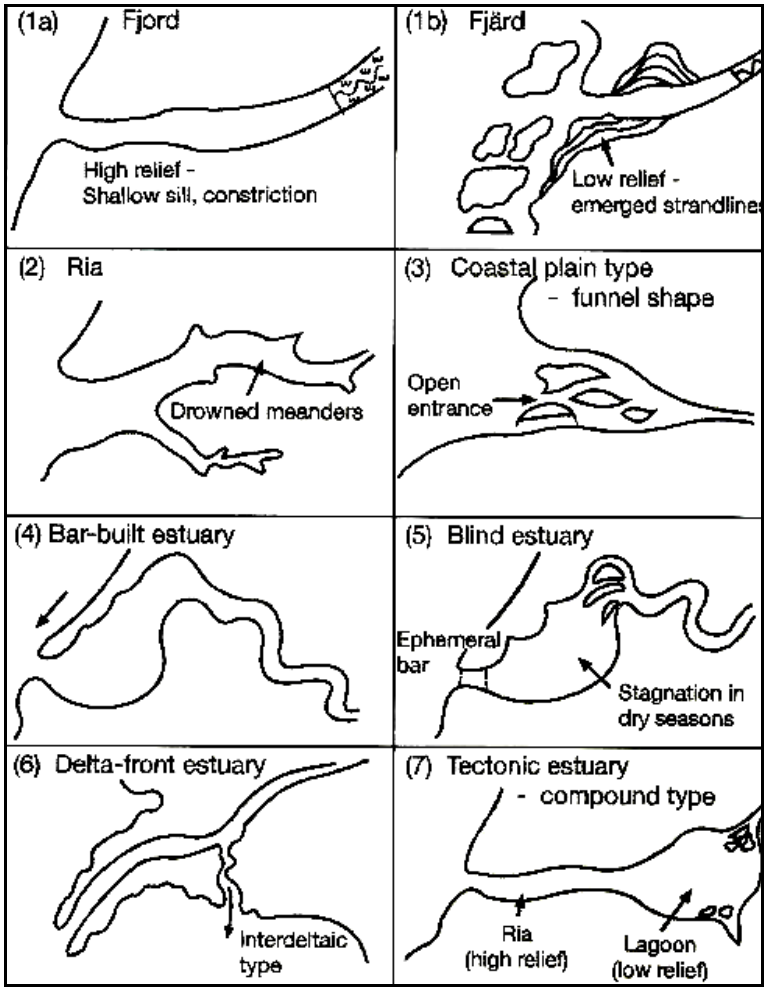

Figure 4.3 – Estuarine sub-types (Source: Fairbridge, 1980)

4.6.3 MORPHODYNAMIC DEVELOPMENT OF ESTUARIES

Most estuaries and major embayments in bedrock have been drowned by the postglacial rise in sea level. Rivers tend to deposit their sediment load when their flow decelerates on entering an estuary, often

building fluvial deltas. Tide processes also influence estuaries and can import sediment from seaward, in some cases forming a tidal delta at the seaward end of the estuary, and it can result in total closure of the embayment, encapsulating a lagoon.

The type of estuary that occurs depends on inherited geological factors, such as bedrock topography, and the relative balance between river discharge and wave energy. Deep, bedrock-controlled embayments have relatively wide entrances, with a sandy tidal delta that forms a sill, over which full tidal exchange can take place. They tend to show little sediment infill relative to the size of the embayment and are termed drowned river valleys. Barrier estuaries are separated from the sea by a sand barrier, with an entrance through which tidal exchange is attenuated. They occur where bedrock is relatively shallow (<30 m), in contrast to drowned river valleys, forming a basement on which barrier accumulation has focused. Strong wave conditions maintain the barrier at the mouth of an incompletely filled embayment, but river discharge is large enough to keep an inlet open at least intermittently. Coastal lagoons, termed saline coastal lakes by Roy (1984), tend to be saline to brackish (but not tidal) water bodies, which remain closed for long periods, although they can open temporarily during major floods and large seas. The simplest estuaries are drowned river valleys. Tide-dominated estuaries are found in areas that have a large tidal range, or where other processes exert only a minor influence. Barrier estuaries are influenced by wave processes and are common wave-dominated settings to barrier estuaries.

4.6.4 ESTUARINE HYDRODYNAMICS

Estuarine circulation has generally been classified into salt-wedge, partially mixed and well-mixed (Pritchard, 1952). Salt-wedge estuaries typically occur where the tidal prism is small and tidal currents are too slow to mix the inflowing and receiving water bodies. Well-mixed estuaries occur at the other end of the continuum of circulation characteristics (Dyer, 2001). Estuaries with a large tidal range, where tidal volumes (prisms) are considerably greater than freshwater river discharge and most of the water in the estuary is moved up and down the estuary by tidal rise and fall, are well mixed. Partially mixed estuaries lie between these extremes. They are typically found in meso-tidal areas; much of the volume of the estuary is moved to and fro with tidal oscillations, but some salinity stratification occurs with deeper waters more saline than surface waters. The estuaries falling under the study area are partially mixed types.

4.6.5 PROCESSES INFLUENCING ESTUARINES

The processes operating in an estuary are a function of the characteristics of the catchment and of the receiving basin into which the river discharges. Although the relative balance of wave, tide and river processes shows to exert considerable control over morphology, estuaries are the product of longer-term evolution in time and space over which boundary conditions change. Estuarine circulation is generally a function of the interaction of marine processes, particularly tides, with fluvial discharge and water already in the system.

There are continuums of river, tide and wave processes that operate within estuaries. Wave-dominated and tide-dominated estuaries were discriminated by Dalrymple *et al*. (1992), whereas river-dominated estuaries have been described by Cooper (1993). Such a morphological approach refers to the relativities of the operation of these processes, not necessarily to any absolute measure of operation (Davis and Hayes, 1984). Most estuaries are influenced by river, tide and wave processes to different extents, and the influence varies geographically from one part of the system to another, and through time, as the system evolves.

River-dominated environments contain deltas with distributaries, flanked by levees, building out into a receiving basin. Where tides dominate, there is a progression from tide-dominated deltas and tide-dominated estuaries, often with extensive tidal flats. On wave-dominated coasts, there are barriers (elongate shore-parallel sand bodies) comprising beach, dunes, tidal deltas, wash-over deposits and spits. Coastal lagoons occur where waves build barriers across embayments. Although waves do not overwhelm the effect of river or tide processes, they often build wave-dominated coastal landforms across river mouths.

4.6.5.1 TIDAL PROCESSES IN ESTUARIES

The velocity of tidal currents depends on tidal range and the topography of the coast. Tidal currents can be the dominant water movements in embayments, estuaries and tidal creeks, resulting in distinctive tide-dominated landforms (Figure – 4.4).

Distortion of tides occurs along major estuaries, in terms of amplitude, symmetry, and duration of flood and ebb. Tidal flows in estuaries are bi-directional. Whereas river discharge is determined by runoff from the catchment and is independent of channel size, tidal discharge is dependent on channel dimensions and tides are forced flows that are 'not going anywhere'. In larger estuaries and tidal creeks, the tide progresses as a wave, and the timing of high (and low) tide varies along the system.

In estuaries, the tidal flow becomes modified as a result of frictional dampening; landwards constriction of the channel and reflection from channel banks, shoals and the channel head. Estuarine channel morphology is both a product of and a determinant of, the hydrodynamics, and tidal velocity, amplitude and tidal harmonics are linked by morphodynamics feedbacks (Friedrichs and Aubrey, 1994).

Estuaries that occur in macrotidal settings are dominated by tidal currents and, where they occur on prograded coastal plains, they are typically funnel shaped with wide entrances tapering upstream (Chappell and Woodroffe, 1994; Wells, 1995). Sandy shoals, elongated parallel with the flow, are often prominent features within the mouth. These estuaries are well mixed as a result of strong bi-directional tidal currents. Rapid flows re-suspend and transport sediments. Three zones with distinct channel morphology can be recognised in many macrotidal estuaries: an upstream river-dominated zone, a central mixed-energy zone and a seaward marine-dominated zone (Dalrymple et al, 1992). The upstream zone is

often relatively straight with net seaward sediment movement by fluvial processes. The central zone is a zone of sediment convergence influenced by both river and marine processes, often with a highly sinuous channel. The seawards zone is relatively straight, its banks are funnel shaped, and sediment moves in a net landward direction.

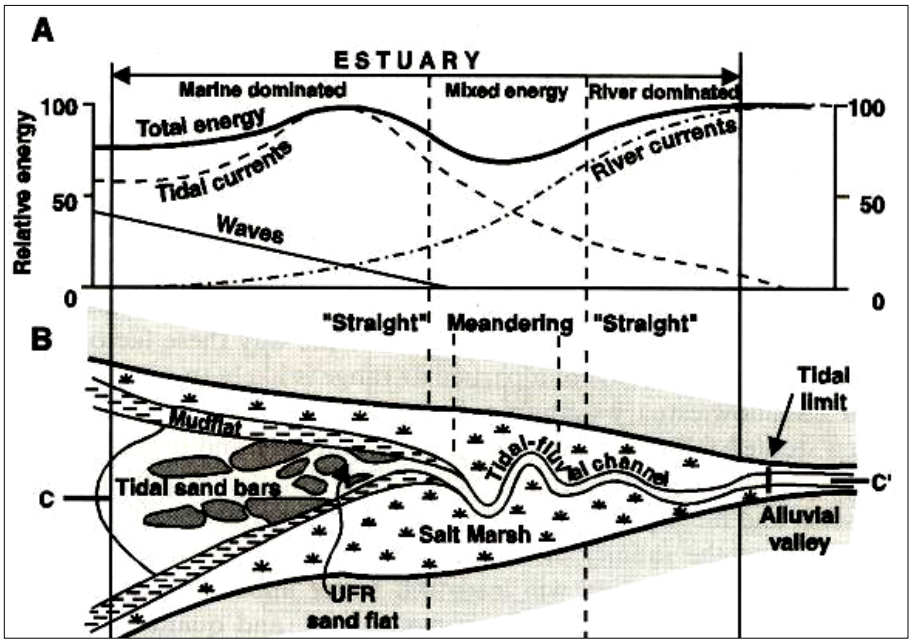

Figure 4.4 – Tide dominated estuary
(A) Relative energy (B) morphology
(Source: Dalrymple et. al.., 1992)

4.6.5.2 WAVE-INFLUENCED ESTUARIES

On wave-dominated coasts, estuaries are generally enclosed or partially enclosed behind wave-built sand barriers. The barrier is generally effective in diminishing the extent to which wave energy can penetrate into an estuary, and barrier estuaries are influenced, rather than dominated, by waves are considered in this section (Figure – 4.5).

Barrier estuaries are separated form the open ocean by a sand barrier as a result of landward reworking of sand from the shelf. The inlet that connects to the sea can intermittently close, and there is gradation into coastal lagoons that may be permanently closed or intermittently open to the sea. Estuary's size, shape, and the rate of infill depend on inherited geological factors, such as bedrock topography, type and rate of fluvial sediment supply from the catchment, and the relative balance of wave, fluvial and tidal influence. Ecological changes in the extent of seagrass and mangrove communities, for instance, also appear related to the stage of estuary infill (Roy, 1984). Entrance conditions influence the degree to which tides are attenuated and the salinity characteristics of an estuary.

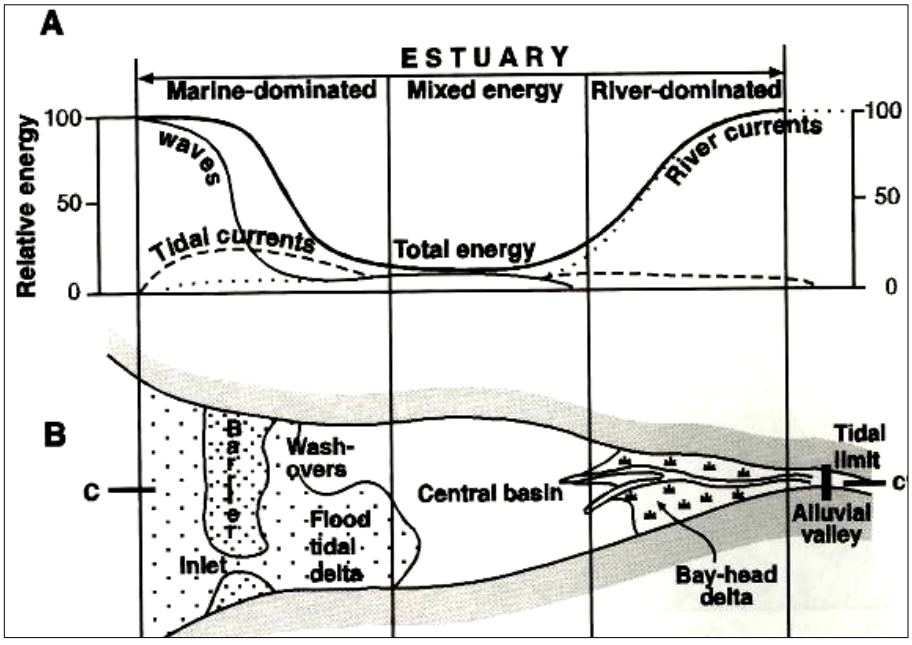

Figure 4.5 – Wave dominate estuary
(A) Relative energy (B) morphology
(Source: Dalrymple et. al.., 1992)

4.6.6 ESTUARINE SEDIMENTATION

The transport and deposition of sediments in estuaries is usually complex and is a function of the hydrodynamic circulation A turbidity maximum is present in many estuaries. This occurs generally towards the landward end of the estuary where freshwater encounters salt water of low salinities (1-5%).

Lateral trapping of suspended sediment is estuaries can occur where sediment-laden water enters tributaries and other secondary water bodies on an incoming tide, but is bypassed, or only gradually mixed on the ebb tide (Wolanski, 1994). Trapping can also occur in deltaic –estuarine mangrove forests where onshore wind, wave or current activity restricts the seaward spread of a sediment plume (Francis, 1992).

Estuarine sediments can derive from the catchment or from off the continental shelf. They can come from the atmosphere; they may be eroded from the shoreline (i.e. from cliffs or the estuarine margin) or they may be produced *in situ*, as biogenic material.

4.6.7 DROWNED VALLEYS

The majority of estuaries are drowned valleys that owe their origin and in particular, their modern morphology to Holocene sea-level rise. The term is especially appropriate for those systems in which the prior bedrock configuration exerts primary control on morphology, such as fjords and rias. Incised valleys, where incision has been into older valley fill sediments, are also considered in this section (Dalrymple et al, 1994). Drowned river

valleys show sandy sediments at their landward and seaward ends, with mud accumulating in between.

4.7 GEOMORPHOLOGICAL LANDFORMS OF ESTUARINE SET-UP

Broad geomorphological descriptions of estuaries indicate that the morphological features are more likely to be related to wave or tide processes but they do not always adequately describe the range of variability that can occur within any one estuary. Entire estuaries can be differentiated in terms of river, wave and tide domination, but more often individual sectors of one particular delta or estuary can be river-wave or tide-dominated to different extents

4.7.1 Stream deposition (Fluvial)

Along the stream, there are likely to be found deposits, namely channel bars, point bars and delta bars depending upon their position and origin.

Streams – Braided streams have excessive load, as opposed to the meandering stream, and are not capable of carrying the lateral erosion. This leads to formation of a braided pattern in the region close towards opening of the river (Figure – 4.6)

.**Mouth bar -** Small shoals or islands at the mouth of estuaries are designated as the mouth bars. The rivers merging with the sea carries huge amount of sediments which gets deposited at the mouth, resulting in the formation of the shoal or islands or mouth bars

Channel bars – They are located in the stream course and are perhaps most characteristic of the braided streams. Because of the erosion in high lands and the deposition take place in the within the channel. When velocity decreases, such bars are developed.

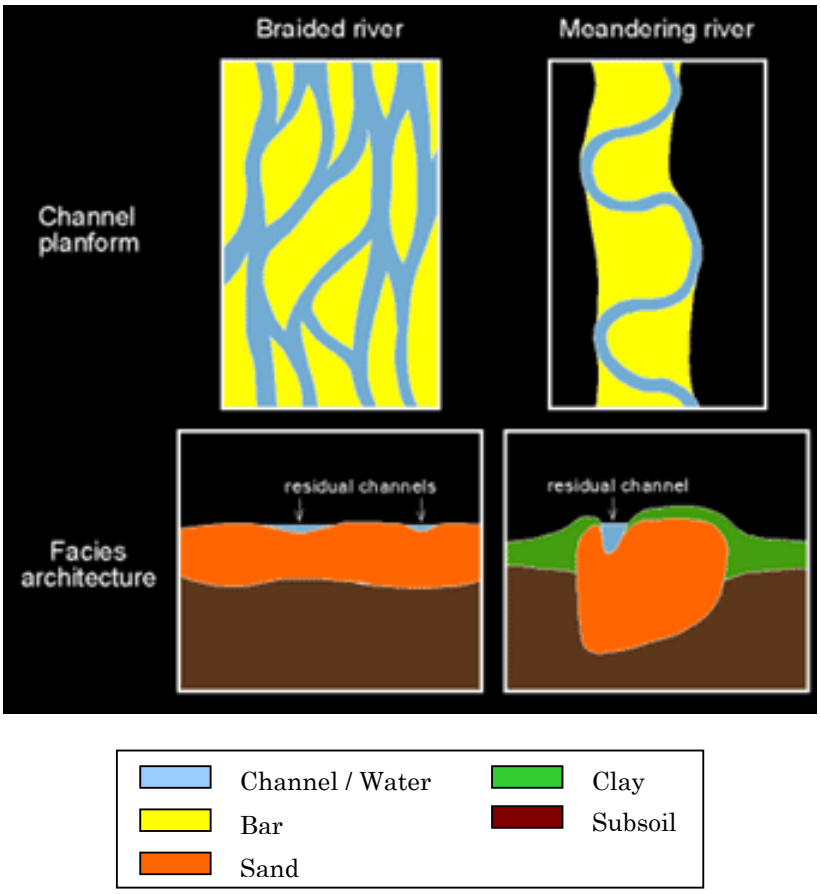

Figure 4.6 - Channel pattern and substratum geometry
Different fluvial styles are associated with different substratum geometries (Source: after Törnqvist).

Point bars – They were once called the meander bars. All the major rivers show presence of the point bars (Figure – 4.7). They are the depositional features, related to the meandering of the channels and are generally crescentic in shape, found on the inner side of the meanders. They are

formed by the slow accretion of the river materials and accompanying the migration of the meanders. They are resultant of the redistribution of the sediments eroded from the outer side of the meanders and later on deposited on the inner side as the point bars. They are found on the convex side of the meanders, because of erosion on the concave side, and grow by individual increments outward into the meander curve.

Natural levees – They are low ridges that are parallel to river course. They are highest near the river and slope gradually away from it. They owe there greater height near the river due to the sudden loss in the transport power of the channel when a river overspreads its banks. They cause the present meander belt of a river to stand up above the floodplain as a low alluvial ridge.

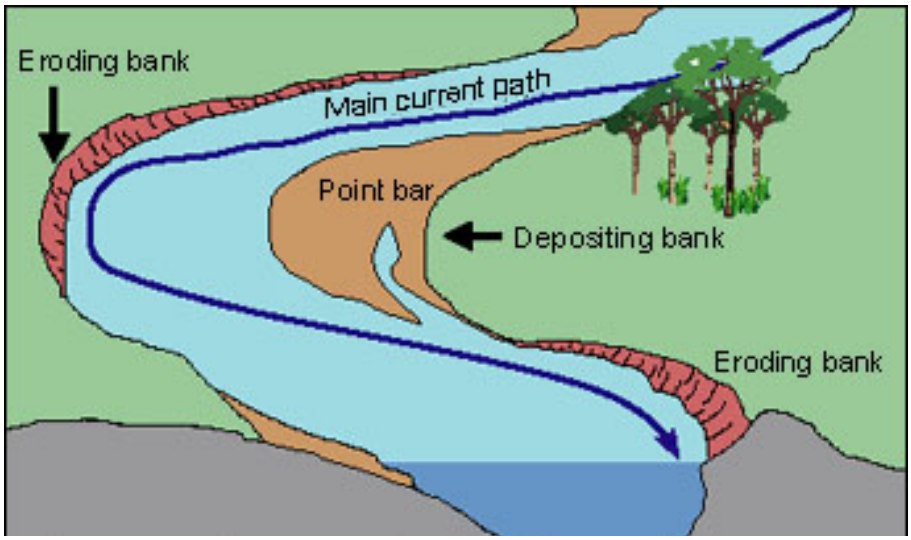

Figure 4.7 Point Bar

(Source:http://nile.riverawarenesskit.org/English/NRAK/RS_L3/html/3_1_3_5_river_channel.html)

Oxbow lake – the channel abandoned during a neck cut off will in time be converted into an oxbow lake, which as the new stream course migrates away from the former site becomes farther and farther removed from the river (Figure – 4.8).

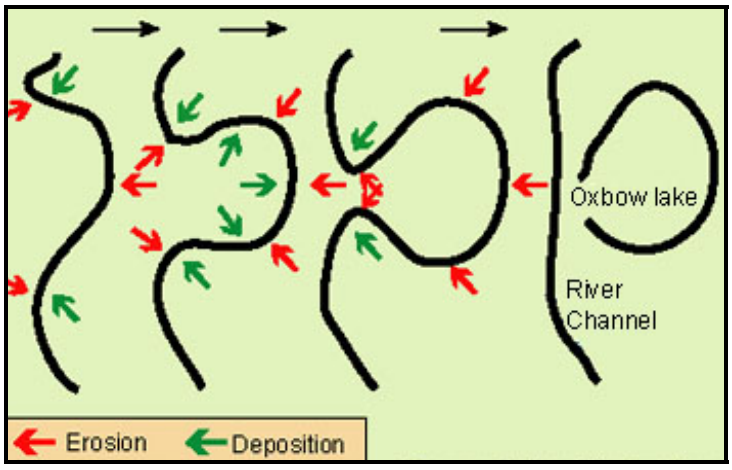

Figure 4.8-Oxbow lake formation

(Source**:**http://nile.riverawarenesskit.org/English/NRAK/RS_L3/html/3_1_3_5_river_channel.html)

Back-swamp deposits – They are the deposits which were laid down in the flood basins back of the natural levees. They consist of extensive layers of silt and clay. They are usually marked by high relief and by drainage networks, which reflect the position of the older drainage lines.

4.7.2 Features resulting from marine deposition

Tidal Mud flats - These mud flats consist of clay and slit. These tidal flat are classified on the basis of their relation with tidal conditions into Subtidal, Intertidal and High tide mud flats.

Numerous creeks dissect these tidal flats, changing their position by reworking mud deposits. Flocculation can be accounted as the major process involved in the deposition of these tidal flats having a fluviatile source material. Tide plays a very vital role in the formation of these mudflats.

Coastal dunes - Coastal dunes are formed when the sand deposited from the shore dries out, and is blown to the back of the beach. Where the tide range is large, sand blown from broad foreshores exposed at low tide is built up as dune topography extending inland from high tide mark. On coasts, where tide range is small, the sand delivered to the beach by wave action may provide sufficient material for dune construction.

Shore platforms - These platforms are developed and widened by the receding cliffs and shaped by the action of waves and other marine processes. They extend from the high tide mark, at the base of the receding cliff, to a level below and beyond low tide mark, in the near-shore zone. It can be hence conveniently described as the inter-tidal shore platforms.

Beach – It is an accumulation of loose sediments, such as sand, shingle and boulders and sometimes confined to backshore but often extending across the foreshore as well. The materials for the beach come from both land and sea.

Spit – A spit is a beach that diverges from the coast. They are the depositional features built along the shore, usually ending in one or more landward hook or ***recurve***. They grow in the predominant direction of longshore sediment flow caused by waves and their outlines are shaped

largely by wave action. They are generally attributed to the movement and deposition of materials by longshore currents.

Coastal ridges - The beach is flanked by backshore coastal ridges over which rests the unconsolidated aeolian sands. In general, these ridges are formed due to presence of strong onshore winds, abundant sand supply, low near shore slope combined with a large tidal range of the study area. These coastal ridges have been stabilized by vegetation over which the recent loose sands are deposited by wind action. They are present as the elongated sub-parallel ridges of mainly sand and some shell fragments stretching continuously almost all along the coast.

Barrier beaches - They are the narrow strips of low-lying depositional land consisting entirely of beach sediment, without surrounding dunes or associated swamps. They are best developed where the tide range is relatively low. A large tide range generates strong ebb and flow currents which maintain gaps through barriers and prevent wave action from depositing sand or shingle to seal them off.

Fore-dunes - They are built up at the back of a beach or on the crest of a beach ridge of sand or shingle where the dune grasses colonize and start to trap the blown off sand. They become higher and wider as the colonization continues.

4.7.3 From Fluvio-marine influence

Estuaries - They are the mouth of rivers, widening as they enter the sea (Emery and Stevenson, 1957; Lauff, 1967). Alternately, estuaries can be

defined in terms of tidal conditions, as the lower reaches of a river subject to tidal fluctuations, or in terms of salinity, as the area where fresh water meets and mixes with salt water from the sea.

An ideal estuary is funnel shaped, opening towards the sea, subjected to tidal fluctuations and influenced by the salinity of the sea (Figure - 4.9). At low tide in such estuaries, there are often number of channels leading from the river to the sea, between banks of sand, silt and clay. These are shaped largely by the tidal currents. The currents tend to change the positions and dimensions of channels, cutting away sediments in one place and building it up in another.

Estuaries are typically areas of active sedimentation, the area drowned by recent submergence being progressively infilled, contracting in volume, dept and surface area until the river winds to the sea through a depositional plain. Sediments are carried in by the rivers, washed in from the sea and derived from the erosion of bordering slopes and shorelines. Deposition of marine sediments in the entrances of estuaries takes a variety of forms such as the formation of spits and barriers across the river mouth.

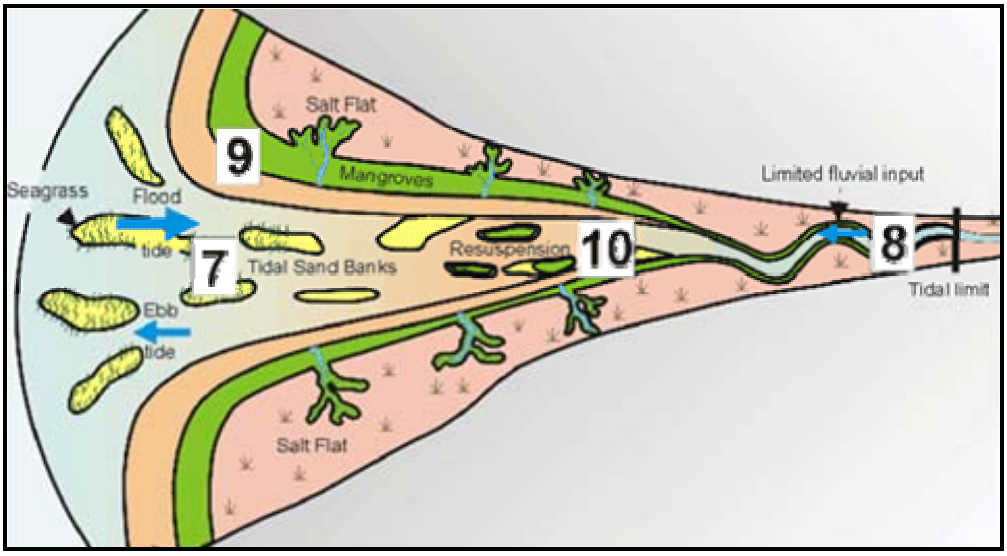

Figure 4.9-Estuarine Set-Up

(Source:
http://www.ozcoasts.gov.au/conceptual_mods/geomorphic/tde/tde_physical.jsp)

Relict features - Relict land forms characterize those features which formed on a pre-existing landscape and have escaped destruction or burial to persist as parts of the present day topography. These relict alluvial patches are few meter above the high water line. This indicates that they are the result of the transgression and the regression of the sea.

Coastal Lagoons - Coastal lagoons are water bodies impounded by a sand barrier; they represent an extreme form of the barrier estuary (Cooper, 1994; Isla, 1995). Coastal lagoons can be connected intermittently to the ocean by one or more restricted inlets through the barrier. On a geological time scale, coastal lagoons are short –lived features, controlled by sea level, climate and tectonic setting (Bird, 1967; Thornbury, 1985; Pethick, 1995).

CHAPTER 5: REMOTE SENSING

Remote sensing is an important tool in mapping the impossible landscape of the mangrove ecosystems. It not only helps in mapping but also in knowing the diversity and in monitoring the changes besides serving as an imperative means for futuristic management practices as well. This chapter describes the What, Why's and How's of the remote sensing, its principles and use of the technique for the present work.

5.1 Principles of Remote Sensing - EMR

Remote sensing works on the basic principle of studying an object by the reflection emitted, without coming in direct contact with it. It does so by using the electromagnetic radiation in one or more regions of the electromagnetic spectrum (Figure 5.1), reflected or emitted from the earth's surface (Figure 5.2). This electromagnetic radiation (EMR) is generated by several mechanism, including changes in the energy levels of electrons, acceleration of electrical charges, decay of radioactive substances and the thermal motions of atoms and molecules. Nuclear reactions within the sun are our major source of electromagnetic radiation (Campbell, 2007).

When the electromagnetic radiations fall on a surface, some energy is absorbed, some is transmitted through the surface and some is reflected. Atmospheric windows allow transmission of Surfaces also naturally emit radiations which at the temperature of the Earth are mostly infra-red

radiation. The upwelling reflected and emitted radiation is recorded on either a photographic film or digitally by a *sensor* (Green et. al. 2000).

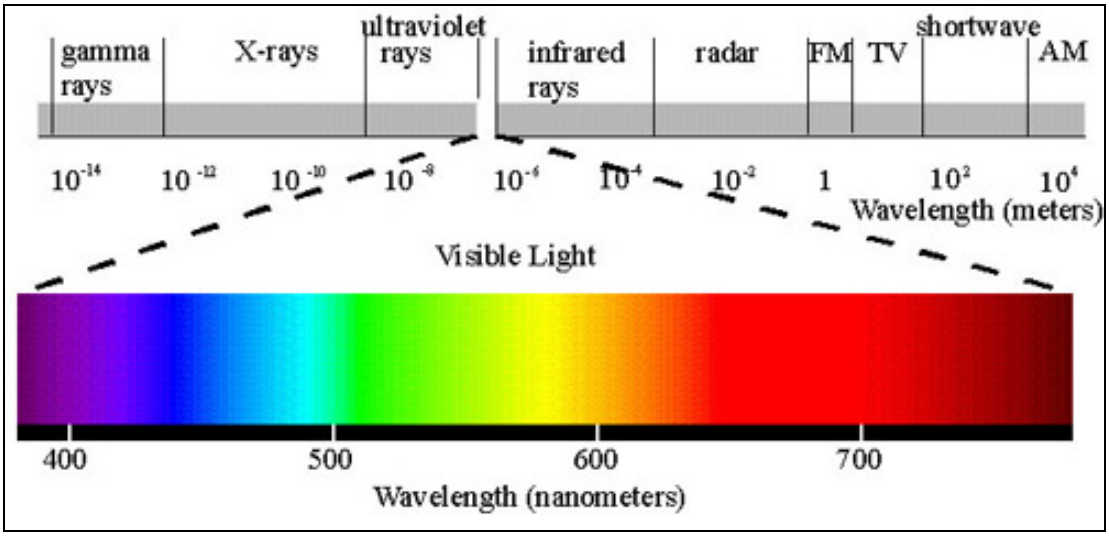

Figure 5.1 – Electromagnetic Spectrum

((Source: http://www.yorku.ca/eye/spectru.htm)

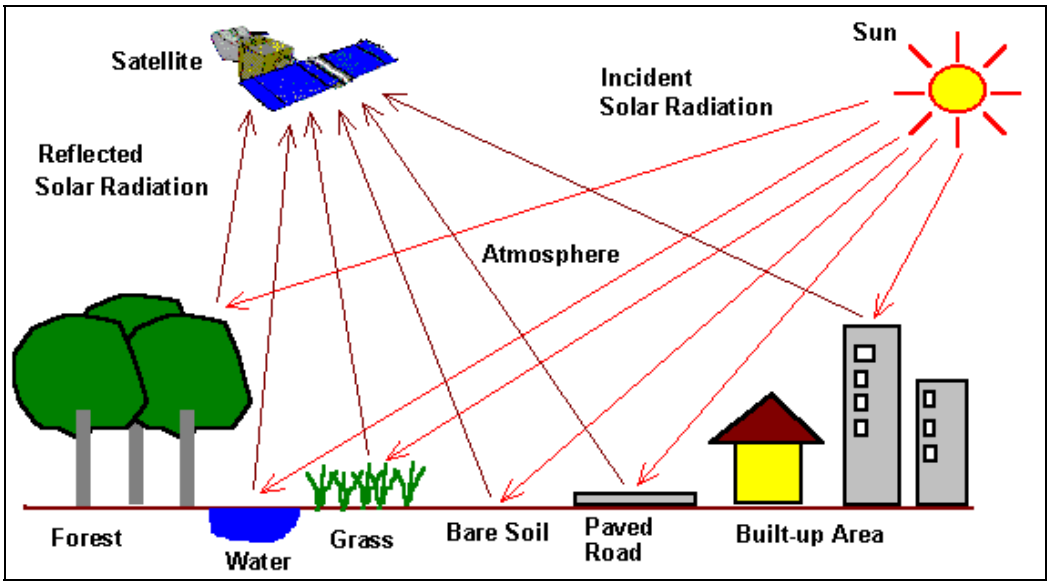

Figure 5.2 – Diagrammatic representation of interactions of the electromagnetic radiations with Earth's surface

(Source: http://www.intechopen.com/books/biomass-and-remote-sensing-of-biomass/introduction-to-remote-sensing-of-biomass)

Sensors

A remote sensing system is composed of sensors carried on a platform. A platform can be either or a satellite or any type of aircraft. The sensor is the device which gathers the energy and converts it into signals. They gather information about the interactions of the electromagnetic radiations, with the Earth's surface (Green et. al., 2000).

. Various types of sensors can measure incoming EMR in different part of the spectrum. There are two types of sensors- Passive and Active. Visible and near infra-red sensors measure the amount of sunlight reflected by the objects on the Earth's surface, whereas thermal infra-red sensors detect heat emitted from the Earth's surface (including water). These sensors are passive as the radiation sources are Sun and the Earth respectively. Microwave sensors are on the other hand active sensors. They send out radar pulses, which are measured as the echoes reflected back from the earth's surface and the objects on it.

The atmosphere lets visible radiation through, except when cloudy, but water vapour, carbon dioxide and ozone molecules absorb EMR, particularly in the infrared part of the spectrum making atmosphere opaque to certain wavelengths. Consequently, satellite sensors are designed to sense in so called transmission windows, where atmosphere allows radiation through (Figure 5.3) (Green et. al., 2000)

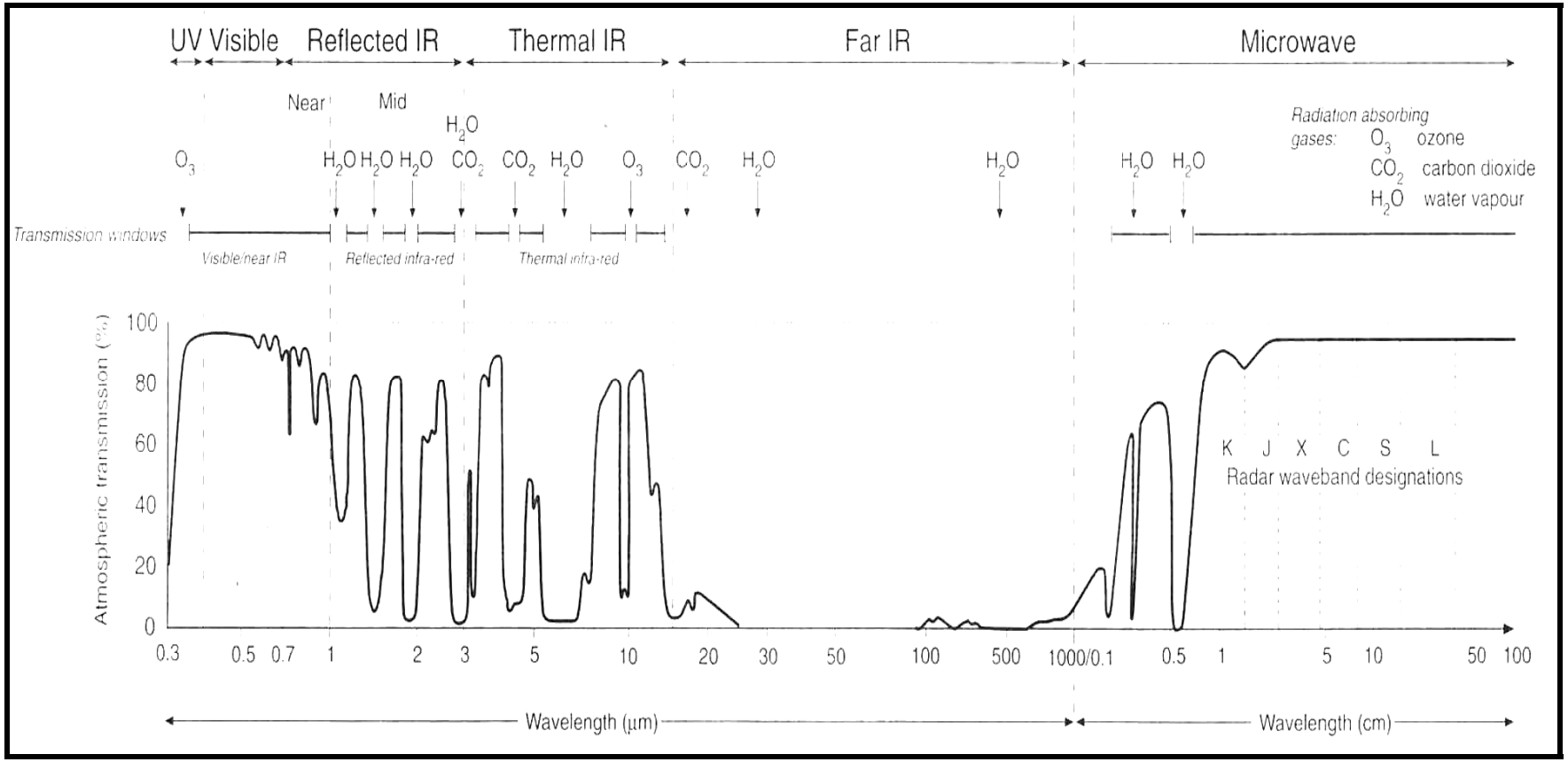

Figure – 5.3 The EMR spectrum ranging from UV to microwave region showing the atmospheric transmission windows, radiation absorbing gases which block transmission at specific wavelengths and the wavebands of a remote sensing systems used in coastal management related applications (Source: Jensen, 2000)

5.2 Characteristic of a sensor

Pixels

Images obtained from digital sensors are basically sets of number with the value being in relation with the amount of radiance coming from a ground area represented by a single cell or a *pixel* (Green et. al., 2000). Pixel is nothing but a *portmanteau* of picture element, which makes up the blocks of an image. Therefore, a digital image is composed of many thousands of pixels, each usually too small to be individually resolved by the human eye. Each of these pixels represents the brightness of a small region on the Earth's surface (Campbell, 2007).

Digital Number

The digital values are recorded in a form which are recorded is suitable form. It is in the form of numeric values. These values are popularly known as digital numbers (DN) or brightness values. Each of this value is recorded as a series of binary digits known as bits. Each bit records an exponent of power of 2, with the value exponent determined by the position of the bit in the sequence. The number of brightness values within a digital image is determined by the number of bits available (Campbell, 2007).

Radiances

Brightness of radiation reflected from the Earth's surface is measured as brightness (watts) per wavelength interval (micrometer) per angular unit (steradian). Thus, the measured brightness is defined with respect to the wavelength (colour), spatial area (angle) and intensity (brightness). Thus,

radiances record actual brightness, measurable in physical units and given as real values (Campbell, 2007).

Resolution

The satellite images can be characterised by the resolution. There are 4 different types of resolution imparting distinctive attribute to a sensor.

Spatial Resolution

It is the measure of an area on ground by each sampling unit (pixel), commonly measured in units of distance - as meters or kilometers. Thus, one can say that the spatial resolution is but the size of a pixel corresponding to that unit area on ground.

Temporal Resolution

Most satellites are sun-synchronous, which means, for any given point on earth, the satellite will pass overhead at the same time. Temporal resolution is thus the time interval between consecutive overpasses by a satellite of a fixed point.

Radiometric Resolution

It refers to the number of digital levels used to express the data collected by the sensor and is therefore a measure of sensitivity.

Spectral Resolution

Sensors are designed to record a specific portion of the electromagnetic spectrum. Sensors which record the radiation over a wide part of the visible spectrum, but in a single waveband are called 'panchromatic'. However, many

sensors record radiation in several distinct bands and are thus called 'multispectral'. Thus, spectral resolution refers to the number and width of bands (Green et. al., 2000).

Since the intensity and the wavelength of the radiations are a function of the surface in question, each surface possesses a characteristic ***spectrum or spectral signature.*** **And, it is this *spectral signature* that forms the fundamentals of the remote sensing**. If different spectra can be distinguished, it is possible to map the extent of such surfaces (Green et. al., 2000).

5.3 Spectral signature for the surface features of earth

The reflectance properties of earth surface features may be quantified by measuring the portion of the incident energy that is reflected. This is measured as a function of wavelength and is called spectral reflectance ρ (λ). It is mathematically defined as –

$$\rho(\lambda) = [\, ER(\lambda) / EI(\lambda) \,]$$

Where, ρ (λ) is expressed as percentage

ρ (λ) = spectral reflectance at a particular wavelength λ

ER(λ) = energy of wavelength λ reflected from an object

EI(λ) = energy of wavelength λ incident on an object

A graph of the spectral reflectance of an object as a function of wavelength is termed as ***spectral reflectance curve***. The configuration of the spectral reflectance curve gives an insight into the spectral characteristics of an object. Figure 5.4 shows highly generalized spectral reflectance curves for three basic types of earth features: 1. Healthy green vegetation 2. Dry bare soil and 3. Clear lake water. It depicts how distinct the curves are for each feature, allowing each object to be separated on the basis of its spectral reflectance (Tso and Mather, 2001; Lillesand and Kiefer, 2002).

Vegetation

Healthy green vegetation always manifests into a peak and valley configuration. The valleys can be attributed to the pigments in the plant leaves. Chlorophyll, for examples, strongly absorbs energy in the wavelength bands 0.45 and 0.67μm. hence our eyes perceive healthy green vegetation as green in color because of the high absorption of blue and red energy and very high reflectance of green energy by the plants' leaves. The reflectance of vegetation also increases dramatically when moved towards the near IR portion of the spectrum at about 0.7 μm. It reflects about 50 percent of the incident energy in the spectrum of 0.7 to 1.3 μm. This is due to the internal structure of the leaves and as this is highly variable between the species, observations in this range often allow discriminating different plant species. Apart from this, dips in reflectance occur at 1.4, 1.9 and 2.7 μm because water content of the leaf

strongly absorbs in this region. Hence, these regions are also known as water absorption bands, which is function of both – moisture content and thickness of the leaf (Lillesand and Kiefer, 2002).

Soil

Some of the factors affecting soil are moisture content, soil texture, surface roughness, presence of iron oxides and organic matter content. These factors are complex, variable and interrelated. The presence of even little moisture in the soil decreases its reflectance. Water absorption bands can be found at the wavelengths 1.4, 1.9 and 2.7 μm. soil moisture is also strongly correlated with the soil texture (Lillesand and Kiefer, 2002).

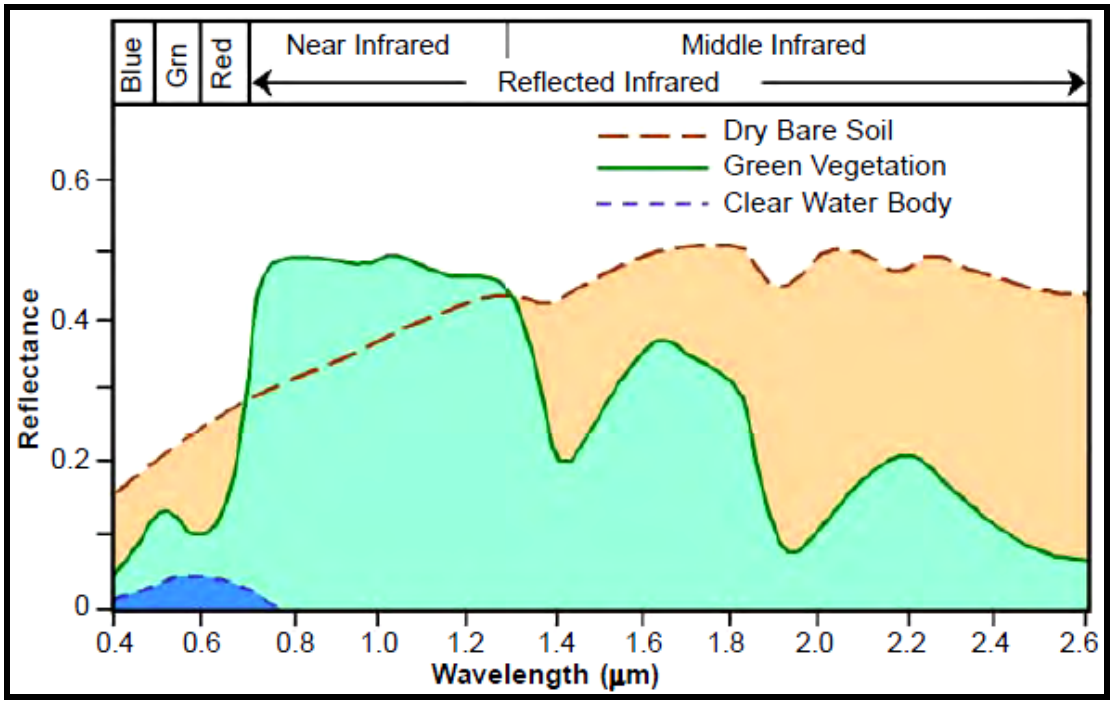

Figure – 5.4 Typical spectral reflectance curve for vegetation, soil and water

(Source: http://remote-sensing.net/concepts.html)

Water

Water absorbs energy beyond the visible red. Locating or delineating the water bodies can be done best in the NIR wavelengths because of its absorption. Longer visible and NIR radiation is absorbed more and thus water appears blue or blue-green which means that it is strongly reflected in shorter wavelengths whereas it will appear darker if seen at red or IR wavelengths (Aggarwal, 2003). However, one must not forget that the reflectance of a water body is function of not only the water per se but also the material in the water. Clear water absorbs relatively little energy having wavelengths less than about 0.6 μm. However, water carrying large amount of suspended particles have greater reflectance than the clearer waters. Increase in chlorophyll is another factor which leads to the decreased reflectance in the blue and increased in the green wavelengths (Lillesand and Kiefer, 2002).

5.4 Importance of remote sensing in the coastal region

Remote sensing techniques are valuable not only in providing the basic information before a field visit but are also important for the post field work, as it provides a means to extend the knowledge of a small area *(a patch)* to a larger region *(entire wetland).* Furthermore, remote sensing approach is best suited for the long term monitoring and management and conservation practices, as the information provided is repetitive and synoptic. Not only this,

change detection studies are easier to carry out with the multitemporal data available. The study of the forests, agricultural lands, oceans are carried out extensively with the aid of the Remote Sensing and GIS technology. The technique also provides information regarding the extent of the habitat and the type of habitat (Green et. al., 2000).The uses of these tools have proven to be important in the study of environment like wetland ecosystems, due to their unique transitional habitat where tidal inundations, networks of creeks, etc constraints make the wetlands often inaccessible for frequent ground visits. Hence, regular assessment and ground survey becomes a little difficult for communities with such unique habitat. Remote sensing technique, along with GIS software thus proves to be a very useful tool where routine monitoring is necessary, without much need of going for the ground surveys. A list of the sensors used for the coastal studies has been given in table 5.1. However, apart from these systems, there are many air-borne sensors, the cost of which is very high and the use limited.

5.5 Remote Sensing Of Vegetation

Approximately 70% of the earth's land surface is covered with vegetation. Vegetation cover not only forms the surface observed by remote sensing instruments over a large portion of earth but is also one of the most important components of the ecosystem. The earth's vegetation cover is often

the first surface encountered by the energy we use for remote sensing (Campbell, 2007).

Need for understanding the vegetation ranges from mapping different forest types, rangelands, agricultural production, etc. It is also useful in understanding the patterns that lay hidden beneath the surface of vegetation like the geologic and pedologic patterns, which are not directly recorded (Campbell, 2007). Moreover, knowledge about variations in vegetation species and community distribution patterns, alterations in vegetation phenological cycles and modifications in plants physiology and thus morphology provide valuable insight into the climatic, edaphic, geologic and physiographic characteristics of an area (Jensen, 2000).

Satellite	Sensor	Resolution				Swath width	Primary coastal applications
		Spectral (Bands)	Spatial (Kms/m)	Temporal (days/hours)	Radio metric (Bits)		
Sensors with spatial resolution of more than 100 mtrs							
NOAA 9-14	AVHRR	5	1.1 km	12 hours	10	2399 kms	Sea surface temperature, ocean color
NIMBUS-7	CZCS	6	0.825 km	6 days	8	1566 kms	Measurement of temperature, chlorophyll concentration, sediment distribution, Gelbstoff concentrations as salinity
SeaStar	SeaWiFS	8	1.1 km	1 day	10	2801 kms	Ocean color and chlorophyll-a measurement
ERS	ATSR	4	1 km	3 days	12	785 kms	Sea state, sea surface winds, ocean circulation and coastal vegetation cover
ADEOS	OCTS	12	0.700 km	3 days	10	1400 kms	Measurement of temperature, chlorophyll concentration, sediment distribution and Gelbstoff concentrations as salinity
Sensors with spatial resolution of 10 - 100 mtrs							
Landsat	MSS	4	80 m	16 days	6	185 kms	Resource inventory, cartographic mapping, baseline environmental monitoring, change detection, bathymetry

Satellite	Sensor	Resolution				Swath width	Primary coastal applications
		Spectral (Bands)	Spatial (Kms/m)	Temporal	Radio metric (Bits)		
Landsat	TM	7	30 m	16 days	8	185	Resource inventory, cartographic mapping, baseline environmental monitoring, change detection, bathymetry
Landsat	ETM+	7+1	30/15 m	16 days	8	185	Resource inventory, cartographic mapping, baseline environmental monitoring, change detection, bathymetry
SPOT 1-3	HRV	3+1	20/10 m	26 days	8	60	Resource inventory, cartographic mapping, baseline environmental monitoring, change detection, bathymetry
SPOT 4	HRVIR	4	20 m	26 days	8	60	Resource inventory, cartographic mapping, baseline environmental monitoring, change detection, bathymetry
IRS 1A – 1B	LISS I – II	4	73/36.5 m	22 days	7	148/146	Resource inventory, cartographic mapping, baseline environmental monitoring, change detection

Satellite	Sensor	Resolution				Swath width	Primary coastal applications
		Spectral (Bands)	Spatial (Kms/m)	Temporal	Radio metric (Bits)		
IRS 1C – 1D	LISS III	4	23.5 m	24 days	7	142 (band 1-3) 148 (band 4)	Resource inventory, cartographic mapping, baseline environmental monitoring, change detection
JERS - 1	OPS	8	18.3 m	44 days	8	75	Resource inventory, cartographic mapping, baseline environmental monitoring, change detection
MOS	MESSR	4	50 m	17 days	8	200	Resource inventory, cartographic mapping, baseline environmental monitoring, change detection
ERS	SAR	1	25 m	3 days	16	100	Terrestrial habitat mapping including the mangrove extent and biophysical parameters (LAI, cover)
RADARSAT	SAR	1	10-100 m	Variable	16	50 to 500	Terrestrial habitat mapping including mangrove extent & biophysical parameters (LAI)
EO-1	Hyperion	220	30 m	16 days	12	36	
EO-1	ALI	10	30 m	16 days	12	7.6	
EO-1	AC	256	250 m	16 days	12	185	

Satellite	Sensor	Resolution				Swath width	Primary coastal applications
		Spectral (Bands)	Spatial (Kms/m)	Temporal	Radio metric (Bits)		
Sensors with spatial resolution of less than 10 mtrs							
IKONOS (multi-spectral)		4	4 m (after resampling)	1.5 or 3-5 days off nadir 144 days true nadir	11	11.3 km at nadir 13.8 km off-nadir	Integral contribution to homeland security, coastal monitoring and facilitates 3D Terrain analysis.
IKONOS (PAN)		1	1 m (after resampling)	2.9 days	11	11.3 km at nadir 13.8 km off-nadir	
QUICK-BIRD 2 (multispectral)		4	2.4 m	2.5 days	11	16.5 kms	Source of environmental data, analyses of changes in land usage, agricultural & forest climates. Applied to host of industries, including Oil and Gas Exploration & Production (E&P), Engineering & Construction & environmental studies
QUICK-BIRD 2 (PAN)		1	0.61 m	5.6 days off-nadir	11	16.5 kms	
ImageSat	EROS A	1	1.8 m	2 days	11	14 kms	
ImageSat	EROS B	1	0.7 m	3 days	10	7 kms	

Satellite	Sensor	Resolution				Swath width	Primary coastal applications
		Spectral (Bands)	Spatial (Kms/m)	Temporal	Radio metric (Bits)		
Cartosat 1	PAN	1	2.5 m	5 days	10	30 kms	Large scale mapping applications, land and water resources management, disaster assessment, land cover change detection, relief planning and management, environmental impact assessment and various other Geographical Information Systems (GIS) applications.
Cartosat 2		1 (0.50-0.85)	<1 Kms	4 days	10	9.6 Kms	

Table – 5.1 Sensors used for coastal applications
(Source: Compiled from various sources)

Many of the remote sensing techniques are generic in nature and may be applied to variety of vegetated landscapes, including: agriculture, forests, rangeland, wetlands and manicured urban area (Jensen, 2000). It is also useful in monitoring areas planted of specific crops, for detecting diseases and insects infestations and for contributing to accurate production forecasts and even in studying the timber volume.

Above all, it may often provide the only practical means of mapping and monitoring changes in major ecological regions that have great long-term significance for mankind (Campbell, 2007).

5.5.1 Spectral Characteristics Of Vegetation

To understand the spectral characteristics of vegetation, one needs to understand the distinctive properties that allows it to impart the unique values which in turn permits to discriminate between different species through the remote sensing analysis.

Plants have adapted their internal and external structure to perform photosynthesis. This structure and its interaction with electromagnetic energy has a direct impact on how leaves and canopies appear spectrally when recorded using remote sensing instruments (Jensen, 2000). Many applications of remote sensing to vegetation patterns depend on knowledge of spectral properties of individual leaves and plants. These properties are best

understood by examining the leaf structure at a rather finer level of detail (Campbell, 2007).

A healthy green leaf intercepts incident radiant flux directly from the Sun or from diffused skylight scattered onto the leaf. This incident electromagnetic energy interacts with the pigments, water and the intercellular air-spaces within the plant leaf. The amount of radiant flux reflected from the leaf (Φ_r), the radiant flux absorbed by the leaf (Φ_α) and the amount of radiant flux transmitted through the leaf (Φ_τ) can be carefully measured as we apply the energy balance equation and attempt to keep track of what happens to all the incident energy. The general equation for the interaction of spectral (λ) radiant flux on and within the leaf is –

$$\Phi_{i_\lambda} = \Phi_{r_\lambda} + \Phi_{\alpha_\lambda} + \Phi_{\tau_\lambda}$$

When variables are divided by the original radiance flux $\Phi_{i\lambda,}$ it yields

$$i_\lambda = r_\lambda - \alpha_\lambda + \tau_\lambda$$

Where r_λ is the spectral hemispherical reflectance of the leaf, α_λ is the spectral hemispherical absorptance and τ_λ is the spectral hemispherical transmittance by the leaf. Most remote sensing systems function in the 0.35 – 3.0 μm region measuring primarily reflected energy where the energy reflected from the plant leaf surface is equal to the incident energy minus the energy absorbed

directly by the plant for photosynthetic or other purposes and the amount of energy transmitted directly through the leaf onto other leaves or the ground beneath the canopy (Jensen, 2000).

Structure of leaf

Pioneering works by Gales et al. (1965), Gausmann et al. (1969), Myers (1970) and others demonstrated the importance of understanding how leaf pigments, internal scattering and leaf water content affect the reflectance and transmittance properties of leaves (Peterson and Running, 1989). The cross section of a typical leaf reveals its essential elements (Figure 5.5). The uppermost layer, the upper epidermis, consists of specialized cells that fit closely together without openings or gaps in between cells. This is upper epidermis, covered by cuticle, a transparent, waxy layer that prevents moisture loss from the interior of the leaf. The underside of the leaf is protected by the lower epidermis, similar to upper epidermis except that it includes openings called stomata which permit the movement of air into the interior of the leaf. Each stomate is protected by a pair of guard cells that can open and close as necessary to facilitate movement of air to the interior of the leaf. The primary function of the stomata is to allow atmospheric CO_2 to enter the leaf for photosynthesis.

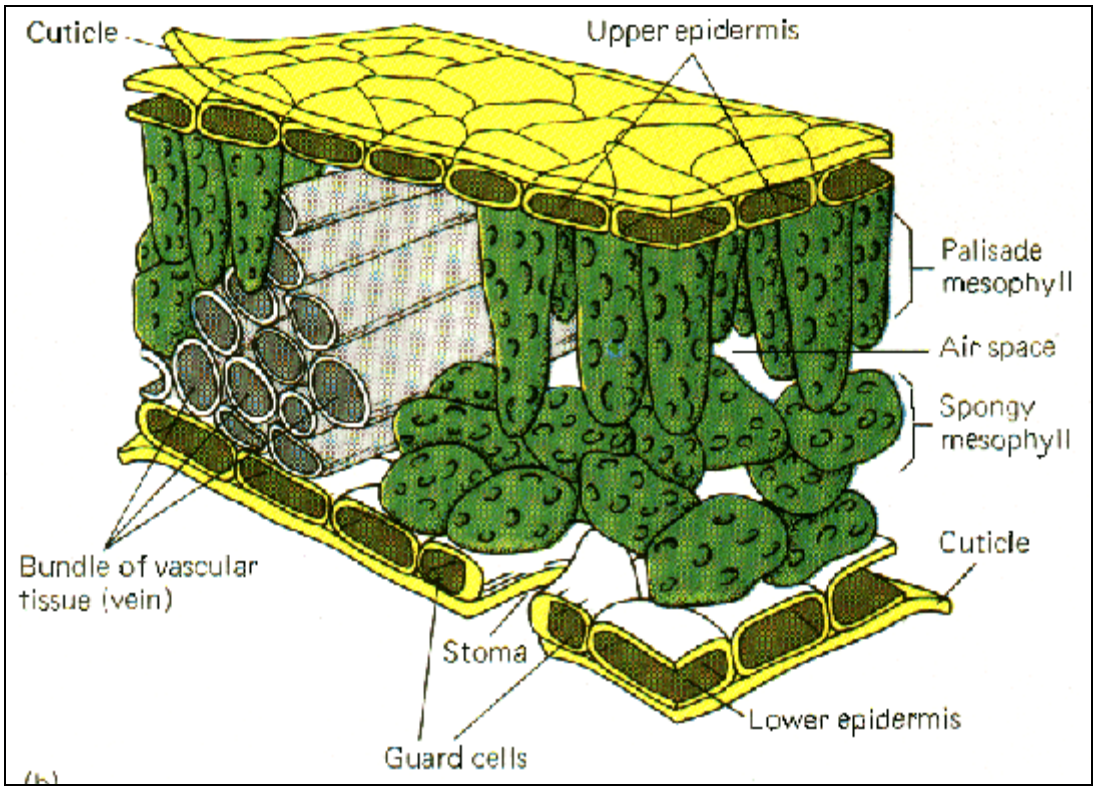

Figure - 5.5 Internal structure of leaf

(Source: http://science.halleyhosting.com/sci/ibbio/plants/notes/intleaf.htm)

Apparently, the positions of stomata on the lower side of the leaf favor maximum transmission of light through the upper epidermis and minimize the moisture loss when stomata are open. On the upper side of the leaf, just below the epidermis, is the palisade tissue consisting of vertically elongated cells arranged in parallel fashion, at right angle to the epidermis. Palisade cells include chloroplasts – cells composed of chlorophyll and other pigments active in photosynthesis. Below the palisade tissue is the spongy mesophyll tissue, which consist of irregularly shaped cells separated by interconnected openings. The mesophyll layer has a very large surface area; it is the site for the oxygen

and carbon dioxide exchange necessary for the photosynthesis and respiration (Campbell, 2007).

The process of food making via photosynthesis determines how a leaf and the associated plant canopy actually appear radiometrically on a remotely sensed image. Dominant factors which control the leaf reflectance in the region from 0.35 – 2.6 μm are summarised below –

- ***Visible light interaction with pigments in palisade mesophyll cells***

Palisade cells are typically 15 X 15 X 60 μm, while spongy parenchyma cells are smaller. The palisade parenchyma mesophyll cells contain chloroplasts with chlorophyll pigments.

Each molecule absorbs or reflects its own characteristic light. Molecules in a typically green plant evolved to absorb wavelengths of light in the visible region of the spectrum, are called pigments. An absorption spectrum for a particular pigment describes the wavelengths at which it can absorb light and enter into excited state. A relative lack of absorption in wavelengths between two chlorophyll absorption bands produces a trough in the absorption efficiency and it is the relatively lower absorption of green wavelength by the leaf that causes healthy green foliage to appear green to our eyes. There are other pigments also present in the palisade mesophyll – the pigments like carotene, xanthophylls, phycoerythrin and phycocyanin. However, the chlorophyll a and b are present in the same absorption band of that of the other pigments like carotene, xanthophylls, phycoerythrin and phycocyanin.

and they (chlorophyll a and b) tend to dominate and mask the effect of the other pigments.

Remote sensing of chlorophyll absorption within a canopy represents a fundamental biophysical variable useful for many bio-geographical investigations. The absorption characteristics of plant canopies may be coupled with other remotely sensed data to identify vegetation stress, yield and other hybrid variables (Jensen, 2000). Thus, many remote sensing studies are involved with monitoring what happens to the photosynthetically active radiation as it interacts with individual leaves and or the plant canopy. Carter (1993) suggests that increased reflectance in the visible spectrum is the most consistent leaf reflectance response to plant stress (Jensen, 2000).

- ***Near infrared energy interaction within the spongy mesophyll cells***

In a typically healthy leaf, the near-infrared reflectance increases dramatically in the region from 700 – 1200 nm. Healthy green leaves absorb very efficiently in the blue and red portions of the spectrum where incident light is required for photosynthesis. The spongy mesophyll layer in a green leaf controls the amount of near infrared energy that is reflected. It is here that the oxygen and carbon dioxide exchange takes place for photosynthesis and respiration. In the near infrared region, healthy green vegetation is generally characterized by the high reflectance, high transmittance through the underlying leaves, and relatively low absorption. The reason for this reflectance is given that if the leaves absorb all this energy with the same

efficiency as they do in the visible region, they could become much too warm and the proteins would be irreversibly denatured. As a result, plants have adapted not to use this energy and simply reflect it or transmit it through to underlying leaves or ground. Thus, resultant reflectance is due to direct reflectance by the spongy mesophyll and the remaining energy penetrates through the leaf to be once again transmitted by the leaves below it. This is also known as leaf additive reflectance.

The high diffuse reflectance of the near-infrared energy from the plant leaves is due to the internal scattering at the cell wall-air interfaces within the leaf (Gausmann et al., 1969; Peterson and Running, 1989). Greater the number of leaf layers in a healthy, mature canopy, theoretically greater the infrared reflectance. This also means if the canopy is sparse and is composed of only a single layer then near-infrared reflectance will not be as great because the energy that is transmitted through the leaf layer may be absorbed by the ground cover beneath (Jensen, 2000).

- ***Middle infrared energy interaction with water in the spongy mesophyll***

Plants require water to grow. A leaf obtains water that was absorbed by plants' roots. In the middle infrared wavelengths, vegetation reflectance peaks occur at about 1.6 and 2.2 µm, between major atmospheric water absorption bands. Water is good absorber of middle infrared energy, so the greater the turgidity of the leaves, the lower the middle infrared reflectance. Conversely,

as the moisture content of leaves decreases, reflectance in the middle infrared region increases substantially. As the amount of water in the intercellular spaces decreases, reflectance in the middle infrared region increases substantially. This is caused as the incident middle infrared energy is more intensely scattered at the interface of the intercellular walls resulting in greater middle infrared reflectance from the leaf. The middle infrared wavelength intervals from about 1.5 – 1.8 μm and from 2.1 – 2.3 μm appear to be more sensitive to changes in the moisture content of the plants than the visible of the near infrared portions of the spectrum.

Much of water content of the plant is lost through transpiration. If the roots cannot replace this lost, the plant may wither and die. Hence, monitoring the moisture content of the plant canopies, which is correlated with the rates of transpiration, can provide valuable information regarding the health of the plant or crop (Jensen, 2000).

Figure 5.6 below depicts the interaction of different tissues of the leaf with the incident wavelength. The transmission of the wavelength due to interaction with the leaf is shows in figure 5.7

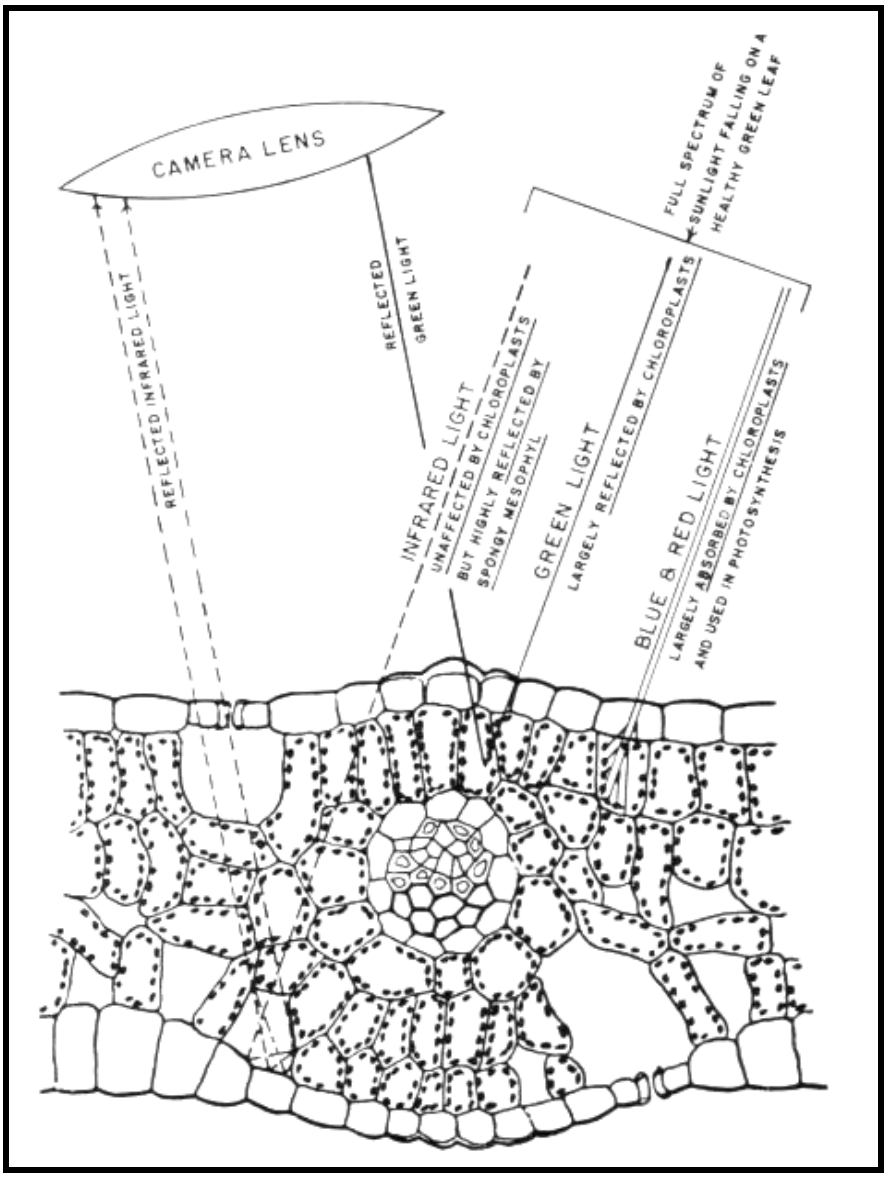

Figure - 5.6 Incident and reflected wavelength from different tissues

(Source: from Colwell, 1956)*

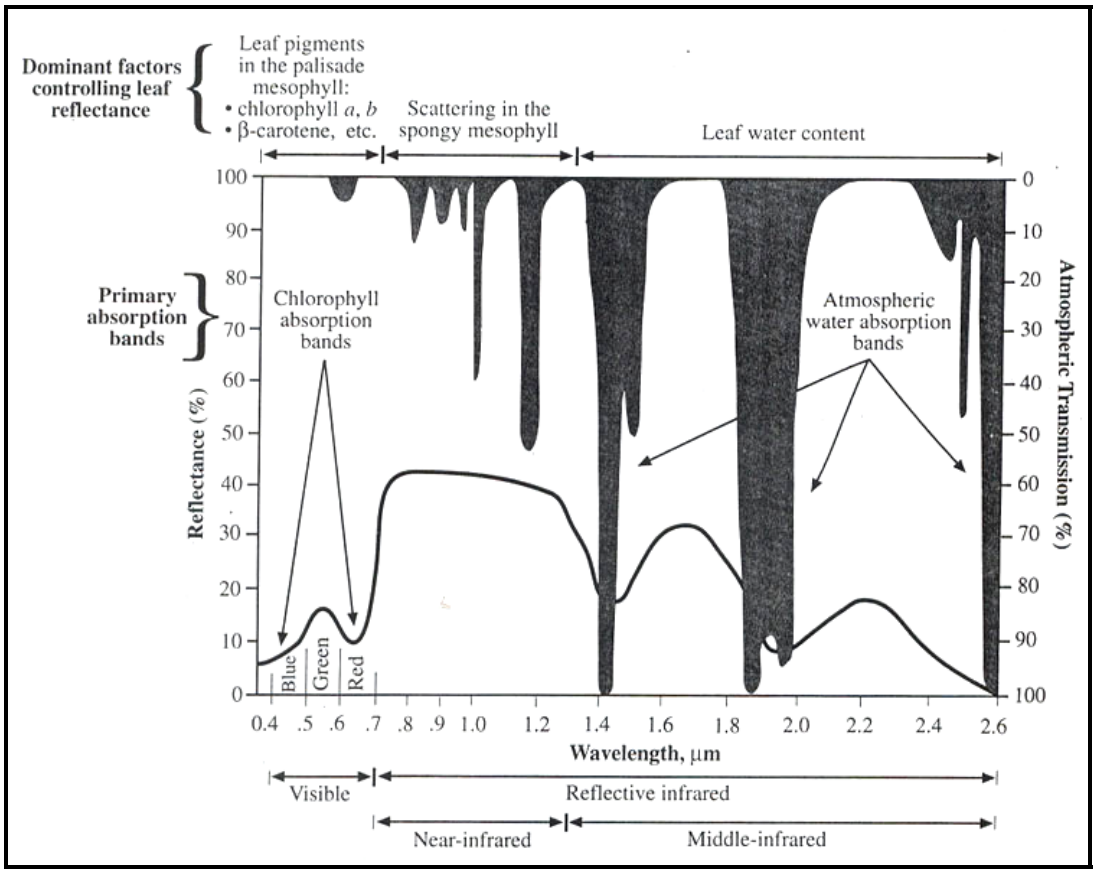

Figure - 5.7 Dominant factors controlling transmission from a leaf

(Source: Jensen, 2000)

Remote Sensing Of Vegetation Change

Analyzing the individual date of remote sensor data to extract meaningful vegetation biophysical information is often of value. However, to appreciate the dynamics of the ecosystem, it is necessary to monitor the vegetation through time and determine what changes in succession are taking place. This is done by the comparison of compatible data of the object in study and thus observed as *change detection* (Jensen, 2000). This not only helps in

the study of the subject of interest, but also in monitoring it and planning for better management practices intended for the future use.

5.5.2 Remote Sensing Of Mangrove Vegetation

Mangrove ecosystems are difficult to monitor *in situ* due to the dense understory and the not so easy terrain of the wetland complex, especially the interior of mangrove stands, are often difficult to access. For these reasons, extensive research of mangrove ecosystems has often been challenging. Therefore, the biological diversity and the extent of the mangroves are not well understood. Remote sensing data provides a means to extend the knowledge of a small area *(a patch)* to a larger region *(entire wetland)* and, therefore, appear to be well suited to the analysis of mangrove ecosystems (Hardisky et al., 1986) [#]. In addition, it is specifically of importance when one has to study the change over the time, especially when it is imperative to deal with some historic data, without having much factual knowledge.

Mangrove ecosystems thrive at an interface of land and water, which is to say in a complex habitat. Studies employing remote sensing have proved to be very useful in such locations (Green et al, 2000). Remote sensing allows information to be gathered from the areas that would otherwise be logistically and practically difficult to survey. Here, the technique was essentially utilised to bring out the diversity (i.e. community zonation), for determining the areal extent and to detect the changes over the time in the mangrove wetlands. A

tool like remote sensing provides information about the subject from a distance, from an overhead perspective, without getting into direct contact.

Mangrove habitat maps have been used for several purposes, but mainly for resource inventory, change detection and management purposes. Mapping the spatial distribution of mangroves is only possible if the mangrove area can be accurately distinguished from the non- mangrove area. An image processing method based on ratios of different red and infrared bands have given the most accurate results as per the study conducted so far (Green et. al., 2000).

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Sensors used for remote sensing of mangroves

Variety of sensors and image processing methods has been used in the remote sensing of mangroves (Table 5.2). Landsat and the SPOT XS are the most commonly used sensors for studying the mangroves.

Despite more then 80 years of applications, the first photographic surveys of mangrove were made in the 1920's and due to the lack of publications of work by aerial photography, it remains is heavily under-represented. Efforts were also made by making the use of the video (Everitt and Judd, 1989; Everitt et. al., 1991, 1996) and color infra-red photography (Reark 1975; Saenger and Hopkins 1975; Ross 1976; Sherrod and McMillan 1981; Everitt and Judd 1989).

The utility of remote sensing data for mangrove mapping is dependent on a fundamental step, the ability of the sensor and image processing

techniques to distinguish accurately between mangrove vegetation and other habitats such as non-mangrove vegetation, bare soil and water. The main aim however always remains the mangrove resource inventory by using the remote sensing techniques, to know the area of mangrove and the distribution of different mangrove habitats. The product here is generally mangrove habitat map, occasionally with supplementary information such as tree height. With the help of the historic data, it is also possible and desirable to obtain the data for mangroves of past, to estimate the amount of deforestation. The selection of aquaculture sites, and planning for more such sites for future, has also been possible through the remote sensing approach.

The Landsat and the SPOT sensors operate in the visible and infra-red portion of the electromagnetic spectrum and suffer from the problem of cloud cover. For this reason, some effort has been made recently to utilize the services of the radar images, specifically Synthetic Aperture Radar (SAR). A summary of satellite remote sensing applications for the management of mangrove areas, with selected example has been given in table – 5.2.

The pioneer workers for the study of mangroves through remote sensing approach at a global level have been Green et. al. (1998, 2000), Aschbacher et. al. (1995), Blasco and Aizpuru (2002), Blasco et. al. (1975, 1998), Dahdouh-Guebas et. al. (2004, 2006), Gao (1999), Proisy et. al. (2000) and likes. The analysis of the literature review also reveals that the approaches taken to

classify remotely sensed data of mangrove fall into five methodological groups (Table 5.3)–

- Visual interpretation
- Vegetation indices
- Unsupervised classification
- Supervised classification and
- Band ratios

Management use	Landsat MSS	Landsat TM	SPOT XS
Resource inventory and mapping of mangrove forests	Lorenzo et. al (1979) Shines (1979) Siddiqui & Shakeel (1989) Vibulsresth (1990) Mohammed et al. (1992) Vits & Tack (1995)	Ranganath et. al. (1989) Vibulsresth (1990) Gray et. al. (1990) Eong et. al. (1992) McPadden (1993) Vits & Tack (1995)	Blasco et. al. (1986) Siddiqui & Shakeel (1989) Chaudhary (1990) Thollot (1990) Populus & Lantieri (1991) Palaganas (1992)
Change detection and studying the deforestation of mangroves	Bina et al (1978) Lorenzo et. al. (1979) Bina et al (1980) Chaudhary (1990) Chitsamphandvej (1991)	Ibrahim & Bujang (1992) Ibrahim & Yosuh (1992) Loo et. al. (1992)	Populus & Lantieri (1991) Loo et. al. (1992) Palaganas (1992)
Aquaculture management – inventory of aquaculture sites in mangroves			Bina et al (1988) Loubersac et. al. (1986) Loubersac & Populus (1990) Chitsamphandvej (1991) Siswandono et. al. (1991)
Site assessment for shrimp aquaculture		Kapetsky et al (1987, 1990) Woodfine (1991) Woodfine (1993)	Loubersac et. al. (1990) Loubersac & Populus (1986) Chitsamphandvej (1991)

Table – 5.2 Summary of satellite remote sensing applications in mangrove areas, with selected example papers, (Source: Green et al., 2000)

Sr. no.	Workers	Sensors	Accuracy	Level of discrimination achieved
UNSUPERVISED CLASSIFICATION				
1	Vits and Tack (1995)	SPOT XS	95%	Four classes (2 fringing, mixed, shrub and logged mangrove)
		Landsat TM	97%	
2	Loo et. al., (1992)	SPOT XS	N/A	Three classes (dense, less dense and cleared coastal vegetation)
		Landsat TM		
	Dahdoug-Guebas et. al. (2004)	IKONOS		
	Coleman et. al.			
3	Woodfine (1991)	Landsat TM	N/A	Failed to distinguish mangrove and non-mangrove forest separately
4	Chaudhary (1990)	SPOT XS	N/A	Four classes (labeled according to the dominant species)
SUPERVISED CLASSIFICATION				
5	Dutrieux Et. al., (1990)	SPOT XS	N/A	Four classes (labeled according to the dominant species and species association)
6	Vits and Tack (1995)	SPOT XS	91%	Four classes (2 fringing, mixed, shrub and logged mangrove)
7	Aschbacher et. al., (1995)	SPOT XS	N/A	Four qualitative density classes (dense and medium, low and very low density)
		Landsat TM		
		MESSR		
		JERS-1		
		ERS-1 SAR		

8	Mohamed et. al. (1992)	Landsat MSS	N/A	Two classes of wetland vegetation
9	Eong et. al. (1992)	Landsat TM	N/A	Three classes (2 labeled according to dominant species, cleared mangrove)
10	Palaganas (1992)	SPOT XS	81%	Two classes (primary and secondary mangrove)
11	Vibulsresth et. al., (1990)	Landsat TM SPOT Pan	N/A	Six classes (4 labeled according to dominant species, 2 mixed mangroves)
12	Bina et. al. (1980)	Landsat MSS MESSR	85%	Mangroves (as separate from non-mangrove vegetation)
13	Lorenzo et. al. (1979)	Landsat MSS	N/A	Mangroves (as separate from non-mangrove vegetation)
14	Green et. al. (1998)	CASI	78%	Six classes (defined from hierarchical cluster analysis of field data)
15	Ramirez-Garcia et. al. (1998)	Landsat TM	N/A	Two classes (based on dominant species)
16	Ratansermpong (1986)	Landsat MSS	N/A	Separated mangrove from non-mangrove
17	Blasco and Aizpuru (2002)	SPOT RESURS	N/A	Ecological classification of mangroves
18	Sulong et. al. (2002)	Landsat TM Aerial photographs	N/A	Seven classes in TM 14 classes in aerial
19	Dahdoug-Guebas et. al. (2004)	IKONOS		Discrimination between con-generic species
20	Gao(1999)	SPOT HRV	81.3%	Eight classes (based on land cover)
		Landsat TM	85.2%	Ten classes (based on land cover)

21	Mahfud and Wier (1999)	SPOT	89%	Seven classes
		Landsat MSS	76%	Five classes
		Landsat TM	88%	Nine classes
		ERS -1	83%	Six classes
		JERS -1	85%	Seven classes
		Radarsat	84%	Seven classes
22	Rasolofoharinoro et.al. (1998)	SPOT 1 HRV		13 classes
		SPOT 2 HRV		
	Sery et. Al. (1995)	SPOT		8-10 mangrove classes delineated
		ERS-1	N/A	
		JERS-1		
		AIRSAR		
23	Woodfine (1991)	Landsat TM	N/A	Five classes (mixed community, complex community, transitional to fresh water, transitional to upland vegetation, cleared mangrove with secondary invasion)
VISUAL INTERPRETATION				
24	Gang and Agatsiva (1992)	SPOT XS	N/A	Five classes (labeled after dominant species or association of species)
25	Roy (1989)	MK6	N/A	Seven classes (labeled after association of dominant mangrove species)
		KATE-140		
26	Aschbacher et.al. (1995)	SPOT HRV	84.8%	4 mangrove classes and 2 non-mangrove classes
		Landsat TM	68.6%	
		MOS – 1		

		MESSR Jers – 1 SAR ERS – SAR		
27	Rasolofoharinoro et.al. (1998)	Aerial photographs	N/A	Ancillary data for digital classification
28	Paterson and Rehder (1985)	Aerial photos	N/A	Four classes (fringing, black, mixed and riverine mangrove)
29	Untawale et. al. (1982)	Aerial photos	N/A	Ten classes (labeled by species or genera)
VEGETATION INDEX				
30	Blasco et. al. (1986)	SPOT	N/A	Two classes (fringing and cleared mangroves)
31	Jensen et. al. (1991)	SPOT XS	N/A	Percentage canopy closure
32	Chaudhary (1990)	Landsat TM	N/A	Two classes (labeled according to dominant species)
BAND RATIONING				
33	Gray et. al. (1990)	Landsat TM	N/A	Three height classes (tall (>10 m), medium (4-10m) and dwarf (,4m) mangroves)
34	Jay et. al. (1991)	Landsat TM	N/A	Mangroves (as separate from the non-mangrove vegetation)
35	Long and Skewes (1994)	Landsat TM	N/A	Mangroves (as separate from the non-mangrove vegetation)
36	Populus and Lantieri (1991)	Landsat TM SPOT XS	N/A	Two classes (high density, mature mangrove and low density, young mangrove)
37	Ranganath et. al. (1989)	Landsat TM	N/A	Mangroves (as separate from the non-mangrove vegetation)

38	Aschbacher et.al. (1995)	SPOT HRV	84.8%	Four mangrove forest classes (homogenous *Rhizophora*, homogenous *Nypa*, mixed dense and mixed open mangrove forest)
		Landsat TM	68.6%	
		MOS – 1 MESSR	52.1% (with last 2 combined)	
		Jers – 1 SAR		
		ERS – SAR	87% (overall accuracy)	
Knowledge based classification / Post classifier for mangrove mapping				
39	Gao et. al.	SPOT	75%	10 classes

Table - 5.3 Approaches to classify remotely sensed data of mangroves

(Source: Compiled from various sources)

Recent times have seen an interest in the mangrove studies world over on the rise. In India, many workers have contributed significantly in the field of remote sensing of mangroves. The major contributors for remote sensing of mangroves in India are Nayak (1982, 1985, 1989, 1992), Bahuguna (1996), Jagtap (1994, 2001), Untawale (1982), Wafar (1988), Blasco and Aizpuru (2002), Krishnamoorty (1996, 2000) and likes. A table on the works carried out on mangroves of India through remote sensing, by different workers, has been given to depict the extensive study so far (Table 5.4).

Apart from individual workers (or group of workers), Space Application Agency (SAC), ISRO, Ahmedabad, Forest Survey of India (FSI), MSSRF are some of the organizations working comprehensively on the efficient data of remote sensing, for the mangroves of the country.

S. No.	Author / Institutions	Year	Area	Data source (Satellite & Sensor)	Approach	Achievement
1	Bahuguna & Nayak	1996	India	IRS 1C LISS III	Unsupervised data	Extraction of coastal information, Zonation of mangroves of the study area
2	Shah et. al.	2005	Marine national Park, Gulf of Kachchh, Gujarat	IRS 1D LISS III	Unsupervised zonation	Zonation of mangroves of the study area
3	Untawale et. al.	1982	Goa	Aerial photogrpahs	Visual & Stereoscopic interpretation	Distribution of mangroves of Goa – 15 species
4	Nayak et. al	1985	Gujarat	Landsat MSS Landsat TM	Visual interpretation	Differentiating the marsh and mangrove vegetation
5	Nayak et. al	1989	Gulf of Kachchh, Gujarat	Landsat MSS Landsat TM	Visual interpretation	Two classes of mangroves based on density
6	Nayak et. al	1989	Gujarat Karnataka	Landsat TM IRS LISS II	Visual interpretation	Two classes of mangroves based on density

S. No.	Author / Institutions	Year	Area	Data source (Satellite & Sensor)	Approach	Achievement
7	Nayak et. al	1992	India	Landsat TM IRS LISS II	Visual interpretation	Two classes of mangroves based on density
8	Krishnamoorthy et. al.	1993	South Andaman islands			(ENVIS)
9	Jagtap et. al.	1994	Maharashtra coast	Aerial photographs Landsat TM	Visual & Stereoscopic interpretation	Mapping environments of mangrove, 17 mangrove species reported
10	Krishnamoorty et. al.	1996	Ennor, Adyar Pichavaram & Muthupet; Tamil Nadu	Landsat MSS Landsat TM IRS LISS II	Visual interpretation	Comparison of various sensors for Classification techniques
11	Krishnamoorty et. al.	1996	Ennor, Adyar Pichavaram & Muthupet	Field data	Field based	Spectral radiance of mangroves
12	Nayak et. al.	1996	Western mangroves	LISS III	Visual interpretation	Two classes on bases of height defined

S. No.	Author / Institutions	Year	Area	Data source (Satellite & Sensor)	Approach	Achievement
13	Nayak	1997	India		Remote sensing	Mangrove distribution over India
14	Krishnamoorty & Ramachandran	2001	Tamilnadu	Aerial photographs Landsat TM IRS LISS II	through various approaches	Overview of mangroves of the region
15	Jagtap et. al.	2001	Central west coast (Maharashtra & Goa)	Landsat TM	Visual interpretation	Mangrove habitat mapping Erosional changes along the coastline
16	Vijaya Kumari et. al.	2001	Guntur, Andhra Pradesh	Landsat MSS IRS 1A LISS – I IRS 1B LISS – II	Supervised classification	Mangrove area estimation, change in the extent of mangroves
17	Nayak & Bahuguna	2001	India	IRS series	Visual interpretation and digital techniques	Usefulness of remote sensing data in density based classification, monitoring and mapping of the coastal habitats, of mangroves of India, mapping spectral characteristics (SCR)
18	Blasco et. al.	2001	Asia	SPOT HRV, RESURS		Studying the change in mangroves (SCR)

S. No.	Author / Institutions	Year	Area	Data source (Satellite & Sensor)	Approach	Achievement
19	Bhattarcharya et. al.	2002	Sunderban	IRS 1C/1D – LISS III IRS 1D PAN	Remote sensing Unsupervised & Supervised classification	Mangrove assemblages in Sunderban
20	Blasco & Aizpuru	2002	Godavari, Ganges, Irrawaddy; Bay of Bengal	SPOT SPOT SPOT & RESURS	Mapping of the mangrove wetlands	Mangrove area, ecological status, mangrove distribution
21	ICMAM, DOD, GoI	2002	Gulf of Khambhat	Landsat TM IRS 1D LISS III	On-screen digitization	Critical habitat information of the study area
22	ICMAM, DOD, GoI	2002	Gulf of Kachchh	Landsat TM IRS 1D LISS III	On-screen digitization	Critical habitat information of the study area
23	Nair	2002	Gulf of Kachchh	IRS IC		
24	Selvam et. al.	2003	Pichavaram,	Landsat TM IRS 1D LISS III	Visual interpretation	Change detection for the mangrove habitat

S. No.	Author / Institutions	Year	Area	Data source (Satellite & Sensor)	Approach	Achievement
25	Shah et. al.	2005	Marine National Park, Gujarat	IRS 1C/1D LISS III	Supervised classification	Zonation of dominant mangrove communities
26	Ramasubramaniam et. al.	2006	Godavari, Andhra Pradesh	i. SOI (1937-38) ii. SOI (1975-76) iii. Landsat TM iv. IRS 1C LISS III v. IRS 1D LISS III	On-screen digitization, visual interpretation	i. Shoreline changes ii. Base data, Shoreline & geomorphological changes iii–v Mangroves mapping & monitoring
27	Upadhyay et. al.	2008	Bhitarkanika, Orissa			Vegetation structure and species distribution patter
28	Bhatt et. al.	2008	Purna estuary, south Gujarat	SOI topographic map IRS 1D LISS III	Visual interpretation Unsupervised zonation	Mapping the changes in the mangrove extent of the study area
29	Bhatt et. al.	2009	Purna estuary, south Gujarat	IRS 1D LISS III	Unsupervised zonation	Diversity of mangroves of the study area

S. No.	Author / Institutions	Year	Area	Data source (Satellite & Sensor)	Approach	Achievement
30	SAC, ISRO		India			Mapping the mangroves throughout the coast of India
31	FSI		India			Mapping the extent of mangroves throughout coastal area of India

Table - 5.4 Major works on mangroves in India

(Source: Compiled from various sources)

CHAPTER 6: DATA USED AND APPROACH

This chapter describes the materials used and the methodology employed for execution of the present work. It mentions the overall processes involved in the generation of data of various nature.

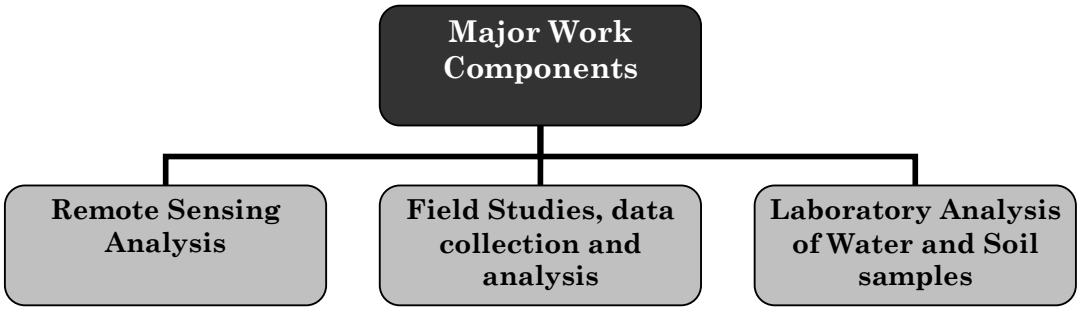
The focus of this thesis is to generate baseline information on the present-day status of mangroves of south Gujarat, while also evaluating their environmental condition on the basis of ground information. The emphasis was to generate such information which can be useful for and by further studies and researchers, giving them an understanding about the diversity and environments of the mangroves of south Gujarat on a whole.

Mangrove ecosystems are difficult to monitor due to their dense understory and the difficult terrain of the wetland complex (Davis and Jensen, 1998; Green et al., 2000; Held et al., 2003). For these reasons, extensive research of mangrove forest ecosystems has often been difficult and thus the biological diversity and the extent of the mangroves are not well known. In addition, the mangrove eco-system is undergoing constant change due to the burgeoning coastal pressures. The species richness of mangroves in many geographical areas is decreasing over time because of the destruction of mangrove forest and exposure to various anthropogenic impacts (Snedaker 1999; Alongi, 2002; Duke et al. 2007). It is important, therefore, to implement accurate, rapid and cost-effective mapping

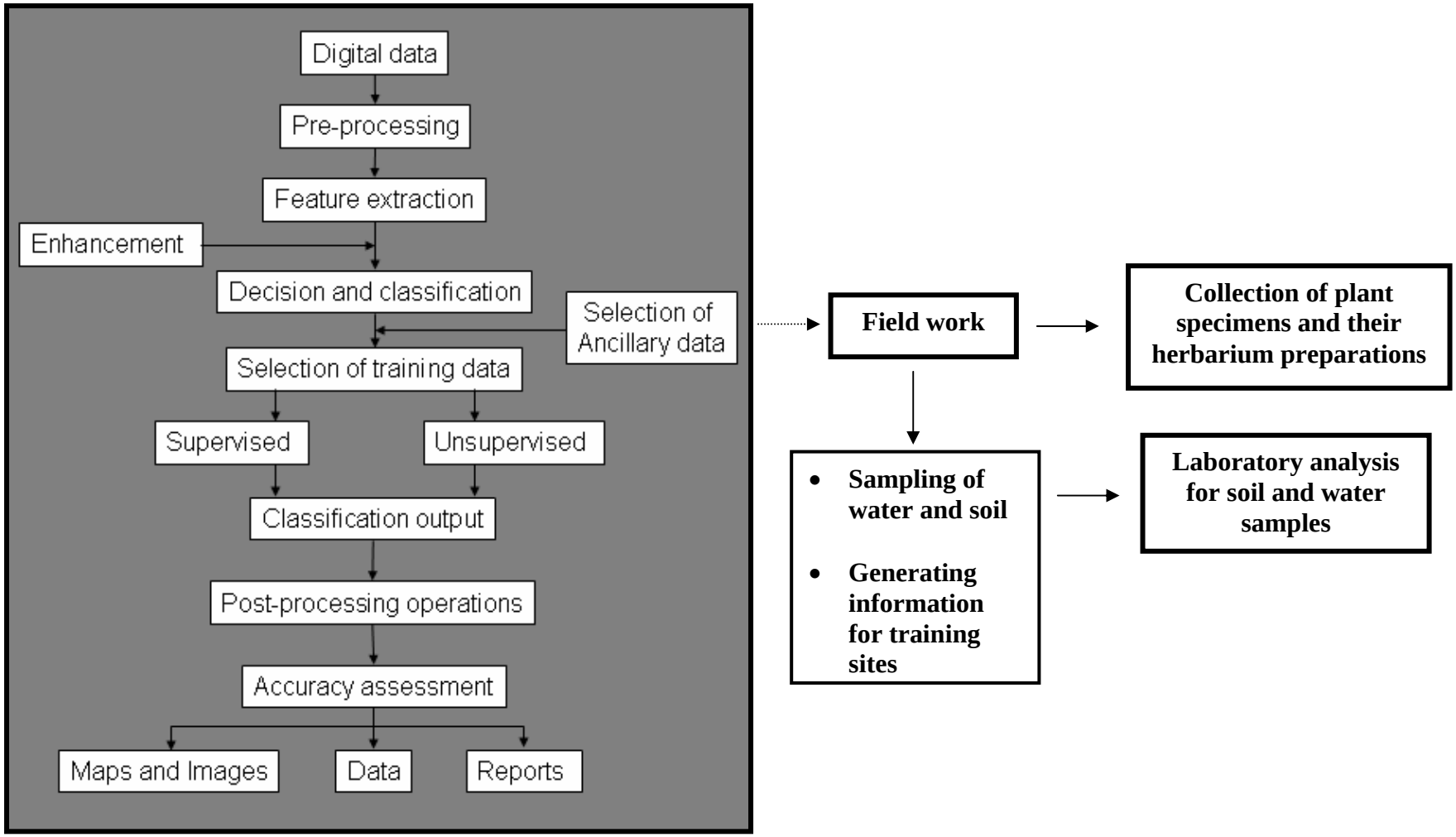
techniques to study mangrove areas effectively. Remote sensing in combination with field survey offers an ideal method to assess the status of mangrove forests and their environment (Green *et al.,* 2000).

The remote sensing technology offers a cost-effective method of extending limited field areas to map large areas of mangroves (Green et al., 2000). Remote sensing data provide a means to extend the knowledge of a small area *(a patch)* to a larger region *(entire wetland)* and, therefore, appears to be well suited to the analysis of mangrove ecosystems (Hardisky et al., 1986). It provides synoptic view and repetitive characteristics for large area (Bahuguna et. al., 1997).

As has been cited in the earlier chapters, information on the coastal wetlands of south Gujarat is inadequate. The methodology was therefore so developed to not only map the mangroves but also to get an insight about the environmental condition of the mangrove ecosystems thriving in this location and that how they have changed over a period of time. The methodology was broadly divided over remote sensing, field studies and lab analysis (Flow chart – 6.1). Detailed work under each was carried out (Flow chart – 6.2).



Flowchart – 6.1 Overall approach employed for the thesis



Flowchart – 6.2 Detailed approach employed for the thesis

6.1 REMOTE SENSING ANALYSIS

Mangrove ecosystems thrive at an interface of land and water, which is to say in a difficult habitat /terrain. Studies employing remote sensing have proved to be very useful in such locations (Davis and Jensen, 1998; Green et al., 2000; Held et al., 2003). Thus, remote sensing approach was used for mapping the mangroves of the study area. The base data used was that of the Survey of India (SOI) topographical map and the recent most available satellite data was used for mapping the current conditions of mangroves. In addition, change detection was carried out to study the density of mangroves then and now and the areal extent of the mangroves was calculated as well (Flow chart – 6.3).

The outputs to be achieved in the present study using remote sensing data are –

1. ***Coastal Wetland Maps,***
2. ***Mangrove wetland maps,***
3. ***Maps depicting change in the study area***
4. ***Coastal geomorphology map***

CRITERIA FOR DATA SELECTION

High tides tend to modify and reduce the signatures reflected from the coastal zone as in the high tide data the signatures of the peripheral features get misrepresented due to the modified reflection. Hence, selection of low tide data is the pre-requisite for mapping mangrove eco-system. In

addition, the cloud cover is a common hindrance for any study on the coastal region. It often significantly reduces the number of images available (Green et. al., 2000). The data selected had to be cloud-free as well so that the mangrove eco-systems could be studied well in the optical system of remote sensing.

6.1.1 DATA USED

Satellite data especially IRS 1A, 1B, Landsat TM (visible and NIR and SWIR bands) has proved to be extremely useful in creating baseline inventory and density wise mapping of mangroves of Indian coast (Bahuguna et. al., 1996; Nayak et. al., 1989, 1991, 1992).

In the present study, data from a large number of sources have been used These include information available from the SOI topographic sheets to satellite data from different satellites and sensors including LANDSAT MSS, LANDSAT TM, LANDSAT ETM and LISS III.

6.1.1.1 Survey of India toposheet (SOI) data

SOI toposheet of the year 1965 was the earliest historical data that was available for the study of the current work. It was hence incorporated as the base map for the studies. SOI toposheets of 1:2,50,000 scale of the study area which were surveyed in the 1880's though available were not incorporated into the study on account of their coarse resolution. As depicted in the Figure 6.1 below the study area falls within the SOI sheet

numbers 46 C/12, 46 C/16, 46 D/9, 46 D/12, 46 D/ 13, 46 D/ 14, 46 D/ 15 and 46 D/ 16.

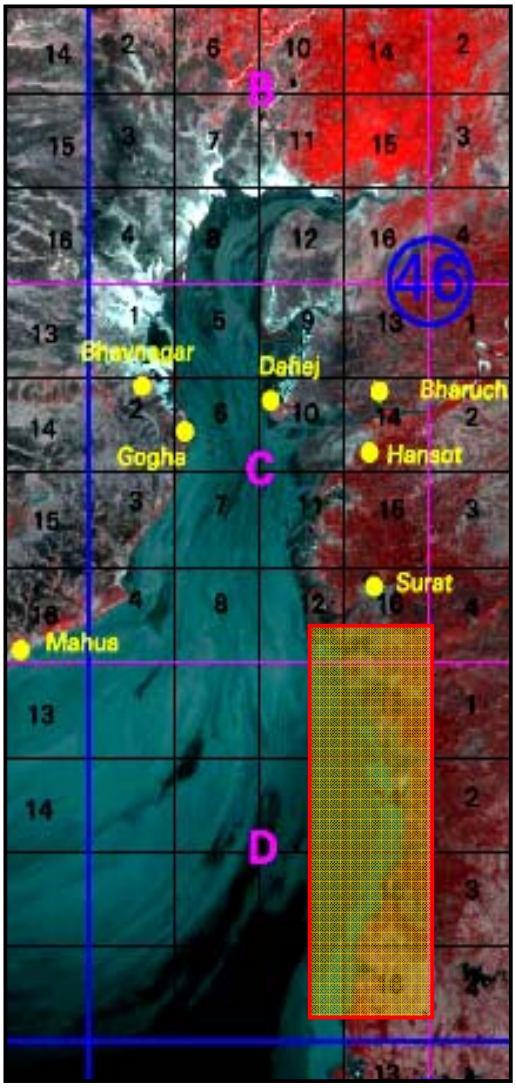


Figure – 6.1 Map depicting the SOI toposheets covering the study area

6.1.1.2 Satellite data

The mangrove environment in South Gujarat is not very extensive like the Sunderban and the Kori Creek area, hence, coarse spatial resolution data would not be useful for the study. Medium to High spatial resolution data would be required for the present study. The current

generation of the IRS satellites which includes IRS ID and RESOURCESAT provide very important and useful data for natural resources monitoring and management. These satellites provide the majority of remotely-sensed digital images for the Indian sub-continent, in use today. The Global Land Cover Facility (GLCF) provides archival LANDSAT data for the whole world. LANDSAT TM, ETM and MSS data of the study area was downloaded form the GLCF website and used for the current study. Data from the Landsat and the IRS series was employed for the present study. Details of all the data used are given in table – 6.1.

Raw satellite data was procured from the National Remote Sensing Centre (NRSC), Hyderabad, on the Compact Disc's (mostly IRS data) and few of the satellite data were taken (free download) from the Global Land Cover Facility (GLCF) website (mostly of the Landsat data series) in form of the digital data.

Software's used

The digital remote sensing data procured can be interpreted by computer programs that manipulate the recorded data in pixels to yield the information about the subjects. This is known as the image processing, which requires a system of specialized computer programs tailored to manipulate the digital image data.

ERDAS IMAGINE version 8.5, software was used for the current studies. This software has proved to be an excellent tool for the digital image processing and analysis of the data generated. The digital data or the raster data was vectorised in the same program and then were analyzed

and worked upon in Geographic Information System (GIS) of ArcView GIS, version 3.2. The analysis of soil samples obtained from the grain size determination was plotted into the Tri Draw software, version 4.5.

Location	Year	Satellite/Sensor
Mindhola	1978	Landsat MSS
	2001	Landsat ETM$^+$
Purna	1978	Landsat MSS
	1988	Landsat MSS
	2005	LISS III
Ambika	1972	Landsat MSS
	2005	LISS III
Auranga	1972	Landsat MSS
	2005	LISS III
Par	1972	Landsat MSS
	2001	Landsat ETM$^+$
	2005	LISS III
Kolak	1972	Landsat MSS
	1999	LISS III
	2001	LISS III
Damanganga – Kalu	1972	Landsat MSS
	1999	LISS III
Varoli	1972	Landsat MSS
	2001	LISS III

Table – 6.1 Details of all the data used for the current work

6.1.2 DATA PROCESSING

THE PRE-CLASSIFICATION PROCESS

The data was transferred from the CD's or other media and were first imported into the computer system into a form recognizable or used by the program / software. This requires the knowledge of the file-structure, organization of the image data, dimensions of image, bands in the image, numbers of bits assigned per each pixel, etc.

The data in the image was either in the generic binary or the GeoTIFF format. The individual bands for each image were imported into the software and then layer stacked to form the multispectral image.

The data obtained from many remote sensing systems' is comprised of different bands, corresponding to different wavelengths (table – 6.2). The requirement and the usage of these bands is study specific. Thermal infrared band is not a requisite for the mangrove studies. It was thus not included for the study. Only the required bands are stacked in the software, called as the layer stacking, and then the output image comprising of the requisite bands was taken up for the study purpose.

Sensor	Spectral Resolution		Spatial Resolution	Swath	Temporal Resolution	Radiometric Resolution
MSS						
G	Band 4	0.5 - 0.6 µm	82 m			
R	Band 5	0.6 - 0.7 µm	82 m			
NIR	Band 6	0.7 - 0.8 µm	82 m	185 km	16 days	6 Bits
SWIR	Band 7	0.8 - 1.1 µm	82 m			
TM						
G	Band 2	0.52 - 0.60 µm	30 m			
R	Band 3	0.63 - 0.69 µm	30 m			
NIR	Band 4	0.76 - 0.90 µm	30 m	185 km	16 days	7 Bits
SWIR	Band 5	1.55 - 1.75 µm	30 m			
ETM+						
G	Band 2	0.52 - 0.60 µm	30 m			
R	Band 3	0.63 - 0.69 µm	30 m			
NIR	Band 4	0.76 - 0.90 µm	30 m	183 km	16 days	8 Bits
SWIR	Band 5	1.55 - 1.75 µm	30 m			
LISS III						
G	Band 2	0.52 – 0.59 µm	23.5 m	141 km	24 days	8 Bits
R	Band 3	0.63 – 0.69 µm	23.5 m			
NIR	Band 4	0.77– 0.85 µm	23.5 m	141 km		
SWIR	Band 5	1.55 – 1.75 µm	70.5 m	148 km		

Table – 6.2 Specifications of different sensors used

6.1.2.1 Geometric Correction/Georeferencing

The raw images procured are not true and accurate representations of the areas they portray (Green et. al., 2000). Raw, remotely sensed image data gathered either by a satellite or an aircraft are representations of the irregular surface of the earth from a far distance. Even images of seemingly flat areas are distorted by both the curvature of the earth and the sensor being used. To rectify these images, Georeferencing process is carried out. Georeferencing refers to the process of assigning map coordinates to the image data.

A satellite image can be rectified using a georeferenced toposheet or another satellite image of the same area. At times, the image data may already be projected onto the desired plane, but not yet referenced to the proper coordinate system. These images need to be georeferenced. Thus, process of geometrically correcting a toposheet or an image is done so that the image can be represented on a planar surface, conform to other images, and have the integrity of a map. Numbers of map coordinate systems are available. These coordinate systems, conform to a grid and are expressed as X and Y (column, row). Each map projection system is associated with a map coordinate system.

For present studies, geometric correction employing reference projection of Geographic Lat/Long and Spheroid and Datum Modified Everest was carried out, using the readings obtained from GPS readings, of the preliminary field survey.

SOI toposheet of the year 1965 was taken as the base map for mapping of the ecological and geomorphological categories. Satellite image for the year 2001 of Landsat ETM$^+$ was taken as the base satellite data to map the coastal wetlands and mangrove communities as well as to study the changes in terms of area, of the recent past. The points chosen on this image were so as they were equally distributed in all parts of the image. Second order of polynomial equation was used with nearest neighborhood resampling method. Rest all images for the years - 1978, 1988, 2003 and 2005; were then subjected to geometric correction as well, on the basis of this corrected imagery of 2001. All the images were always superimposed on the base map to check the geometric error/shift due to the geometric correction, which was found to be within the range of $\pm$1 pixel. Further analysis, of mapping the wetland features, was carried out on these images, using the classification techniques.

Nearest neighbor method was employed for resampling the image in which the digital number of the pixel that is closest to the retransformed coordinates becomes the new value of the pixel in the output image. This is the least computationally intensive method. The nearest neighbor method transfers the original data values without averaging them and it can be performed before classification (Green et. al., 2000).

6.1.3 IMAGE ANALYSIS / CLASSIFICATION STEPS

Image analysis involves the theme or the objective of the work as the pre-requisite, as it forms the basis on which and for which the classification would be carried out.

The broad requirements for analysis of a data are –

1. A *classification scheme,*
2. *Image enhancements techniques,*
3. *Classification techniques*

6.1.3.1 Classification scheme

Classification is usually performed with the objective of the desired output into consideration i.e., set of target classes in mind. Such a set is called a classification scheme (or classification system in general parlance). The purpose of such a scheme is to provide a framework for organizing and categorizing the information that can be extracted from the data (Jensen 1983). The proper classification scheme includes classes that are both important to the study and discernible from the data on hand. A number of classification schemes have been developed by specialists who have inventoried a geographic region (ERDAS IMAGINE, Field Guide, 1999). Keeping in mind the objectives of the present work, the classification system developed by SAC (Nayak et. al., 1992, 2003), Ahmedabad, with necessary modification, has been adapted (Table – 6.3, 6.4) as this classification system deals with the eco-geomorphic classes, merging the habitat classification scheme with the geomorphological landforms formed at the coastal interface. The changes in the classification system were required as there were many mangrove and mangrove associated classes which were located in the study area and not mentioned in the original classification system. The coastal wetland maps were prepared at the III

level of the habitat classification system whereas for mapping the mangrove community zonation III level of classification was used as it classifies the density of the mangroves, along with mapping the non-mangrove or mangrove's associated vegetation and helps in distinguishing the different tidal-flat zones, which are important for diverse species of mangroves. Level IV of the community zonation classification system was selected. Mapping of the geomorphological maps was carried out at Level III.

6.1.3.2 Image enhancement

It is the process of making an image more interpretable for a particular application (Faust, 1989). Enhancement makes important features of raw, remotely sensed data more interpretable to the human eye. Enhancement techniques are often used instead of classification techniques for feature extraction—studying and locating areas and objects on the ground and deriving useful information from images. Several algorithms and techniques are available for image enhancement within the interface itself, such as filtering, princpal component analysis (PCA), tasseled cap, band ratios, histogram equilization, etc.

For the current study, histogram equalization was employed. Histogram equalization is resulted due to the contrast stretch of the data, resulting in increase in contrast in some areas whereas decrease in the others. It is nothing but the re-distribution of pixel values with a nonlinear contrast stretch so that there are approximately the same number of pixels with each value within a range. The result approximates a flat histogram.

Therefore, contrast is increased at the peaks of the histogram and lessened at the tails. Histogram equalization can also separate pixels into distinct groups if there are few output values over a wide range which gives the visual effect of a crude classification.

6.1.3.3 Classification techniques

Classification is the process of sorting pixels into a finite number of individual classes, or categories of data, based on their data file values. If a pixel satisfies a certain set of criteria, the pixel is assigned to the class that corresponds to that criterion (Anon., 1999).

Level I	Level II	Level III	Level IV
Non [Vegetated	Mud/Tidal flat	High Tidal	
		Inter tidal	
		Sub tidal	
	Sand	Sand	
	Coral Reef	Mud Over Reef	
		Sand Over Reef	
Vegetated Wetland	Mangroves	Dense	*Avicennia*
			Rhizophora –Ceriops mixed
		Sparse	*Avicennia*
			Rhizophora –Ceriops mixed
		Transitional	
		Defoliated	
	Marsh Vegetation	Dense	
		Sparse	
	Algae	Dense	
		Sparse	
	Mudflat	Mud with vegetation	
	Coral Reef	Reef Vegetation	
	Sand	Sand Vegetation	
Water Bodies	Estuary		
	Creek		
	Bay		
	Lagoon		
Shore Land	Saline area		
	Terrestrial area		
Other landforms	High water Line		
	Low water Line		
	Salt Pan		

Table – 6.3 Classification system for mangrove habitats

Level I	Level II	Level III	Level IV
Onshore areas	Beach	Muddy Sandy	Fringe tidal mangroves No mangroves
	Estuary	Sandy clay intertidal mudflat	Rhizophora, Sonneratia, Avicennia, Bruguiera (pure/mixed communities)
		Silty clay intertidal mudflat	Avicennia, Rhizophora, Aegiceras, Sonneratia, (pure/mixed communities) Salt marsh vegetation Saline blanks
		Hightidal mudflat	Salt marsh vegetation Saline blanks
		Freshwater zone	Bruguiera, Excoecaria, Heritiera (pur/mixed communities) Fresh water species
		Elevated estuarine area	Grass
	Deltaic complexes	Seaward margins of intertidal mudflats	*Avicennia marina, Avicennia alba, Avicennia officinalis* (pure)
		Intertidal mudflats	Pure communities of Rhizophora, Sonneratia, Avicennia, Bruguiera, etc Mixed mangrove communities Salt marsh vegetation Grass/Acanthus Saline blanks
		Hightidal mudflats	Salt marsh vegetation Saline blanks
		Muddy silt near river mouths	*Sonneratia, Bruguiera, Excoecaria, Heritiera* (pure/mixed communities)
		Recent alluvial soils	Grass
		Transitional areas	Saline blanks Grassy banks Trees/shrubs
	Gulf region	Sandy clay intertidal mudflat	Pure/mixed communities of Rhizophora, Avicennia, Ceriops
		Hightidal mudflats	Salt marsh vegetation Grass/Acanthus Saline blanks

Table - 6.4 Classification system for mangrove community zones

Unsupervised classification

By spatially and spectrally enhancing an image, pattern recognition can be performed with the human eye as the human brain automatically sorts certain textures and colors into categories. However, this discrimination power is limited and variable from person to person. When little is known about the data before classification, Unsupervised Classification technique is employed. Unsupervised training is more of computer-automated technique. It enables to specify some statistical patterns that are inherent in the data, which may not necessarily correspond to directly meaningful characteristics of the scene. These patterns are simply clusters of pixels with similar spectral characteristics. In the end, unsupervised training is dependent upon the data itself for the definition of classes. Thus, this technique is thus usually used to prepare a pre-field map, when little is known about the area, as in case of this area (Campbell, 1996).

A georeference image of the study area was taken. Subset pertaining to a particluar coastal wetland was created, to reduce the processing time, which was then subjected to unsupervised classification. Many permetutaions and combinations of classes and the iterations subjected to the image were tried to get a most informative image for the coastal vegetation. ISODATA ("Iterative Self-Organizing Data Analysis Technique") clustering was used for this. It is iterative in that it repeatedly performs an entire classification (outputting a thematic raster layer) and

recalculates statistics. "Self-Organizing" refers to the way in which it locates the clusters that are inherent in the data.

This clustering method uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster means or means of an existing signature set, and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration.

The output file was a gray color scheme, which was then classified on the basis of clusters and their DN values. The so generated unsupervised classified map was used as a pre-field map, when visiting the location for the first time. In cases where merging of mangrove and non-mangrove classes was observed, GPS readings were taken and then necessary changes were incorporated on the map to resolve the 'confused clustering' or the heterogeneous classes.

After assessing with numerous permutations of classes, a total of 50 classes were finalized for each unsupervised classification, as the data then neither overlapped (by taking lesser classes) nor became repetitive (by taking more classes). The convergence threshold was taken at 0.990 – 0.995, which is the maximum percentage of pixels whose cluster assignments can go unchanged between iterations. This threshold prevents the ISODATA utility from running indefinitely. By specifying a convergence threshold of .95, you would specify that as soon as 95% or more of the pixels stay in the same cluster between one iteration and the next, the utility should stop processing. In other words, as soon as 5% or fewer of the

pixelschange clusters between iterations, the utility will stop processing (Anon., 1999).

Maximum iterations 25 – 30 were selected for the image, which signifies that the ISODATA utility should recluster the data 25 – 30 times. This parameter prevents this utility from running too long, or from potentially getting "stuck" in a cycle without reaching the convergence threshold

The unsupervised classification has limitations in the grouping of natural classes. Clear matches between spectral and informational classes are not always possible (Campbell, 1996). This can be accounted to the merging of the pixels and thus inappropriate classification. It also can be attributed to the spatial resolution of the data in use. However, it was found that this problem can be over-come by use of ancillary data such as obtained from field work. This data helps in generating spectral signatures for a known category on the satellite data, based on the ground information, thus helping in classifying it by assigning the correct category.

Supervised classification

Supervised training is closely controlled by the analyst. Knowledge of the data, and of the classes desired, is essential in this form of classification before proceeding further. This form of classification is thus generally carried out after at least one field visit to the location.

Supervised classification has been the most frequent method by which remotely sensed data of mangrove areas has been classified. Field data or

aerial photographs have been used as training data (Green et. al., 1998). In this technique, the pixels that represent patterns or specific wetland category in this case, which are recognizable and identified on ground, are selected. This selection is often made on the basis of the ground information already available. Upon identifying these categories, we have to instruct the computer system to identify pixels with similar characteristics, the ***training sites***. The result of training is a set of signatures that defines a training sample or cluster. Each signature corresponds to a class which is used with a decision rule to assign the pixels in the image file to a class (Campbell, 1996; Green et. al., 2000).

Maximum Likelihood was used in the current work, which is based on statistical parameters (e.g., mean and covariance matrix) of the pixels that are in the training sample or cluster. The maximum likelihood decision rule is based on the probability that a pixel belongs to a particular class. The basic equation assumes that these probabilities are equal for all classes, and that the input bands have normal distributions.

During many of the field surveys carried out verifying the unsupervised map, data was collected regarding the mangrove species, height and physiognomical condition, etc. These, then became the sites which were used as training sites for supervised classification of the mangrove habitats and communities. Training sites are thus actually set of pixels selected to represent a potential class.

For each category, at least 5 training sites were given (depending upon the proportionate area occupied by that class). These pure signature

classes were then merged according to a single individual class or into their categories. This process of merging the classes of one category into a single class is known as recoding where the user assigns a new class value number to any or all classes of an existing file, creating an output file using the new class numbers.

POST CLASSIFICATION ANALYSIS

Contextual editing

It is the application of common sense to habitat mapping. When thematic maps are created from digital data using image classification, contextual information has to be added as a series of explicit decision rules. To ensure that contextual editing does not create any bias to map accuracy, the decision rules must be applicable throughout an image and not confined to the regions most familiar to the analyst.

Contextual editing can be applied to an image after classification in which case it improves accuracy. For this, the classified map was converted into vector format and selection of misclassified pixels was done to reclassify them into their appropriate classes (Green et. al., 2000). This step proves to be significant as it takes into account the user's knowledge or the secondary information and aides in improving the over-all/users' accuracy for the map.

Accuracy Assessment

Accuracy is the criterion against which the success of an image processing method should be judged no matter how innovative or sophisticated the classification procedure, the value of any map is severely

compromised if its accuracy is insufficient to fulfill project objectives. The lack of accuracy is by no means unique to remote sensing work on mangroves. Rather it appears to be a feature of remote sensing in the wider tropical coastal management context (Green et. al., 1996)

A carefully produced habitat map does not guarantee high accuracy and inaccurate information can mislead decision makers. Hence, for this reason assessing the accuracy of the so generated map is needed. If data have been subjected to multispectral classification then thematic accuracy is also known as classification accuracy (Stehmen, 1997). This accuracy refers to the correspondence between the class label and the 'true' class, which is generally defined as what is observed on the ground during field surveys. In other words, how much of the class labeled as mangroves on a classified image is actually mangrove associate *in situ*.

However, it is usually not practical to ground truth or otherwise test every pixel of a classified image, especially in dense forests or as here, in the mangrove wetlands, due to the difficulties posed by the terrain. Therefore, a set of reference pixels is usually used. Reference pixels are points on the classified image for which actual data are (or will be) known. The reference pixels to be selected should be at random so that the possibility of bias is lessened or eliminated (Congalton, 1991).

Error matrices

An error matrix is a square array of rows and column in which rows and columns represents all the observed categories in the classification. Each cell contains the number of sampling sites assigned to a particular category

(Green et. al., 2000). Conventionally, the columns represent the reference data and the rows indicate the classification generated from the remotely sensed data. The *error matrix* simply compares the reference points to the classified points in a $c \times c$ matrix, where c is the number of classes (including class 0). The accuracy report calculates statistics of the percentages of accuracy, based upon the results of the error matrix (Anon., 1999).

In order to evaluate the classification accuracy, ground checks were made all over the study area while keeping in mind the fact that areas used as training sites were not used during the accuracy estimation. They were carried out during the later part of 2007 and for the year 2008.

Kappa analysis

It is always desirable to have an overall accuracy of the whole image across all the classes. Kappa analysis is discrete multivariate technique used to assess classification accuracy from an error matrix.

The Kappa coefficient expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification. For example, a value of .82 implies that the classification process is avoiding 82 percent of the errors that a completely random classification generates (Congalton 1991).

Kappa Coefficient K=	$\frac{N \sum_{I=1}^{r} X_{ii} - \sum_{I=1}^{r} (X_{i+} \cdot X_{+i})}{N^2 - \sum_{I=1}^{r} (X_{i+} \cdot X_{+i})}$

Area estimation

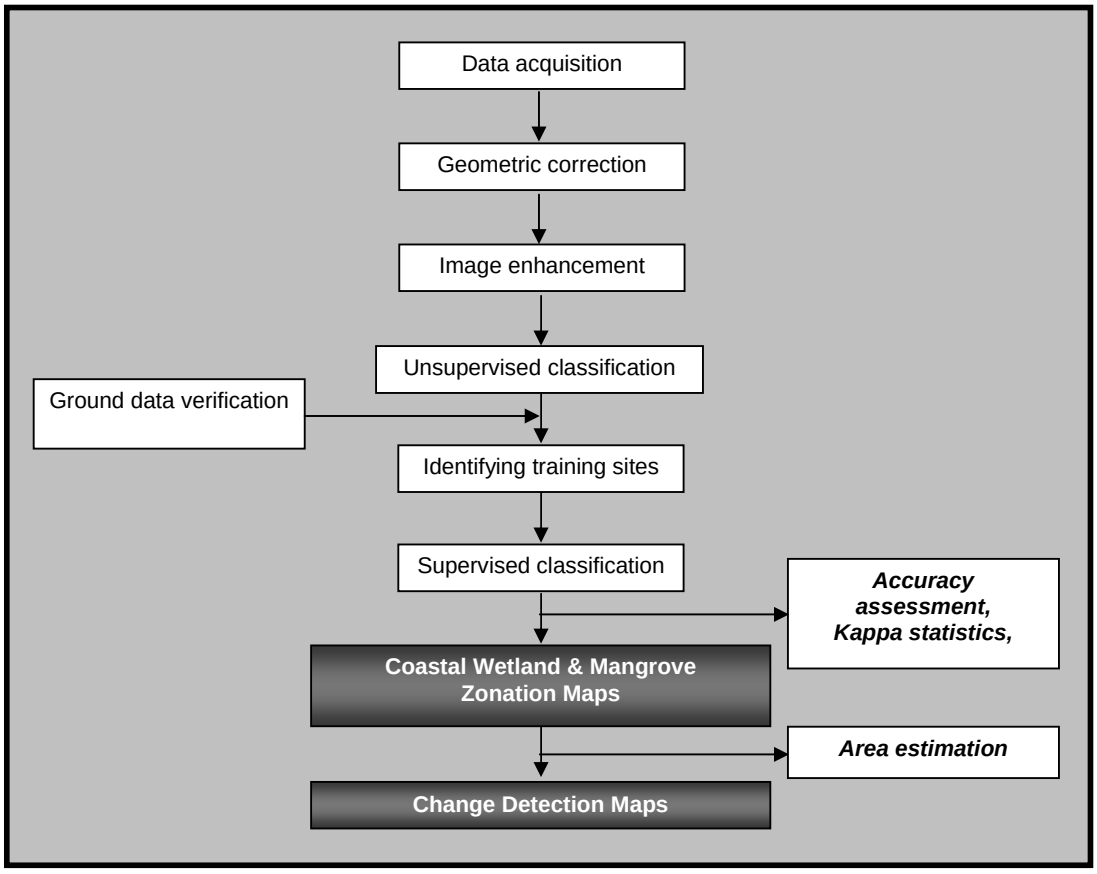
Based on the remote sensing data, mangroves can be accessed in terms of i) extent, ii) density of the community iii) condition iv) diversity in terms of habitat evaluation and identification of pure and homogenous communities (Bahuguna et. al., 1996). After contextual editing, the extent of different classes in the map was extracted,

Change detection

Application of remotely sensed data for coastal zone study has increased during the last two decades; especially in field of change detection analysis (Jayappa et al., 2006). Change detection is the process of identifying differences in the state of an object by observing it at different times (Singh, 1989; Deer, 1995). This practice is important as it gives an insight over the shifts and helps in management practices. Change detection analysis approach can be broadly divided in to either post-classification change methods or pre-classification spectral change detection. Change detection is an important process in monitoring natural resources and urban development, as it provides a quantitative analysis of their spatial distributions. While monitoring natural resources, it is necessary to detect the changes that have occurred, measure its areal

extent and spatial pattern (Singh, 1986). Apart from this, manual handling of data for change detection using sequential imagery is a difficult task. Digital satellite data make it easy amenable for computer-aided analysis (Jayappa et al., 2006). Change detection process computes the differences between two images and highlights the changes that exceed a user-specified threshold.

As different sets of data (SOI toposheets, LANDSAT TM, LANDSAT ETM and IRS LISS III) were used for the current study, the Post-classification change detection study was followed in the current study. The technique described in Shah et. al. (2004) has been followed in the current study. Change detection was employed to study the changes in the extent of mangroves as well as other categories related to mangroves, which suggested radical changes over the period. The earliest and latest available data sets were compared to observe the changes in the mangrove and mangrove associate categories. ArcView GIS 3.2 A was used for this purpose. The shape files generated were finalized in the vector module of ERDAS Imagine for generation of the map.



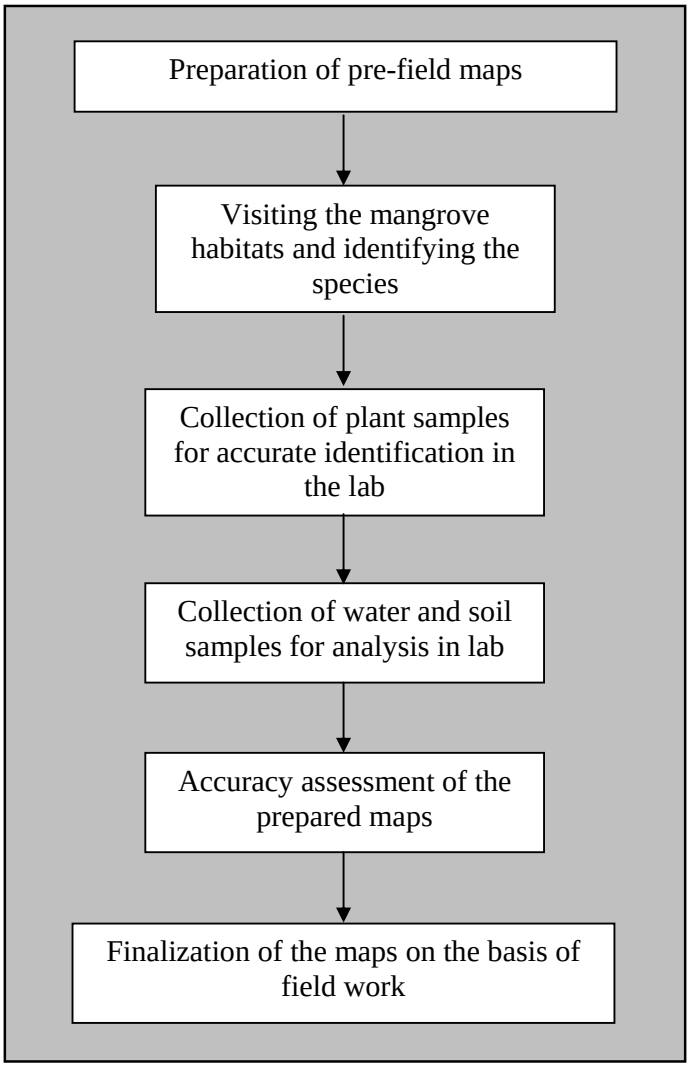
Flowchart – 6.3 Processes involved in remote sensing of mangroves

6.2 FIELD STUDIES

Ground data studies forms a foundation for any environmental study. They give precise information on the status of different environmental parameters under study. Detailed field work is more important for locations where little or no prior information is available.

Almost every remote sensing exercise will require field surveys at some stage. Field surveys should be planned to represent the range of physical environments within a study area. In the present study, ground survey has been carried out with the following aims (Flow chart – 6.4)

- To make an inventory of the mangrove vegetation and associated flora growing in the area,
- To identify large contagious sites which can be used as training sites for image classification.
- To collect soil and water samples for analysis of the environmental parameters, thus generating baseline information.
- To estimate the accuracy of the maps produced.



Flowchart – 6.4 Methodology employed for field work

In addition, training sites of mangrove communities in the area were identified to help classification of the area at habitat and mangrove community levels.

Field surveys were carried through the years 2006-2008 for the pre-monsoon and post-monsoon seasons. As mangrove community zonation was one of the objectives of the study, the basic practice followed during this work was that of carrying out observations along transects perpendicular to the coast or across the islands, whichever the case (or random stratified to ensure that all categories are adequately represented by field data, a stratified random sampling strategy was adopted (Congalton, 1991). The unsupervised classified map and a map of depicting the major physical features of the environments were used for the stratified sampling effort. A similar number of sites were obtained in each area.

The unsupervised maps generated, of each area, were used as the base maps to carry out the field surveys. On field information regarding the mangrove species, the mangrove associated vegetation, height of different species and their physiognomy was collected.

Global Positioning Systems (GPS)

For field work, a Global Positioning System (GPS) is an essential piece of equipment to estimate the surveyor's location on the Earth's surface. In the context of the present investigation, a GPS has the following two major applications:

1. To measure the position of prominent features on an image in situ which can be used to provide ground control points for geometric correction
2. To assign positions to field data. These field data can then be correlated with spectral information at the same point on a geometrically corrected image. Conversely, a group of image pixels of particular interest can be surveyed in the field by using a GPS to navigate to that location.

A hand held Magellan Explorist 220 was used for the current work, which gave an accuracy of $\pm$ 10 mtrs.

Training Sites

The pre-field maps prepared by the unsupervised classification method shows a number of mixed classes, wherein there is misclassification as well as merging of two discrete classes. The information obtained from the ground survey during the tenure of work was incorporated and used to identify training sites for mangrove community zonation.

For this, mangrove patches covering large areas were selected so as to avoid mixed patches and to find the 'pure pixels' patches which could be identified on the remote sensing images. Field data collected during the survey included identification of the mangrove community, species composition, vegetation height, etc.

Collection of Plant specimens:

All the possible islands and locations were surveyed so as to get a detailed view of the mangrove patches. Mangrove specimens from field visits were collected and pressed to make herbarium specimens. The

specimens that were collected were then compared with various floras and confirmed when in doubt by authorities. This exercise gave a list of species present in the study area.

Soil and Water Sampling:

A general protocol was followed to store all the soil samples before analyzing them in the laboratory, as analyzing them in the field was difficult due to the obvious conditions of the ecosystem.

Protocol for the collection of the soil sample

- The soil was dug up to 12 - 15 inches and then the sample was collected.
- Same sample was employed for collecting the samples for studying the pH, salinity, EC and grain size
- The collected soil samples were tagged in the field with appropriate labels and locations and then were transferred to lab

Protocol for the collection of the water sample

The sampling strategy was to study seasonal and spatial variability in a number of parameters. Accordingly, systematic sampling was carried out in the entire mangrove environment during April 2007 (pre-monsoon), November 2007 (post monsoon) and November 2008 (post monsoon), to better understand the various processes operating in this regions' mangrove ecosystem.

- Samples of water were collected in polyethylene bottles at the surface from the middle of channels and creeks.
- pH, salinity, conductivity and Total Dissolved Solids (TDS) were measured on the very evening of sample collection so as to have near real-time observations.
- This was achieved with the help of a portable soil kit 'Microprocessor Water and Soil Analysis kit 1160' which measures pH, Conductivity, TDS, Salinity & Temperature and is mains cum battery operated.
- The Temperature of the water was measured using field thermometer directly in ^{0}C.

6.3 LABORATORY ANALYSIS

Environmental factors, including temperature, salinity and rainfall are important key determinants that have a strong influence over the growth, survival and distribution of mangroves (Blasco, 1984). This is mainly because mangroves are tightly bound to the coastal environments in which they thrive.

Soil and water characteristics are one of the most important environmental factors directly affecting mangrove productivity and structure. The major chemical and physical properties of the mangrove soils are pH (hydrogen ion concentration), Eh (Redox, potential), salinity and particle size (Kathiresan, 2010). A laboratory study using standard operating procedures was carried out for studying the grain size particles

and the pH, Eh and salinity of the soil. Water sample were also analyzed for the pH, salinity concentrations and temperature of the river channels and creeks in the mangrove ecosystem.

Mangroves of south Gujarat are flushed by perennial and seasonal rivers and abundant monsoon waters as compared to the other parts of Gujarat (Gulf of Kachchh and the western mangroves), which sustains on the seasonal rivers and more than often meager monsoon showers. As a result, a difference in environmental conditions and therefore species diversity was expected in the mangrove areas of south Gujarat and other parts of Gujarat. In addition, there is an observed gradation (change) in the various physico-chemical parameters of the soil and water samples when one moves away from the coast to the main-land. This affects the diversity of mangrove species resulting in *zonation of mangroves.*

To demonstrate this, soil and water sample analysis was carried out for the study area. Moreover, the data of soil and water samples, or to say the environmental parameters, was unavailable as no such work in the past has been carried out for the same. So considering the need of the hour, and to corroborate the work further, physico-chemical analysis for the soil and water samples of the study area was carried out in the present work.

Instruments used

Portable water and soil kit instrument 'Microprocessor Water and Soil Analysis kit 1160' was used for used for measuring the salinity, pH, EC and turbidity. Hand held refractometer was also used for monitoring the

salinity. Thermometer was used for measuring the temperature of the mangrove waters.

Protocol for Soil Sample Analysis

Soil properties have a major impact on mangrove nutrition and growth (Kusmana, 1990; V.B. Rao *et al.*, 1992; Pezeshki *et al.*, 1997).

- After the collection of soil samples from field, the soil was brought to lab and was air dried
- The dried samples were then mixed thoroughly by the coning and quartering method and then sampling size taken and analyzed for the respective parameters. This exercise was done carried out following the methodology given by K. Kathiresan (Kathiresan, 2010)

For the pH, Eh and salinity a portable soil kit 'Microprocessor Water and Soil Analysis kit 1160' was used (Figure 6.2). The buffer solutions for all required tests to be carried were prepared fresh. Grain size analysis was carried out following the methodology of Folk (Folk, 1974).

Figure – 6.2 Portable soil and water analysis kit

pH

pH is a measure of the acidity or alkalinity of a solution. pH can be measured with Universal Indicator, litmus paper or the data logger. pH measurements are made on a scale from 0 (very acidic) to 14 (very alkaline), 7 is neutral.

The acidity of the soil influences the chemical transformation of most nutrients and their availability to plants. Most mangrove soils are well buffered, having a pH in the range of 6 to 7, but some have a pH as low as 5. Measurement of the acidity or alkalinity of soils using pH must be done with fresh samples to avoid oxidation of iron pyrites (a common constituent

of mangrove soils) to sulphuric acid, thus giving a much lower value of pH than normally occurring *in situ* (Kathiresan, 2010)

The methodology given by Jackson (1967) was followed in which soil to water ratio of 1:2.5 was taken. 20 g of soil samples were taken in 100 mL beaker to which 50 mL of distilled water was added. The suspension was stirred at regular intervals for up-to 30 minutes and pH was later on recorded. The suspension was stirred well also before immersing the pH electrode.

Salinity

Salinity is the total of all the salts dissolved in water. Salinity is measured in parts per thousand or at times in parts per millions (ppt or ppm). Salinity in the field can be measured with a hand refractometer. The salinity of ocean water is 35 ppt whereas the salinity within the estuary where the river meets the sea can range from 0 to 35 ppt depending on the input of freshwater into the system and mixing of sea water due to tidal influence. Salinity greatly influences the distribution of plants and animals depending upon the amount of salinity they can tolerate.

Soil salinity is the amount of salt contained in the soil. Soil salinity within the mangroves/saltmarsh environment is influenced by the frequency of inundation by tides and frequency of flooding with brackish waters after periods of heavy rain. The soil salinity in the field can be measured using the hand held refractrometer. When recording soil salinity, note should also be made of the frequency of tidal influence on the location.

Same methodology for salinity was followed as for the measuring the pH of the samples.

Electrical conductivity (EC)

Since ions are the carrier of electricity, the electrical conductivity (EC) of the soil water system rises according to the content of soluble salts. The measurement of EC can be directly related to the soluble salts concentration of soil at any particular temperature (Jackson, 1967).

Grain size

All soils and sediment (unconsolidated or 'loose' deposits) are composed of particles with a wide range of sizes. These are generally divided into 3 major groups: gravel (greater than 2 millimetres), sand (0.062 to 2 millimetres) and mud (silt and clay). The mud fraction is further divided into coarse silt (62 to 15.6 µm), fine silt (15.6 to 3.9µm) and clay (less than 3.9 µm). A graded scheme for soils is given by the Wentworth Grade Scale (Folk, 1974). The species composition and growth of mangroves is directly affected by the physical composition of mangrove soils. The proportions of clay, silt and sand, together with the grain size, dictate the permeability (or hydraulic conductivity) of the soil to water, which influences soil salinity and water content. Nutrient status is also affected by the physical composition of the soil with clay soils, which are generally higher in nutrients than sandy soils (English *et al*., 1997).

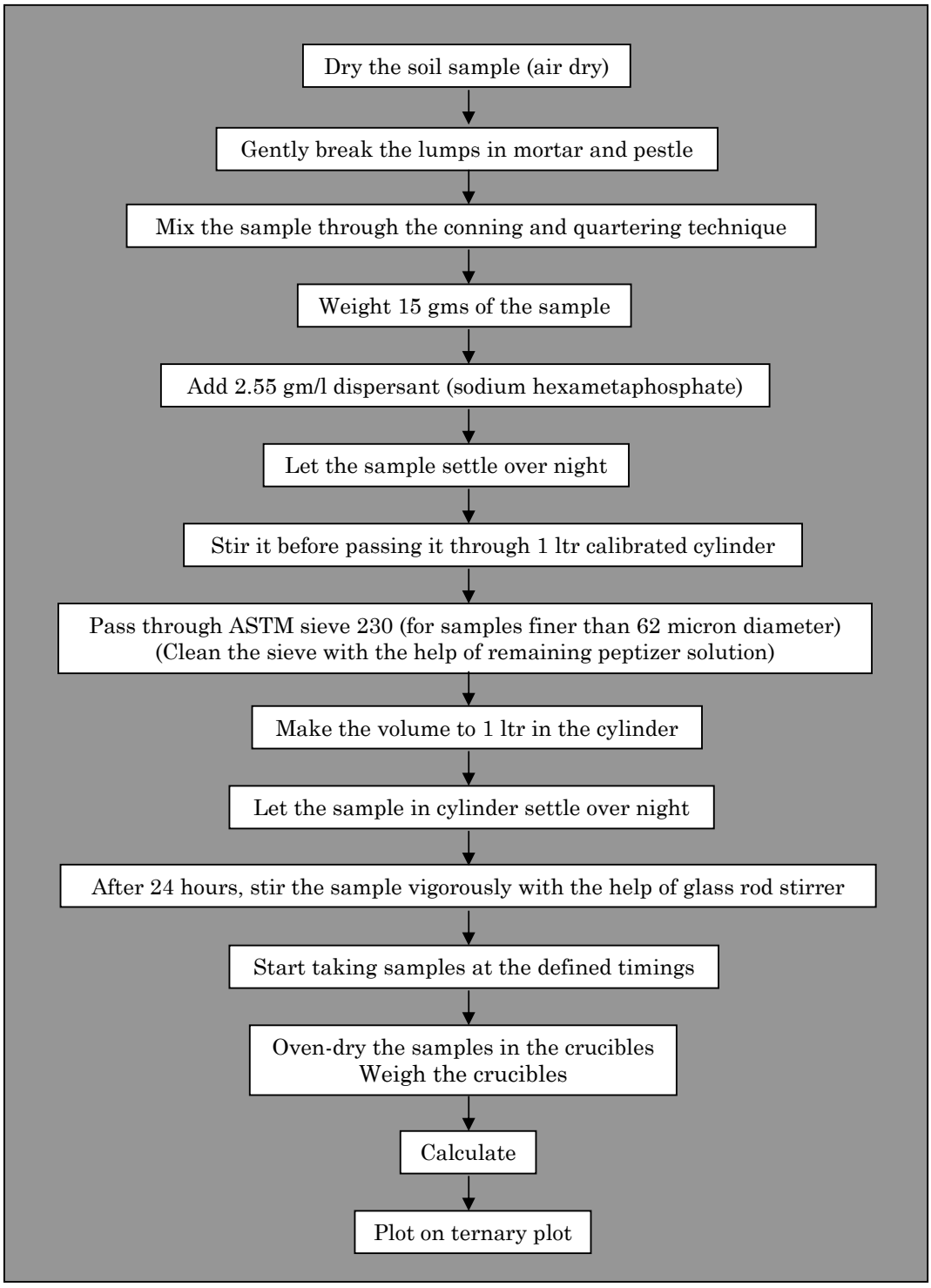
There are several methods of analysis of silts and clays (finer than 4ø or 62 microns diameter) in common use. The finer particles can be studied by two different approaches, through a 'hydrometer method' and through 'pipette method'. The most common method is by pipette. Hydrometer and decantation methods are more difficult and less accurate. For the present study, analysis of soil samples by the pipette method was in implemented following the methodology given by Folk (1974) (Flowchart – 6.5).

- Dry the soil sample (air dry)
- Gently break the lumps in mortar with rubber base pestle
- Mix the sample properly with conning-quartering technique
- Weigh 15 gms of this sample for carrying out the analysis
- Add 2.55gm/litre of sodium hexametaphosphate dispersant
- Wear a rubber glove and muddle the sample until even the tiniest lumps are crushed
- Stir the sample vigorously and let it stand overnight
- Transfer this sample to the cylinder after 24 hours, ensuring no sample is lost (wash repeatedly with the remaining dispersant solution)
- This sample has to pass through a 230 ASTM sieve to remove all the particles bigger then 62 microns
- Make up the volume in the cylinder up to 1 liter with the help of remaining dispersant
- Stir the cylinder vigorously; starting at the bottom and working up until all the material, (even the coarsest) is distributed uniformly throughout the column

- End up with long, smooth strokes the full length of the column, from the very bottom until the rod breaks surface
- As soon as the stirring rod emerges for the last time, start the time.
- At the end of 20 seconds, insert the pipette to a depth of 20 cm and withdraw exactly 20 ml (most important single step, as on it the subsequent analyses are based, so sample should be as close to 20.0 ml as possibly can)
- Expel the suspension into a weighed 50 ml. beaker, suck up 20 ml of distilled water to rinse out the pipette, and expel the rinse water into the same beaker
- Continue withdrawals at the specified time intervals.
- Do not stir the suspension at any time after the first stirring
- Prepare a data sheet giving diameters, depths and times of withdrawal listed on it.
- Place the beakers in an over with cover glass on top, and evaporate them to dryness (they should be dried at least 24 hours at 100-130° C).
- Remove them from the oven and let them cool to room temperature.
- Let them remain open in the room where weighing is to take place for several hours, until they come to equilibrium with the moisture content of the atmosphere
- Weigh them to 0.001 gm. on a chemical balance; if possible weigh all beakers at nearly the same time.
- Tabulate the data. Subtract the weight of the cleaned, air-dried beaker from the weight of the beaker plus sample.

- Calculate the weight of dispersant in the entire liter of water (computed by using molecular weight and normality), and divide this value by 50. This gives the weight of dispersant in each of the small beakers. This weight must be subtracted from the weight of the sample.

The principle behind the computation is this: if the fine sediment is uniformly distributed throughout the entire 1000 ml. column by stirring, and drawing off exactly 20 ml. at stated times, then the amount of mud in each withdrawal in equal to 1/50 of the total amount of mud remaining suspended in the column at that given time and at that given depth (*i.e.*, the amount of mud finer than the given diameter; all particles coarser than the given diameter will have settled past the point of withdrawal). The first withdrawal is made so quickly after stirring (20 seconds) and at such a depth that particles of all sizes are present in suspension; therefore if we multiply the weight of this first withdrawal by 50 (after subtracting dispersant weight), we will obtain the weight of the entire amount of mud in the cylinder. Then if we withdraw a sample at a settling time corresponding to a diameter of 6ø, and multiply it by 50, then we know that the product represents the number of grams of mud still in suspension at this new time, therefore the grams of mud finer than 6ø.



Flowchart – 6.5 Methodology for soil sample size analysis

Water samples

For pH, salinity, conductivity and Total Dissolved Solids (TDS) as well same methodology was employed. The samples were collected into water sample bottles in the field, from the river channels and creeks, and they were analyzed upon reaching back to the posting place for the particular day.

Temperature

Temperature is an important limiting factor in determining the distribution of plant. Temperature can be measured with the thermometer or the data logger. Temperature has a significant affect upon water quality. Temperature influences the amount of dissolved oxygen in water, the rate of photosynthesis by plants, and the sensitivity of living things to toxic wastes and diseases.

CHAPTER 7: RESULTS AND DISCUSSION

At the intersection of land and sea, mangrove forests support a wealth of life, from the smallest molluscans to people, and may be more important to the health of the planet than we ever realize.

The present study was carried out to study the mangrove wetlands of south Gujarat region and to understand how various environmental parameters affect therein. Mangrove diversity was studied, enlisting each species estuary wise. Habitat maps were prepared for all the estuaries. These maps indicate the extent of the mangrove and the mangrove associates present in all the estuaries. Community zonation maps for mangroves of all the estuaries were prepared. The idea here was to map the dominant mangrove communities of the study area. Geomorphological maps of the study area were prepared to observe the changes that have occurred over the span of about 40 years. This exercise was important as mangrove ecosystems are believed to augment sedimentary accretion processes, thus at times bringing out change in the estuarine setups. Laboratory analysis of soil and water samples was conducted for understanding various physico-chemical aspects of the samples.

From all these efforts, a comprehensive output on the environment of the mangrove wetlands of south Gujarat has been generated. This work will stand important any day, as it is first of its kind for south Gujarat as well

mangroves of Gujarat, in terms of the analysis of physico-chemical parameters.

7.1 Diversity of the mangrove wetlands of south Gujarat

Mangrove diversity of south Gujarat is not restricted to very few species as had been described earlier. Mangrove species thrive in specific ecological conditions, which are the deciding factors for the growth and diversity of mangroves. Diversity of mangroves thus can be an indicator of the conditions of that environmental condition of the area. Greater diversity of mangroves is thus an intimation of the favorable and conducive ecological conditions of the region.

The study of the mangroves of south Gujarat brought out a whole new perspective to the mangrove diversity of Gujarat. The species which were never reported from this part of the state were reported for the first time. New occurrences for the state have also been discovered as the species that were believed to be extinct from the state have also been reported from the study area. So all in all the study of mangroves of south Gujarat has been a worthwhile exercise.

The diversity study is based on the field surveys taken over the entire study during the duration of the work done. The estuarine areas and the islands were traversed to and fro randomly, making an inventory of the species inhabiting them.

The studies were predominantly made for the mangrove species and the mangrove associates. Mangrove associates are the plants that grow in

the same habitat as that of the mangroves, but which lack one or more of the key deciding features which sets mangroves apart from the rest of the vegetation. Mangrove associates may include the salt marsh vegetation and (or) the grasses that grow over the mudflats. The list of the mangrove species and the associated species encountered during the study is given in table – 7.1 and table – 7.2

Sr. No.	Mangrove species
	Family: Avicenniaceae
1.	*Avicennia marina* (Forsk.) Vierh.
2.	*Avicennia officinalis* L.
	Family: Sonneratiaceae
3.	*Sonneratia apetala* Buch. Ham.
	Family: Rhizophoraceae
4.	*Ceriops tagal* (Perr.) C.B. Roinson
5.	*Rhizophora mucronata* Lam.
6.	*Bruguiera cylindrica* (L.) Bl.
	Family: Myrsinaceae
7.	*Aegiceras corniculatum* (L.) Blanco
	Family: Acanthaceae
8.	*Acanthus ilicifolius* L.
	Family: Combretaceae
9.	*Lumnitzera racemosa* Willd.
	Family: Euphorbiaceae
10.	*Excoecaria agallocha* L.

Table – 7.1 Overall mangrove diversity of south Gujarat

The different geomorphological settings and the varied environmental conditions leads to the occurrence of mangrove species being diverse over the different estuaries. Some species were found growing predominantly across few estuaries whereas some were found to be restricted to one of the estuaries. The different species observed and their occurrence has been described estuary wise.

Sr. no.	Genus
1.	*Aleuropes lagopoides* (L.) Trin. ex Thw.
2.	*Arthrocnemum indicum* (Willd.) Moq.
3.	*Caesalpinia crista* L.
4.	*Canavalia gladiata* (Jacq.) DC
5.	*Clerodendron inerme* (L.) Gaertn.
6.	*Cressa cretica* L.
7.	*Derris trifoliata* Lour.
8.	*Ipomoea biloba* Forsk.
9.	*Porteresia coarctata* (Roxb.) Tateoka
10.	*Salicornia brachiata* Roxb.
11.	*Salvadora persica* L. dam
12.	*Sesuvium portulacastrum* (L.) L.
13.	*Suaeda fruticosa* Forsk.
14.	*Suaeda nudiflora* (Willd.) Moq.
15.	*Thespesia populnea* (L.) Sol. ex Corr.
16.	*Polygonum sps.*
17.	*Solanum xanthocarpum* (sand)
18.	*Xanthium strumarium* (sand)
19.	*Cuscuta* sps. L. (sand)
20.	*Prosopis juliflora* (Sw.) DC. (sand)
21.	*Hygrophila auriculata* (Schumach.) Heine (water logged)

Table – 7.2 Overall mangrove associates' diversity of south Gujarat

Mangrove diversity of coastal wetland of Mindhola estuary

Avicennia marina is the dominant species found in the Mindhola estuary. It occurs in patches throughout the intertidal mudflats. *Acanthus ilicifolius* is also present in abundance particularly at the drier parts of the mudflats. *Sonneratia apetala* was encountered at few patches especially adjacent to the creeks.

Amongst the mangrove associates, *Derris trifoliata* was found in abundance at one location of the estuary. *Cyperus* sps were found at the higher mudflats. The diversity of mangrove associates has been listed in table – 7.3.

Sr. No.	Mangrove and mangrove associates
1	*Avicennia marina*
2	*Sonneratia apetala*
3	*Acanthus ilicifolius*
4	*Aleuropes lagopoides*
5	*Clerodendron inerme*
6	*Cressa cretica*
7	*Derris trifoliata*
8	*Porteresia coarctata*
9	*Salicornia brachiata*
10	*Salvadora persica*
11	*Sesuvium portulacastrum*
12	*Suaeda fruticosa*
13	*Suaeda nudiflora*

Table – 7.3 Wetland biodiversity of Mindhola estuary

Mangrove diversity of coastal wetland of Purna estuary

This estuary represents myriad patches of mangroves varying in the diversity. It is one of the most diverse mangrove areas in the entire south Gujarat coastal stretch. *Avicennia marina* is the common species found

occurring abundantly over the mudflats, along the creeks and over the islands of the estuary. Partial co-dominance is exhibited by *Sonneratia apetala*, which is found mostly along the creeks and at times strewn across the mudflats. *Acanthus ilicifolius* can be listed next in the order of occurrence. It occurs over the drier mudflats, where other mangrove species are not inhabitant. The species which were not reported to occur in this part of the area were also seen in this estuary – *Rhizophora mucronata* and *Ceriops tagal*. There occurrence is sparse but they can be encountered frequently over the estuarine setup. First ever report of *Bruguiera cylindrica* was also observed from this estuary, after it being reported extinct by many authors.

The estuarine area being large, mangrove associates were also observed here in abundance. *Clerodendron inerme* was mostly found along the creeklets and hardly ever the tidal-flats' expanse. *Salvadora persica* was usually found over the drier parts of the mudflats, where there used to be open mangroves or at times no mangroves present at all. *Aleuropes lagopoides* dominated the mudflats where there was little disturbance. Patches of *Derris trifoliata* were observed all over this area, at times climbing over the *Sonneratia apetala*. *Suaeda fruticosa, Suaeda nudiflora*, *Sesuvium portulacustrum*, *Salicornia brachiata*, *Arthrocnemum indicum* and *Cressa cretica* are the common salt marsh vegetation occupying the drier intertidal and hightidal mudflats. *Porteresia coarctata* was observed along the fringes of the islands. Mangrove and mangrove associate vegetation of Purna estuary has been listed in table – 7.4.

Sr. No.	Mangrove and mangrove associates
1	*Avicennia marina*
2	*Sonneratia apetala*
3	*Ceriops tagal*
4	*Rhizophora mucronata*
5	*Bruguiera cylindrica.*
6	*Acanthus ilicifolius*
7	*Aleuropes lagopoides*
8	*Arthrocnemum indicum*
9	*Caesalpinia crista*
10	*Canavalia gladiata*
11	*Clerodendron inerme*
12	*Cressa cretica*
13	*Derris trifoliata*
14	*Hygrophila spinosa*
15	*Ipomoea biloba*
16	*Polygonum sps.*
17	*Porteresia coarctata*
18	*Prosopis sps.* (sand)
19	*Salicornia brachiata*
20	*Salvadora persica*
21	*Sesuvium portulacastrum*
22	*Suaeda fruticosa*
23	*Suaeda nudiflora*
24	*Thespesia populnea*

Table – 7.4 Wetland biodiversity of Purna estuary

Mangrove diversity of coastal wetland of Ambika estuary

Six species of mangroves have been observed in this estuary. *Avicennia marina* dominates along the intertidal mudflats and occurs along the creeks and the fringes. *Acanthus ilicifolius* is the co-dominant species of the area occurring over the intertidal and the hightidal mudflats. *Sonneratia apetala* was observed along the creeks and many times towards the centre of the islands. It is also seen scattered along the mudflats. *Bruguiera cylindrica* was observed generally growing behind the *Avicennia*

marina fringes. Few *Rhizophora mucronata* and *Ceriops tagal* were encountered along the study area of this estuary.

Salvadora persica was observed along the open mangrove patches. *Derris trifoliata* occurs in this estuary as well. *Suaeda fruticosa, Suaeda nudiflora, Sesuvium portulacustrum* and *Porteresia coarctata* have been observed here as well. The sandy beaches harbors species like *Ipomoea biloba, Xanthium strumarium, Solanum xanthocarpum, Prosopis juliflora* and *Cuscuta*; twinning over *Prosopis juliflora*. Table 7.5 enlists the biodiversity of coastal wetland of Ambika.

Sr. No.	Mangrove and mangrove associates
1	*Avicennia marina*
2	*Sonneratia apetala.*
3	*Ceriops tagal*
4	*Rhizophora mucronata*
5	*Bruguiera cylindrica.*
6	*Acanthus ilicifolius*
7	*Aleuropes lagopoides*
8	*Arthrocnemum indicum*
9	*Clerodendron inerme*
10	*Cuscuta* sps. (sand)
11	*Derris trifoliata*
12	*Ipomoea biloba*
13	*Porteresia coarctata*
14	*Prosopis juliflora* (sand)
15	*Salvadora persica*
16	*Sesuvium portulacastrum*
17	*Solanum xanthocarpum* (sand)
18	*Suaeda fruticosa*
19	*Suaeda nudiflora*
20	*Xanthium strumarium* (sand)

Table – 7.5 Wetland biodiversity of Ambika estuary

Mangrove diversity of coastal wetland of Auranga estuary

Only two mangrove species were observed here. Auranga estuary is dominated by *Avicennia marina*. *Acanthus ilicifolius* is frequently encountered as well, but it never forms a pure stand.

The common mangrove associates includes *Salvadora persica*, *Derris trifoliata, Suaeda sps., Sesuvium portulacustrum, Aleuropes lagopoides*. *Capparis* sps was observed growing on the high tidal flats of the island present. Table 7.6 represents the coastal wetland's vegetation biodiversity.

Sr. No.	Mangrove and mangrove associates
1	*Avicennia marina*
2	*Acanthus ilicifolius*
3	*Aleuropes lagopoides*
4	*Clerodendron inerme*
5	*Porteresia coarctata*
6	*Salvadora persica*
7	*Sesuvium portulacastrum*
8	*Suaeda fruticosa*
9	*Suaeda nudiflora*

Table – 7.6 Wetland biodiversity of Auranga estuary

Mangrove diversity of coastal wetland of Par estuary

The estuarine set-up is very small here as compared to the estuaries north to it, hence there is little place available for the mangroves to thrive. *Avicennia marina* forms the dominant mangroves species harboring the wetlands and the islands of Par estuary. *Acanthus ilicifolius* is found to grow in patches along the wetland. One of the patches shows co-dominance with *Acanthus ilicifolius* being interspersed with *Avicennia marina*.

Suaeda sps., Sesuvium portulacustrum, Aleuropes lagopoides and *Porteresia coarctata* are the common associates observed in Par estuary (table 7.7).

Sr. No.	Mangrove and mangrove associates
1	*Avicennia marina*
2	*Acanthus ilicifolius*
3	*Aleuropes lagopoides*
4	*Porteresia coarctata*
5	*Prosopis sps.* (sand)
6	*Sesuvium portulacastrum*
7	*Suaeda fruticosa*
8	*Suaeda nudiflora*

Table – 7.7 Wetland biodiversity of Par estuary

Mangrove diversity of coastal wetland of Kolak estuary

It was in Kolak estuary that the *Aegiceras corniculatum* was observed for the first time along this study course. As in rest of the estuaries, *Avicennia marina* was dominant in Kolak estuary as well. *Sonneratia apetala* was also found to be growing along in this estuary. *Acanthus ilicifolius* showed a strange pattern of growing only when and where there were open patches, which allowed the sunlight to penetrate through the dense canopy of *Avicennia marina* and *Sonneratia apetala*. *Ceriops tagal* was spotted at a single location along the entire survey.

Porteresia coarctata was found to be growing along the fringes. *Suaeda sps., Sesuvium portulacustrum, Aleuropes lagopoides* were the common associates observed along the estuary of Kolak. The mangroves and mangrove associates of Kolak estuary have been enlisted in table – 7.8.

Sr. No.	Mangrove and mangrove associates
1	*Avicennia marina*
2	*Sonneratia apetala*
3	*Aegiceras corniculatum*
4	*Acanthus ilicifolius*
5	*Aleuropes lagopoides*.
6	*Sesuvium portulacastrum*
7	*Suaeda fruticosa*
8	*Suaeda nudiflora*

Table – 7.8 Wetland biodiversity of Kolak estuary

Mangrove diversity of coastal wetland of Damanganga estuary

The diversity of Damanganga is no different then Kolak river in terms of number of mangrove species, except that the *Ceriops tagal* of Kolak has been replaced by *Avicennia officinalis* in the Damanganga region. The dominance of *Avicennia marina* can be seen through the scattered mangrove patches. *Sonneratia apetala* makes an appearance at only one of the patches. At places, *Aegiceras corniculatum* can be seen growing along with *Avicennia marina*.

The commonest salt marsh vegetation is that of *Aleuropes lagopoides, Porteresia coarctata* and *Suaeda sps*. The mangrove and mangrove associates observed at Damanganga estuary have been listed in table – 7.9.

Mangrove diversity of coastal wetland of Kalu estuary

Estuarine area of Kalu River harbors a single patch of mangroves, that of *Avicennia marina*. The little patch of mudflat was covered by the fish that were kept for drying. Hence, not much of salt marsh vegetation

was observed here. Table – 7.10 enlists the mangroves and mangrove associates of Kalu estuary.

Sr. No.	Mangrove and mangrove associates
1	*Avicennia marina*
2	*Avicennia officinalis*
3	*Sonneratia apetala*
4	*Aegiceras corniculatum*
5	*Acanthus ilicifolius*
6	*Aleuropes lagopoides*
7	*Sesuvium portulacastrum*
8	*Suaeda fruticosa*
9	*Suaeda nudiflora*
10	*Prosopis juliflora*
11	*Portresia coarctata*
12	*Clerodendron inerme*
13	*Thespesia populnea*

Table – 7.9 Wetland biodiversity of Damanganga estuary

Sr. No.	Mangrove and mangrove associates
1	*Avicennia marina*
2	*Porteresia coarctata*
3	*Aleuropes lagopoides*

Table – 7.10 Wetland biodiversity of Kalu estuary

Mangrove diversity of coastal wetland of Varoli estuary

Mangroves of Varoli estuary also show highest diversity of south Gujarat region. As in all the estuaries, Varoli estuary also shows dominance of mangrove *Avicennia marina*. *Sonneratia apetala* is also seen in abundance. *Acanthus ilicifolius, Aegiceras corniculatum* and *Avicennia*

officinalis too were observed growing along the estuary of Varoli River. Two additional species for the state were reported from this area, for the first time. *Lumnitzera racemosa* and *Excoecaria* agallocha were observed for the first time in the record of mangroves of Gujarat.

The mangrove associates comprised of *Derris trifoliata*, *Clerodendron inerme, Sesuvium portulacustrum, Suaeda sps.* and *Aleuropes lagopoides*. *Thespesia populnea* was also observed to be growing along the mangrove wetlands of Varoli River. Table – 7.11 enlists the mangroves and mangrove associates of south Gujarat.

Sr. No.	Mangrove and mangrove associates
1	*Avicennia marina.*
2	*Avicennia officinalis*
3	*Sonneratia apetala.*
4	*Aegiceras corniculatum*
5	*Acanthus ilicifolius*
6	*Lumnitzera racemosa*
7	*Excoecaria agallocha*
8	*Aleuropes lagopoides*
9	*Clerodendron inerme*
10	*Derris trifoliata*
11	*Salvadora persica*
12	*Sesuvium portulacastrum*
13	*Suaeda fruticosa*
14	*Suaeda nudiflora*
15	*Thespesia populnea*

Table – 7.11 Wetland biodiversity of Varoli estuary

Before this work was carried out, the overall mangrove diversity of Gujarat was of eight species, with three being reported to be extinct (Singh, 2006). Kori area now shows presence of only one mangrove species *Avicennia marina*. Diversity of mangroves of Jakhau has now increased because of plantation efforts by forest department. It now harbors *Avicennia marina, Avicennia marina var. acutissima, Ceriops tagal* and *Rhizophora mucronata.* At Mundra, *Avicennia marina* is the only genus surviving. In the Marine National Park and Sanctuary (MNP & S) area, the number of mangrove species varies but the commonly occurring species are *Avicennia marina, Ceriops tagal, Rhizophora mucronata,* with occasional occurrence of *Aegiceras corniculatum*.

The current work brings out the diversity of the south Gujarat region to be of 10 mangrove species, with Purna, Ambika and Varoli estuary bearing the highest number of mangrove species as seven (Chart 7.1). *Avicennia officinalis*, *Lumnitzera racemosa* and *Excoecaria agallocha* are exclusive to the south Gujarat area, while the later two are exclusive to Varoli from the entire Gujarat's mangroves.

The reason for presence of diverse species in south Gujarat region could be because of the difference in the set-up and environmental conditions. The mangroves of Kori creek, Jakhau, Mundra and various islands of the gulf of Kachchh region are rarely fed by fresh water as the river discharge here is during rainy seasons only and the rainfall is scanty. Whereas, the south Gujarat region receives ample rainfall and the rivers are also perennial here. This ensures constant supply of fresh water which

is important in keeping the salinity in check. Salinity of south Gujarat waters is found to be less then the mangrove patches of gulf of Kachchh and western mangrove patches. This seems to be one of the main reason of increased mangrove diversity over the mangrove wetlands of south Gujarat, although the overall area is much less then the mudflat areas gulf of Kachchh and western mangroves.

Of the earlier works conducted for the south Gujarat region only three species were reported. Of these reported species, one species had also been considered extinct. Prior to the current work, not much information was available on the mangroves of south Gujarat. The coastal wetlands of the south Gujarat were believed to be devoid of mangroves with occasional mention of presence of mangroves. Very few works of that were carried out by Shah, 1978; Bhagwanani, 1980; Kothari & Rao, 1991a, 1991b; Kothari & Singh, 1998 and that of Singh 2002, 2006 and a report by Forest Survey of India (FSI)(Anon 2005b) suggested that the coastal wetlands of south Gujarat also harbor mangroves. However, this information was very vague and was indistinctly mentioned. Precise information on mangrove distribution and diversity for any estuarine area in south Gujarat was never presented except for mentioning *Bruguiera cylindrica* in the Umargaon creek (Kothari & Rao 1991a, 1991b; Kothari & Singh 1998), and *Rhizophora mucronata* at sea coasts near Bulsar (now Valsad) (Shah 1978). In addition to this, the general occurrence of *Acanthus ilicifolius* in the estuarine area of South Gujarat has also been reported (Singh 2002; Singh 2006). During the same duration as of this thesis work GEER foundation in

recent times reports to have observed *Excoecaria agallocha* (Newspaper Report, was confirmed during field work). Apart from these species, no other mangrove species are reported to occur along the south Gujarat coast. Plate 7.1 to 7.25 shows the diversity of mangrove and mangrove associates of south Gujarat observed during current work.

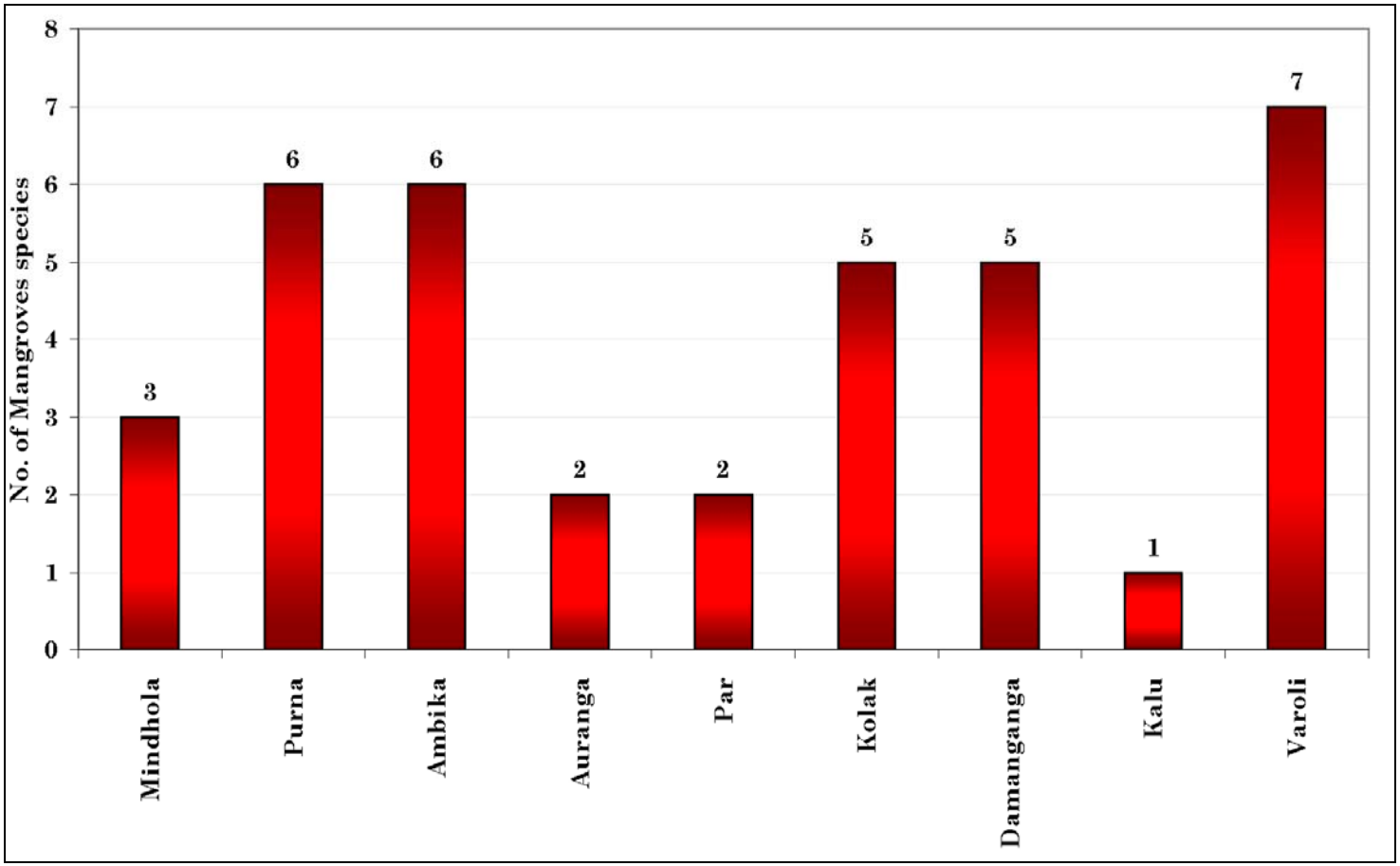


Chart - 7.1 Number of mangrove species of coastal wetlands of south Gujarat region

Mangroves and mangrove associates of the study area

Flowering of *Acanthus ilicifolius*

Canopy of *Avicennia marina*

Plate 7.1 – Mangrove biodiversity of south Gujarat

Flowers of *Avicennia marina*

***Avicennia marina* fruiting**

Plate 7.2 – Mangrove biodiversity of south Gujarat

Natural recruits of *Avicennia marina*

Pneumatophores of *Avicennia marina*

Plate 7.3 – Mangrove biodiversity of south Gujarat

Avicennia officinalis

Aegiceras corniculatum

Plate 7.4– Mangrove biodiversity of south Gujarat

Flowering of *Aegiceras corniculatum*

Fruiting of *Aegiceras corniculatum*

Plate 7.5– Mangrove biodiversity of south Gujarat

***Bruguiera cylindrica* (in association with *Ceriops tagal*)**

Flowers of *Bruguiera cylindrica*

Plate 7.6– Mangrove biodiversity of south Gujarat

Ceriops tagal

Propagules of *Ceriops tagal*

Plate 7.7– Mangrove biodiversity of south Gujarat

Flowers of *Ceriops tagal*

Excoecaria agallocha
Plate 7.8– Mangrove biodiversity of south Gujarat

Root structure of *Excoecaria agallocha*

Lumnitzera racemosa

Plate 7.9– Mangrove biodiversity of south Gujarat

***Lumnitzera racemosa* flowers**

Rhizophora mucronata

Plate 7.10– Mangrove biodiversity of south Gujarat

***Rhizophora mucronata* propagules**

***Rhizophora mucronata* recruits**

Plate 7.11– Mangrove biodiversity of south Gujarat

Sonneratia apetala

Flower of *Sonneratia apetala*

Plate 7.12– Mangrove biodiversity of south Gujarat

Flowering of *Aleuropes lagopoides*

Arthrocnemum indicum

Plate 7.13– Mangrove associates of south Gujarat

Canavalia gladiata

Capparis sps

Plate 7.14– Mangrove associates of south Gujarat

Flowering of *Clerodendron inerme*

Cressa cretica

Plate 7.15– Mangrove associates of south Gujarat

Cyperus sp.

***Derris trifoliata* growing along an island**

Plate 7.16– Mangrove associates of south Gujarat

Flowering of *Derris trifoliata*

Fruiting of *Derris trifoliata*

Plate 7.17– Mangrove associates of south Gujarat

***Derris trifoliata* dominated patch**

Hygrophila auriculata

Plate 7.18– Mangrove associates of south Gujarat

***Ipomoea biloba* - beach/sand vegetation**

Fringe of an island colonized by *Portresia coarctata*

Plate 7.19– Mangrove associates of south Gujarat

Pongamia pinnata

Prosopis juliflora

Plate 7.20– Mangrove associates of south Gujarat

***Salvadora persica* patch**

***Salvadora persica* fruiting**

Plate 7.21– Mangrove associates of south Gujarat

***Salvadora persica* fruiting**

Flowers *Sesuvium portulacustrum*

Plate 7.22– Mangrove associates of south Gujarat

Distinction between the salt marsh community (*Sesuvium portulacustrum)* and the grass along with *Bruguiera cylindrica*

Suaeda species

Plate 7.23– Mangrove associates of south Gujarat

Thespesia populnea

Solanum xanthocarpum

Plate 7.24– Mangrove associates of south Gujarat

Colocassia sps

Plate 7.25– Mangrove associates of south Gujarat

7.2 MAPPING OF MANGROVE HABITATS

The importance of mangroves is well known. Although, the studies on mangroves have been carried out globally on a large scale over last two decades; however, there exists data gaps for the lesser known mangrove areas.

The current work was carried out to identify and demarcate the mangrove wetlands and their diversity, in the south Gujarat region, as little or inadequate information was available about them. The first step was thus to identify and delineate the mangrove areas in the study area. This was achieved with exhaustive field surveys to study the different patches of mangroves and then preparing the mangrove habitat maps on the satellite data, for each area. Mapping was carried out at III level using the classification system by SAC, ISRO for mapping mangrove habitats as has been described in chapter of data used and approach.

Keeping in view the extent of all the estuaries in the study area, the estuaries were divided and mapped into different segments and for each estuary, habitat maps were prepared of the recent most available data and they were subsequently studied and analyzed for change detection with other data dates.

The enhanced images were classified using unsupervised classification using 50 classes. Mangrove habitat maps are often prepared on the basis of density of the mangroves, which is determined by the canopy cover. Dense mangroves were classified for the mangroves with canopy cover more then 60%. The mangroves having canopy cover less then 60%

were classified as sparse mangroves. Dense mangroves attained height of 2 – 7 meters and sparse mangroves attained height of about 1 – 2 meters. Most of the estuaries did harbor dense mangrove patches. However, the estuaries where mangroves were in scattered patches formed sparse mangrove patches.

Accuracy assessment was carried out to check the accuracy of the maps prepared. After ensuring satisfactory level of accuracy, the areas for each of the estuaries' mangroves were calculated from the final maps.

Mangrove habitat map of Mindhola estuary

Habitat map for the year 2001 was prepared for Mindhola estuary. The habitat map of Mindhola estuary for 2001 shows presence of mangroves and salt marsh vegetation. Dense and sparse mangroves are observed in Mindhola estuary. The extent of each category is given in table - 7.12. The dense mangroves were of height 2-7 meters and the sparse mangroves varied in height from 1-2 meters. Dense mangroves occupy very small patch on the southern flank of Mindhola River. Rest of the mangrove area of Mindhola estuary is composed of sparse mangroves.

SR NO	CATEGORY	Area (in ha.) 2001
1	Dense Mangroves	51.33
2	Sparse Mangroves	231.25
3	Salt Marsh	2153.60

Table – 7.12 Area of density classes of Mindhola estuary

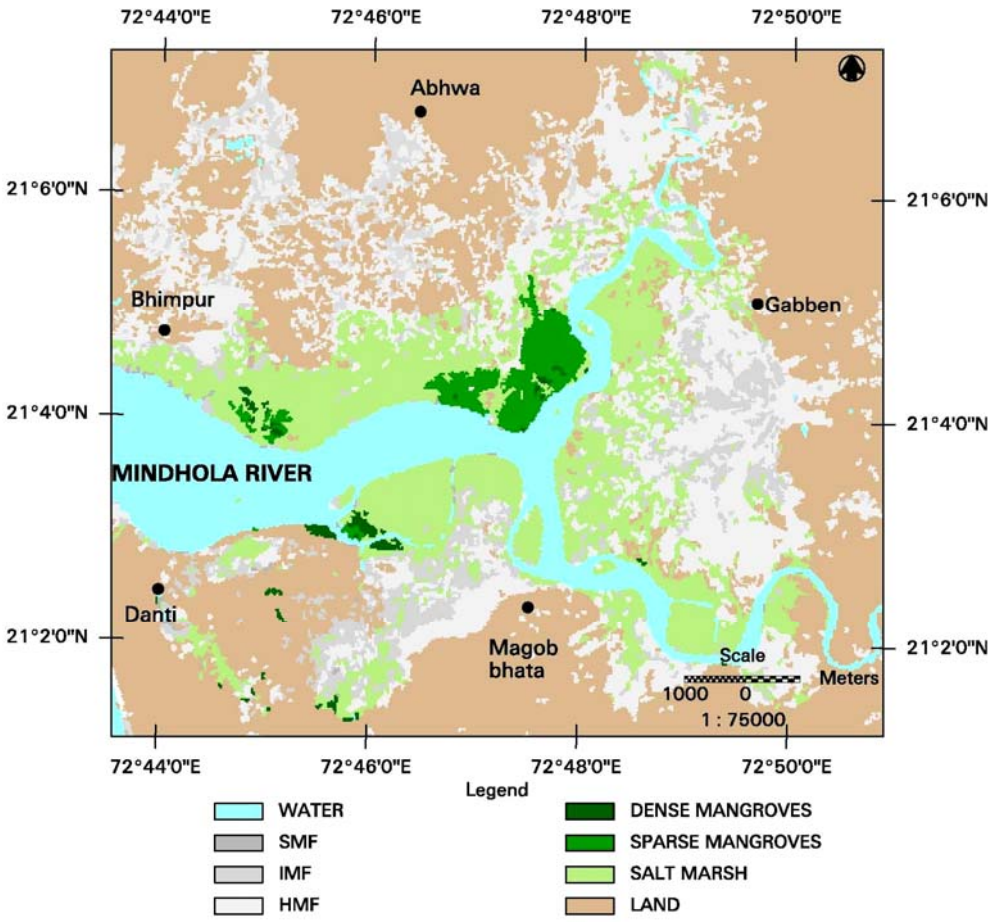


Figure – 7.1 Habitat map of Mindhola estuary

Mangrove habitat map of Purna estuary

The habitat map of Purna estuary for 2005 shows extensive occurrence of mangroves and salt marsh vegetation. Dense and sparse mangroves are observed in Purna estuary. The extent of each category is given in table - 7.13. Dense mangroves were of height 2-7 meters and the sparse mangroves varied in height from 1-2 meters. Dense mangroves mostly occupied the channel bars and the sparse mangroves were found on mudflat area, where they were under the anthropogenic influence

SR NO	CATEGORY	Area (in ha.) 2005
1	Dense Mangroves	467
2	Sparse Mangroves	281
3	Salt Marsh	2402

Table – 7.13 Area of density classes of Purna estuary

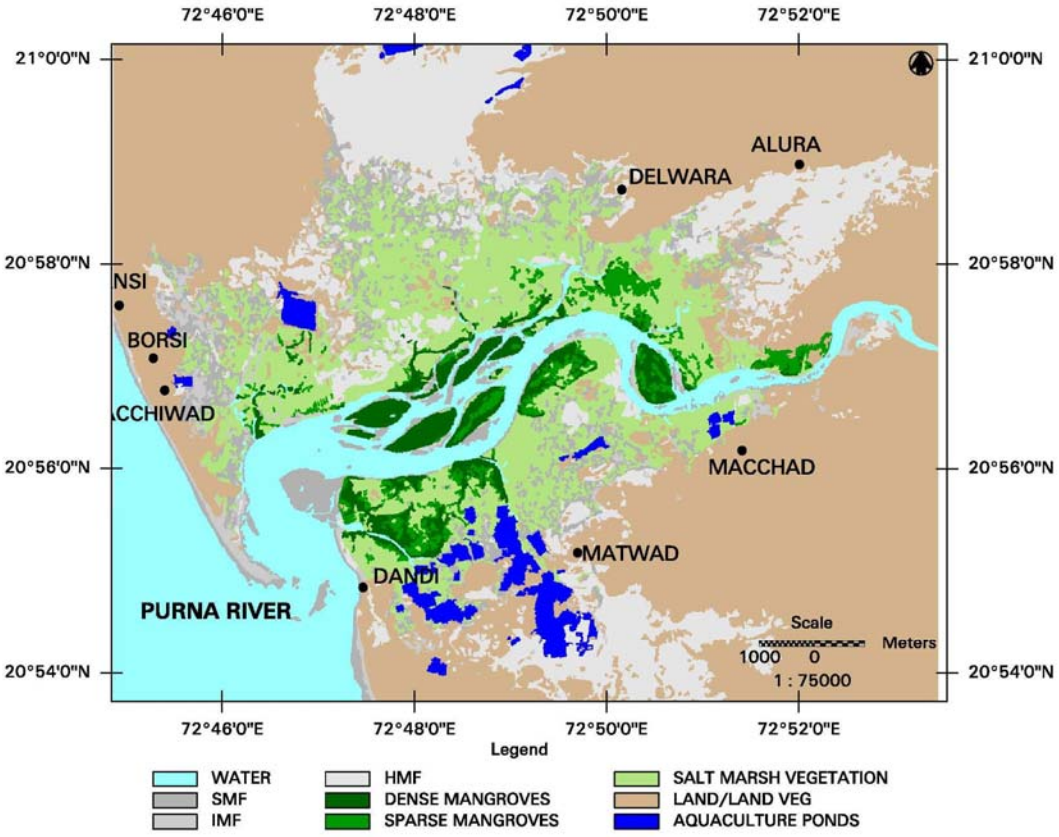


Figure – 7.2 Habitat map of Purna estuary

Mangrove habitat map of Ambika estuary

The extent of Dense and sparse mangroves of Ambika estuary is given in table – 7.14. The dense mangroves here were of height 2-5 meters and the sparse mangroves varied in height from 1-2 meters.

SR NO	CATEGORY	Area (in ha.) 2005
1	Dense Mangroves	378
2	Sparse Mangroves	134
3	Salt Marsh	2459

Table – 7.14 Area of density classes of Ambika estuary

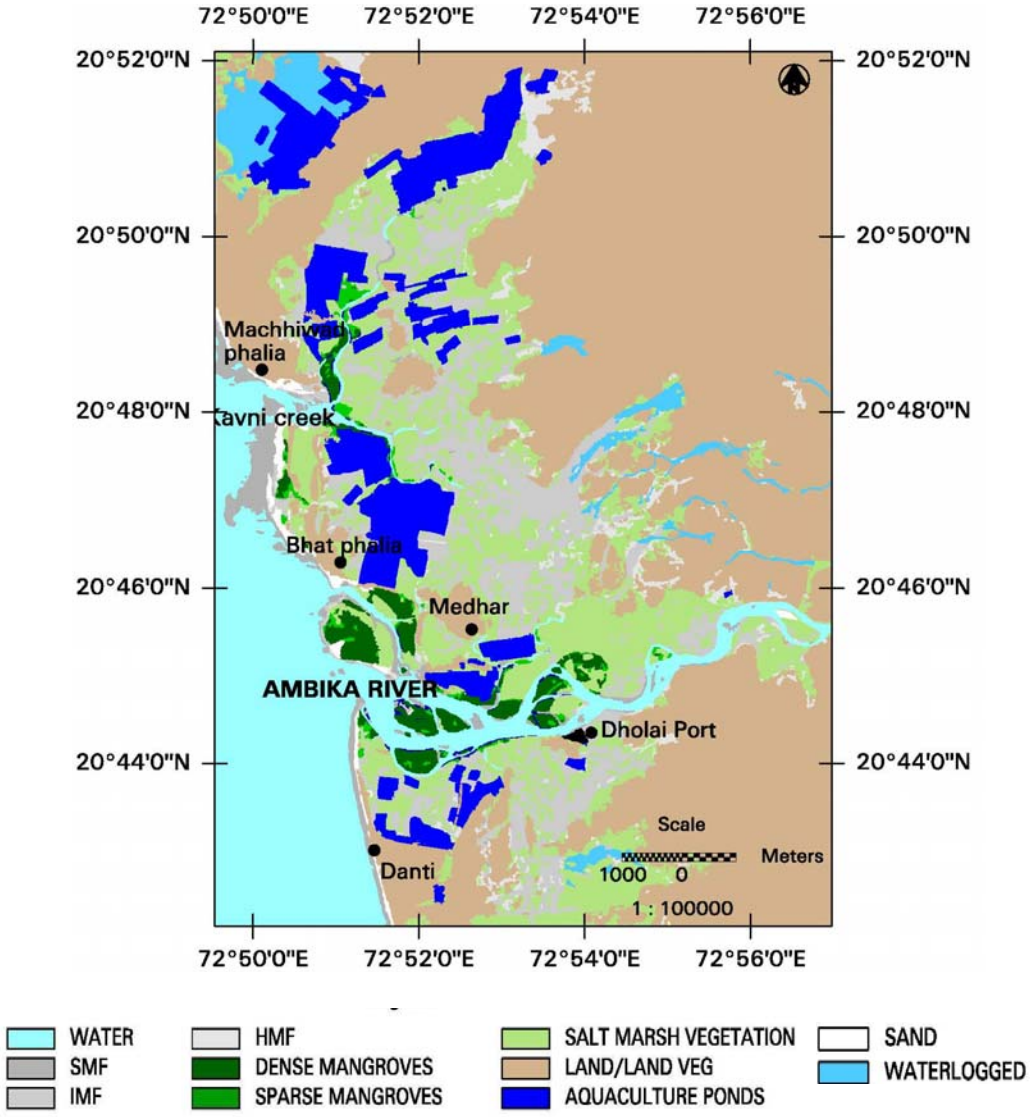


Figure – 7.3 Habitat map of Ambika estuary

Mangrove habitat map of Auranga estuary

The mangrove habitat map of Auranga estuary was prepared for year 2005. The height of dense mangroves ranges from 2-6 meters and of sparse mangroves ranges from 1-2 meters. The area occupied by different categories is given in table – 7.15.

SR NO	CATEGORY	Area (in ha.) 2005
1	Dense Mangroves	28
2	Sparse Mangroves	13
3	Salt Marsh	461

Table – 7.15 Area of density classes of Auranga estuary

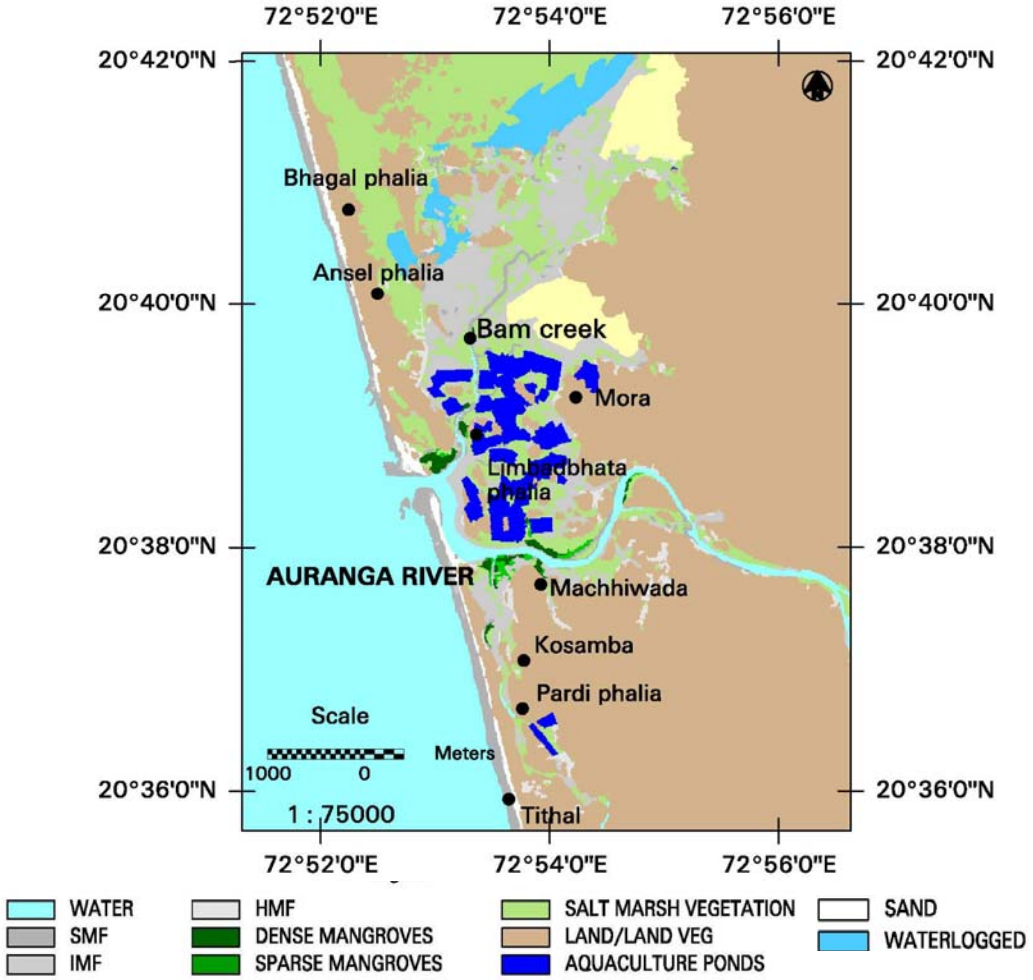


Figure – 7.4 Habitat map of Auranga estuary

Mangrove habitat map of Par estuary

Par estuary harbors very less mangroves and mangrove patches though dense, are smaller in height. The mangroves are of maximum 1.5 meters in height. Table 7.16 shows the extent of the mangrove density class of Par estuary.

SR NO	CATEGORY	Area (in ha.) 2005
1	Dense Mangroves	49
2	Sparse Mangroves	0
3	Salt Marsh	163

Table – 7.16 Area of density classes of Par estuary

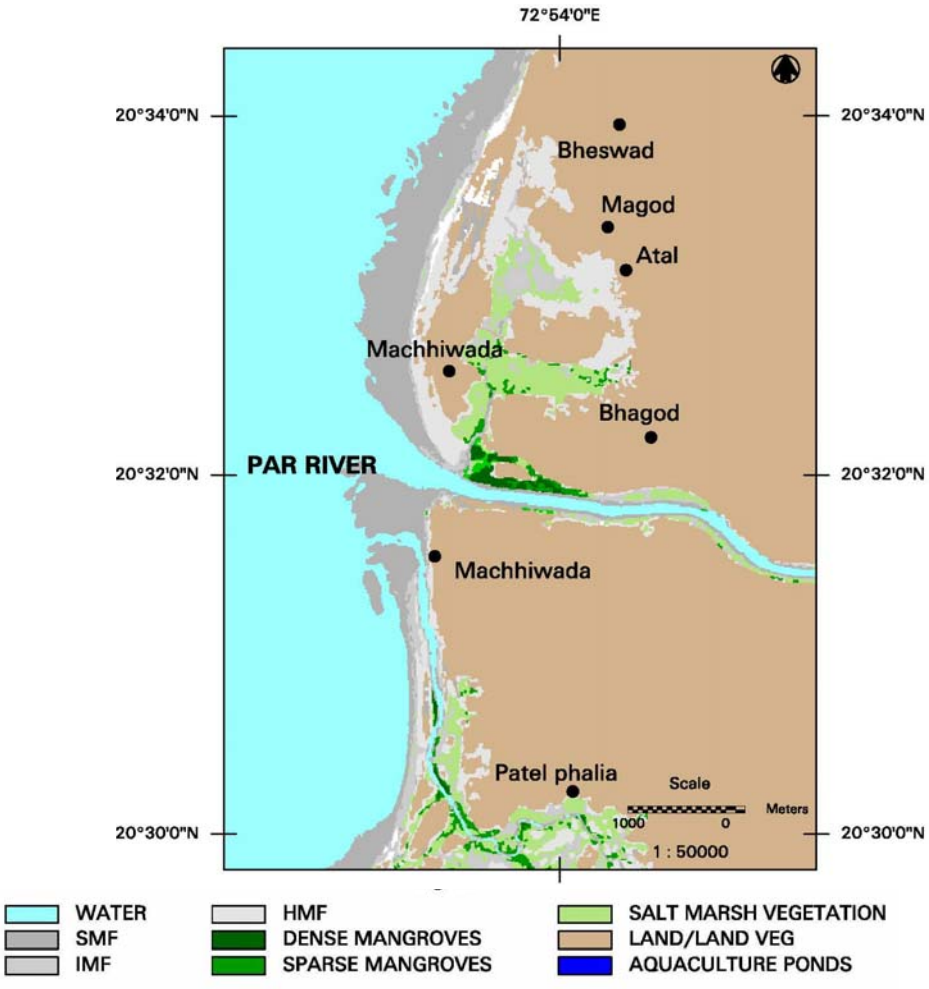


Figure – 7.5 Habitat map of Par estuary

Mangrove habitat map of Kolak estuary

The estuarine area of Kolak is very small but it harbors some of the tallest mangroves of south Gujarat. The mangroves here are denser, although less in terms of the areal extent. The dense mangrove height varies from 3-7 meters. Table – 7.17 gives the areal extent of density classes of mangroves of Kolak estuary.

SR NO	CATEGORY	Area (in ha.) 2001
1	Dense Mangroves	26
2	Sparse Mangroves	11
3	Salt Marsh	6

Table – 7.17 Area of density classes of Kolak estuary

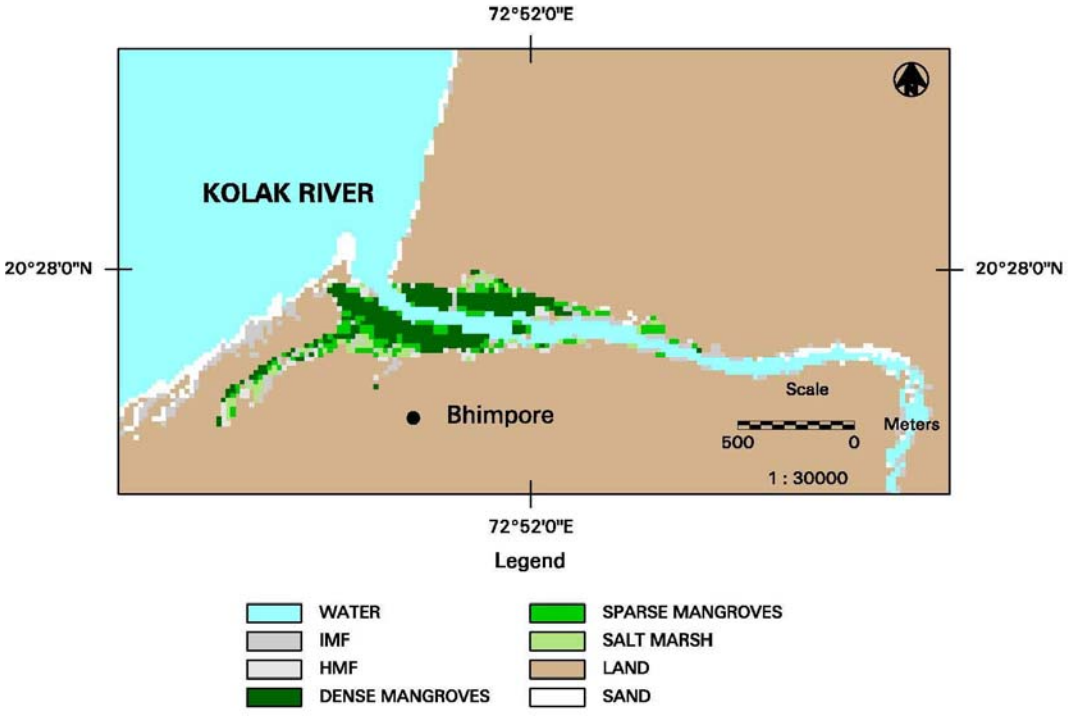


Figure – 7.6 Habitat map of Kolak estuary

Mangrove habitat map of Damanganga-Kalu estuary

Mangroves of Damanganga vary in height from one location to another. The denser patches harbor tall mangroves with maximum height of about 7 meters. The sparse mangroves are made up of height 1-2 meters.

The disparity in the height is due to the scattered occurrences of mangroves in Damanganga estuary. The areal estimates of different density classes of mangroves of Damanganga estuary are given in table – 7.18.

SR NO	CATEGORY	Area (in ha.) 1999
1	Dense Mangroves	10
2	Sparse Mangroves	16
3	Salt Marsh	83

Table – 7.18 Area of density classes of Damanganga estuary

Mangrove habitat map of Kalu estuary

Kalu estuary forms a very small and harbors single patch of mangroves. It harbors tall mangroves of about 3-6 meters. This mangrove occupies only 0.25 meters of the area (table – 7.19).

SR NO	CATEGORY	Area (in ha.) 1999
1	Dense Mangroves	0.25
2	Sparse Mangroves	00
3	Salt Marsh	00

Table – 7.19 Area of density classes of Kalu estuary

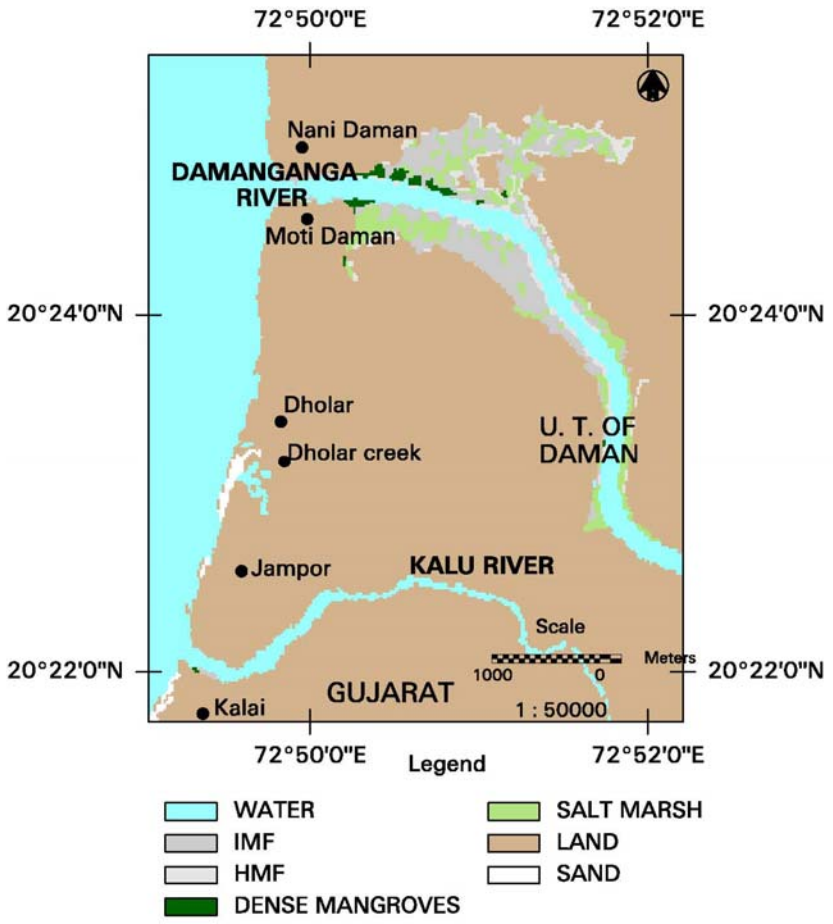


Figure – 7.7 Habitat map of Damanganga and Kalu estuary

Mangrove habitat map of Varoli estuary

The mangroves at Varoli estuary are quite dispersed and varied as the wetland area here is extensive. However, the dense patches and the dispersed mangroves are quite tall as well. The maximum height here is about 5-7 meters. Table – 7.20 gives the areal estimates of the mangroves of different density classes of Varoli estuary.

SR NO	CATEGORY	Area (in ha.) 2001
1	Dense Mangroves	40
2	Sparse Mangroves	24
3	Salt Marsh	636

Table – 7.20 Area of density classes of Varoli estuary

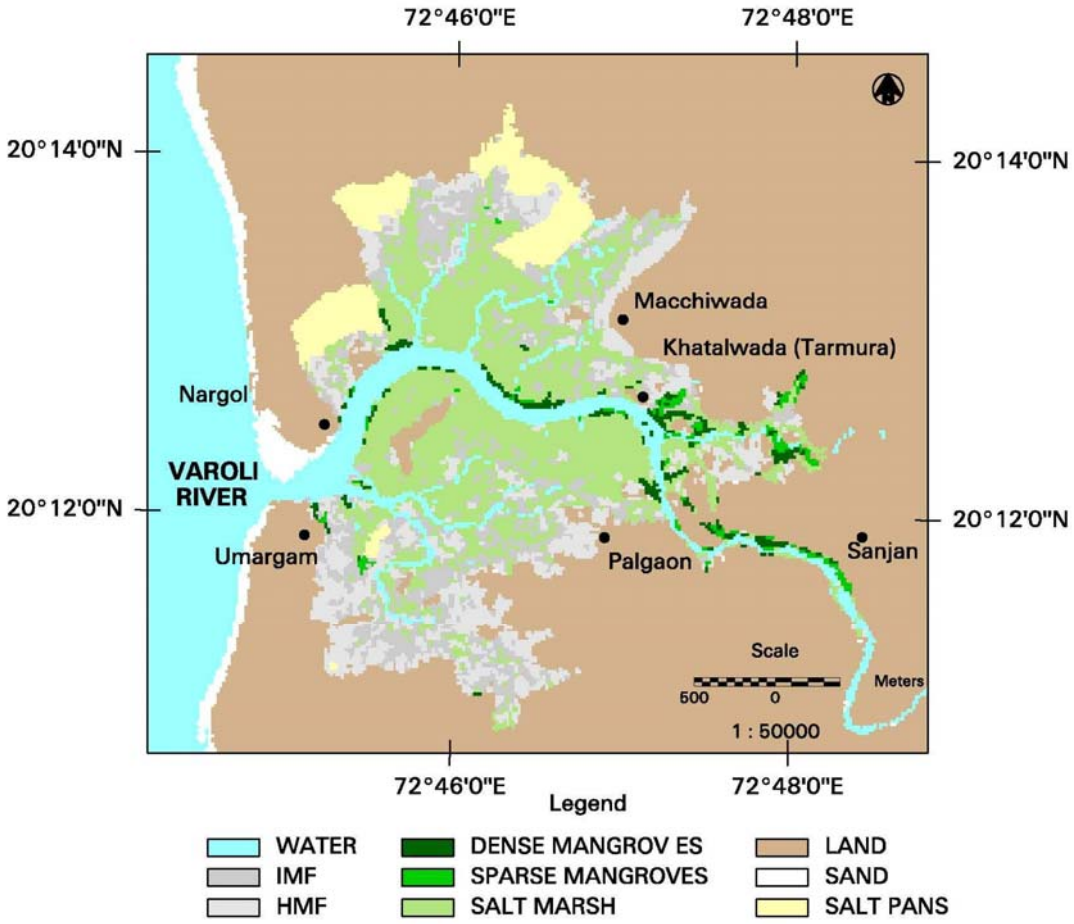


Figure – 7.8 Habitat map of Varoli estuary

Table – 7.21 gives a comparative account of mangroves and mangrove associates across all the estuaries of the study area. Total mangrove area comes to 2062 hectares, albeit over different years. In addition, the over all wetland vegetation area is found to be 8026 hectares.

Also smaller mangroves at few estuaries *vis – a – vis* others of south Gujarat suggests different times of establishment of mangroves. Moreover, it also suggests that the mangroves that are still smaller in height and will possibly grow up into a dense forest subsequently.

SR. NO.	ESTUARY/YEAR	AREA (in ha.)				
		DENSE MANGROVES	SPARSE MANGROVES	TOTAL MANGROVES	SALT MARSH	TOTAL (MANGROVES & SALT MARSH)
1	Mindhola 2001	51	231	**282**	2154	**2436**
2	Purna 2005	467	281	**748**	2402	**3150**
3	Ambika 2005	378	134	**512**	2459	**2970**
4	Auranga 2005	28	13	**41**	461	**502**
5	Par 2005	49	0	**49**	163	**212**
6	Kolak 2001	26	11	**37**	6	**43**
7	Damanganga 1999	10	16	**26**	83	**109**
8	Kalu 1999	0.25	0	**0.25**	0	**0.25**
9	Varoli 2001	40	24	**64**	636	**700**
TOTAL		**1049**	**1013**	**1759**	**5964**	**8026**

Table – 7.21 Areal estimates of mangroves and salt marsh vegetation of the estuaries of south Gujarat

ACCURACY ASSESSMENT OF HABITAT MAPS

Accuracy is defined as how any class, feature, or material being classified is meaningfully set forth with proper descriptors. The user and producer accuracy are used to measure class accuracy. The producer's accuracy refers to the probability that a certain category on the ground is classified as such, while the user's accuracy refers to the probability that a pixel labeled as a certain category in the map is really this class. A measure for the overall classification accuracy can be derived from this table by counting how many pixels were classified the same in the satellite image and on the ground and dividing this by the total number of pixels.

All the habitat maps were analyzed for the accuracy assessment. To evaluate the accuracy of the maps, minimum of 50 classes were randomly selected for each map. Only the wetland categories were selected for random distribution of points to be assessed for accuracy i.e., mangroves, salt marsh vegetation, aquaculture ponds, salt pans, waterlogged areas, subtidal mudflats, intertidal mudflats, hightidal mudflats and beach sand were selected while water and land category were not selected for accuracy assessment. In most of the maps, it was found that confusion occurred between the salt marsh vegetation and the mangrove categories. However, the mudflats were also often confused with the salt marsh vegetation.

As observed from table – 7.21 the accuracy of all the wetlands were satisfactory. Lowest classification accuracy was 86% for Varoli estuary and highest is 94%, that of Purna estuary.

Sr. No.	Data/year	Producers Accuracy	Users Accuracy	Overall Classification Accuracy	Kappa Statistics
1	Mindhola 2001	90%	89%	92%	0.87
2	Purna 2005	94%	93%	94%	0.88
3	Ambika – Auranga 2005	97%	93%	92%	0.88
4	Par 2005	96%	93%	90%	0.86
5	Kolak 2001	87%	83%	90%	0.87
6	Damanganga – Kalu 1999	97%	93%	92%	0.88
7	Varoli 2001	93%	87%	86%	0.81

Table – 7.22 Accuracy assessment and Kappa statistics

7.3 COMMUNITY ZONATION OF MANGROVES

Mangroves have been noted for their definitive spatial variation. Spatial variation in species occurrence and abundance has been noted in differing ecosystems throughout the world. Mangroves grow in monospecific bands parallel to the shoreline, very often with seagrass bed and coral reef system adjacent to the assemblage under the sea. A general description of mangrove zonation depicts a pattern that extends from shore to inland regions (usually higher in elevation).

Each mangrove species has distinct ecological requirements and tolerances that determine its spatial distribution within mangrove communities. The tidal inundation, salinity, elevation, etc form the deciding factors for the distribution of mangroves in a given area itself. Based on this, mangroves form different zonation pattern. The mangrove vegetation shows distinct zones characterized by dominance of a particular species or communities of species, owing to its specific responses to the surrounding physico-chemical environment. The zonation may also result from each species' optimal niche for productivity. It is therefore, common to find distinct zonation in which each zone is dominated by one or two dominant species. Information regarding different mangrove community zonation is a vital remote sensing based input. Studying the spectral behavior of the mangroves facilitates in identification as well as determination of the spatial distribution and delineation of major mangroves communities, for assessing the environmental condition of the habitat and for the preparation of management plans for conservation. In addition, knowledge

of mangrove communities would help immensely in planning preventive measures for cyclone, sea level rise, etc, as some species have high resistance for storm and cyclone (*Bruguiera sps* and *Rhizophora sps*) whereas some also modify local currents and promote further sedimentation (*Sonneratia sps* and *Avicennia sps*) (Nayak et. al., 2003).

Supervised classification was used for Purna estuary and unsupervised classification was found satisfactory for rest other estuaries. This was done because the spatial distribution of mangrove species was limited in all other estuaries, whereas in Purna estuary the diverse mangroves were interspersed and spatially more or less evenly distributed.

COMMUNITY ZONATION OF MANGROVES OF SOUTH GUJARAT

There are very few works highlighting the species-wise identification using satellite data. As such, the mangroves of south Gujarat were being studied thoroughly for the first time. Hence, the community mapping of this area was also undertaken in the present study in an attempt to bring out the major communities of mangroves of south Gujarat.

The recent most available data (1999, 2001 or 2005 satellite data) was used for preparing one-time community maps. Ten mangrove species were found in the study area. The aim was to prepare a community map of all the different mangroves observed in the study area. However, not all formed pure communities and most of the species, except *Avicennia marina* and *Acanthus ilicifolius,* were found scattered throughout the estuarine areas. In most of the estuaries of the study area, *Avicennia marina*

dominated. The distribution of the mangrove species rare in this region like *Avicennia officinalis, Bruguiera cylindrica, Ceriops tagal, Lumnitzera racemosa, Rhizophora mucronata* and *Excoecaria agallocha* was restricted to few patches of few estuaries rather then the entire estuarine area of all the estuaries. Moreover, these mangroves rarely formed pure communities in this area which could be mapped on the satellite data. This also was partly due to the fact that the spatial resolution of the satellite data formed the limiting factor for discrimination between different mangroves at 28 mtrs (for LANDSAT ETM+) and 23.5 mtrs (for LISS III) resolution. Hence, most of the estuaries here could be classified broadly in to two categories/communities *Avicennia marina* pure and mixed communities. All the other communities occupied very small patches and were generally composed of association of mangrove – salt marsh or more then two mangrove species.

COMMUNITY ZONATION OF MANGROVES OF MINDHOLA COASTAL WETLAND

Avicennia marina community

Figure 7.9 describes the various communities of coastal wetland of Mindhola. This community includes the dense and sparse categories of the same genus (Table - 7.23). Few patches are located on the mudflat of this river. The trees of dense patches are about 3 – 5 m in height. Sparse *Avicennia marina* patch are also present in this area. The height of *Avicennia marina* in this category ranges from 1 – 3 m.

***Acanthus ilicifolius* & *Derris trifoliata* community**

Dense association of this community was observed at a single patch. This category makes up for the maximum area.

Other categories

Other mangrove species such as *Sonneratia apetala* and *Acanthus ilicifolius* are also found scattered through the estuarine area, never forming a pure patch.

Salt marsh

Apart from the mangrove community, the salt marsh actually occupies the largest area of the wetland vegetation. It is composed generally of *Suaeda* sps., *Sesuvium portulacustrum*, *Salvadora persica*., etc. Aleuropes dominates the intertidal flats devoid of any kind of vegetation.

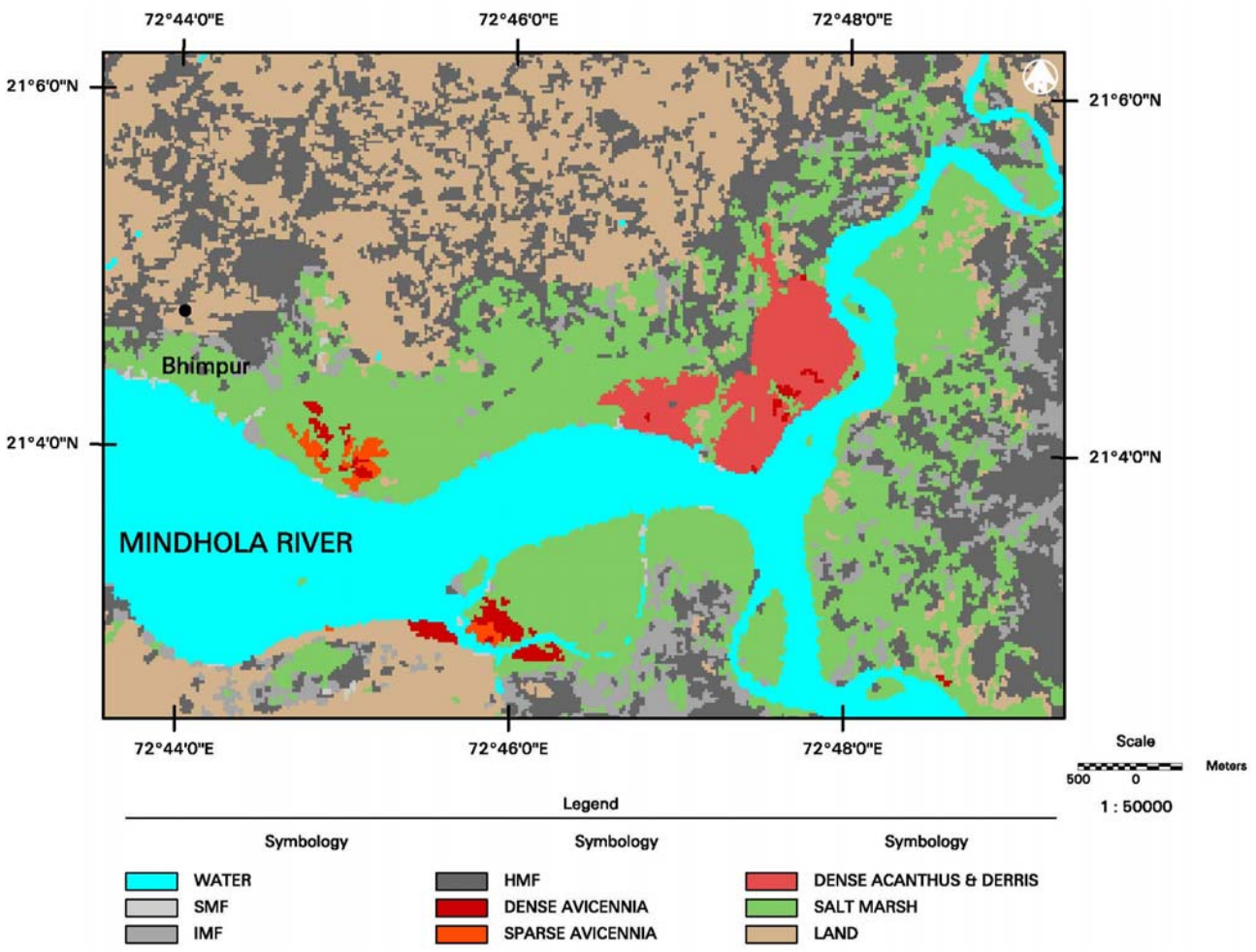


Figure – 7.9 Community map of Mindhola wetland (2001)

Sr. no.	Community	Area (in Ha.)
1	Dense *Avicennia marina*	51.33
2	Sparse *Avicennia marina*	21.77
3	Dense *Acanthus ilicifolius* & *Derris trifoliata*	209.48
	Sub-total (Mangroves)	**282.58**
4	Salt marsh vegetation	2153.60
	Total (Mangroves + Salt marsh)	**2436.18**

Table – 7.23 Areal extent of different communities of coastal wetland of Mindhola

COMMUNITY ZONATION OF MANGROVES OF PURNA COASTAL WETLAND

Avicennia community

This formed the largest dominant community is Purna estuary (Table - 7.24). This community encompasses the dense and sparse categories of the same genus (Figure – 7.10). It also includes the fringe vegetation, which at all the estuaries is composed of *Avicennia marina* only. The dense community forms the largest community in Purna estuary. Major patches are located at all the islands of the river. This could be probably because these islands are the least disturbed areas. Dense patches are also found along the creeks of the estuarine set-up. The trees of dense patches are about 3 – 7 m in height. Sparse *Avicennia marina* patch form the second dominant community of the area. It is present as few patches on the islands as well as the mudflats of the estuarine area. The height of *Avicennia marina* in this category ranges from 1 – 3 m. In addition, a separate fringe category for *Avicennia* marina could be extracted for the Purna wetland.

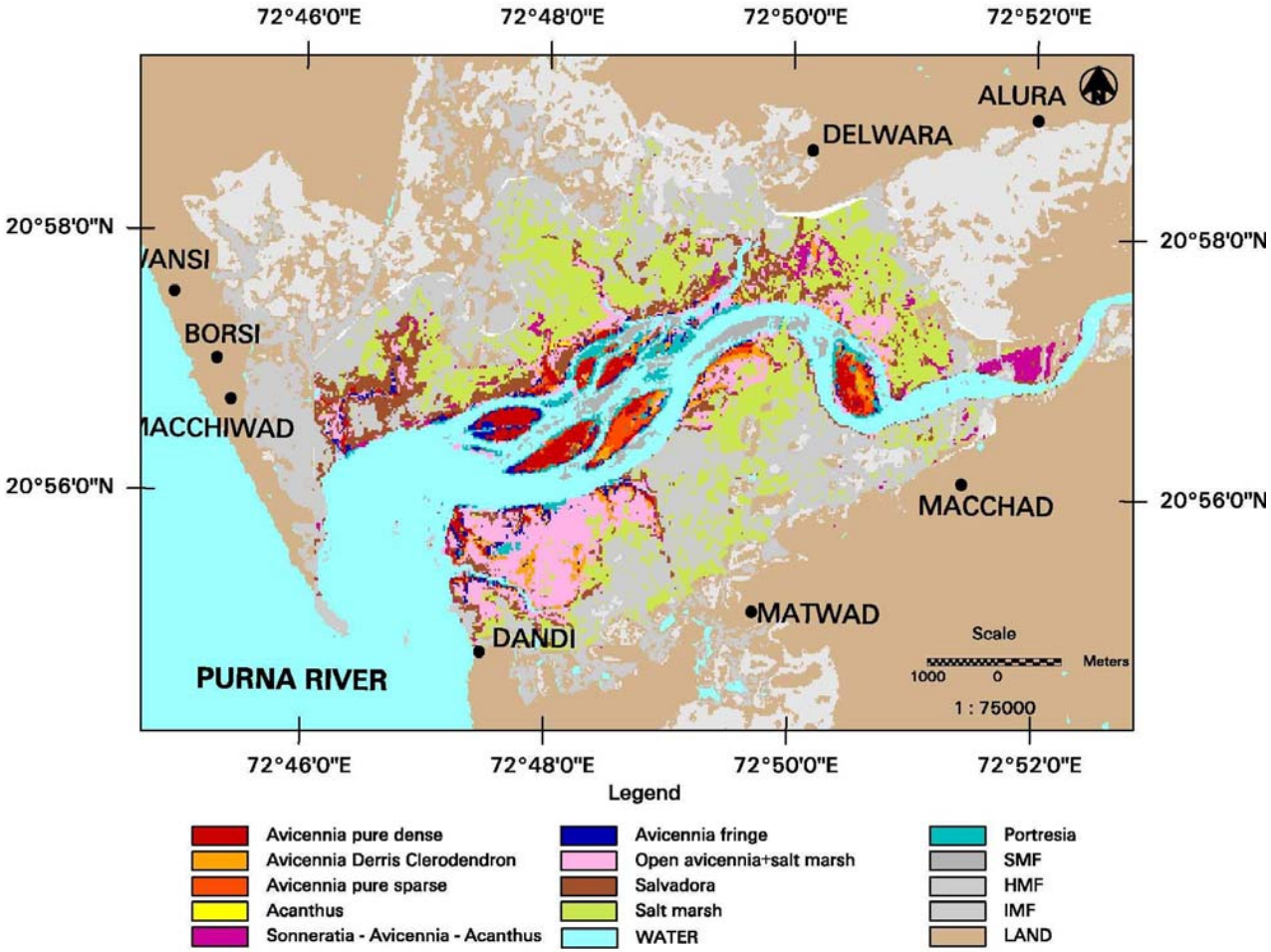


Figure – 7.10 Community map of Purna wetland (2003)

Avicennia – Sonneratia – Acanthus community

This community occupies most of the creeks areas and a patch off Alura. It is observed here that *Sonneratia apetala* shows preference for the creeks. However, no pure patch of *Sonneratia apetala* was observed. It was always found associated with *Avicennia marina* and at many occasions with *Acanthus ilicifolius*.

Acanthus – Derris – Clerodendron community

Association of this community was observed at few patches across the estuarine area of Purna River. As a dense discernable patch, it was observed at the islands and on the mudflats off Matwad.

Acanthus community

Although it occupied a small area, nevertheless, pure *Acanthus ilicifolius* patch could be demarcated at a single location. Usually it is associated with *Avicennia marina* and occupies the high-tidal flats, but at this instance, it was observed in the intertidal area, as pure community, and thus posing difficulty to walk through it.

Mixed sparse community

Majority of the estuarine area is occupied by this category of mangroves. This sparse mixed patch includes *Avicennia marina*, *Sonneratia apetala*, *Acanthus ilicifolius* and the mangroves *Bruguiera cylindrica, Ceriops tagal* and *Rhizophora mucronata*, which were found scattered through the estuarine area but never formed patch pure enough to be demarcated separately.

Salt marsh

Apart from the mangrove community, the salt marsh actually occupies the largest area of the wetland vegetation. It is composed generally of *Suaeda* sps., *Sesuvium portulacustrum*., *Salvadora persica., Clerodendron inerme* and *Salicornia brachiata. Aleuropes lagopoides* dominates the intertidal flats devoid of any kind of vegetation. *Portresia coarctata* is found colonizing the newly accreted mudflats, adjacent to the islands, in the river channel, and it forms a pure community.

Sr. no.	Community	Area (in Ha.)
1	*Avicennia marina* dense	141
2	*Avicennia marina* sparse	51
3	*Avicennia marina* fringe	69
4	*Avicennia marina– Sonneratia apetala– Acanthus ilicifolius*	85
5	*Avicennia marina – Derris trifoliata– Clerodendron inerme*	84
6	*Acanthus ilicifolius*	3
7	Mixed sparse (Open *Avicennia marina* and salt marsh)	47
	Sub-total (Mangroves)	**478**
8	Salt marsh vegetation	1945
9	*Portresia coarctata*	109
	Total (Mangroves + Salt marsh)	**2533**

Table – 7.24 Areal extent of different communities of coastal wetland of Purna

COMMUNITY ZONATION OF MANGROVES OF AMBIKA COASTAL WETLAND

Avicennia community

This formed the largest dominant and the single mangrove community in the estuarine area of Ambika River (Figure - 7.11). This community includes the dense and sparse categories of *Avicennia marina.*

It also includes the fringe vegetation. The dense community occupies the largest area in Ambika estuary (Table - 7. 25). Most of the patches are located at all the islands of the river. The trees of dense patches in Ambika estuary are about 1 – 4 m in height. Sparse *Avicennia marina* patch forms the second dominant mangrove community. The plants of this category generally are of 1 – 2 m in height. Fringe *Avicennia marina* are also included in this community category.

Salt marsh

The salt marsh vegetation covers the largest area of the wetland vegetation. It is dominantly composed of *Aleuropes* sps. and other species like *Salvadora, Sesuvium* sps., *Suaeda* sps., *Derris* sps., etc. *Portresia coarctata* is found colonizing the recently accreted areas, forming a pure community.

Other categories

Although *Avicennia marina* is the single most dominant and pure community, other mangrove species such as *Sonneratia apetala*, *Acanthus ilicifolius*, *Bruguiera cylindrica, Ceriops tagal* and *Rhizophora mucronata*, were found in lesser quantity, scattered through the estuarine area, never forming a pure patch.

Sr. no.	Community	Area (in Ha.)
1	*Avicennia marina* dense	378
2	*Avicennia marina* sparse	104
3	*Avicennia marina* fringe	30
	Sub-total	**512**
4	Salt marsh vegetation	2,382
5	*Portresia coarctata*	77
	Total	**2970**

Table – 7.25 Areal extent of different communities of coastal wetland of Ambika

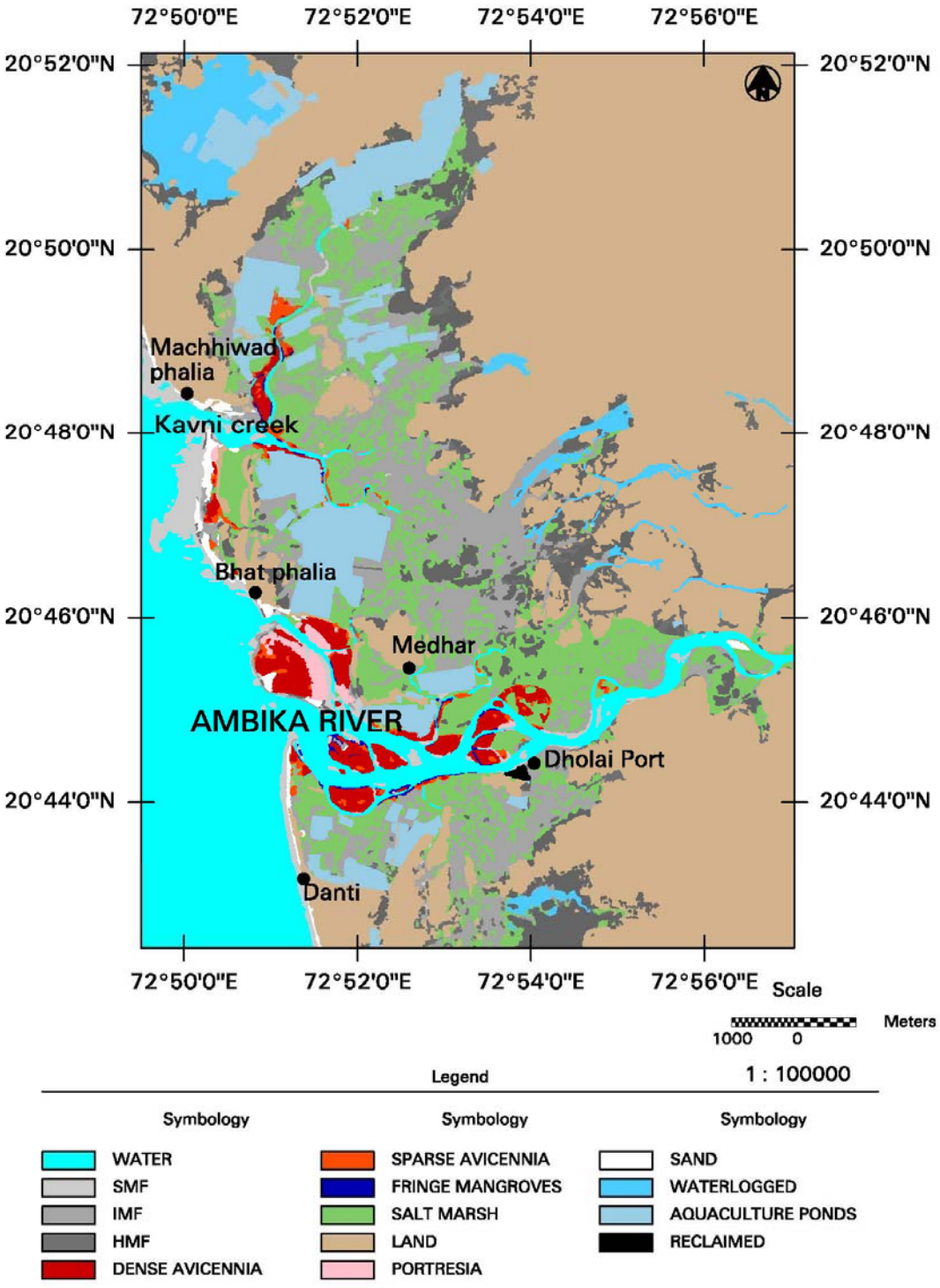


Figure – 7.11 Community map of Ambika wetland (2005)

COMMUNITY ZONATION OF MANGROVES OF AURANGA COASTAL WETLAND

Avicennia community

In Auranga estuary also, Avicennia marina forms the single largest dominant (Figure – 7.12). It comprises of the dense, sparse and the fringe category as well. The dense community occupies the largest area in Auranga estuary (Table – 7.26). The trees of dense patches in Auranga estuary are about 2 – 4 m in height. Sparse *Avicennia marina* patch forms the second dominant mangrove community. The plants of this category generally are of less then 1 – 2 m in height.

Sr. no.	Community	Area (in Ha.)
1	*Avicennia marina* dense	28
2	*Avicennia marina* sparse	13
	Sub-total	41
3	Salt marsh vegetation	461
	Total	502

Table – 7.26 Areal extent of different communities of coastal wetland of Auranga

COMMUNITY ZONATION OF MANGROVES OF PAR COASTAL WETLAND

Avicennia community

Avicennia marina dominates the mangrove community of Par estuary (Figure – 7.13). However, the height of the dense category of *Avicennia marina* on the northern flank of this estuary is not more then 2 m. Few dense patches of *Avicennia marina* are observed on the southern flank of the estuary which is of the height range 2 – 4 m. Table – 7.27 gives the areal statistics of different communities of coastal wetland of Par.

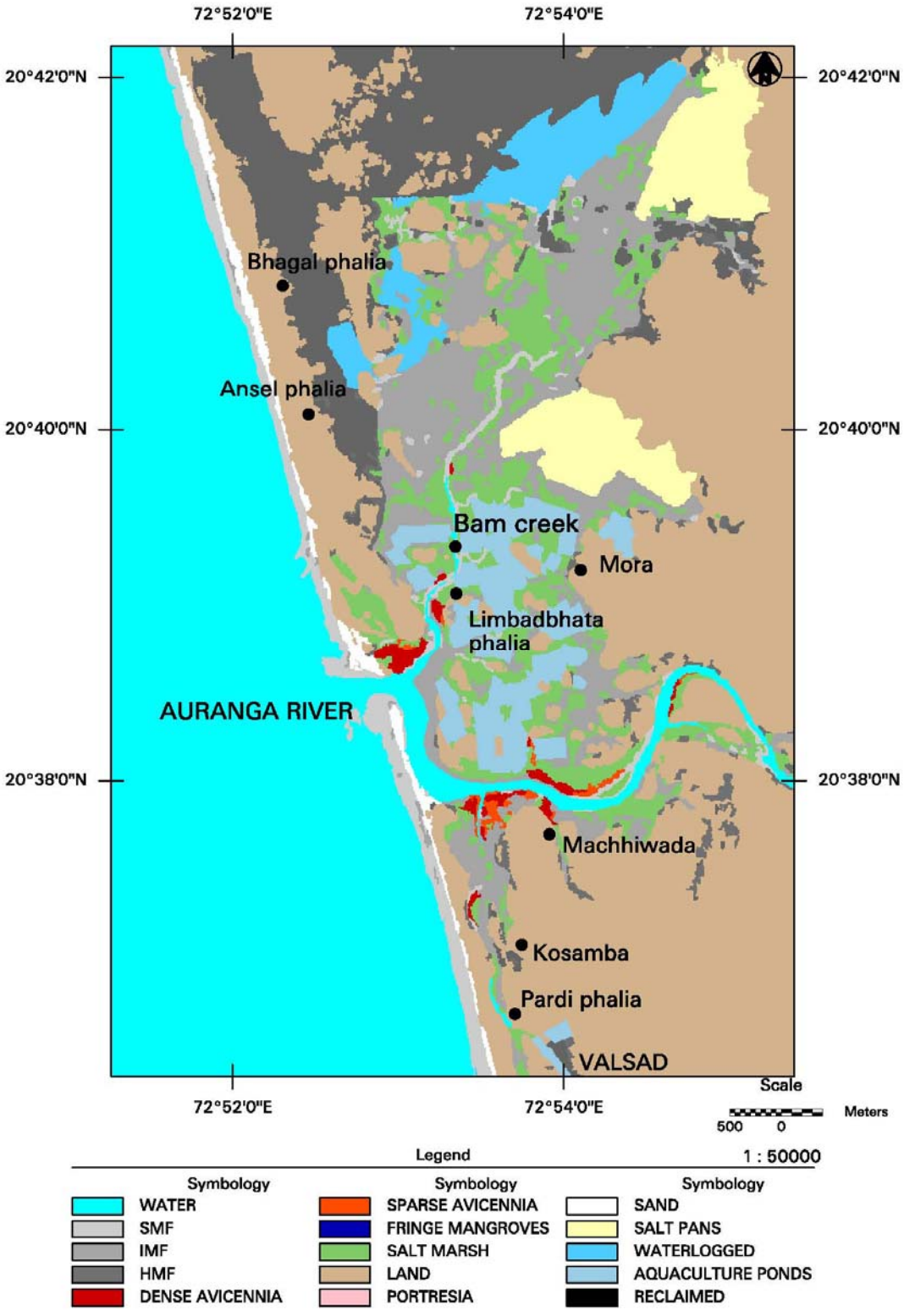


Figure – 7.12 Community map of Auranga wetland (2005)

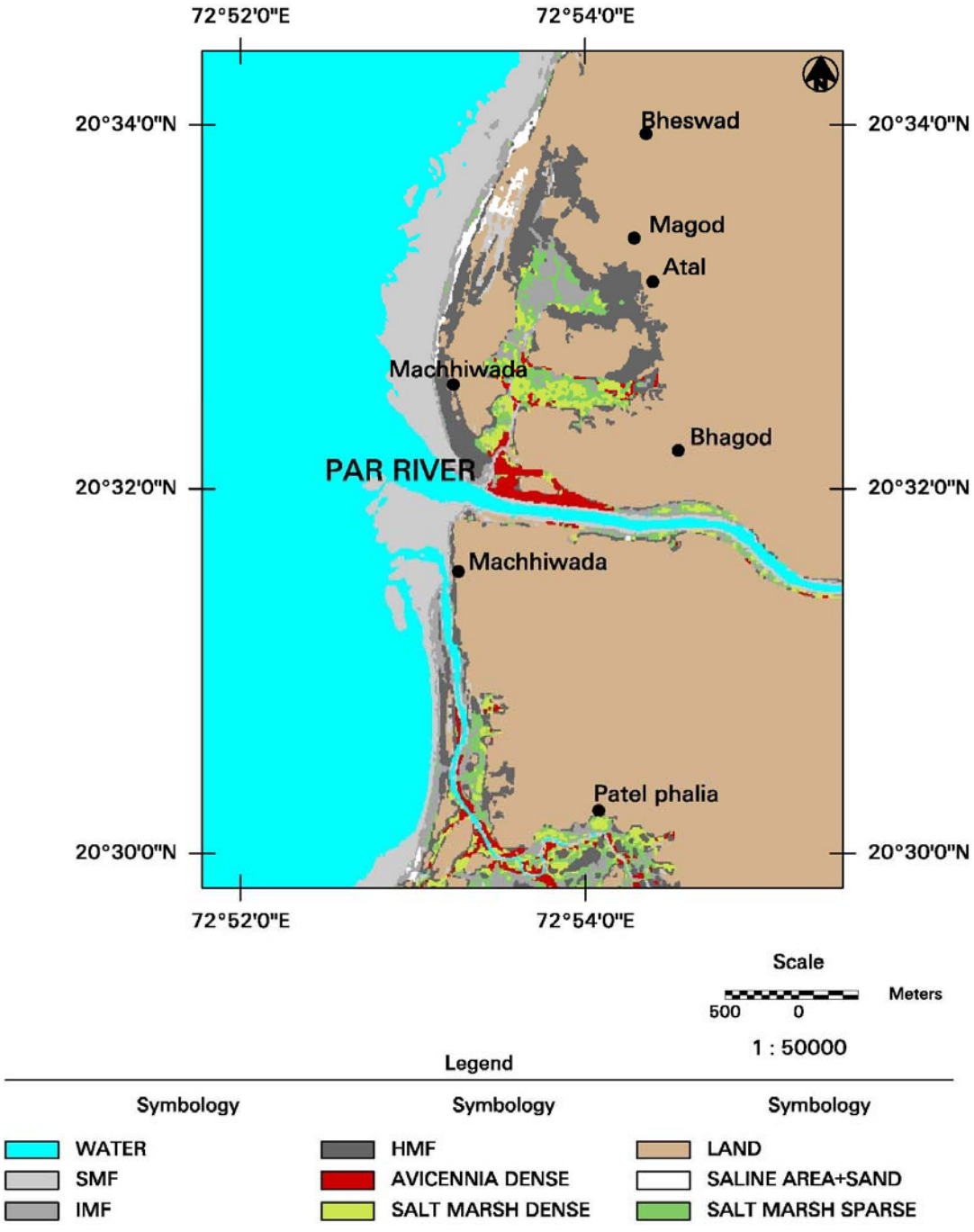


Figure – 7.13 Community map of par wetland (2005)

Other categories

Partial co-dominance of A*canthus ilicifolius* is observed on the northern flank of the estuary, however it doesn't form patch pure enough to be categorized separately. *Acanthus ilicifolius* is also present towards the southern flank of the estuary, but is present in modest extent only.

Salt marsh

Major area of the wetland is occupied by the salt marsh vegetation. It is mainly comprised of *Aleuropes lagopoides* with indiscriminate occurrences of *Sesuvium portulacustrum, Suaeda sps*, etc.

Sr. no.	Community	Area (in Ha.)
1	*Avicennia marina* dense	14
2	*Avicennia marina* sparse	35
	Sub-total	**49**
3	Salt marsh vegetation	163
	Total	**211**

Table – 7.27 Areal extent of different communities of coastal wetland of Par

COMMUNITY ZONATION OF MANGROVES OF KOLAK COASTAL WETLAND

Avicennia community

The estuarine area of Kolak is small as compared to other estuaries but then it comprises of four different mangrove species. However, here too *Avicennia marina* forms the dominant mangrove community (Figure – 7.14). Dense and sparse categories are observed along with the fringe *Avicennia marina* category (Table – 7.28). However, the dense *Avicennia marina* forms the dominant community. The height of *Avicennia marina* in Kolak estuary ranges from 2 – 7 m. *Avicennia marina* of Kolak estuary are

perhaps the tallest of all the mangroves found in the study area, along with that of Purna region.

Other categories

Tall *Sonneratia apetala* (5 – 7 m) are also observed. A*canthus ilicifolius* is observed on the relatively open patches of the wetland, where the light can penetrate through the dense canopy of tall Avicennia marina and *Sonneratia apetala*. *Aegiceras corniculatum* is the other mangrove encountered frequently in Kolak estuary but always scattered, never forming a pure patch, consequently not demarcated on the map. *Ceriops tagal* is also present scattered through the Kolak estuary.

Salt marsh

The dense and tall trees in Kolak estuary makes it difficult for the light to penetrate through the canopy. This does not enable the salt marsh vegetation to grow and thrive. However, wherever there is gap and availability of light salt marsh species such as *Aleuropes lagopoides, Sesuvium portulacustrum, Suaeda fruticosa* and *Suaeda nudiflora* can be observed. *Aleuropes lagopoides* is also observed in the transitional zone from the mangrove to non-mangrove category. *Portresia coarctata* was observed at places on the fringe of the wetland.

Sr. no.	Community	Area (in Ha.)
1	*Avicennia marina* dense	26
2	*Avicennia marina* sparse	11
	Sub-total	**37**
3	Salt marsh vegetation	6
	Total	**42**

Table – 7.28 Areal extent of different communities of coastal wetland of Kolak

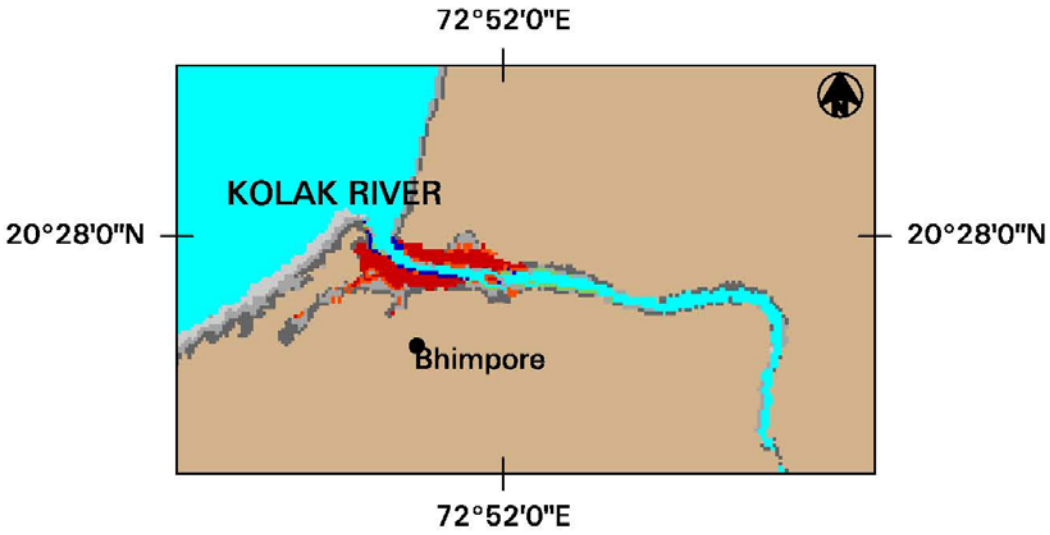


Figure – 7.14 Community map of Kolak wetland (2001)

COMMUNITY ZONATION OF MANGROVES OF DAMANGANGA - KALU COASTAL WETLAND

Avicennia community

The estuarine area of Damanganga and Kalu River is dominated by *Avicennia marina* community (Figure 7.15, table - 7.29, 7.30). Dense and open categories are observed along with the fringe *Avicennia marina* category. The height of *Avicennia marina* in Kolak estuary ranges from 2 – 5 m.

Other categories

Sonneratia apetala, A*canthus ilicifolius, Aegiceras corniculatum* and *Avicennia officinalis* are other mangroves observed in Damanganga estuary. They are scattered and very few in quantity. Tall *Sonneratia apetala* (5 – 7 m) are observed at the ending of creeks along the northern and the southern flank of Damanganga River. A*canthus ilicifolius* is also observed dispersed on the intertidal mudflats of Damanganga estuary. *Aegiceras corniculatum* is observed randomly scattered through the wetland

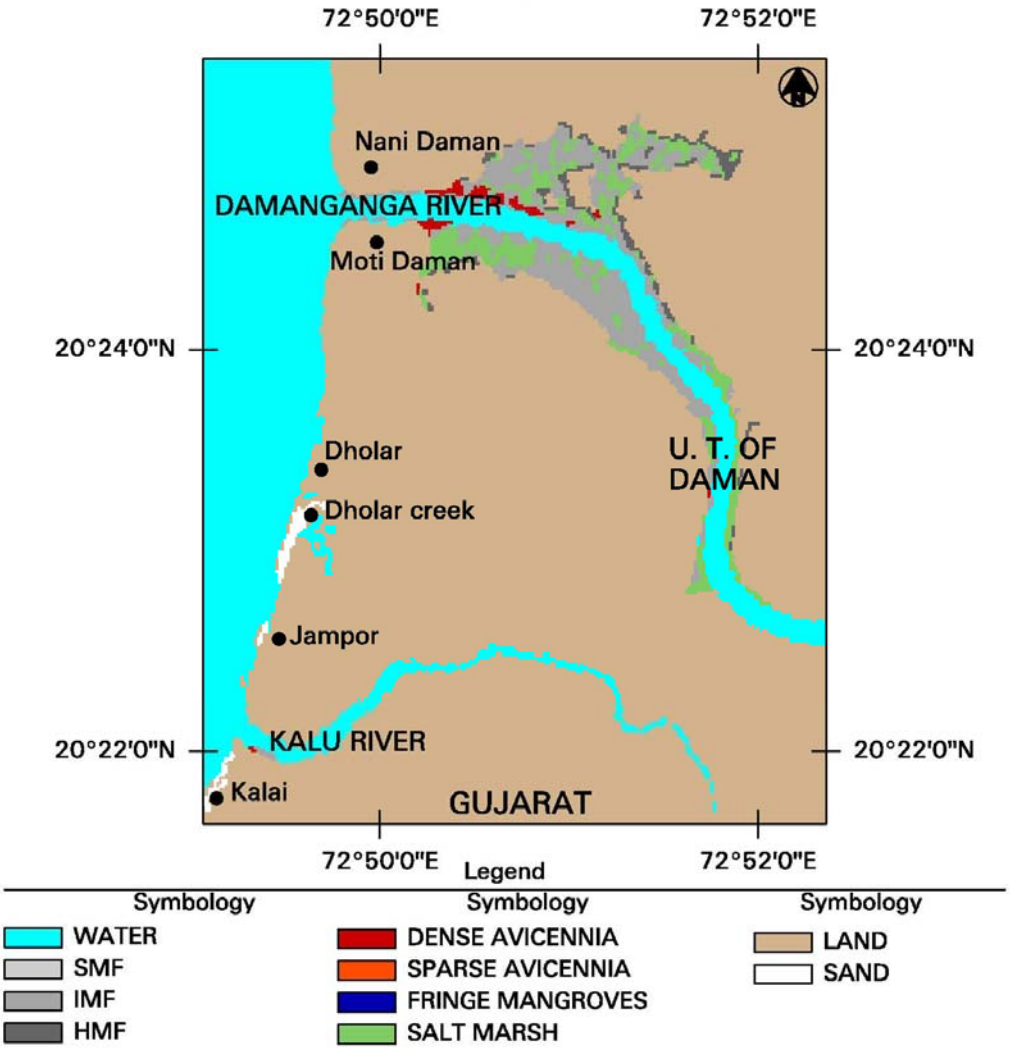


Figure – 7.15 Community map of Damanganga and Kalu wetland (1999)

area of Damanganga estuary. *Avicennia officinalis* is also observed along the patch of mangroves at Dholar creek, south to the Damanganga River.

Salt marsh

The salt marsh vegetation of Damanganga estuary forms the major area occupying category and it comprises mainly of *Aleuropes lagopoides*, *Sesuvium portulacustrum* and *Suaeda sps. Clerodendron inerme* was

observed at its preferred position, along the creeks, on the southern flank of Damanganga wetland.

Sr. no.	Community	Area (in Ha.)
1	*Avicennia marina* dense	10
2	*Avicennia marina* fringe	16
	Sub-total	**26**
3	Salt marsh vegetation	83
	Total	**109**

Table – 7.29 Areal extent of different communities of coastal wetland of Damanganga

Sr. no.	Community	Area (in Ha.)
1	*Avicennia marina* dense	0.25
	Total	**0.25**

Table – 7.30 Areal extent of different communities of coastal wetland of Kalu

COMMUNITY ZONATION OF MANGROVES OF VAROLI COASTAL WETLAND

Avicennia community

Varoli estuary forms the southern most estuary of study area. The distribution of mangroves here is patchy and scattered throughout the expanse of the wetland area (Figure 7.16). This estuary also, like rest others of the study area, is dominated by *Avicennia marina*. Dense and sparse categories of *Avicennia marina* occur throughout the estuary (Table - 7.31). The height of dense *Avicennia marina* here ranges from 2 – 7 m. the sparse category has height range of 2 – 3 m. A small but mature patch of *Avicennia marina* at Nargol, is of the height range 3 – 6 m, but is not separated as a class on the map as the mangroves are found growing at a distance rather then growing together, in a cluster.

Other categories

Excoecaria agallocha and *Lumnitzera racemosa* were two additional species which were recorded for the first time in this area. Although they form a pure patch, however the patch is not big enough to be distinguished from the surrounding areas, as it covers very small area. Both these mangroves are present as the back mangroves. *Excoecaria agallocha* shows height range of 3 – 5 m and a single large *Excoecaria agallocha* of about 8 m was observed at one instance. The height of *Lumnitzera racemosa* is about 1 – 2 m. trees of *Sonneratia apetala* (2 – 5 m) are also present in Varoli estuary, which again do not form pure patch. *Aegiceras corniculatum* is another mangrove species which is observed growing towards the creek ends of wetland. It shows good growth in terms of height, of about 2 m, as compared to the smaller patches observed else where in the study area. Scattered A*canthus ilicifolius* is observed on the relatively open patches of the wetland, intermingling with the sparse *Avicennia marina. Avicennia officinalis* is another mangrove species observed mixed with *Avicennia marina* at few of the patches.

Salt marsh

The salt marsh category occupies the largest area coverage in Varoli estuary. Here the wetland area is not profusely inhabited by the mangroves, which gives scope of growth of the salt marsh vegetation almost throughout the estuary. The salt marsh vegetation is usually dominated by the species of *Aleuropes lagopoides, Derris trifoliata, Clerodendron inerme, Sesuvium portulacustrum, Suaeda fruticosa* and *Suaeda nudiflora* can be

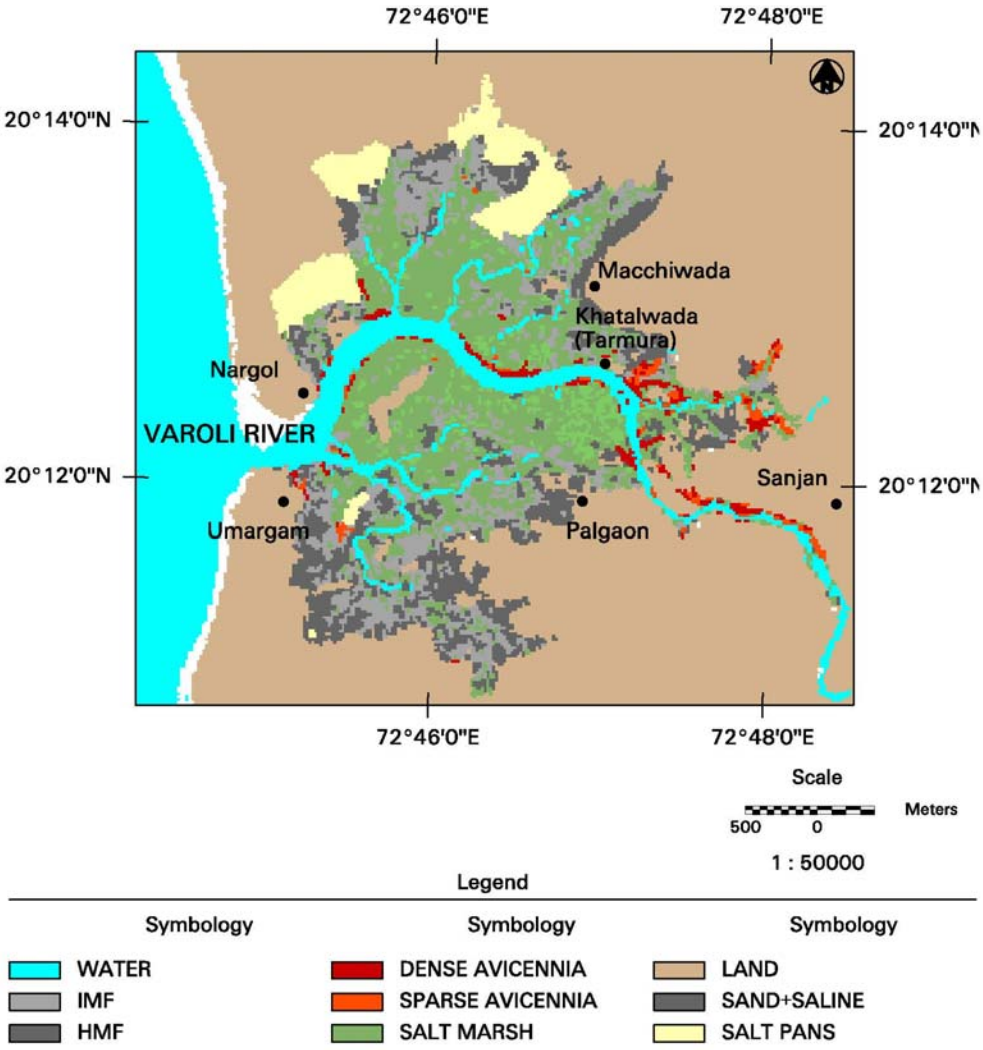


Figure – 7.16 Community map of Varoli wetland (2001)

observed. *Aleuropes lagopoides* is also observed in the transitional zone from the mangrove to non-mangrove category. *Portresia coarctata* was observed at places on the fringe of the wetland.

Sr. no.	Community	Area (in Ha.)
1	*Avicennia marina* dense	40
2	*Avicennia marina* fringe	24
	Sub-total	**64**
3	Salt marsh vegetation	636
	Total	**700**

Table – 7.31 Areal extent of different communities of coastal wetland of Varoli

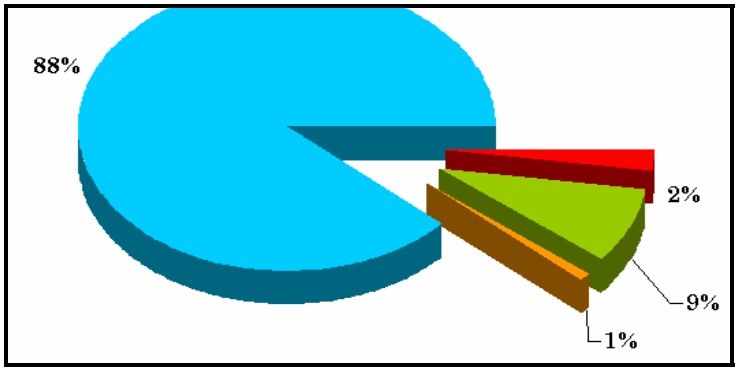
Thus, although *Avicennia marina* dominated most of the estuaries, following categories were also demarcated on the community zonation map of coastal wetlands of south Gujarat.

1. *Avicennia marina* community
2. *Acanthus ilicifolius - Derris trifoliata*
3. *Avicennia marina – Sonneratia apetala – Acanthus ilicifolius* community
4. *Avicennia marina – Derris trifoliata – Clerodendron inerme* community
5. *Acanthus ilicifolius* community
6. Mixed sparse community

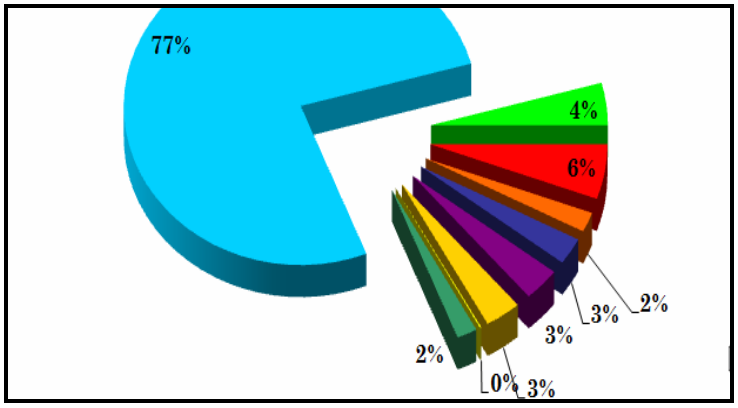
Avicennia marina community was predominantly present over all the estuaries and covered the maximum area. Dense, sparse and fringe categories of *Avicennia marina* community could be mapped at most of the coastal wetlands. The *Acanthus ilicifolius* and *Derris trifoliata* community was observed at Mindhola estuary only. This community was found growing profusely on the drier mudflats of Mindhola estuary.

Since the diversity of Purna estuary is more and as the mudflat area is also extensive, many communities could be mapped here. *Avicennia marina – Sonneratia apetala – Acanthus ilicifolius, Avicennia marina – Derris trifoliata – Clerodendron inerme, Acanthus ilicifolius* and mixed sparse community are observed on the coastal wetland of Purna estuary. This suggests not only dominance of *Avicennia marina* but also co-dominance of

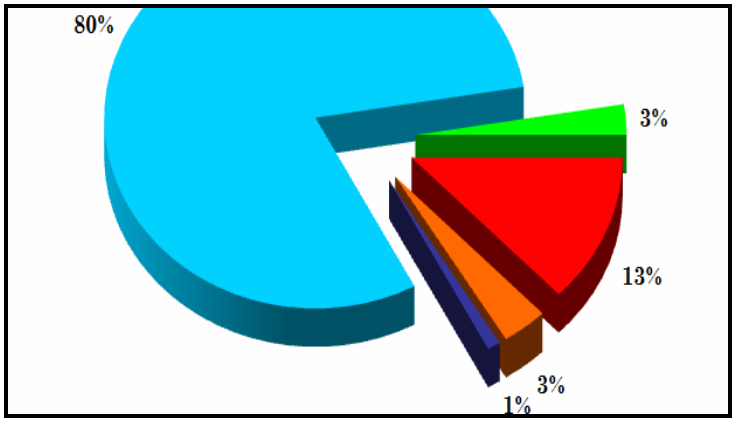
mangroves *Sonneratia apetala* and *acanthus ilicifolius* along with that of mangrove associates *Derris trifoliata* and *Clerodendron inerme*. Also due to the heterogeneity, mixed sparse category was classified as a separate community which mainly comprises of *Avicennia marina, Acanthus ilicifolius* and salt marsh vegetation. Apart from rest all species of salt marsh vegetation, which co-existed, *Porteresia coarctata* also showed prominent spatial distribution, especially on the fringes of channel bars as well as the mudflats of most recent origin, especially when they are still barren. Ambika estuary does harbor diverse mangroves but the distribution is patchy. Moreover, mangroves ecosystem here is not as mature as that of Purna estuary (on the basis of height and girth of mangroves). Hence, due to not enough canopy expanse also not all the species stood out in the community maps. *Avicennia marina* was the only mangrove community which could be mapped. The diversity of all other coastal wetlands – Auranga, Par, Kolak, Damanganga – Kalu and Varoli estuary dominantly comprises of *Avicennia marina*. Hence, only this community could be mapped. Although diversity of Varoli estuary is highest in the south Gujarat region, the mangroves here are patchy and scattered. Hence, the diversity of this region could not be translated on the community zonation map. Plates 7.26 to 7.28 shows the percentage composition of different mangrove communities of the coastal wetland of south Gujarat.



Mindhola



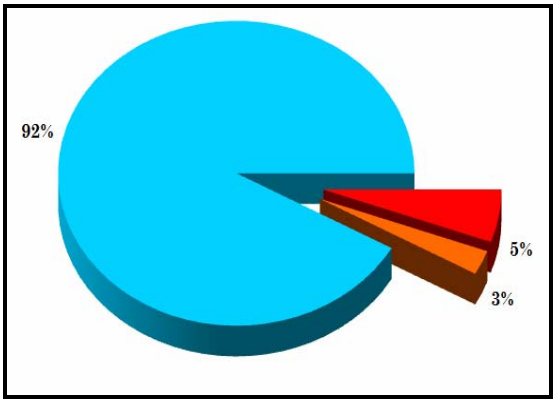
Purna



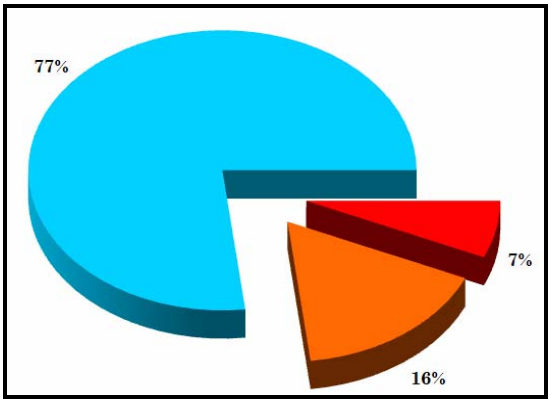
Ambika

- Avicennia marina dense
- Avicennia marina sparse
- Avicennia marina fringe
- Avicennia – Sonneratia – Acanthus
- Avicennia – Derris – Clerodendron
- Acanthus ilicfolius
- Mixed sparse
- Salt marsh vegetation
- Portresia
- Dense Acanthus ilicifolius & Derris trifoliata

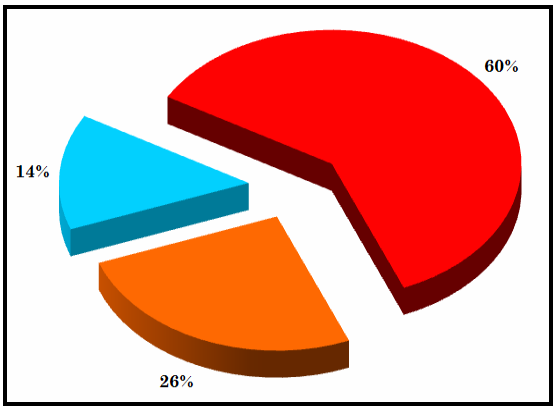
Plate 7.26 - Composition of mangrove community categories in south Gujarat



Auranga



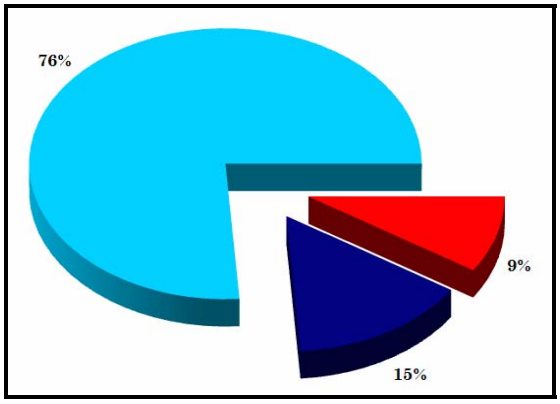
Par



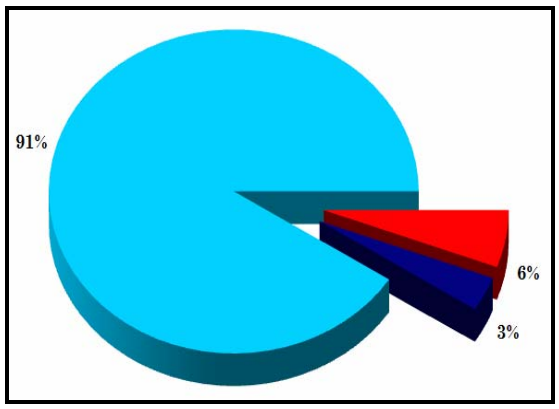
Kolak

■ Avicennia marina dense ■ Avicennia marina sparse ■ Salt marsh vegetation

Plate 7.27 - Composition of mangrove community categories in south Gujarat



Damanganga



Varoli

Avicennia marina dense Avicennia marina fringe Salt marsh vegetation

Plate 7.28 - Composition of mangrove community categories in south Gujarat

Thus, it is very apparent that overall composition of mangroves of south Gujarat is dominated by single species *Avicennia marina and at places by Sonneratia apetala* and *Acanthus ilicifolius*. However, worth mentioning is the occurrence of the newer species for the region as well as for the state of Gujarat – *Ceriops tagal, Rhizophora mucronata* and *Bruguiera cylindrica, Lumnitzera racemosa* and *Excoecaria agallocha.*

However sadly enough, in the current scenario, they do not form a spatially big enough patch to be mapped and are thus not observed as a category or class on any of the community maps.

Accuracy assessment was carried out to check the accuracy of the community maps prepared (Table – 7.32).

Sr. No.	Data/year	Producers Accuracy	Users Accuracy	Overall Classification Accuracy	Kappa Statistics
1	Mindhola 2001	89%	90%	90%	0.86
2	Purna 2005	93%	87%	86%	0.81
3	Ambika - Auranga 2005	94%	88%	94%	0.87
4	Par 2005	91%	100%	89%	0.87
5	Kolak 2001	87%	92%	92%	0.89
6	Damanganga - Kalu 1999	96%	91%	95%	0.92
7	Varoli 2001	96%	86%	94%	0.81

Table – 7.32 Accuracy and Kappa statistics of community maps of the costal wetlands of the south Gujarat

7.4 GEOMORPHOLOGICAL SETUP AND CHANGES OVER 4 DECADES

The estuarine geomorphology is usually governed by various factors. When the base data was compared with that of the recent most available, many changes were observed, especially in the river mouth areas – with development of numerous channel bars. This was observed particularly in case of the rivers Purna and Ambika rivers, which are the larger rivers of this region. A major aspect of the present day estuarine environment of the most of the rivers is that they harbor mangrove and salt marsh vegetation.

Mudflats, salt marshes and mangroves are significant and their importance has been described in earlier chapters. Geomorphologically, they are locations of fine sediment build up and preserve a record of changing environments within their sediments (Woodroffe, 2002).

For this reason, the assessment of the geomorphic changes along the study area in the past 40 years was taken up. These studies were focused more along the estuarine area of river Purna, as major changes have been observed here. Reconstruction of the sequence of mangrove-habitat expansion along with the parallel formations of the channel bars from the available satellite images over the last 40 years offers a prominent insight into this.

As described earlier, mangroves are endowed with the ability of soil accretion. A plant belonging to the grass category has been observed in many of the locations in study area. This plant, *Portresia coarctata* is believed to be the pioneer vegetation of the mangrove community. It starts

with accretion of soft mud and gradually, is replaced by the mangrove vegetation, which with their specialized root systems, binds the soil and builds up the area. *Portresia coarctata* has unique signature, due to which it is easy to identify it on the satellite data. The same vegetation has also been observed in the earlier satellite data's (1972, 1978), when there was very little occurrence of mangroves in the areas and no channel bars in most of the river's channels. It is thus believed, in the study area, that *Portresia coarctata* initiated land building, which was gradually taken up by the mangroves present then. Later on, the mangroves, with its root systems, enhanced the capacity of land accretion, which facilitated areas for other mangroves to grow; thus leading to mangrove-habitat expansion and related geomorphological changes.

General observations

The geomorphology of the South Gujarat coastline is that of a prograding shoreline. The shoreline profiles of all the rivers typically reveal relicts of the Flandrian high strandline. The shoreline here is essentially controlled by two strandlines, the higher one during the Flandrian and the lower one of the present day.

The Flandrian transgression had caused the drowning of the coastline formations of estuarine river creeks. The beaches are present day deposits brought about by wave actions and long shore currents on the sediments derived from inland as well as near-shore (Joottun et. al., 1982).

The area behind the shoreline is covered by a thick alluvium (50-200 m) & these deposits owe their origin to various large rivers flowing from the east. Various features observed in this area i.e., alluvial plain, flood plain, terraces, point-bars, meanders & abandoned channels. Shoreline features observed typically represents a drowned alluvial coast. The present configuration is due to the last marine transgression, which stabilized 6000 years B.P. (Vashi and Ganapathi, 1982)

Tidal flats

Tidal flats are observed along all the estuarine area. They are the horizontal mud deposits, characterizing the present day intertidal zone. They essentially comprise a land feature that ideally reflects a receding sea level which, during the early Holocene, had risen several meters and had given rise to numerous estuaries, behind the barrier ridge complex. These mudflats are constantly under the influence of tides and are thus featureless mud accumulations, controlled by mixed environment. The areal extent of these flats vary from few meters of width as at Kolak to about two – six kilometers, as in case of Purna, Ambika. The mud flats are generally invaded by the halophytic plants, which is comprised of the mangroves and or the salt marsh vegetation.

The river borne sediments are trapped in the estuaries by the predominantly landward flow of estuarine bottom waters (Meade, 1969). The river channels contribute enormously to the development of these flats. Channels often rework their deposits and results in the change of the morphology of the tidal flats.

The raised tidal flats are the higher tidal flats which receive very little tidal inundation, and thus are more or less stabilized. They are generally devoid of the mangrove vegetation and mostly are occupied by the salt marsh vegetation or at times *Prosopis*.

Relict alluvial features

This form one of the most striking features of the coastal areas. They are the islands of thickly vegetated and fertile alluvium within the barren mudflats. They typically comprise of the relicts projecting from the dissected alluvial terrain which was submerged under the tidal waters of a Flandrian sea. They are raised features compared to the surrounding tidal flats. They are results of the geological events that took place during the Quaternary period. During the last glacial stage, when the sea receded about 20m below the present mean sea level, the rivers deposited huge alluvial deposits in the coastal zones and during the Flandrian transgression the low lying alluvial areas that were submerged, were gradually filled with tidal sediments. Tidal creeks criss - crossed this area resulting in mud deposits gradually filling these areas, hence the relict features are now surrounded by old mudflats.

Such features are observed along all the estuaries of the study area, except at Kolak and Kalu River. However, they are much more prominent and more in number between the stretch of Ambika and Auranga river. A discontinuous patch of about eight kms is present over here. These features have not undergone any change over the time.

Channel morphology (mouth region)

The width of the channel increases in the coastal plains. The channel morphology in the estuarine region generally shows very little meandering. However, meanders are observed along the estuarine areas of Purna, Ambika, Auranga and Varoli, as the tidal expanse here is more compared to the Par, Kolak, Damanganga and Kalu River, which lack meanders in the tidal region.

Point bars

All the major rivers show presence of the point bars. They are the depositional features, related to the meandering of the channels and are generally crescentic in shape, found on the inner side of the meanders. They are formed by the slow accretion of the river materials and accompanying the migration of the meanders. They are resultant of the redistribution of the sediments eroded from the outer side of the meanders and later on deposited on the inner side as the point bars.

Channel bars

The major rivers of the study area, such as Purna, Ambika and Auranga, show presence of channel bars. They are found in the middle of the channels and alter the morphology of channel from being barren to braided or anastomosing. When the transportation capacity of the river diminishes, the sediments are deposited in the middle of the channels. They act as trap for other sediments and gradually grow up in size. They become permanent features upon stabilization.

These channel bars are present in abundance in the estuarine area of the rivers Purna, Ambika and there extent is such that they perhaps form the most conspicuous features of all.

The observations have been discussed estuary wise for the ease of study, as not all estuaries show same changes, and the estuarine areas of the smaller rivers have remained mostly unchanged, except for stabilization of the tidal flats by the mangrove vegetation. However, work was not carried out for Mindhola estuary as it was not possible to ground truth enough geomorphic features for this estuary.

GEOMORPHOLOGICAL SET-UP OF PURNA ESTUARY

Geomorphology of Purna estuary is perhaps the most interesting in the entire study area, as many changes have been observed in the estuarine region of this area.

OBSERVATIONS OF 1965

The historic data, SOI toposheet of 1965, shows presence of three distinct zones with distinct channel morphology - an upstream river dominated zone, a central mixed energy zone and a seaward marine dominated/estuarine zone (Figure 7.17). Majority of the estuarine area is the mudflat. The estuarine zone comprises of intertidal mudflats, sand beach, spits, tidal creeks and relict features. The lower most reaches of the river form extensive mudflats. Tidal waters reach the mudflats through a

dense creek network. The present day river mouth supports numerous channel bars.

OBSERVATIONS AND CHANGES FROM 1965 – 1978

Historic data of 1965 show presence of predominantly the tidal zone but it shows the absence of any channel bars at the river mouth. The geomorphological setup as observed from the satellite image of the year 1978 shows a little deposition in form of a narrow elongated bar (Figure 7.18). As far as the mangrove vegetation is concerned, map of 1978 suggests that the mangroves at this date mainly colonized the mudflats of the river on the northern as well as southern flank and to a small extent had colonized the incipient bars as well

OBSERVATIONS AND CHANGES FROM 1978 – 1988

The geomorphological setup observed from the satellite image of the year 1988 however shows augmented deposition, where two prominent channel bars can be observed (Figure 7.19). Also it can be observed that the sandy beach on the northern flank now terminates into a prominent spit. This intermediate date of 1988 supports the fact that the mangroves are augmenting the accretion processes. This date shows that the channel bars which were showing presence of very small patch mangrove have now increased in the extent with concurrent increase in the expanse of the mangroves. This process of colonization can be direct result of estuarine sedimentation coupled with the mangrove induced accretion and thus further expansion. Most important thing to be noticed here is the mudflats

occupied by *Portresia coarctata* have been gradually colonized by the mangrove vegetation.

OBSERVATIONS AND CHANGES FROM 1988 – 2003

The geomorphological setup of the year 2003 offers a view on presence of numerous channel bars and same have been confirmed during the ground surveys as well (Figure 7.20). The formation of these channel bars has led to the braiding of the channel which was earlier straight, in the estuarine region. The observations from the map of 2003 shows that these mangrove habitats have now expanded which now mainly colonize the numerous channel bars formed in the recent past.

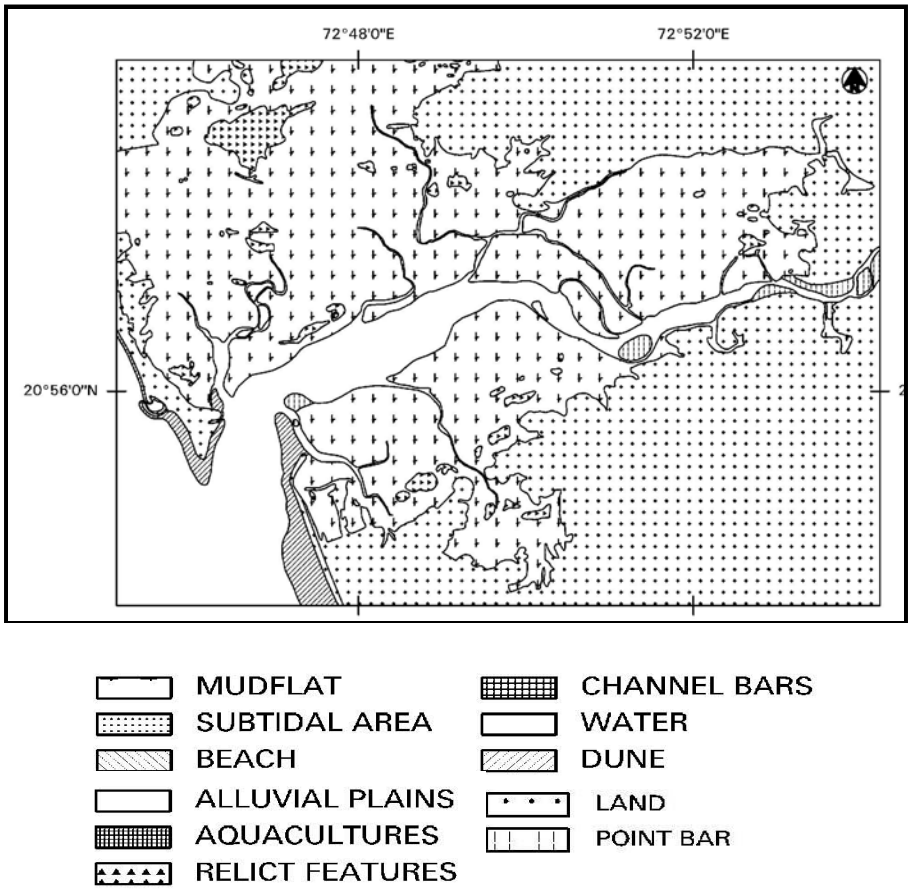


Figure 7.17 – Geomorphological map of Purna estuary - 1965

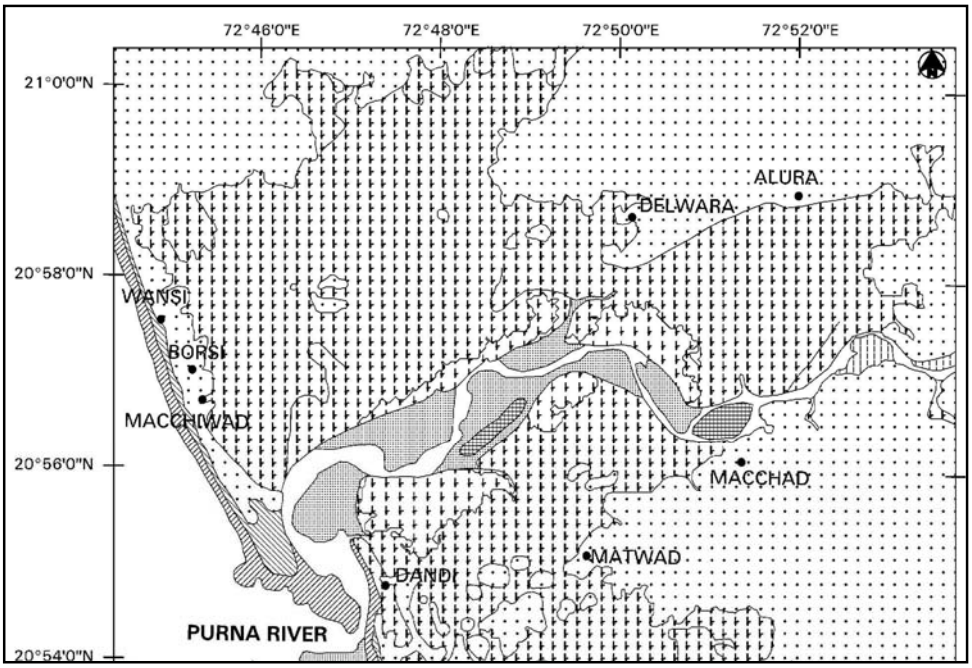


Figure 7.18 – Geomorphological map of Purna estuary - 1978

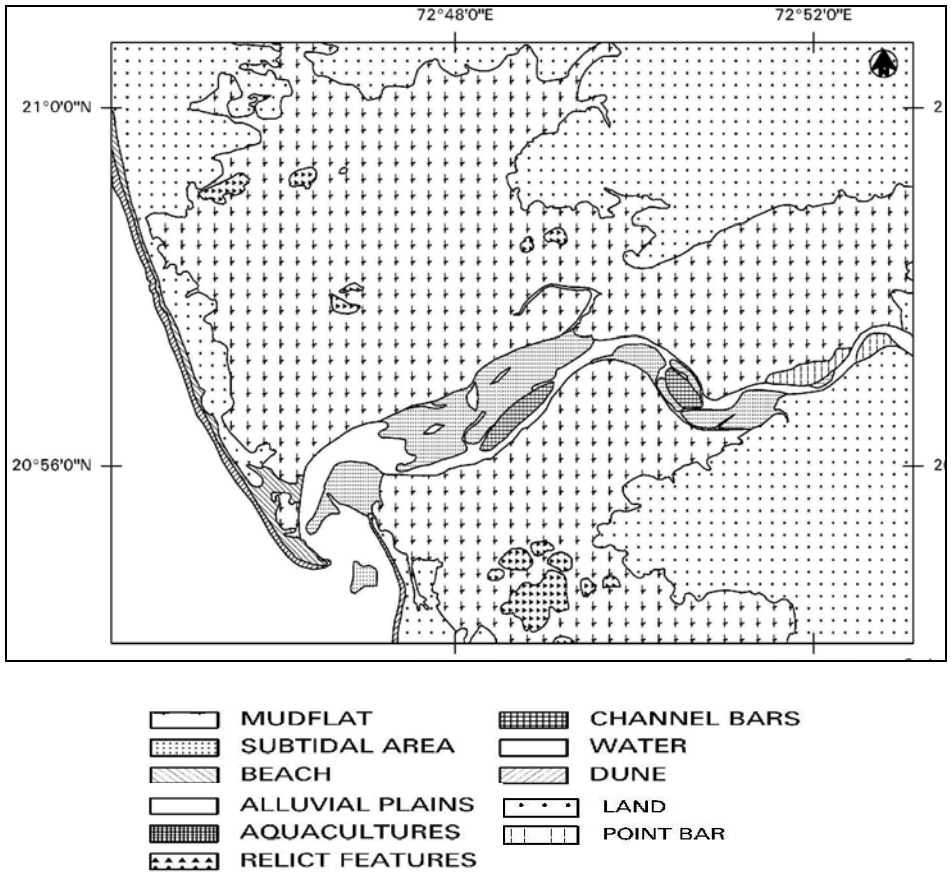


Figure 7.19 – Geomorphological map of Purna estuary – 1988

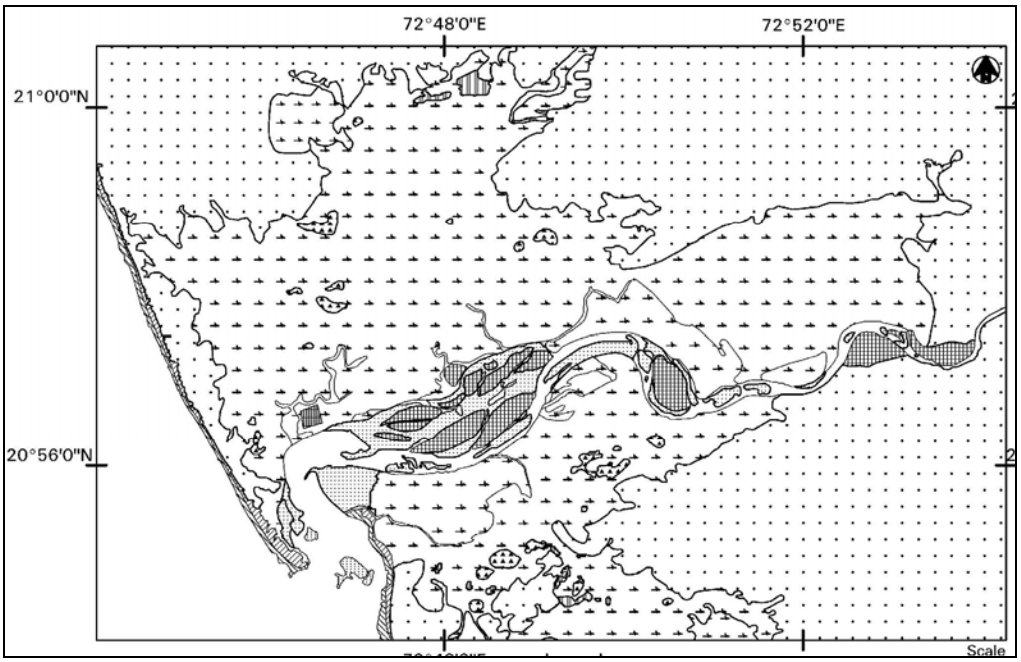


Figure 7.20 – Geomorphological map of Purna estuary - 2003

MUDFLAT
SUBTIDAL AREA
BEACH
ALLUVIAL PLAINS
AQUACULTURES
RELICT FEATURES
CHANNEL BARS
WATER
DUNE
LAND
POINT BAR

GEOMORPHOLOGICAL SET-UP OF AMBIKA – AURANGA ESTUARY

OBSERVATIONS 1965

This data, unlike in case of Purna river, shows presence of few channel bars (Figure 7.21). Nevertheless, all these bars are still incipient, unstabilised, and devoid of any kind of vegetation. This can be said from the changes in their position and morphology as observed from the 2001 data.

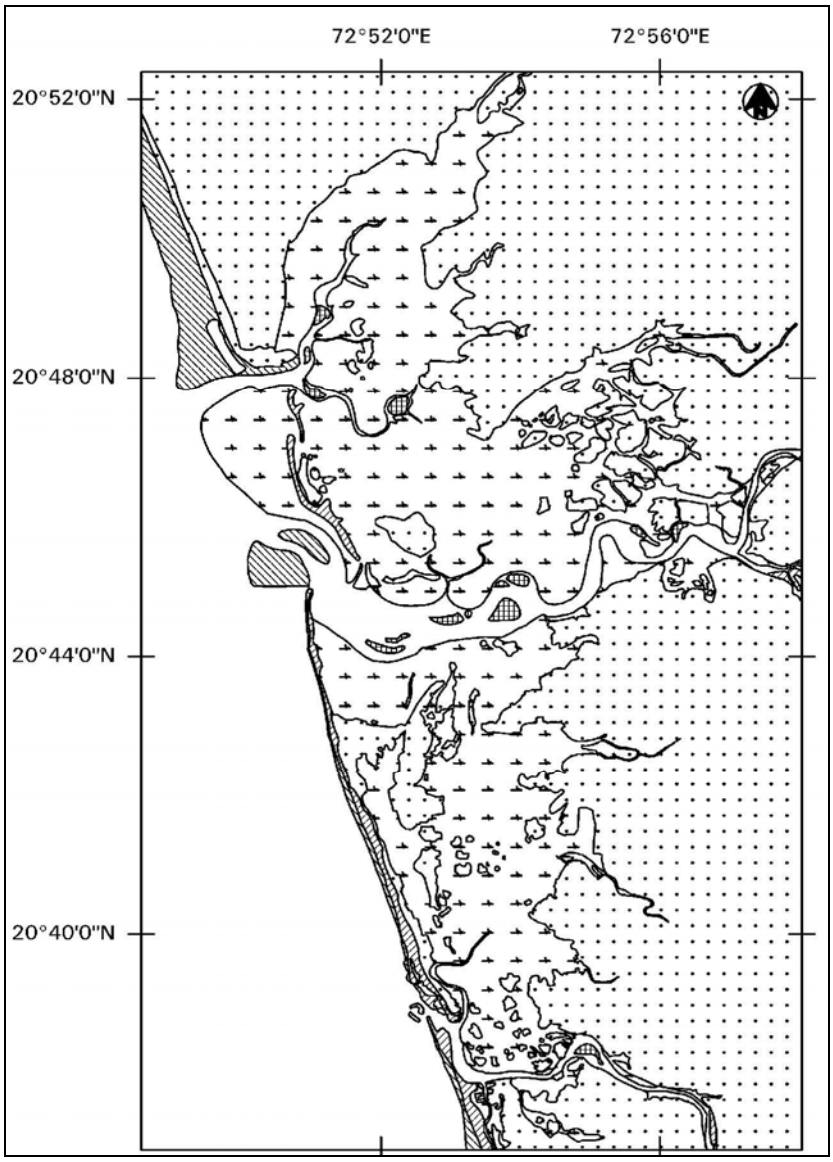


Figure 7.21 – Geomorphological map of Ambika - Auranga estuaries - 1965

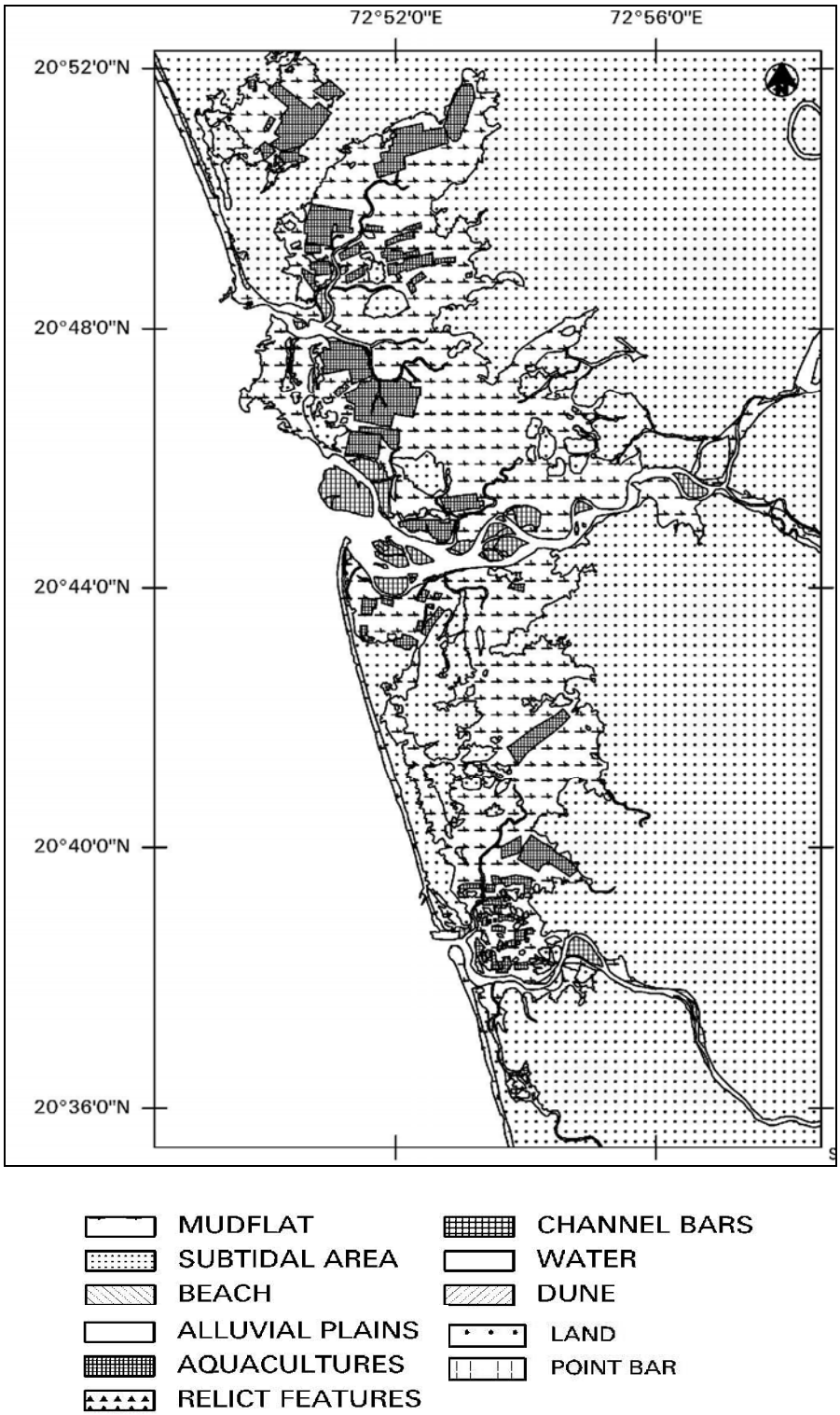


Figure 7.22 – Geomorphological map of Ambika - Auranga estuaries

- 2005

OBSERVATIONS AND CHANGES FROM 1965 – 2005

The satellite data of 2005 shows many changes in the estuarine area of the Ambika River (Figure 7.22). The meanders that were not so prominent are notably seen. In addition, the shoal structures which were inconspicuous in 1965 are very prominent now. Moreover, many of these channel bars are now harbored by mangrove vegetation.

Most of the channel bars have now stabilized and shows presence of mangrove vegetation. A mouth bar present at the region off Bhat village however shows shift in this duration, besides being harbored by mangrove vegetation.

An anthropogenic modification of the tidal flats can be observed in the 2005 data, where there are numerous aquaculture and salt pans present.

GEOMORPHOLOGICAL SET-UP OF PAR ESTUARY

OBSERVATIONS AND CHANGES FROM 1965 - 2005

Estuarine area of par is relatively small, with very little tidal expanse (Figure 7.23, 7.25). There were no changes observed in the estuarine region per-se, except here too one can see the presence of mangrove vegetation on the mudflats, especially on the northern flank.

GEOMORPHOLOGICAL SET-UP OF KOLAK ESTUARY

OBSERVATIONS AND CHANGES FROM 1965 - 2005

Kolak forms small estuarine area as well (Figure 7.24). Here too, when the recent data (2005) is compared with the historical data, the

geomorphological changes were not discerned, except for the growth of mangroves in the estuarine region (Figure 7.25).

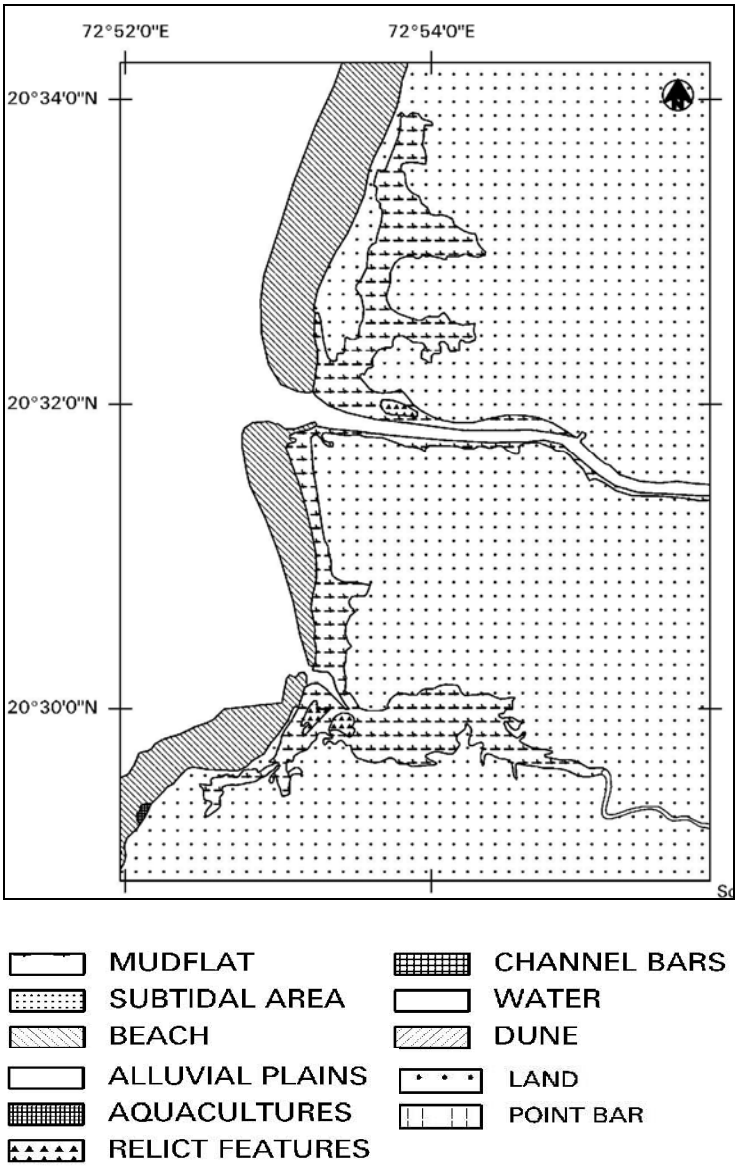


Figure 7.23 – Geomorphological map of Par estuary - 1965

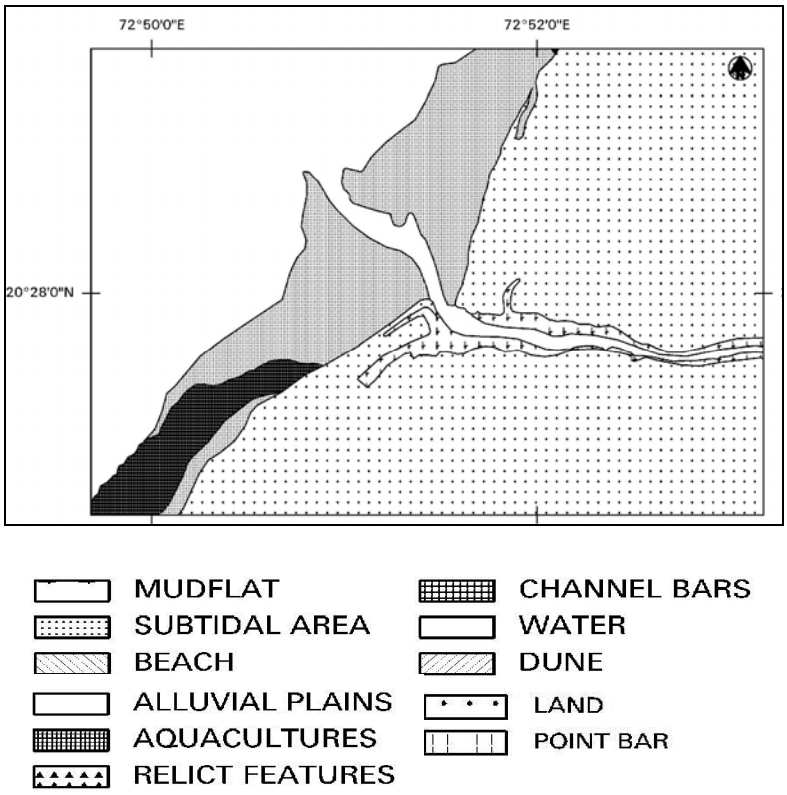


Figure 7.24 – Geomorphological map of Kolak estuary - 1965

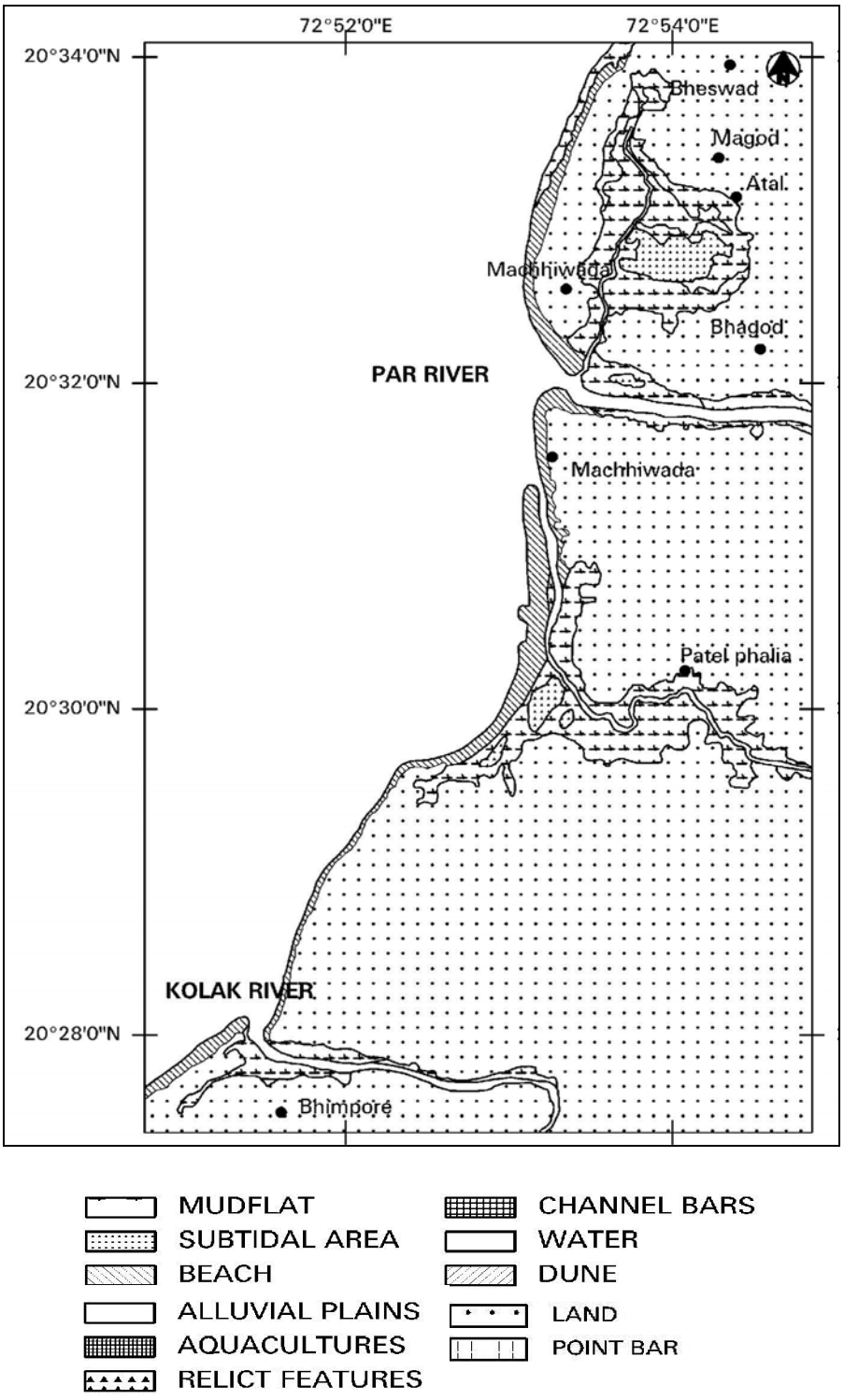


Figure 7.25 – Geomorphological map of Par and Kolak estuary - 2005

GEOMORPHOLOGICAL SET-UP OF DAMANGANGA-KALU ESTUARY

OBSERVATIONS AND CHANGES FROM 1965 - 2001

Estuarine set-up of Damanganga – Kalu River too, like that Par and Kolak River, forms a small estuarine area (Figure 7.26). There were no remarkable geomorphological changes observed here when the 2001 data (Figure 7.27) was compared with the data of 1965. Nevertheless, again, the tidal flats in these rivers also support the mangrove vegetation.

GEOMORPHOLOGICAL SET-UP OF VAROLI ESTUARY

OBSERVATIONS AND CHANGES FROM 1965 - 2001

The estuarine area of Varoli River is relatively more, as compared to that of the river Par, Kolak, Damanganga and Kalu. However, this doesn't lead to any major geomorphological changes in the estuarine area of this river as well (Figure 7.28 & 7.29).

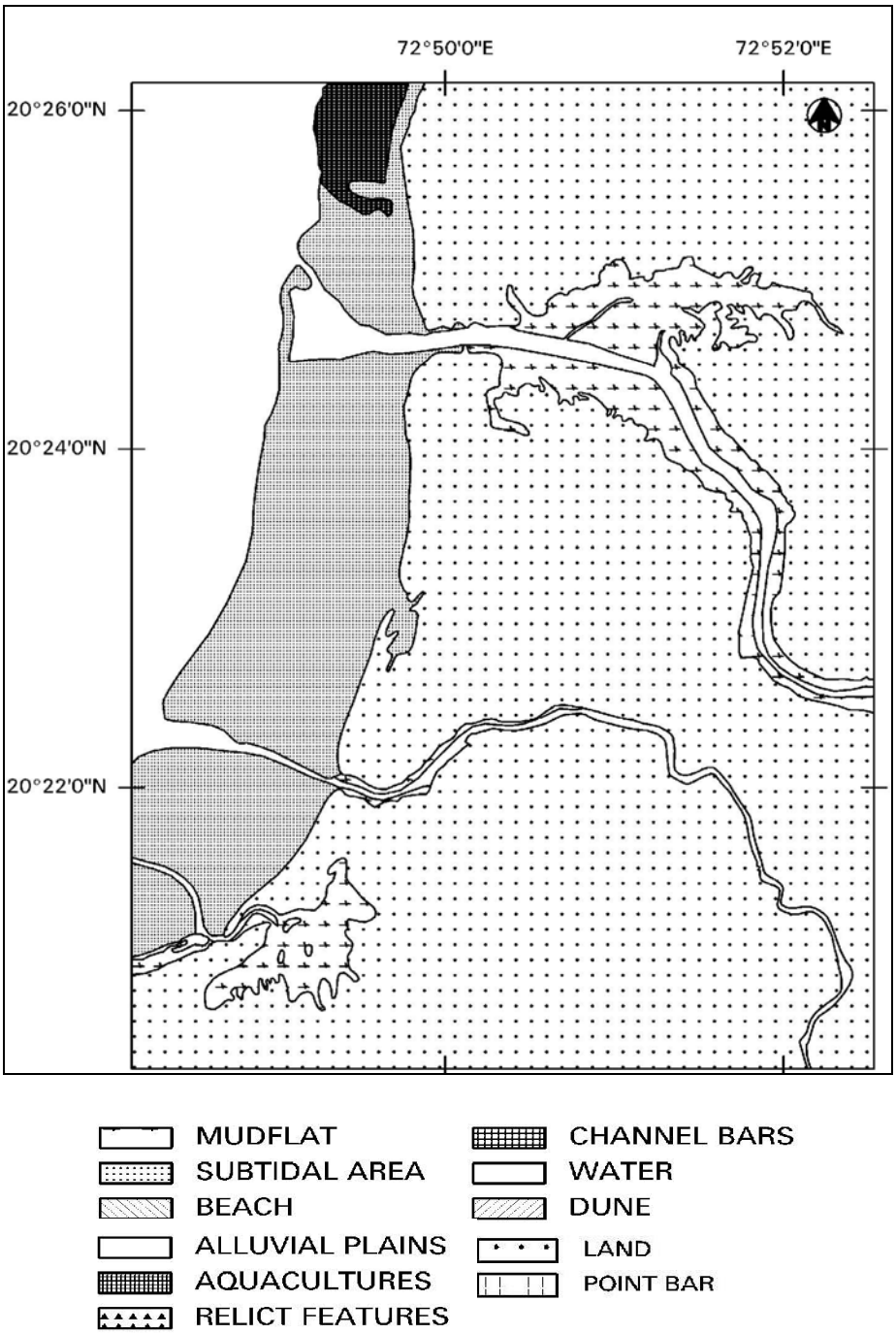


Figure 7.26 – Geomorphological map of Damanganga estuary - 1965

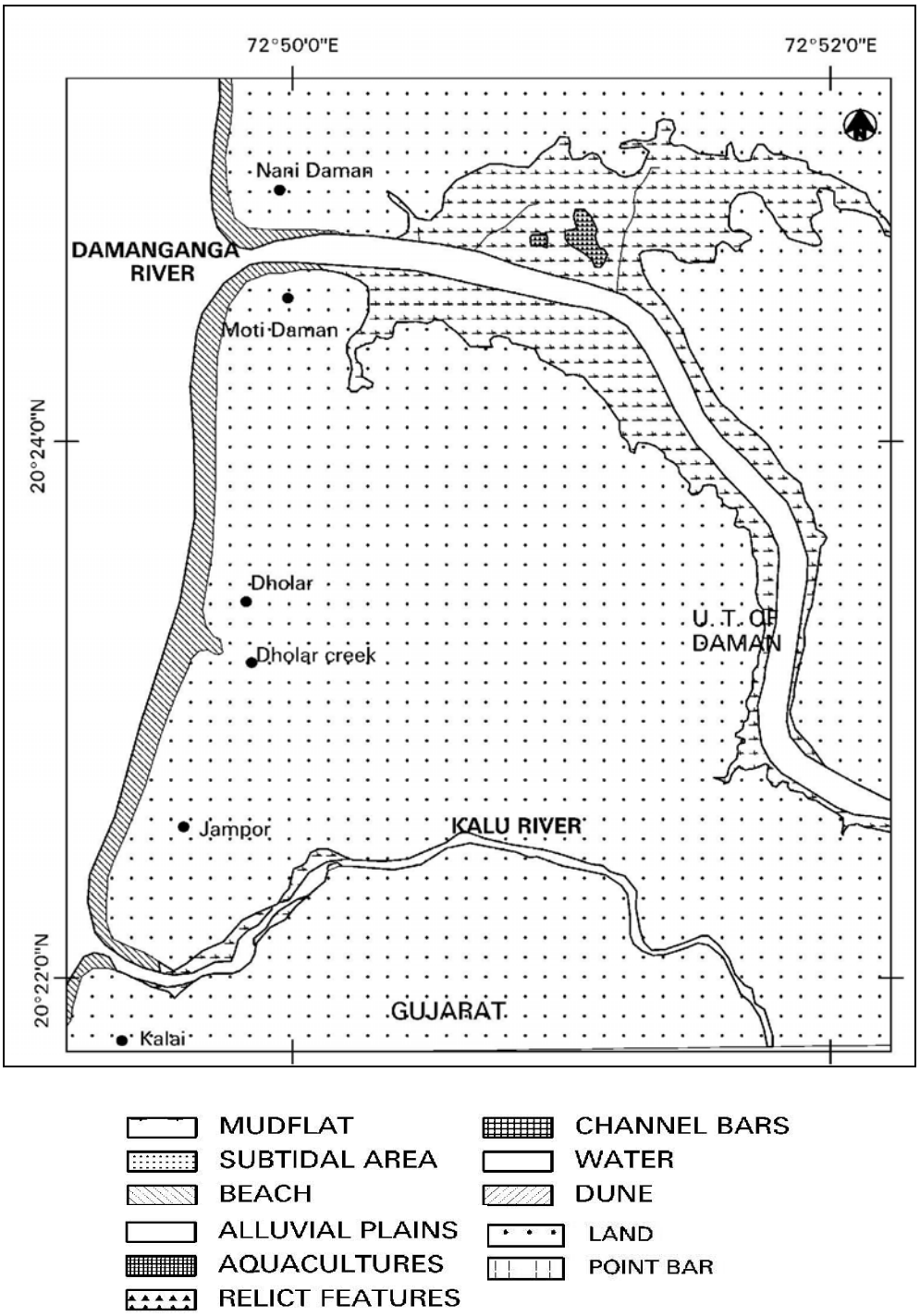


Figure 7.27 – Geomorphological map of Damanganga estuary - 2001

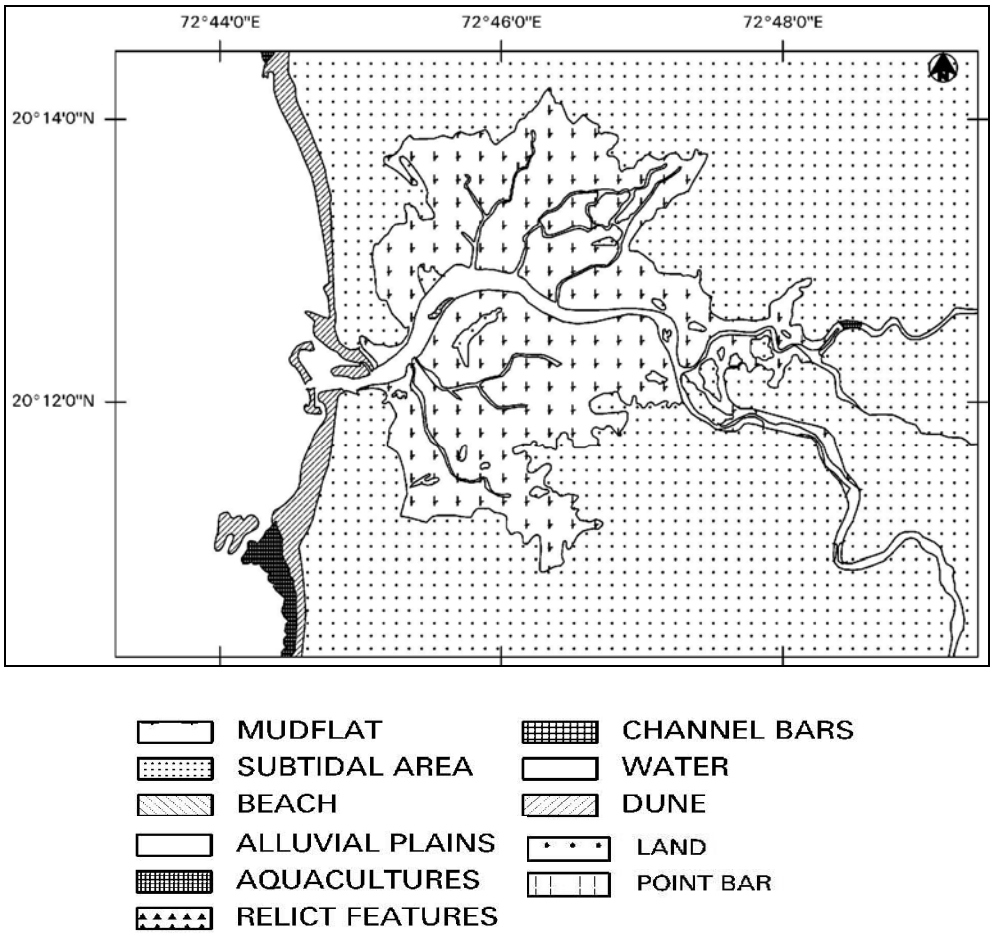


Figure 7.28 – Geomorphological map of Varoli estuary - 1965

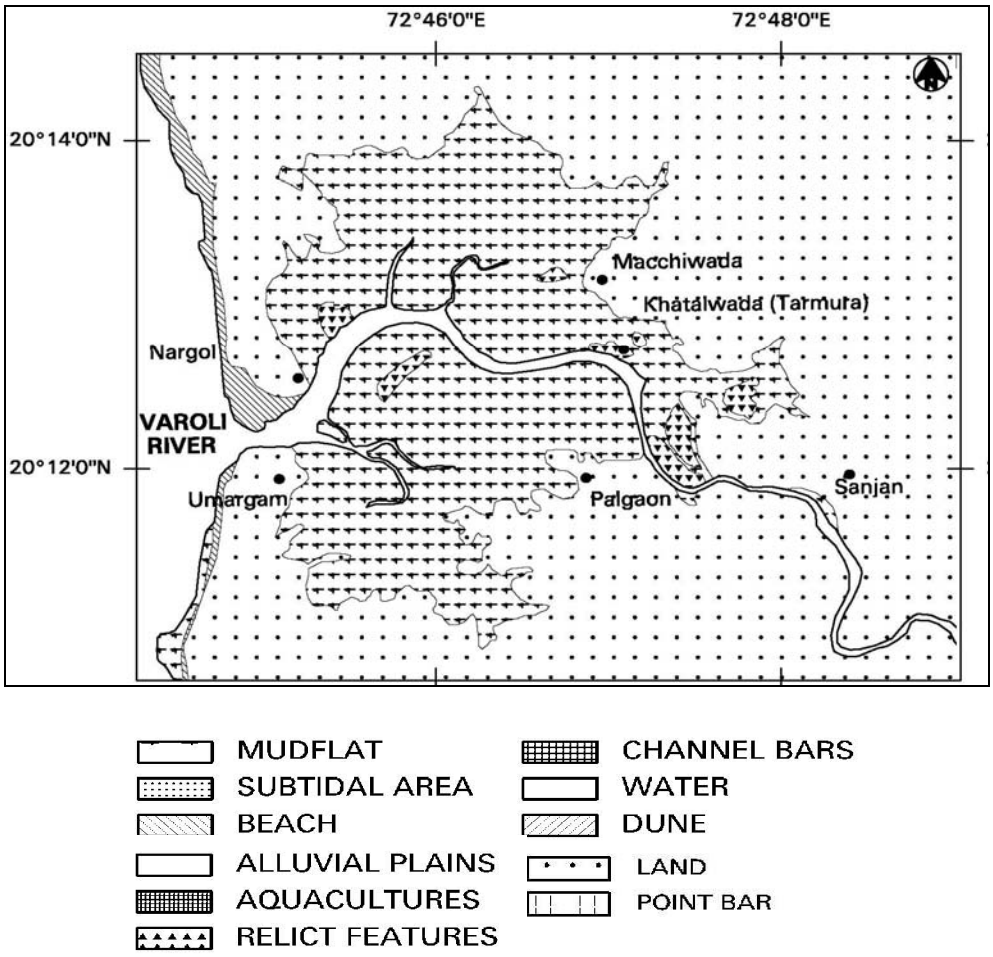


Figure 7.29 – Geomorphological map of Varoli estuary - 2001

It is justifiable by saying that the entire south Gujarat region is not undergoing uniform geomorphic changes. Moreover, the estuarine set-up of all the estuaries is varying. The coastal zone from Mindhola to Auranga is relatively straight and is dominated by the mudflats, showing a very narrow beach. The beach is flanked by backshore sandy ridge with unconsolidated aeolian sands. Through the mouths of these rivers, the tidal waters enter inland for several kilometers, resulting in the development of extensive mudflats behind the ridges. Raised or the hightidal mudflats are

commonly observed and the alluvial plains rise gradually above the mudflats.

The southern part of the study area, from Par to Varoli estuary is marked with almost continuous sandy beach and localized occurrence of mudflats along various river mouths. However, all these coastal deposits thin out, gradually, from south of Kolak, such that the lower fore-shore is more or less rocky and forms a basaltic platform over which rests relatively thin sand and mud deposits. The alluvial gradually thins out and towards the southern region, beyond Umargaon, the coast areas become rocky. This in turns reduces the estuarine/mudflat area of these estuaries.

Many changes have been observed to happen in the estuarine set-up, especially in that of Purna and Ambika estuary. Occurrence of the prominent tidal zones and the wider channel near the river mouth might be the reason for the changes in the estuarine region of Purna, Ambika and Auranga rivers. These changes are observed mainly in form of the development of the channel bars.

Numerous channel bars have found due to primarily redistribution of sediments and importantly also due to the accelerated accretion processes due to presence of the mangroves. It is observed during the older datasets (1978 for Purna and 1972 for Ambika) that newly accreted mud shows presence in the channel of the estuarine set-up. This mud starts shaping up as channel bars gradually. Plate 7.29 depicts the key geomorphological features of the south Gujarat estuaries.

Subtidal mudflat exposed during low tide

Estuary mouth and the intertidal mudflat

Hightidal mudflat

Channel bars

Plate – 7.29 Geomorphological features

7.5 CHANGE DETECTION

Post classification approach was used to determine the change in the area of various categories of the mangrove wetlands. Comparison analysis between the oldest available satellite data and the recent most available was carried out. The analysis was carried out in GIS interface as it allows analyzing large data sets in relatively easy manner. .

The comparison of multi dates covering time span of more than 30 years shows colossal changes in the mangrove and non-mangrove categories. Major changes have been observed on the mangrove wetlands of Purna and Ambika-Auranga. Thus, these areas were studied in details for change detection. One of the main reasons of the major change in these estuaries is the change in the geomorphology, remarkable increase in the extent of mangroves as well as setting up of many aquaculture ponds in these areas leading to major changes in the non-vegetated changes as well. Change detection of coastal wetlands of Mindhola, Par, Kolak, Damanganga and Varoli has been carried out in terms of areal extend from the prepared coastal habitat maps. GIS analysis for these wetlands has not been carried out, as not major changes were observed in terms of mangroves' area as well as otherwise.

PURNA ESTUARY 1978 – 2005

As described earlier, the SOI (surveyed in 1965) map of Purna estuary shows complete absence of mangrove vegetation throughout the entire estuarine environment of Purna River (Figure – 7.30). However, satellite

data for the year 1978 (Figure – 7.31) does show the presence of mangroves along the mudflats and the creeks. One can see the formation of islands taking shape in this particular date. The map of 1988 (Figure – 7.32) however shows that many of the islands harbor the mangroves, along with the patches present on the mudflats and along the creeks. However, the increase that can be observed in the satellite map prepared from 2005 year (Figure – 7.33) is most remarkable. It shows increase in the area of mangroves, especially on the islands, whereas mangroves along the mudflats abutting land area are diminishing,

Marsh vegetation

For the year 1978, the salt marsh vegetation has not been properly differentiated due to the coarseness of the spatial resolution of the data. In the satellite data for the year 2005, the salt marsh category can be distinguished and occupies the major part of the wetland area.

The change detection map is prepared between the data of 1978 and 2005 (Figure – 7.34).

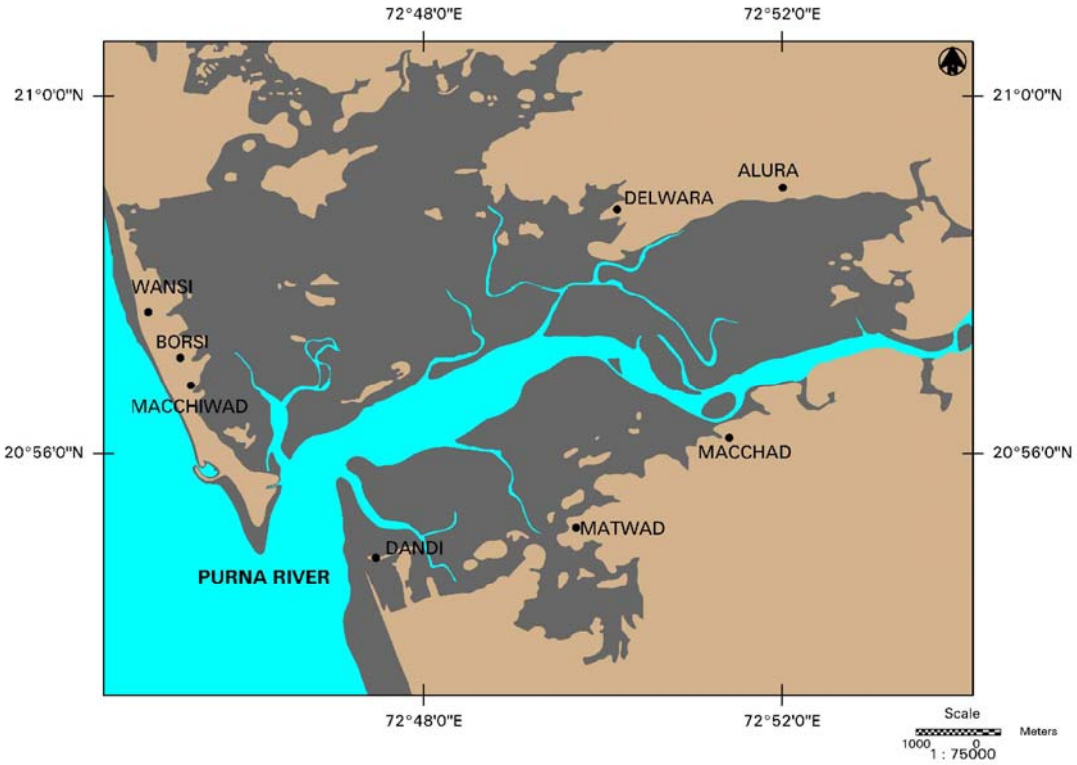


Figure – 7.30 Map of Purna - 1965

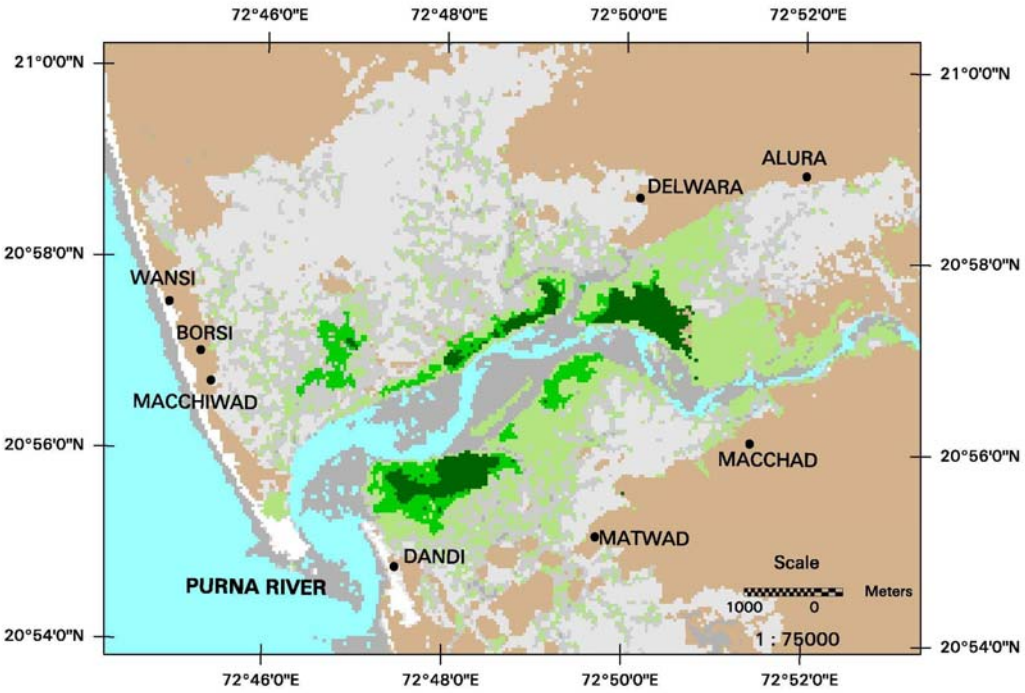


Figure – 7.31 Map of Purna - 1978

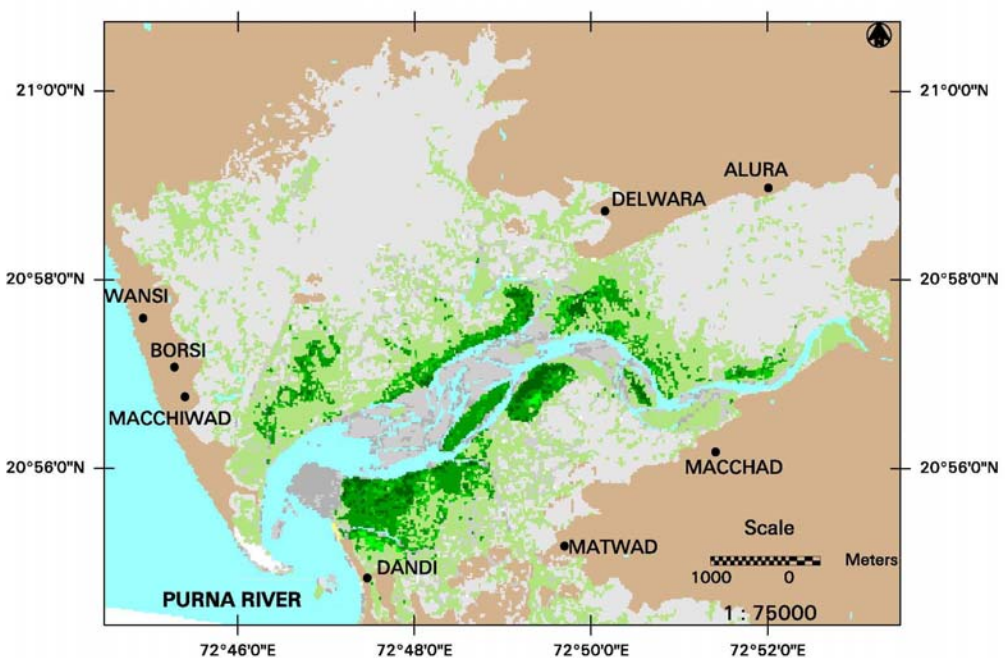


Figure – 7.32 Map of Purna - 1988

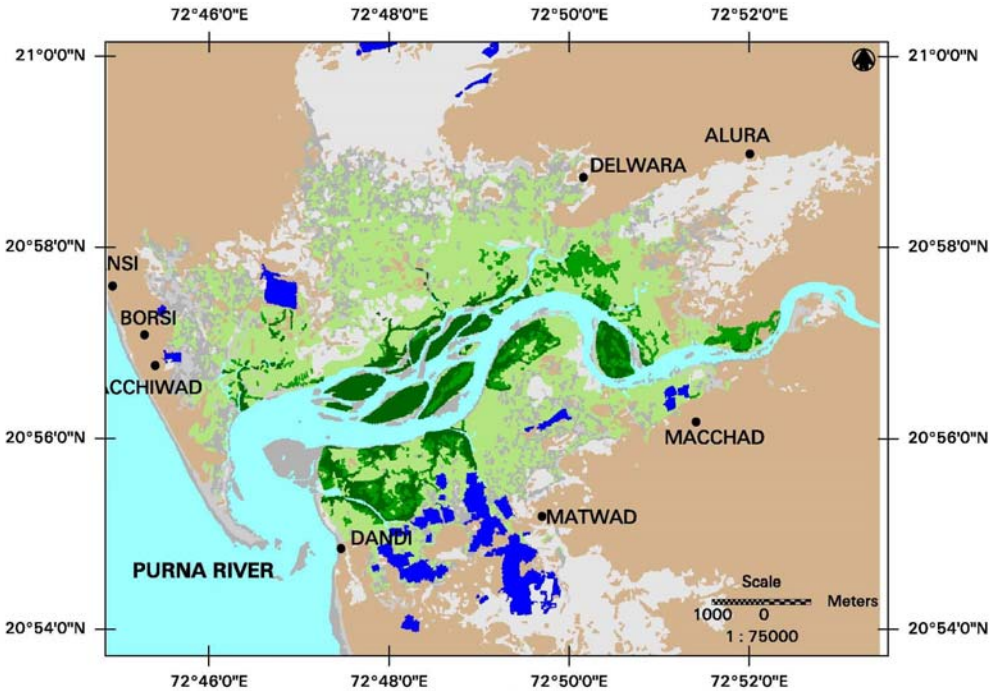
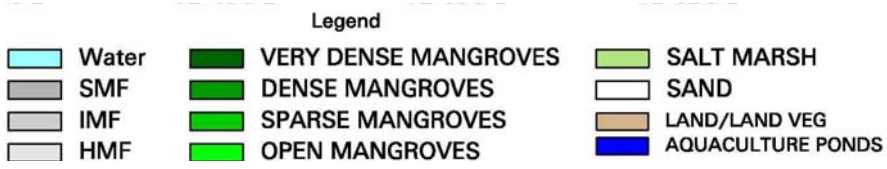


Figure – 7.33 Map of Purna - 2005



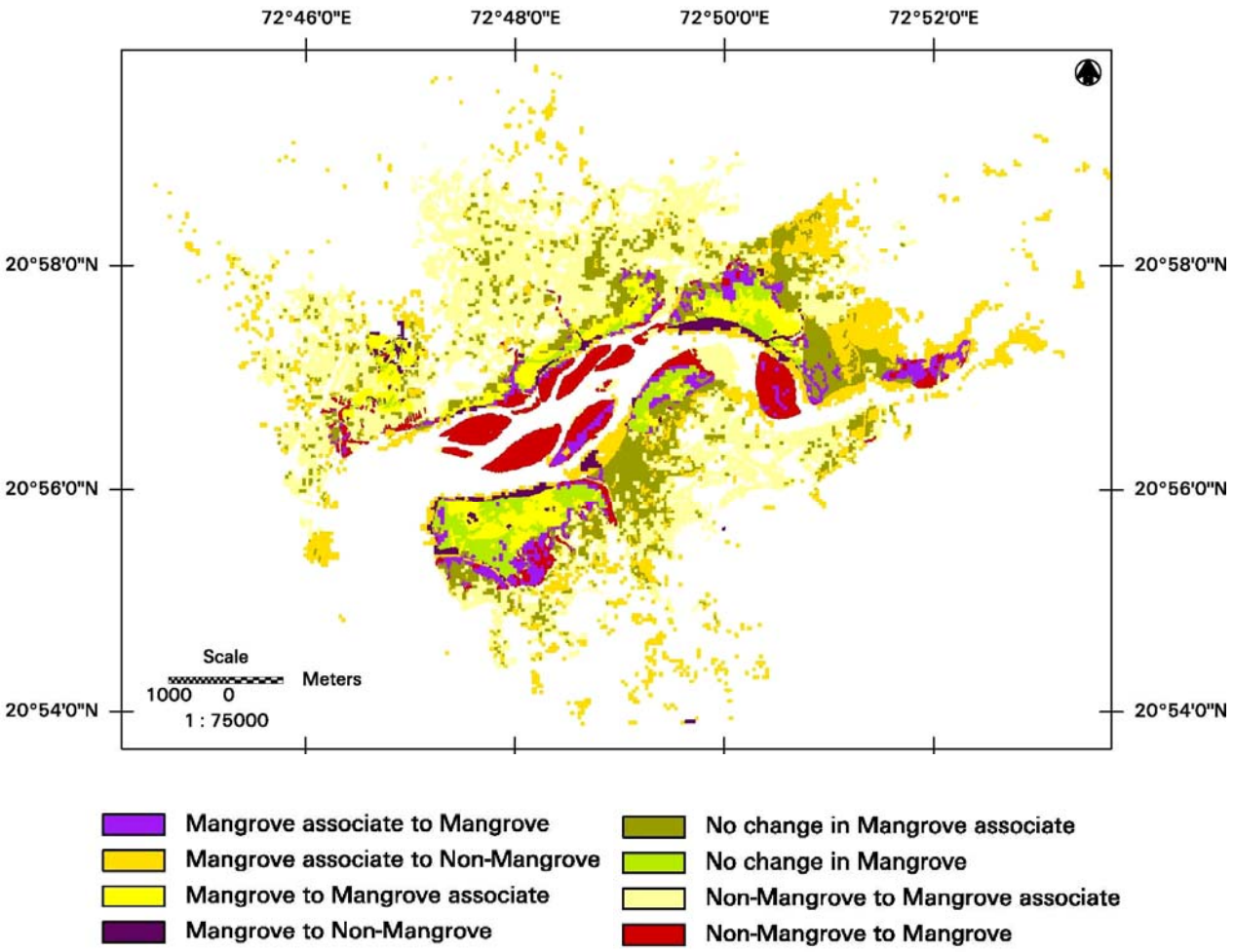


Figure – 7.34 Change detection map of Purna – 1978 to 2005

Area evaluation

The change in the area occupied by different wetland vegetation categories of Purna estuary is given in Table – 7.33. The change in the wetland vegetation categories were analyzed between the year 1978 and 2005. Chart – 7.2 depicts the change in various categories.

SR. NO.	YEAR / AREA (in ha.)	Dense mangroves	Sparse mangroves	Salt marsh vegetation
1	PURNA 78	284	326	1605
2	PURNA 88	595	177	2549
3	PURNA 05	467	281	2402

Table – 7.33 change in wetland vegetation category of Purna estuary from 1978 – 1988 – 2005

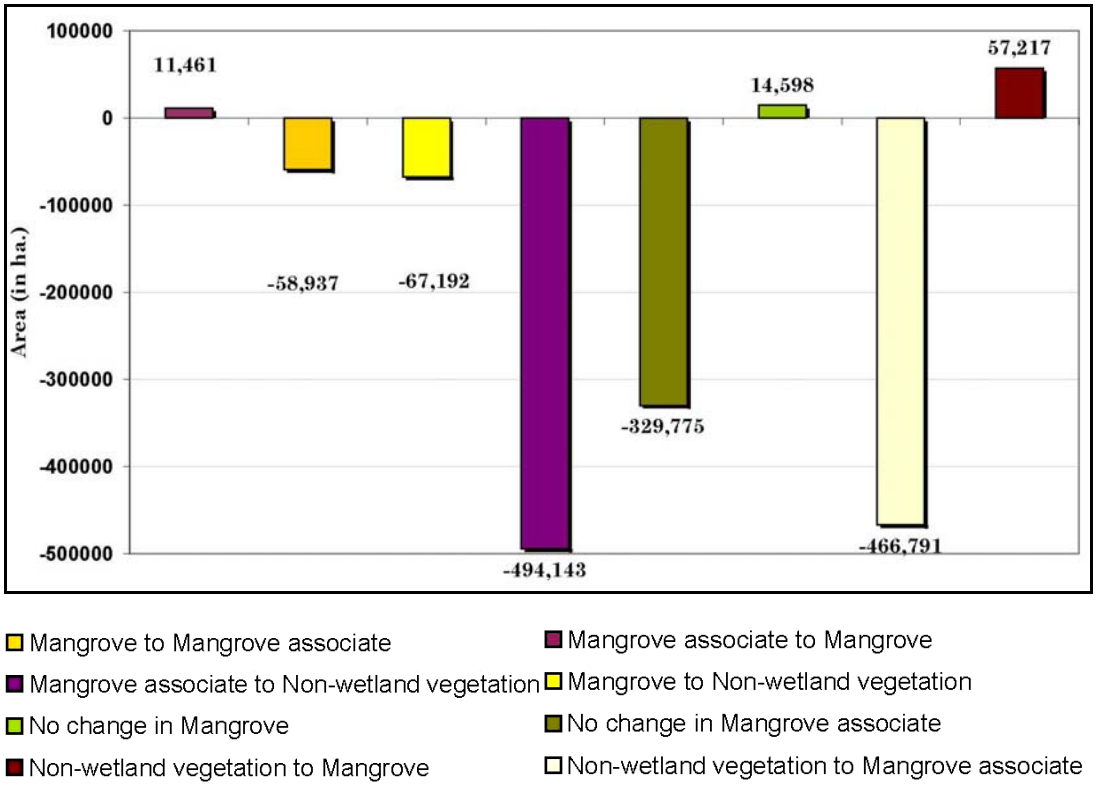


Chart – 7.2 Change in categories of Mangrove and Mangrove associates of Purna estuary - from 1978 to 2005

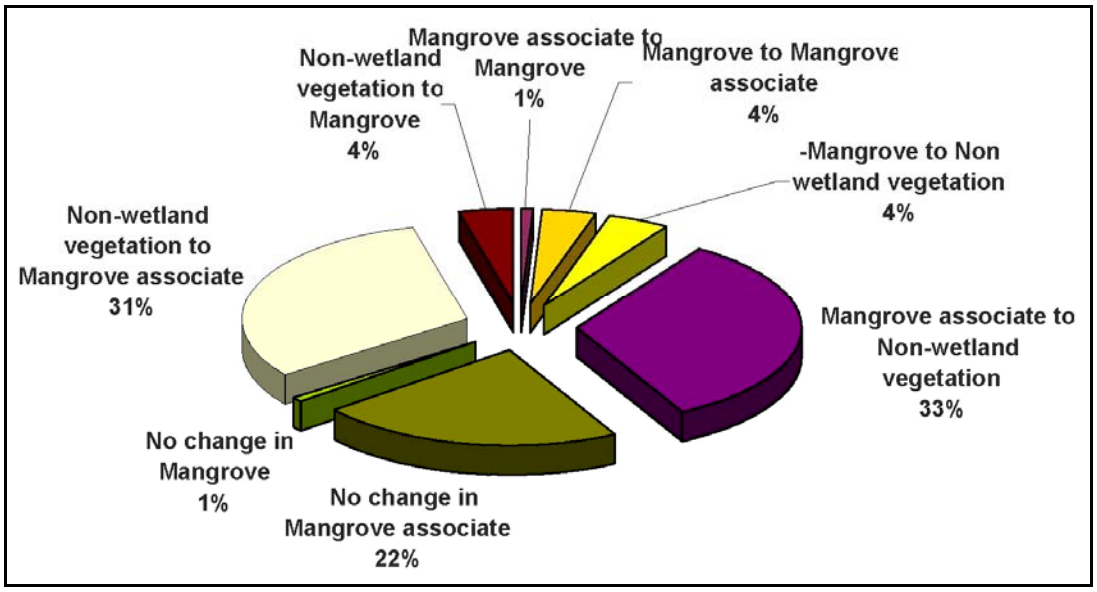


Chart – 7.3 Percentage of change of wetland categories of Purna estuary

4% of increase in the area of mangrove can be observed from the above chart. From the graph, it is very clear that major changes can be observed where the mangrove associates have been converted to non-wetland vegetation category (33%). This change is predominantly because many areas of Purna estuary are occupied now by aquaculture ponds and at places, the vegetated mudflats are now converted into barren mudflats as well. In addition, on the other hand, the classes which were not covered by any wetland vegetation are now covered by mangrove associate to a large extend (31%). Therefore, it can be said that the overall area of salt marsh vegetation has not been affected, as on one side when the mangrove associates are converted to non-wetland vegetation categories, the previously non-vegetated categories have now converted to mangrove-associates category.

AMBIKA ESTUARY 1972 – 2005

Just like the Purna estuary, the SOI (surveyed in 1965) map of Ambika estuary shows complete absence of mangrove vegetation throughout the entire estuarine environment of Ambika River (Figure – 7.35). However, satellite data for the year 1972 (Figure – 7.36) does show the presence of mangroves along the mudflats near the Kavni creek. Formation of islands at the main river channel can be seen during 1972. When observed on the 2005 map, the mangroves have increased dramatically in terms of the areal extent (Figure – 7.37) is most remarkable. The mangroves can now be observed harboring the channel bars of the main channel, near Kavni creek and mudflat area off Medhar and other locations

Marsh vegetation

The mudflat expanse of Ambika estuarine area is vast. During the period of 1972, there were no major mangrove patches present in this area. Consequently, the mudflats have been occupied for the major part by the salt marsh vegetation. In the satellite data for the year 2005, the salt marsh category can be observed again occupying the major part of the wetland area, however many of the previously occupied salt marsh classes are now harbored by mangroves as well.

Change in other categories

It also observed that numerous aquaculture ponds have come up during 2005, whereas it was present only at one location during 1972.

The change detection map is prepared between the data of 1972 and 2005 (Figure – 7.38).

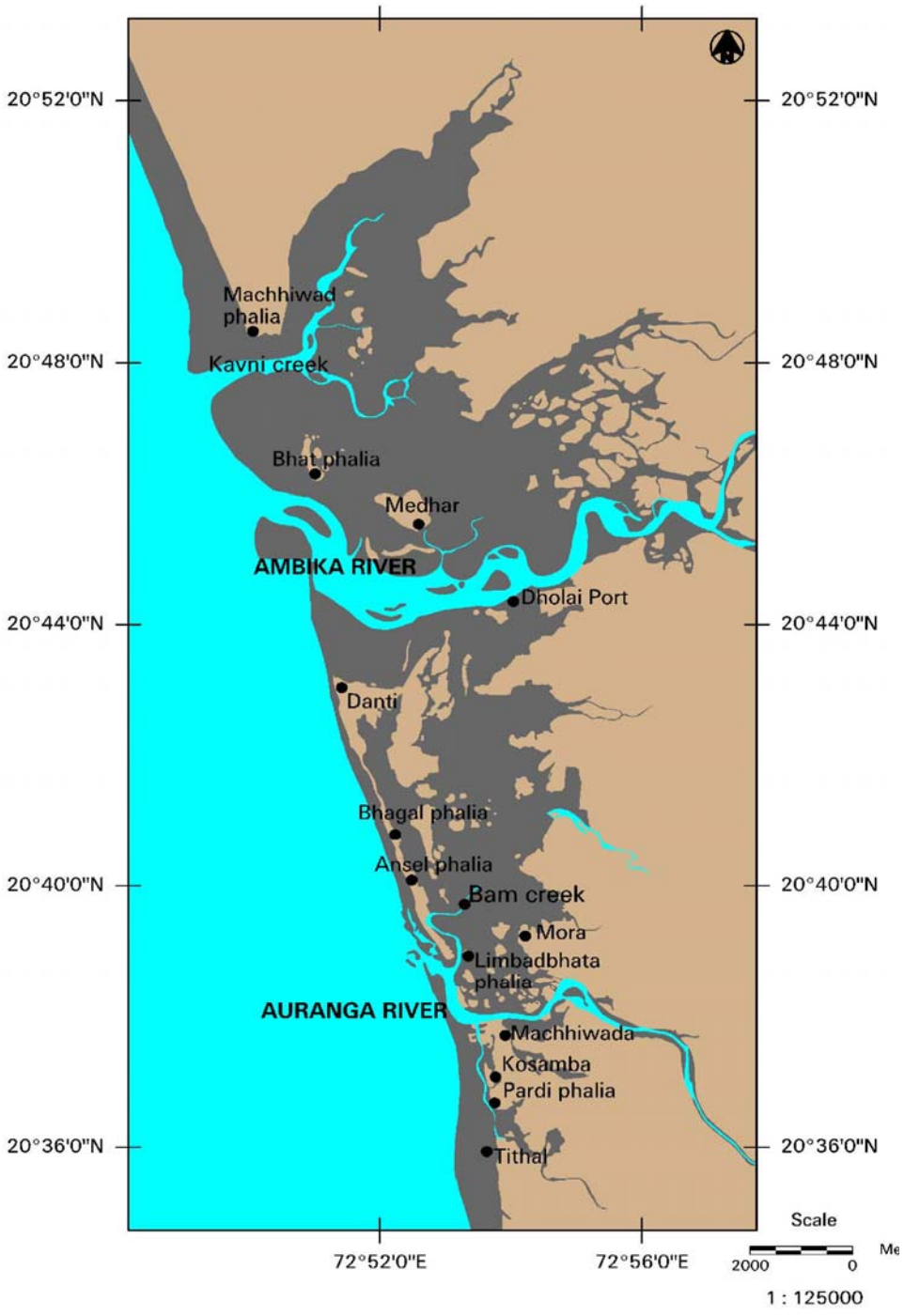


Figure – 7.35 Map of Ambika - 1965

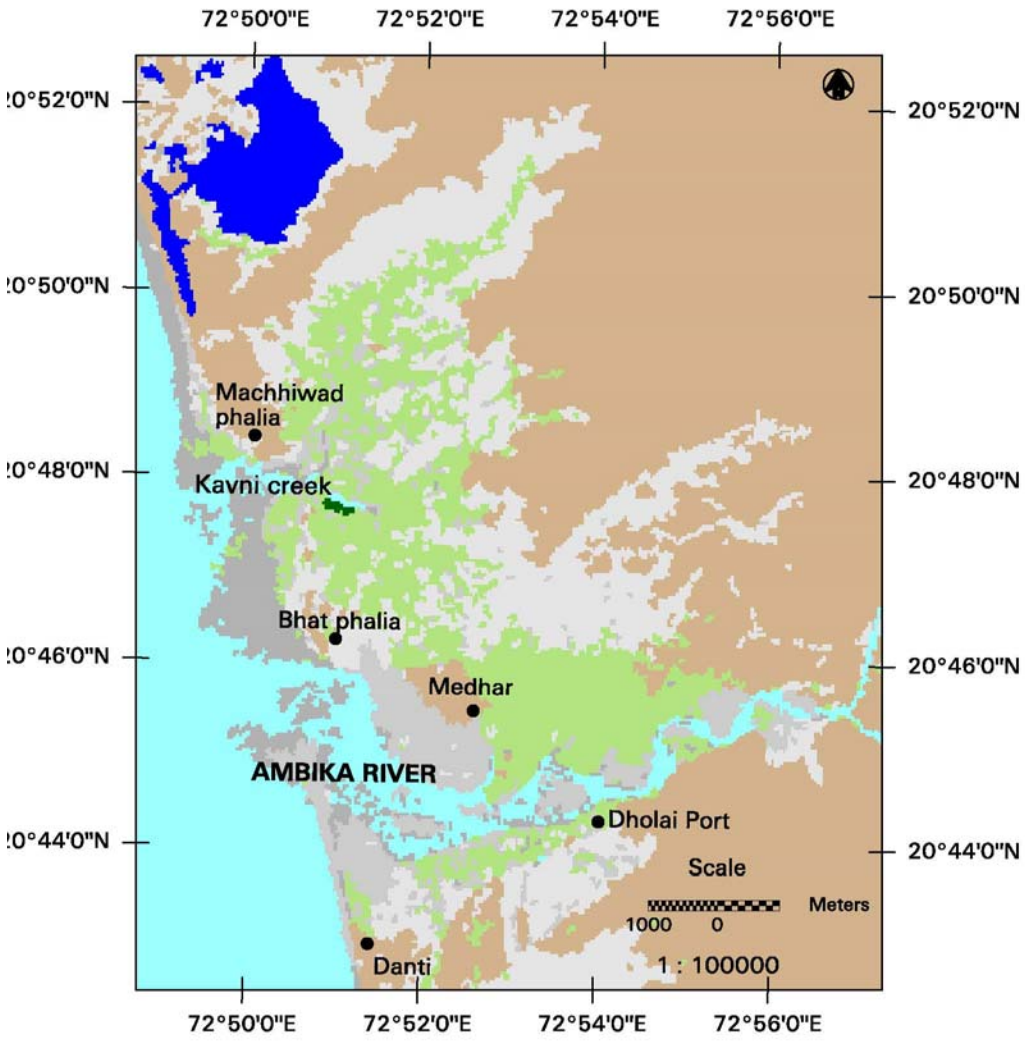


Figure – 7.36 Map of Ambika – 1972

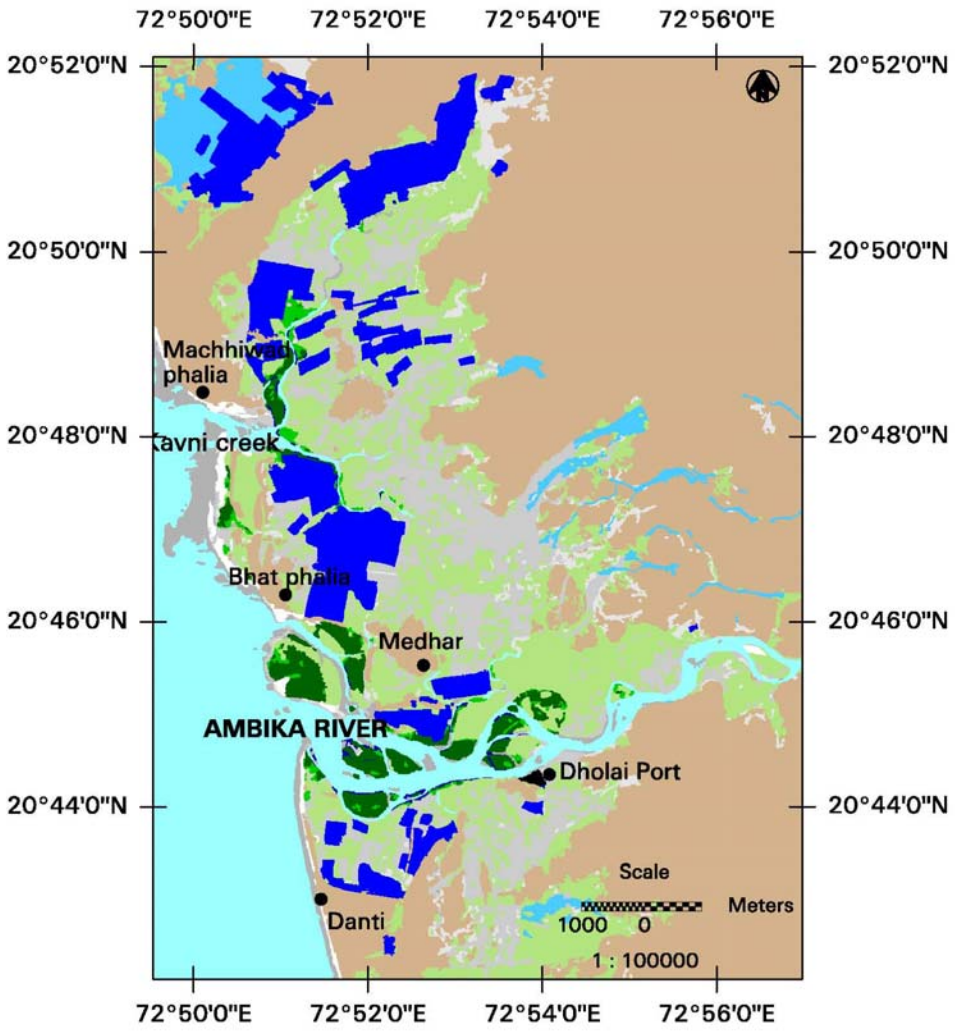


Figure – 7.37 Map of Ambika - 2005

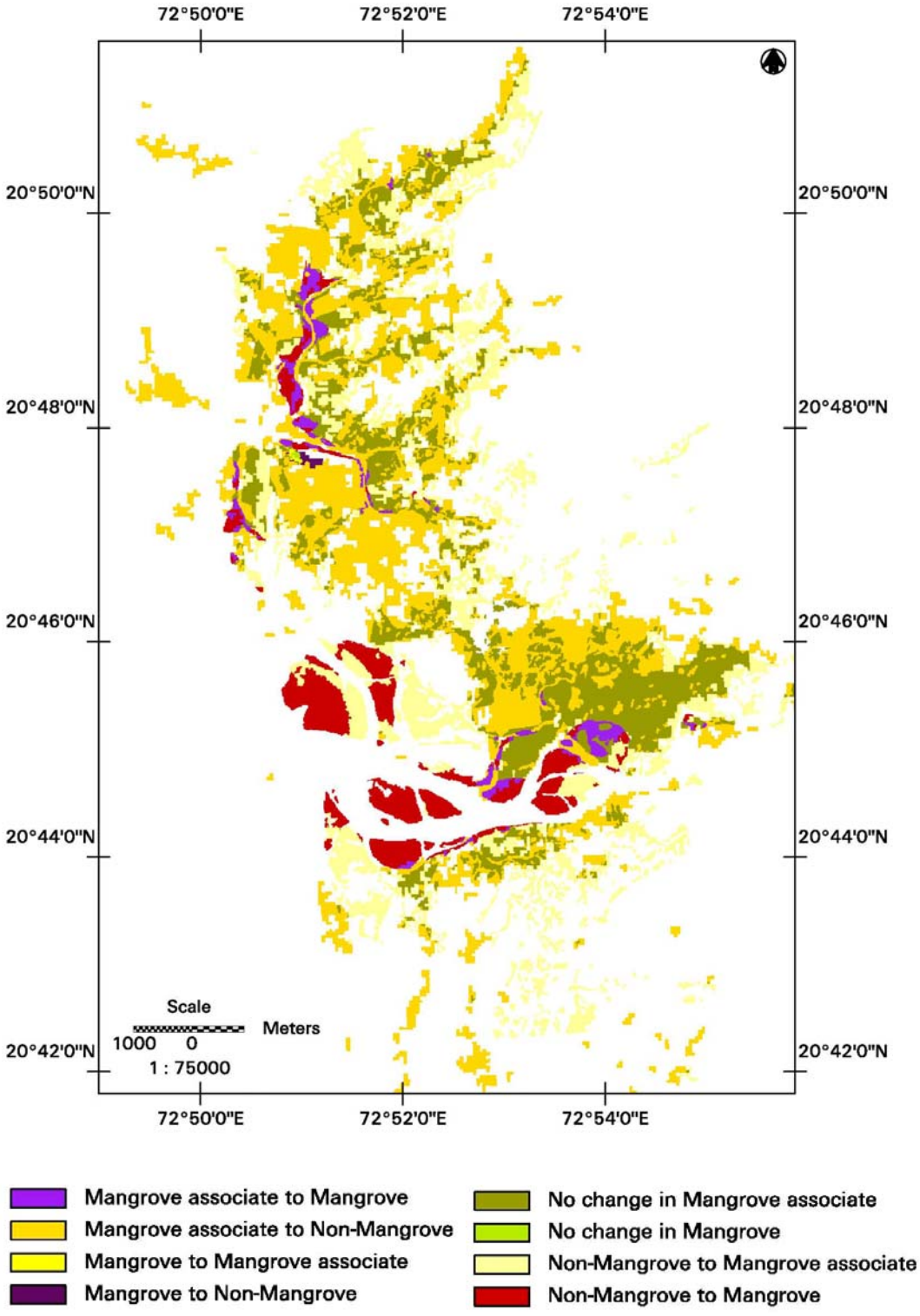


Figure – 7.38 Change detection map of Ambika – 1972 to 2005

Area evaluation

The change in the area occupied by different wetland vegetation categories of Ambika estuary is given in Table – 7.34. The change in the wetland vegetation categories were analyzed between the year 1972 and 2005. Chart – 7.4 depicts the change in various categories.

SR. NO.	YEAR / AREA (in ha.)	Dense mangroves	Sparse mangroves	Salt marsh vegetation
1	AMBIKA 72	10	0	3189
2	AMBIKA 05	378	134	2459

Table – 7.34 Change in wetland vegetation category of Ambika estuary from 1972 – 2005

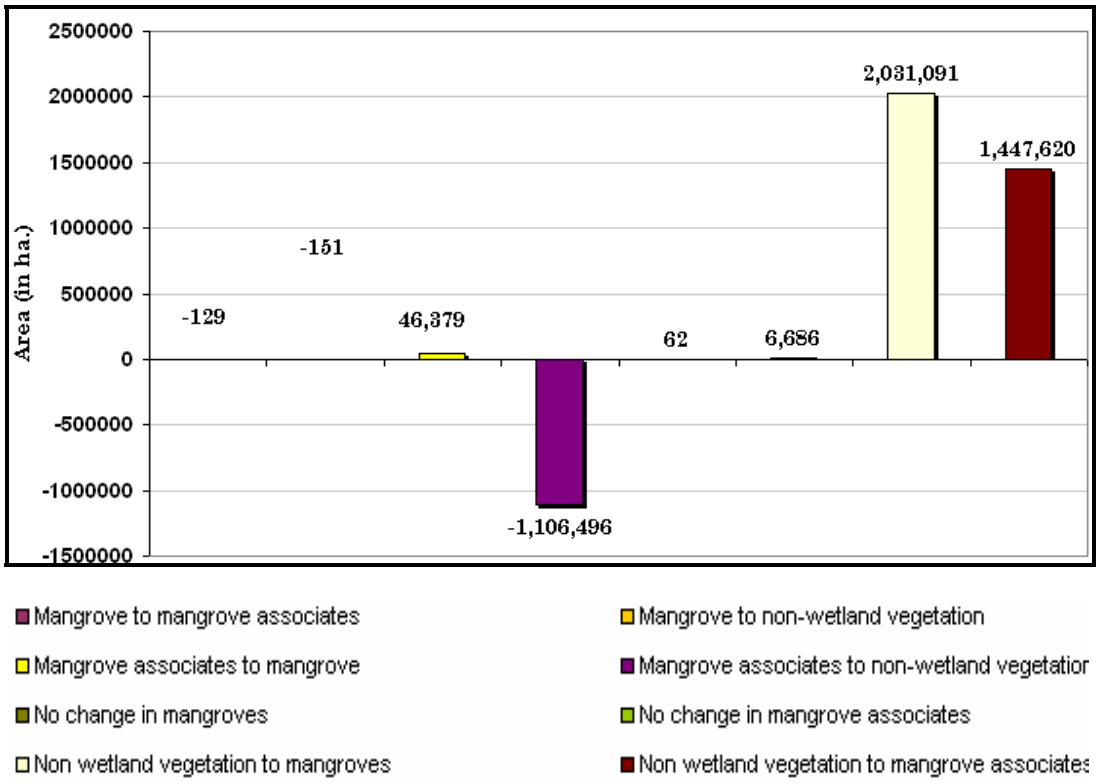


Chart – 7.4 Change in categories of Mangrove and Mangrove associates of Ambika estuary - from 1972 to 2005

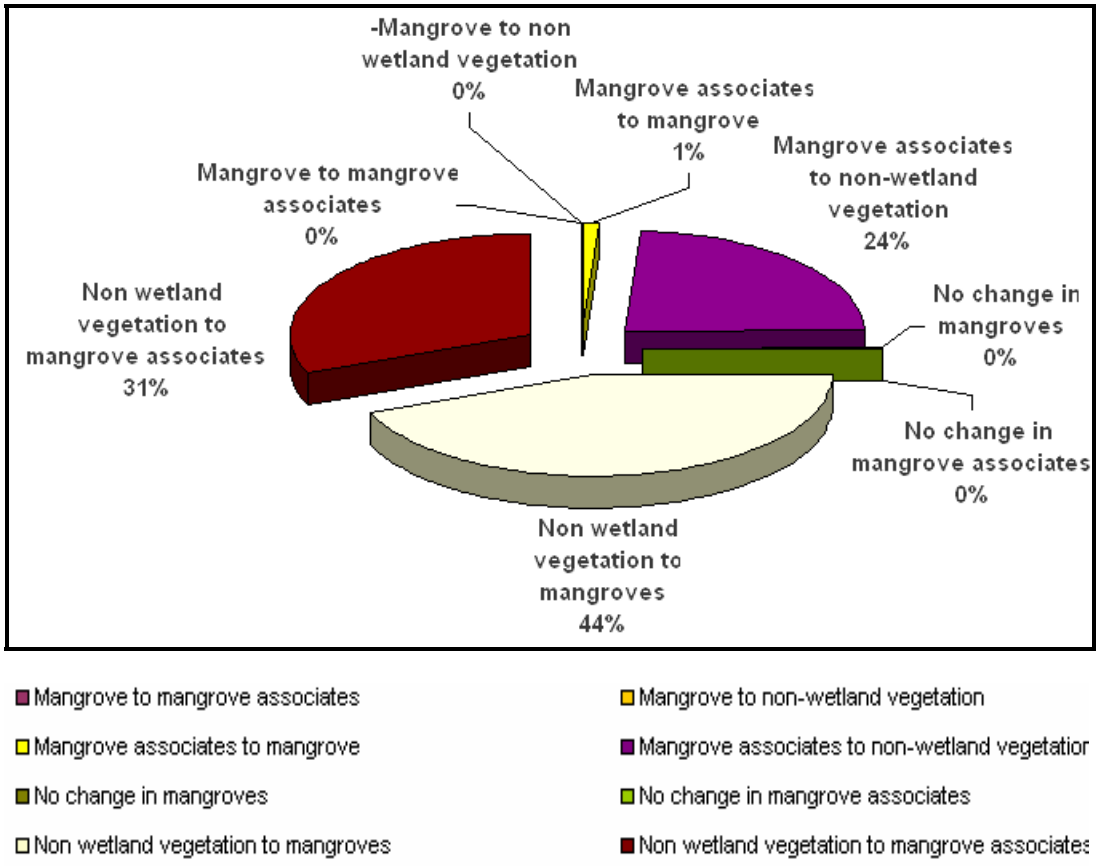


Chart – 7.5 Percentage of change of wetland categories of Ambika estuary

The non wetland vegetation category has converted to mangrove vegetation category from 1972 to 2005 (44%). This is one of the most positive changes in the study area. This can be attributed to the formation of numerous channel bars which currently harbor the mangrove vegetation. Also 31% of the changes are observed where the non vegetated wetlands have converted to mangrove associates. It also observed that about 24% change is seen where the mangrove associates class is changed in non-wetland vegetation category. This is primarily due to the numerous aquaculture ponds which have come up in this area

AURANGA ESTUARY 1972 – 2005

The SOI (surveyed in 1965) map of Auranga estuary shows complete absence of mangrove vegetation throughout the entire estuarine environment of Auranga River (Figure – 7.39). However, satellite data for the year 1972 (Figure – 7.40) does show the presence of mangroves along the mudflats Bam creek and Limbabhata phalia. The mudflat expanse of the estuarine area of Auranga River is relatively smaller. The mangroves of Auranga estuary are also thus less in extent. It harbors larger estuarine area towards the northern flank then on the southern flank. Unlike Purna and Ambika estuary, one can not see the formation of channel bars at the main river channel, as the width of the Auranga River is smaller then Purna and Ambika River. The 2005 map (Figure – 7.41) shows presence of mangroves at main river channel of Auranga and a little inland at a single channel bar. Mangroves are also observed to be growing along the creek which runs south of the par river channel, parallel to the coast. The area of mangroves thus has definitely increased but not as significantly as in case of Purna and Ambika estuary. Main reason for this remains the limited mudflat area in case of Auranga River

Marsh vegetation

The mudflat area of Auranga is vast and one can observe salt marsh vegetation dominating the mudflats for the year 1972. In the satellite data for the year 2005, the salt marsh category can be observed again occupying the major part of the wetland area.

Change in other categories

It also observed that numerous aquaculture ponds have come up during 2005, whereas it was present only at one location during 1972.

The change detection map is prepared between the data of 1972 and 2005 (Figure – 7.42).

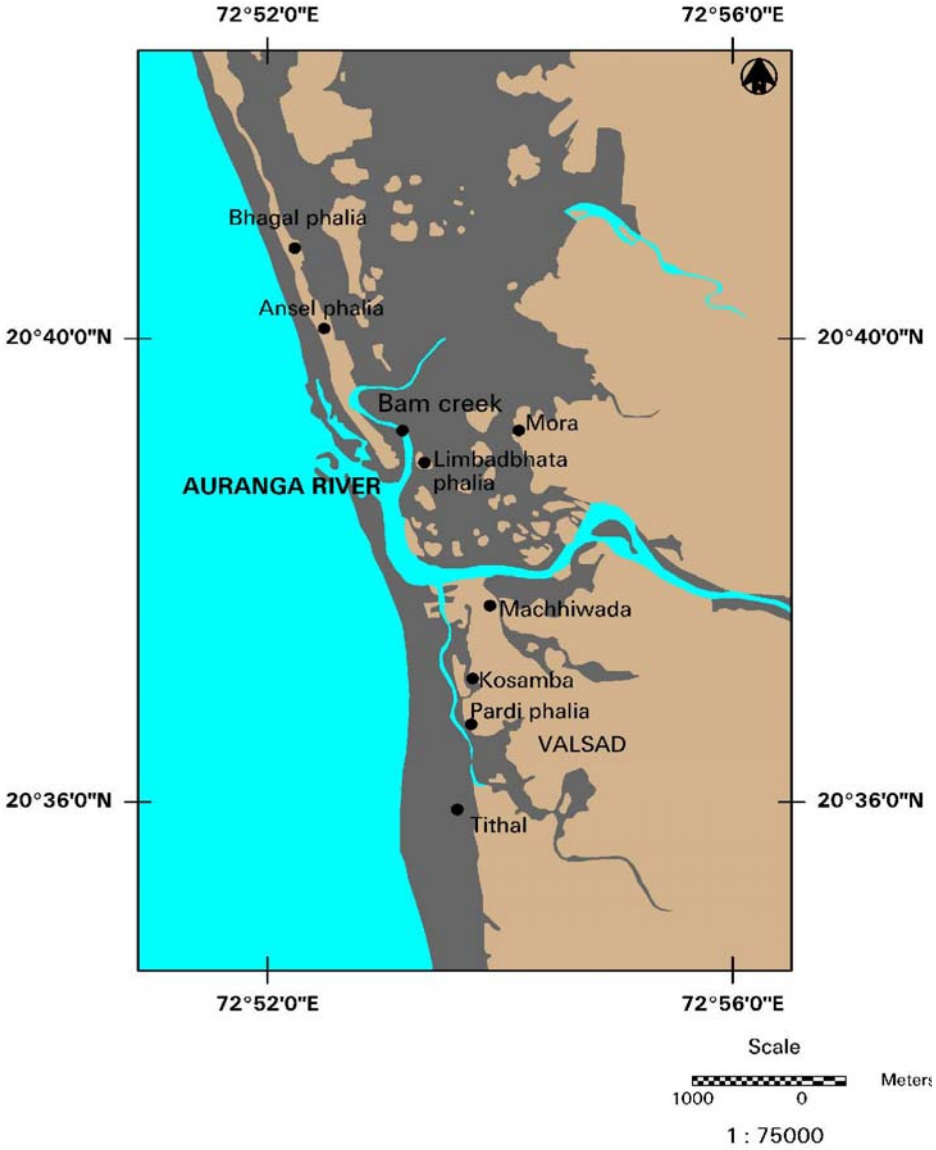


Figure – 7.39 Map of Auranga - 1965

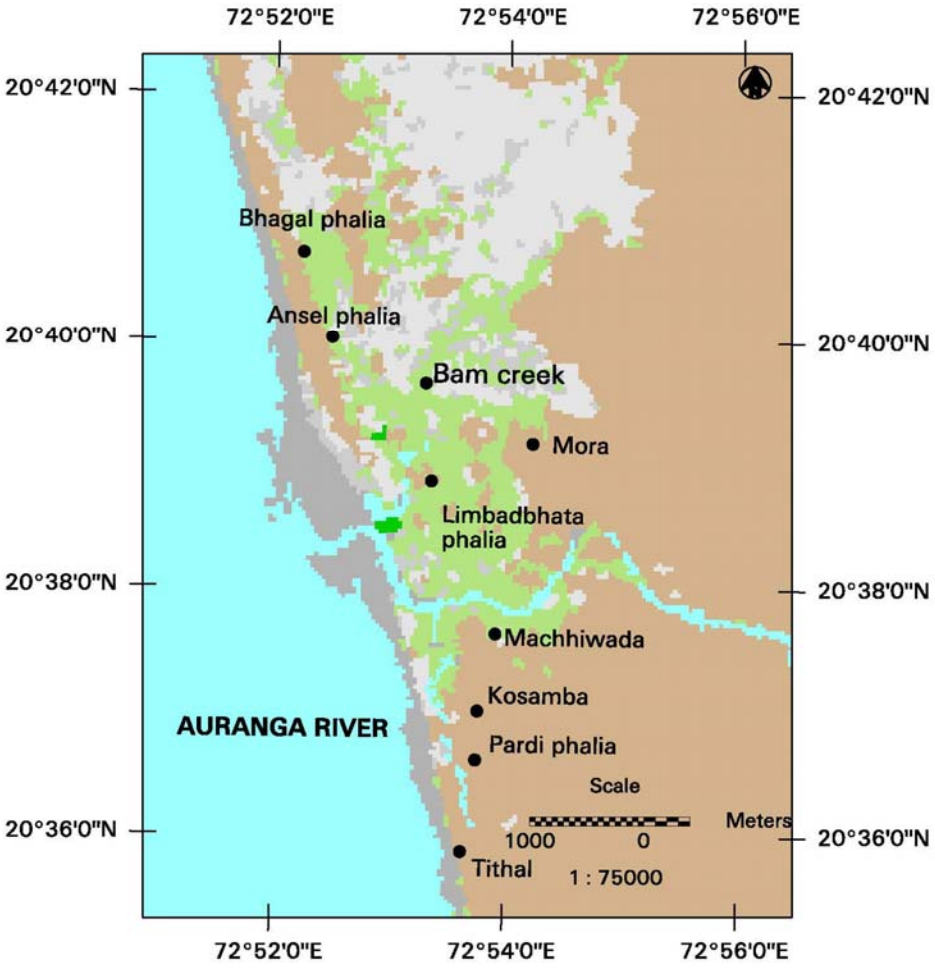


Figure – 7.40 Map of Auranga - 1972

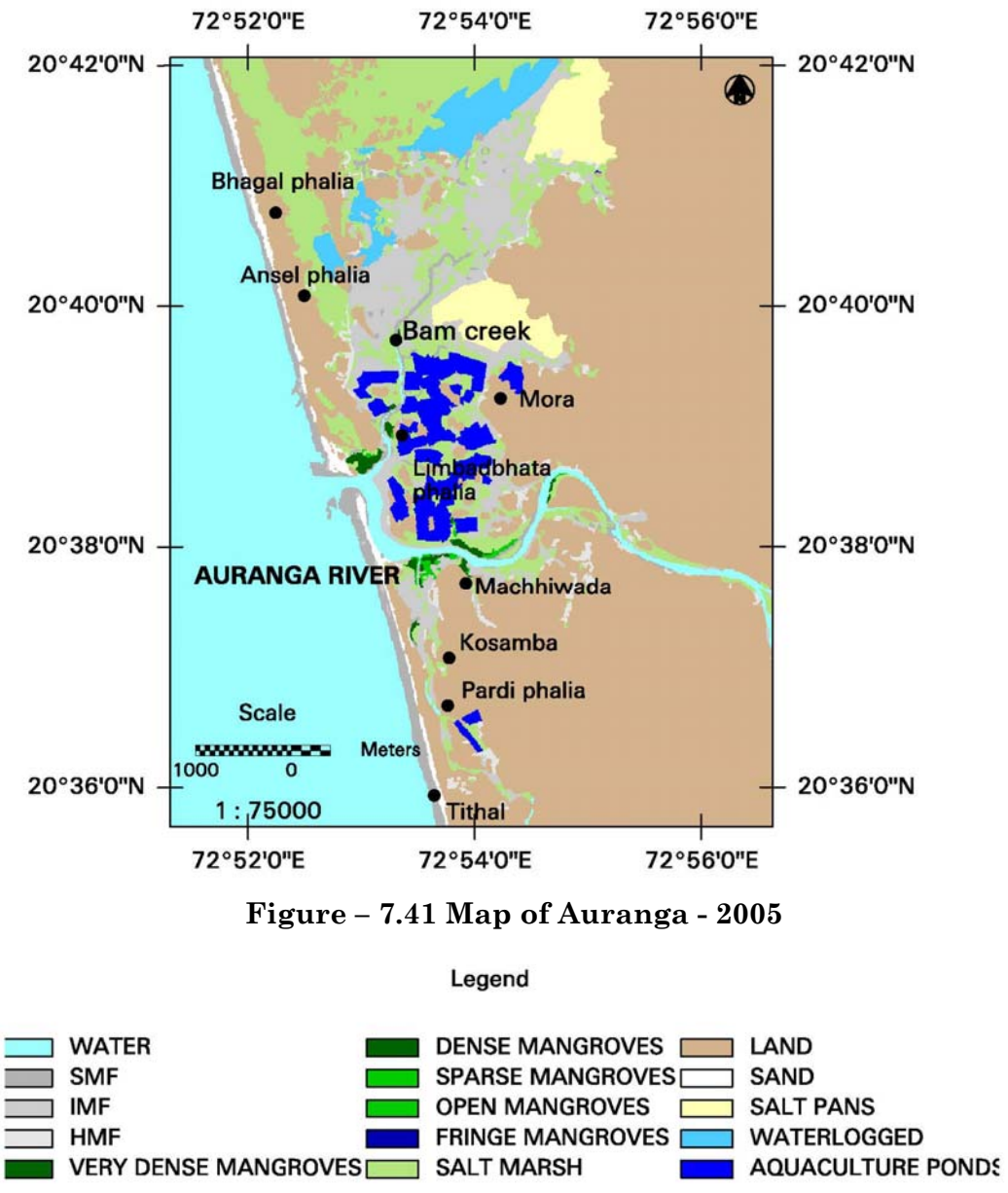


Figure – 7.41 Map of Auranga - 2005

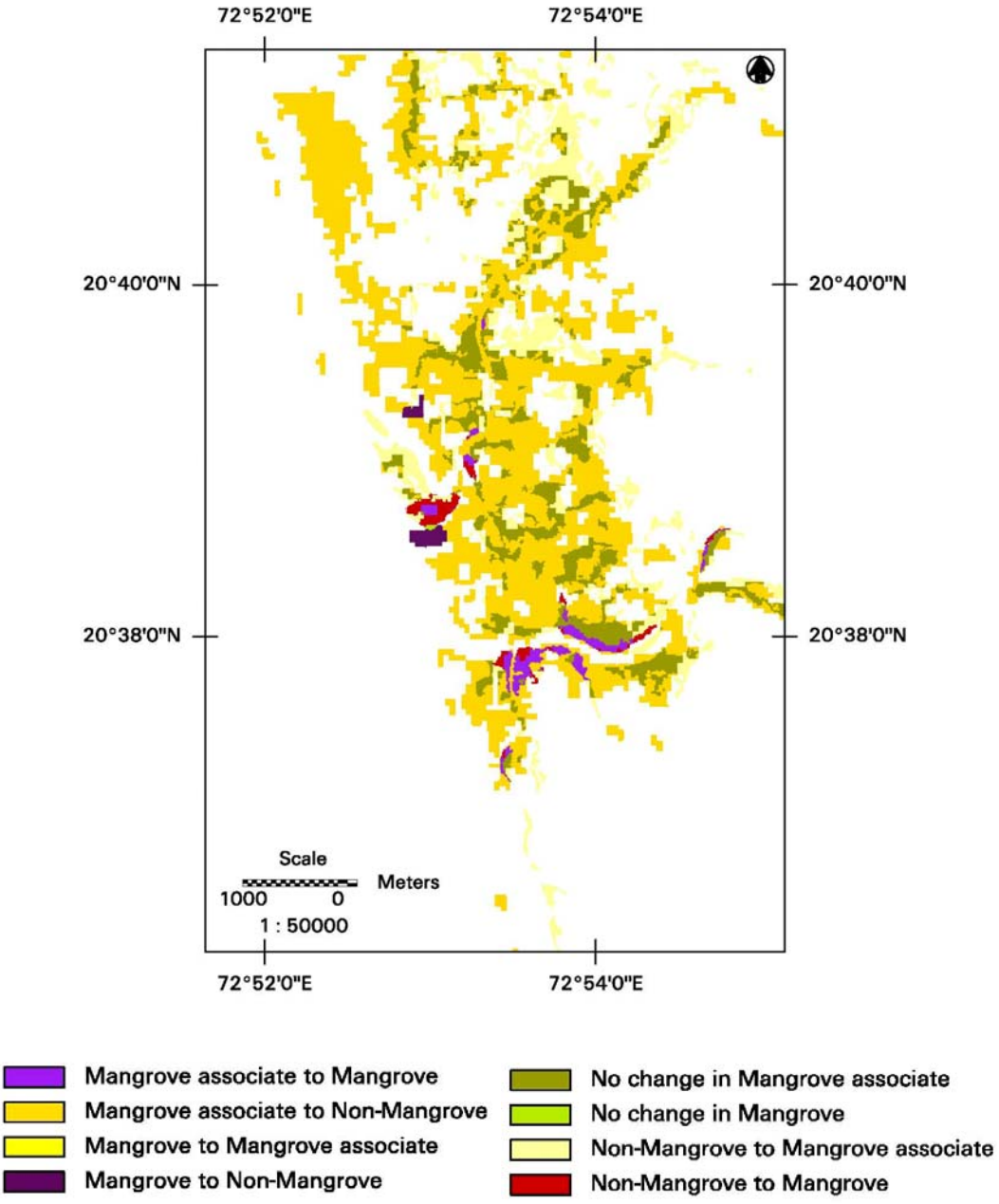


Figure – 7.42 Change detection map of Auranga – 1972 - 2005

Area evaluation

The change in the area occupied by different wetland vegetation categories of Auranga estuary is given in Table – 7.35. The change in the wetland vegetation categories were analyzed between the year 1972 and 2005. Chart – 7.6 depicts the change in various categories.

SR. NO.	YEAR / AREA (in ha.)	Dense mangroves	Sparse mangroves	Salt marsh vegetation
1	AURANGA 72	10	0	1121
2	AURANGA 05	28	13	461

Table – 7.35 Change in wetland vegetation category of Auranga estuary from 1972 – 2005

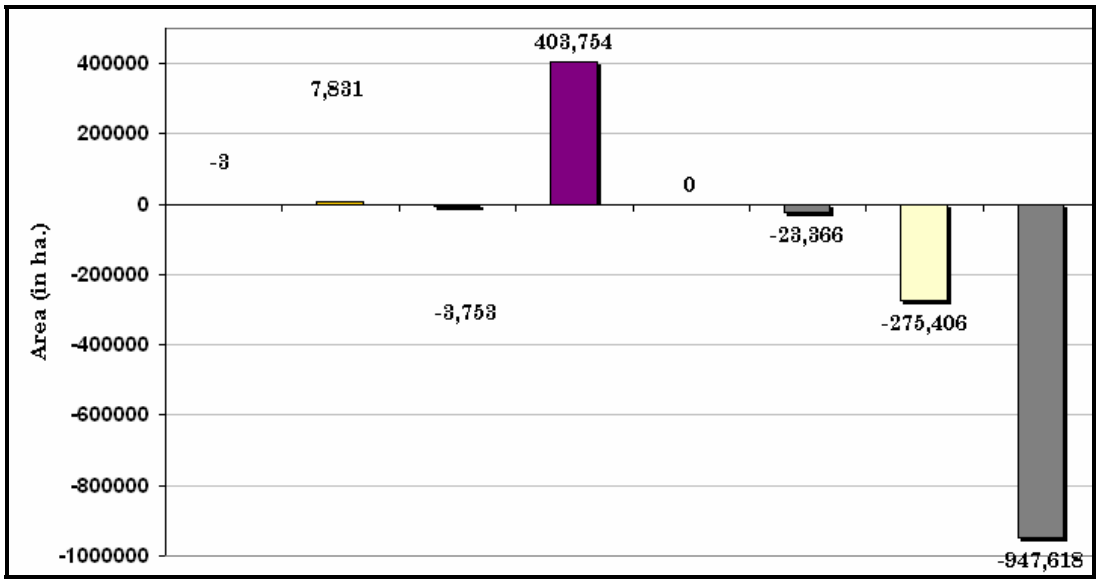


Chart – 7.6 Change in categories of Mangrove and Mangrove associates of Auranga estuary - from 1972 to 2005

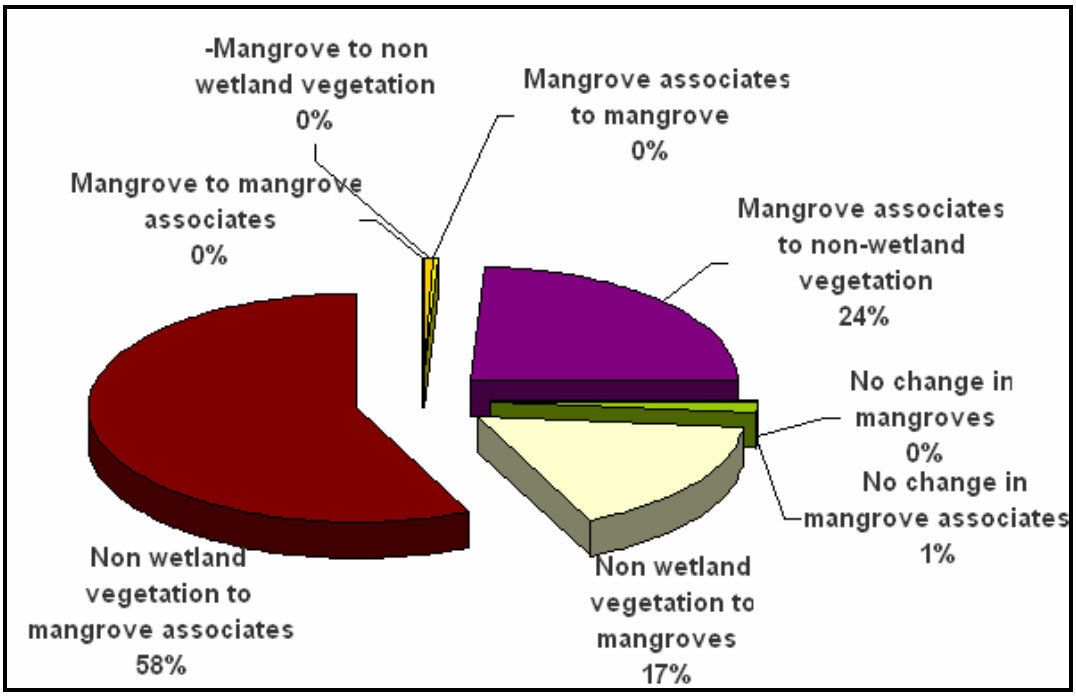


Chart – 7.7 Percentage of change of wetland categories of Auranga estuary

The non wetland vegetation category has converted to mangrove vegetation category from 1972 to 2005 by 17%. This is one of the most positive changes in the study area. This can be attributed to the formation of numerous channel bars which currently harbor the mangrove vegetation. Also 58% of the changes are observed where the non vegetated wetlands have converted to mangrove associates. It also observed that about 24% change is seen where the mangrove associates class is changed in non-

wetland vegetation category. This is primarily due to the numerous aquaculture ponds which have come up in this area as well.

Although the SOI toposheets of 1965's do not show any presence of mangroves for any of these three estuaries of south Gujarat coastline, it is quite evident that the mangroves subsequently have grown on these estuarine areas. The earliest indication of presence of mangroves, but occupying very little area of the mudflats, can be observed in the satellite data used of 1972 and 1978. Whereas, the recent most data of year 2005 shows phenomenal increase in areal extent of mangroves of these three estuaries of south Gujarat. The mudflats, those were without mangrove during 1972/1978, are also harboring the mangroves during 2005. However, there are also few mangrove patches, which have now been replaced by mangrove-associate vegetation, as in case of Purna estuary. This clearly demonstrates that mangroves are finding the coastal wetlands of south Gujarat conducive. This, I would like to attribute mainly to the geomorphological set-up of the study area and conducive environment, which is promoting not only the growth of mangroves in terms of density and areal extent but also allowing diverse mangrove species to sustain in this area.

Attention-grabbing fact here is that, when this channel bars were still in early stage, presence of *Portresia coarctata* harboring this area was observed. Same has been confirmed in the current day scenario (over a period of 4 years) where the smaller and newly formed bars are still harboring *Portresia coarctata*. This vegetation of *Portresia coarctata*

gradually has been taken over by the mangrove vegetation (confirmed by the local people as well). It is already a documented fact that *Portresia coarctata* is the pioneer vegetation of the mangrove ecosystems, which help in the accretion of mud, which is later on taken over by the mangrove species, which accelerates the process of accretion thus forming channel bars as in this case.

7.6 SOIL AND WATER SAMPLE ANALYSIS

The water quality, comprising the environmental master factors such as temperature, salinity, oxygen, besides organic matter, nutrients and trace metals, forms the basis for the mangrove ecosystems. The interactive physical, chemical and biological processes operating in the mangrove ecosystems sustain higher levels of productivity, as reflected in a wide spectrum of flora and fauna, leading to richness in biodiversity. The mangrove ecosystems are so specialized that any minor variation in their hydrological or tidal regimes causes noticeable damages,

Sampling for water samples were done across different locations of the estuaries over a period of three years (2006 - 2008). The pH, salinity, conductivity and TDS were measured for the waters of the mangrove areas. The samples were collected from across the estuaries and different tidal timings. While most of the samples were collected from the main channel during high as well as low tides, few were also collected from the creeks during high tides. Samples were collected from all the estuarine areas. However, reasonable and detailed collection was possible from the estuaries of Purna, Ambika, Auranga, Par and Kolak. Sampling from Damanganga and Varoli estuary has been only representative and hence much emphasis on data of these estuaries has not been given in the present work. Sampling for Mindhola was not possible at all, as there was no opportunity of collecting water sample at all. This was because the waters of Mindhola are highly polluted and acidic

and the boatmen refused to go through into the waters of Mindhola River. The data here has been represented estuary wise and a comparative account is given for all the parameters as well.

Water Temperature (^{0}C) of all estuaries

The temperature of the surface water of all the estuaries varied between 18^{0}C and 23^{0}C and no significant difference was observed in the temperature of different stations.

Purna water properties

Total nineteen water samples were collected for the assessing the parameters across Purna estuary. The samples were collected for two different seasons at different tide timings as well (low tide and high tide) to observe if the properties changes over a small temporal range during these two different tidal phases.

Purna Water pH

The pH of water samples of Purna estuarine area varied from 6.82 to 8.07, with average pH value being 7.42. The tidal conditions were also observed while collecting the samples to study the correlation of the tides and the pH. However, no particular trend was observed in between the pH values and the tidal conditions.

Purna Water Salinity

Mangroves grow well in low salinity conditions. Salinity of sea water is established to be 35. Mangrove waters are directly influenced by sea water. However, they are also under the influence of the fresh water, at the confluence of which they grow, hence there salinity is expected to be low, which also favors good growth of mangroves.

The salinity of water at Purna estuary ranges from 2.23 to 30.5 ppt, with average salinity reading of 23.6 ppt. It was observed here that the salinity decreased with moving further upstream. This could be attributed to the fact that there is source of fresh water, i.e. the Purna River itself, which helps in keeping the salinity in check. This ultimately favors in good growth of mangroves.

Purna Water Conductivity

Electrical conductivity (EC) values were found in the range 8.48 – 40.6 μS, with average reading being 31.45. It is considered that the Na content may control the level of EC of the soil, since EC positively and significantly related to Na concentration ($r = 0.556^{**}$, $P \leq 0.01$). This was observed in case of Purna were the salinity and EC followed similar trend.

Purna Water TDS

TDS values were found in the range of 5.5 – 26.4 ppt.

Sr. No.	Sampling date	Chemical Parameters				
		Tidal influence	pH	Salinity (ppt)	Conductivity (µS)	TDS (ppt)
1	Apr-07	+ve tide	7.5	28.4	38	24.7
2	Apr-07	-ve tide	7.16	25.2	33.7	21.8
3	Apr-07	-ve tide	7.48	24.8	33.2	21.5
4	Apr-07	-ve tide	7.45	28.8	38.5	25
5	Apr-07	-ve tide	7.3	30.4	40.6	26.4
6	Apr-07	-ve tide	6.9	30.5	40.5	26.4
7	Nov-07	-ve tide	8.07	2.23	2.97	0.32
8	Nov-07	+ve tide	7.46	10.62	14.17	9.2
9	Nov-07	-ve tide	7.61	14.83	20.1	12.8
10	Nov-07	mid tide	7.33	22.9	34.1	25.6
11	Nov-07	+ve tide	7.26	25	33.5	21.7
12	Nov-07	mid tide	7.30	25.7	33.6	26
13	Nov-08	+ve tide	7.89	6.35	8.48	5.5
14	Nov-08	+ve tide	7.63	12.25	16.32	10.62
15	Nov-08	+ve tide	7.52	13	17.35	11.27
16	Nov-08	+ve tide	7.5	20.7	27.7	18.02
17	Nov-08	+ve tide	7.38	21.1	28.1	18.37
18	Nov-08	mid tide	7.27	26.8	35.7	23.2
19	Nov-08	+ve tide	6.82	27.5	38	24.3

Table 7.36 Tide wise seasonal water properties of Purna

(pH, salinity, conductivity and TDS)

. The Purna mangrove water is alkaline in nature without drastic any systematic spatial variation irrespective of seasons. As observed from the above table the pH values for all the samples have remained alkaline, as expected. It was also found that there is not major difference in the values of pH during the high tide or low tide. pH shows strong inverse relation with the salinity. Overall, salinity, conductivity and TDS tends to show an inverse relationship with the pH and with very little increase in the values of pH, the values of salinity, conductivity and TDS decreases significantly. Conductivity and salinity are showing positive correlation with TDS. The samples were

collected over span of two years for pre-monsoon and post-monsoon period, and marginal difference has been observed in the readings of different samples.

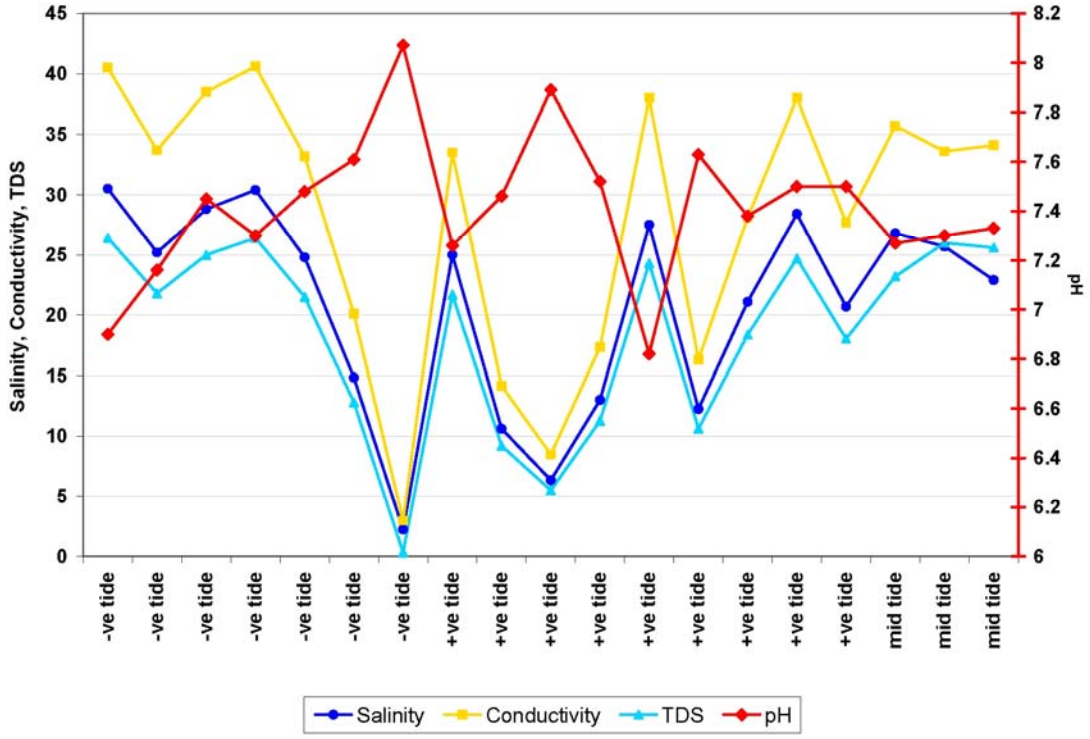


Chart – 7.8 Tide wise pH, salinity, conductivity and TDS of Purna water samples

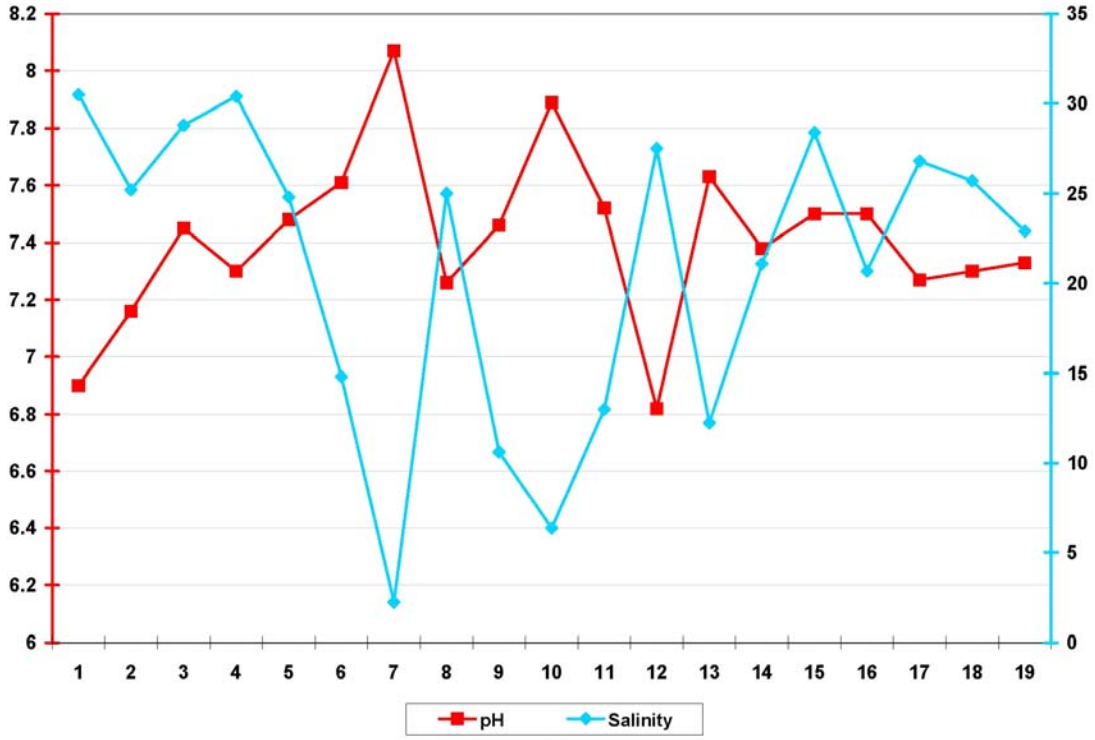


Chart – 7.9 Relationship between pH and salinity of Purna water samples

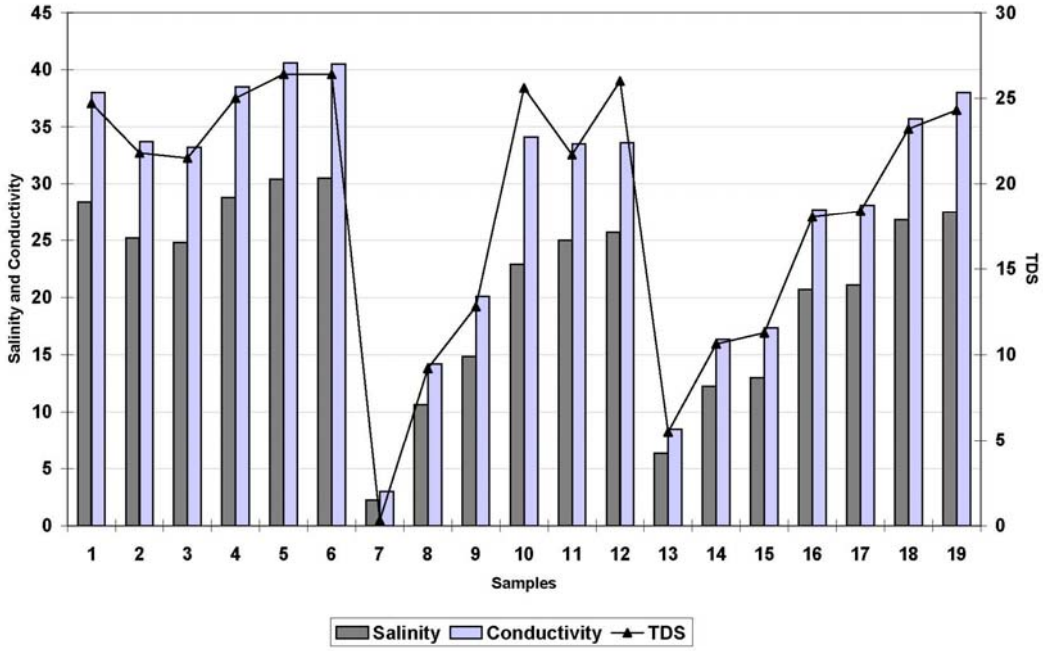


Chart – 7.10 Correlation between salinity, conductivity and TDS of Purna water samples

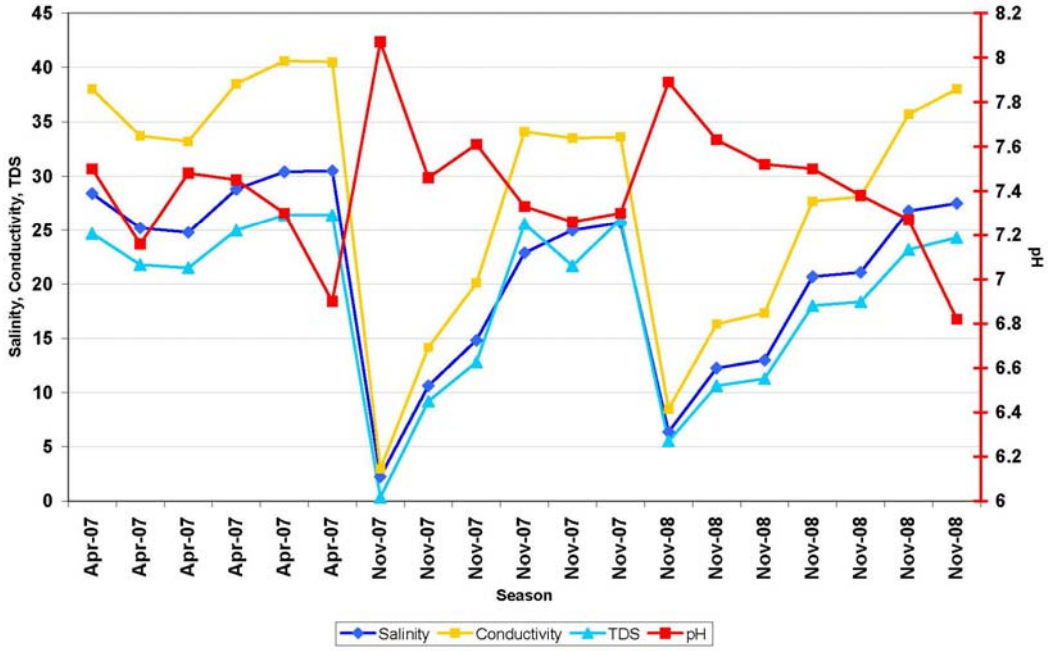


Chart – 7.11 Seasonal variations of pH, salinity, conductivity and TDS of Purna water samples

Ambika water properties

Ambika estuary forms one of the major estuaries of the study area. Sampling here was done for two dates – May 2008 and November 2008 (pre-monsoon and post monsoon)

Ambika water pH

The pH of water samples of Ambika ranges from 7.02 to 9.46 with average value being 8.18. No marked seasonal difference in the pH values was observed for the samples collected over two seasons. In addition, tide-wise no particular trend could be observed.

Ambika water salinity

The salinity of water samples of Ambika Estuary ranges from 16.56 to 39.6 ppt. No trend was observed in the water salinity across different tidal timings and different seasons as well.

Ambika water conductivity

The conductivity of water samples of Ambika Estuary are found to be in the range of 21.8 to 52.2 μS, with an average reading of 45.36 μS.

Ambika water TDS

Samples of Ambika estuaries' water shows TDS reading minimum of 14.23 and maximum of 35.2 ppt, with the average reading being 30.37 ppt.

Sr. No.	Sampling date	Chemical Parameters				
		Tidal influence	pH	Salinity (ppt)	Conductivity (µS)	TDS (ppt)
1	May 2008	-ve tide	8.85	38.7	51.6	33.5
2	May 2008	-ve tide	8.79	36.5	51.1	33.4
3	May 2008	-ve tide	9.46	39.6	52.2	35.2
4	May 2008	-ve tide	7.02	36.3	48.2	31.4
5	May 2008	-ve tide	7.95	35.2	46.9	30.4
6	May 2008	-ve tide	7.92	27.8	37.3	24.1
7	Nov-08	-ve tide	7.95	16.56	21.8	14.23
8	Nov-08	-ve tide	7.79	35.3	47.3	30.6
9	Nov-08	-ve tide	7.1	33	47.5	31.7
10	Nov-08	-ve tide	7.95	36.4	32.8	30.2
11	Nov-08	mid tide	7.94	35.2	46.9	30.4
12	Nov-08	+ve tide	9.43	39.2	52	34.6
13	Nov-08	+ve tide	7.75	37.2	49.7	32.2
14	Nov-08	+ve tide	8.6	33	49.7	33.2

Table 7.37 Tide wise seasonal water properties of Ambika (pH, salinity, conductivity and TDS)

It was observed in Ambika Estuary as well that there was no major change in the readings of water samples over the season as well as over different tide times. The trend of pH values showing inverse relation with salinity and the correlation of salinity, conductivity and TDS was apparently observed in the water samples of Ambika estuary.

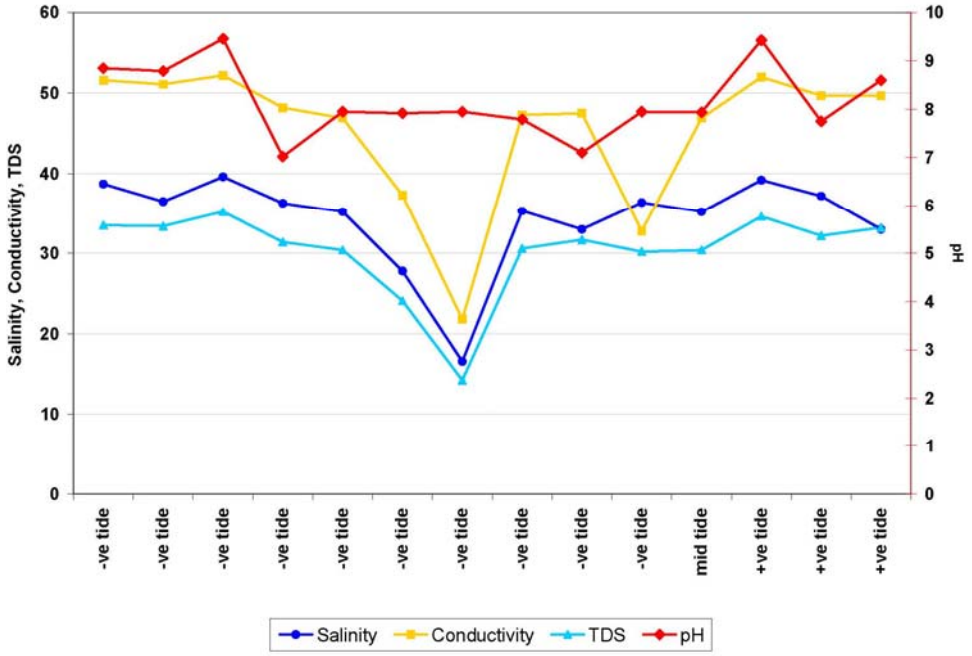


Chart – 7.12 Tide wise pH, salinity, conductivity and TDS of Ambika water samples

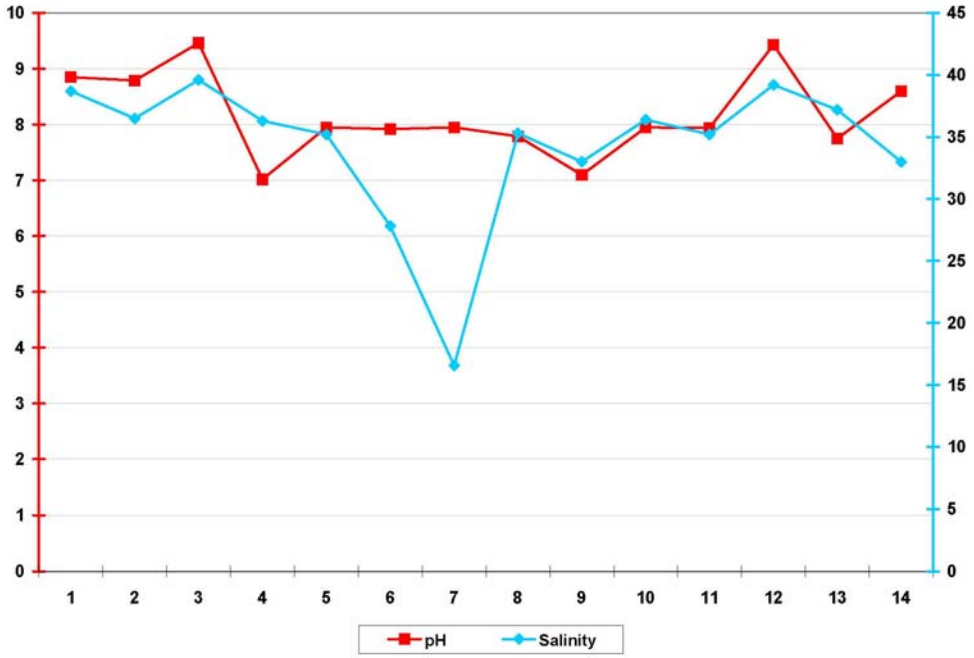


Chart – 7.13 Relationship between pH and salinity of Ambika water samples

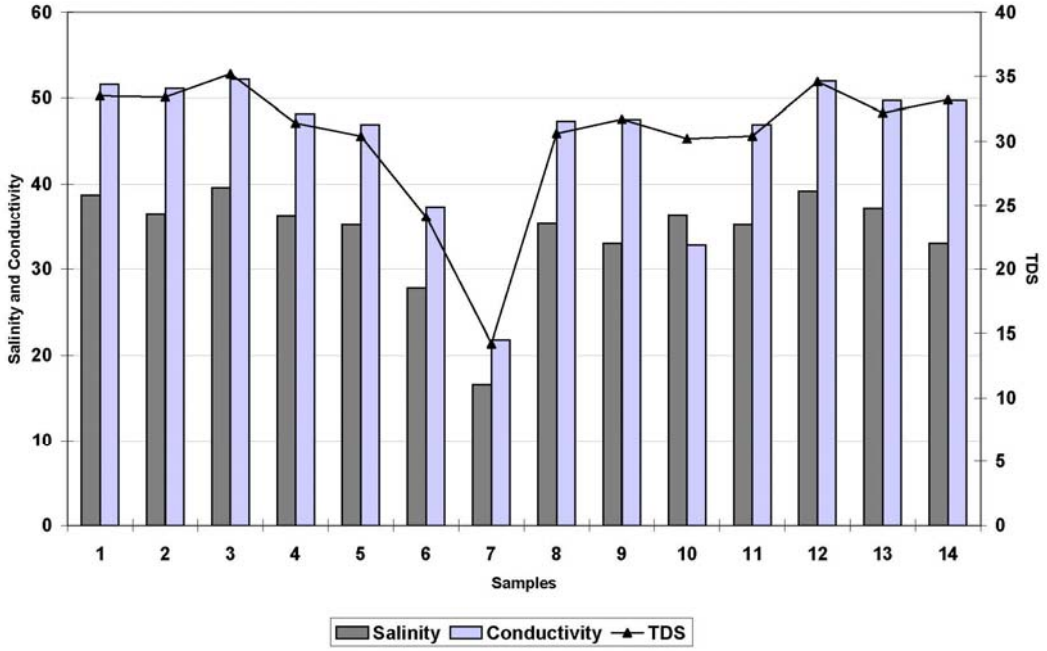


Chart – 7.14 Correlation between salinity, conductivity and TDS of Ambika water samples

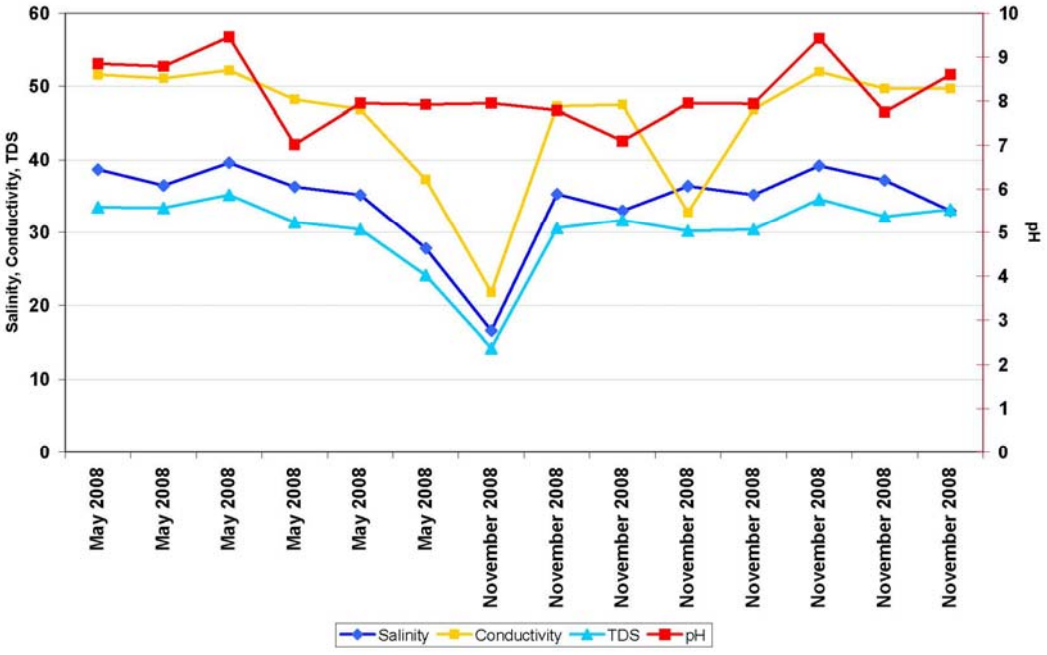


Chart – 7.15 Seasonal variations of pH, salinity, conductivity and TDS of Ambika water samples

Auranga water properties

Auranga forms a relatively smaller estuary, with not many creeks crisscrossing over the estuarine set-up. Hence, the sampling also was very less. Four samples in total were collected from the estuarine area of Auranga. Sampling was done over a period of two years.

Auranga water pH

The pH values varied from 7.64 to 7.91, with 7.76 showing as average pH reading.

Auranga water salinity

The salinity of water samples of Auranga estuary range from 22.4 to 33.6 ppt, with average reading being 28 ppt.

Auranga water Conductivity

The conductivity of water samples of Auranga estuary range from 29.8 to 45 μS, with average reading being 37.85 μS.

Auranga water TDS

The TDS of water samples of Auranga estuary range from 19.38 to 29.2 ppt, with average reading being 24.82 ppt.

Sr. No.	Sample Number	Chemical Parameters				
		Tidal influence	pH	Salinity (ppt)	Conductivity (µS)	TDS (ppt)
1	May 2008	+ve tide	7.64	33.6	45	29.2
2	May 2008	+ve tide	7.78	28	37.4	24.29
3	November 2008	-ve tide	7.91	22.4	29.8	19.38
4	November 2008	+ve tide	7.72	30.60	39.20	26.40

Table 7.38 Tide wise seasonal water properties of Auranga

(pH, salinity, conductivity and TDS)

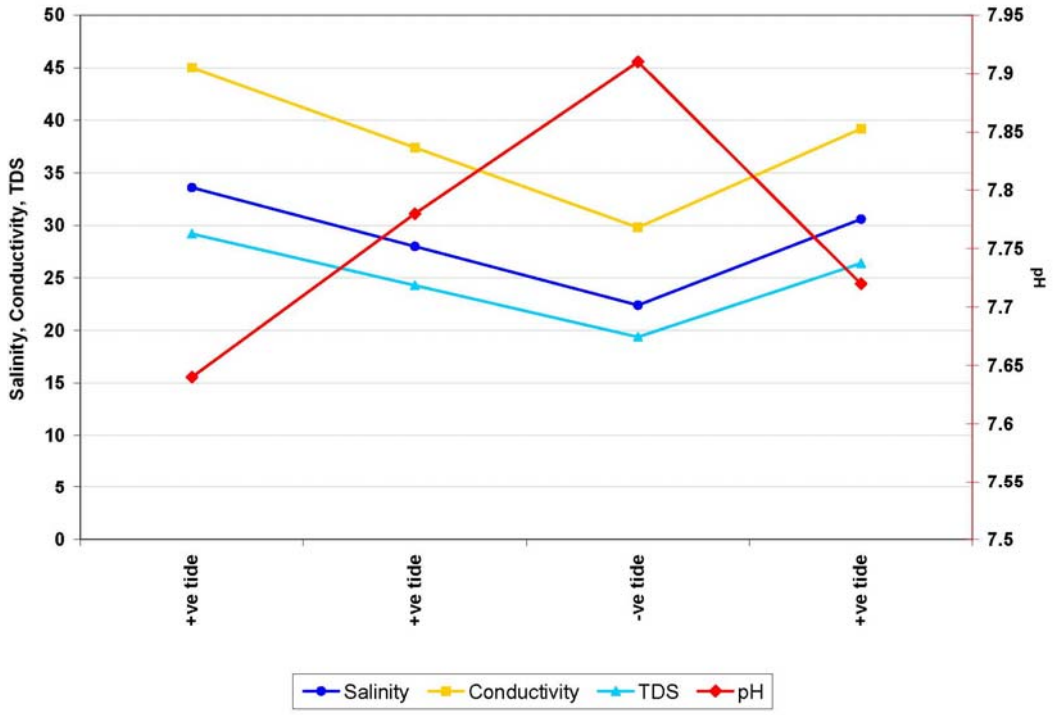


Chart – 7.16 Tide wise pH, salinity, conductivity and TDS of Auranga water samples

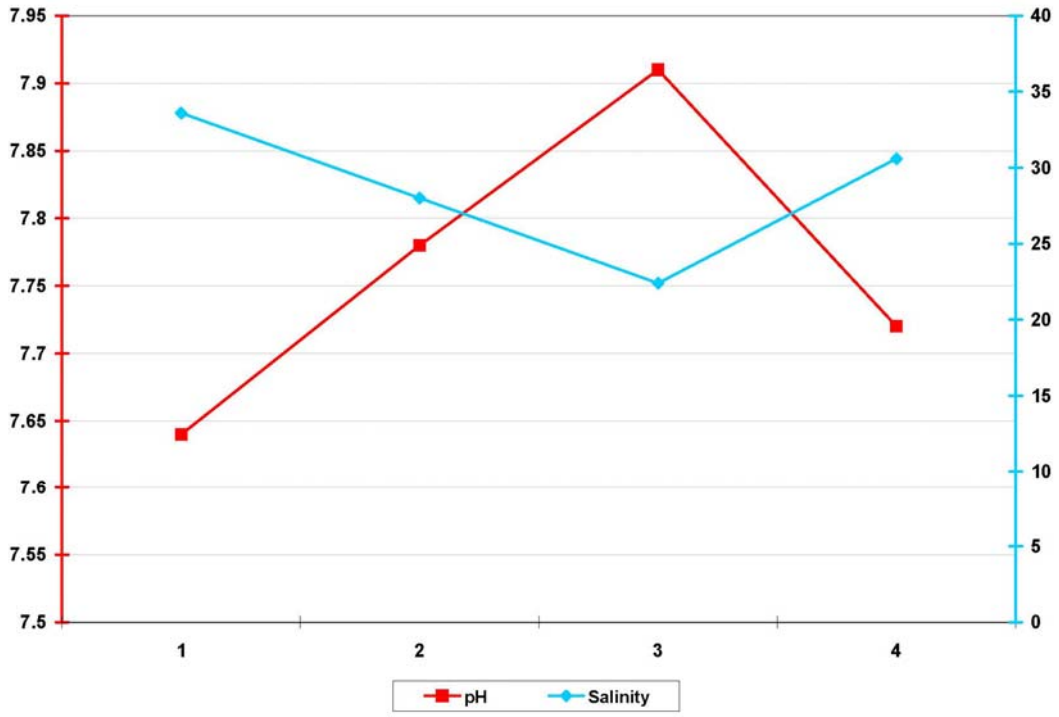


Chart – 7.17 Relationship between pH and salinity of Auranga water samples

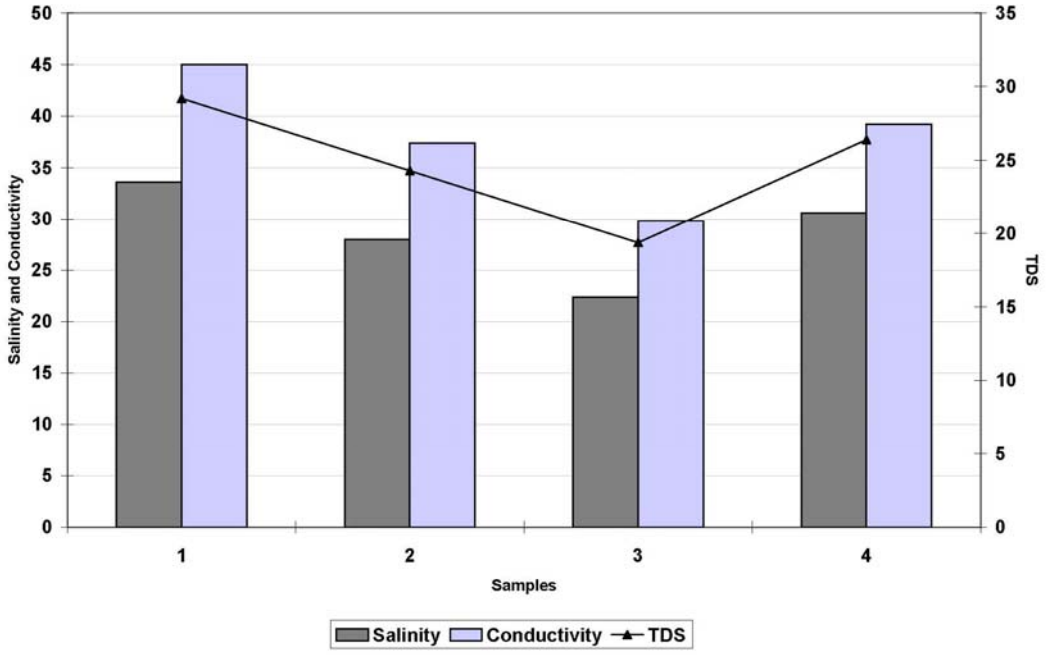


Chart – 7.18 Correlation between salinity, conductivity and TDS of Auranga water samples

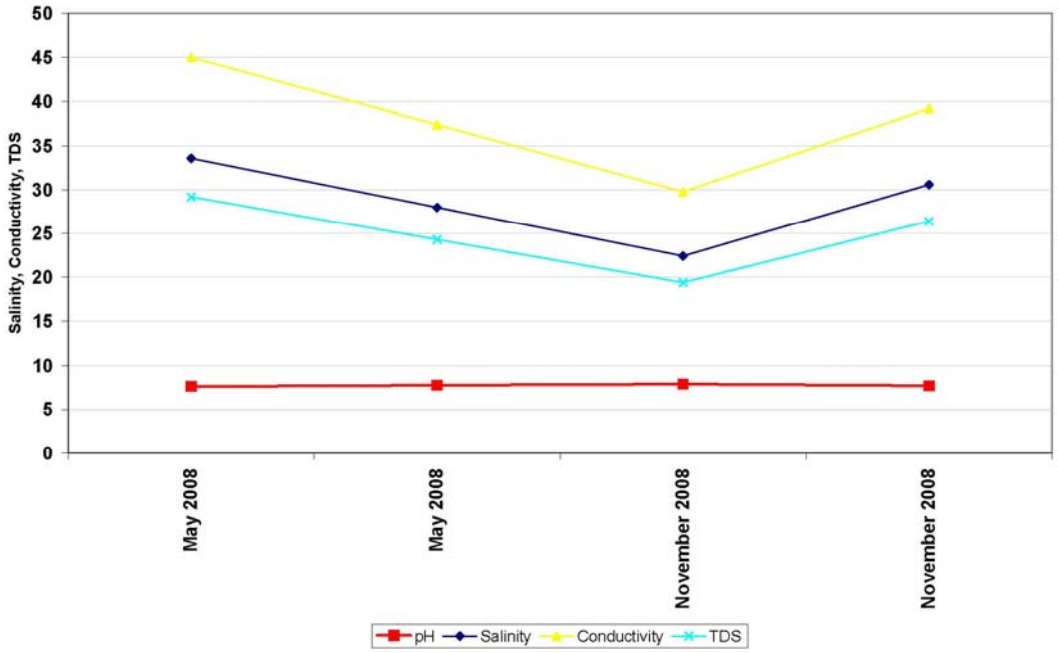


Chart – 7.19 Seasonal variations of pH, salinity, conductivity and TDS of Auranga water samples

Since the sampling was small not much can be inferred about the behavior over a period. However, from the current sampling, it is observed at Auranga River that the pH increased and the corresponding salinity, conductivity and TDS have decreased in the post-monsoon readings.

Par water properties

Par estuary is also one of the smaller estuarine set-ups of the study area. Not many channel bars and creeks are found in this estuary. Sampling was done for one season (post-monsoon) for this estuary, over different tidal timings. Total seven water samples were collected from different locations of this area.

Par water pH

The pH values of water sample of Par ranges from 7.79 to 9.93, the average value of which comes out to 8.20. No correlation between the tidal flushing was observed for the pH values

Par water Salinity

The salinity of water samples for Par estuary varies from 13.72 to 35.3 ppt and the average value comes up to 26.60 ppt.

Par water Conductivity

The conductivity of water samples range from 20.2 to 47.3 μS with average values being 35.74 μS.

Par water TDS

The TDS of water samples range from 11.7 to 30.6 ppt with the average value 22.97 ppt.

Sr. No.	Sample Number	Chemical Parameters				
		Tidal influence	pH	Salinity (ppt)	Conductivity (μS)	TDS (ppt)
1	November 2008	+ve tide	11.93	0.97	0.72	0.64
2	November 2008	Tide +ve	7.94	35.2	46.9	30.4
3	November 2008	Tide +ve	7.95	35.2	46.9	30.4
4	November 2008	Mid Tide	7.92	27.8	37.3	24.1
5	November 2008	Mid Tide	7.95	16.56	21.8	14.23
6	November 2008	Low tide	7.79	35.3	47.3	30.6
7	November 2008	Low tide	7.91	22.4	29.8	19.38

Table 7.39 Tide wise seasonal water properties of Par

(pH, salinity, conductivity and TDS)

No correlation could be observed between different sample readings and the tide timings. However, it was observed that pH and salinity did show inverse relationship and that the salinity, conductivity and TDS showed a positive correlation, showing simultaneous increase in the values, irrespective of the tidal flushing.

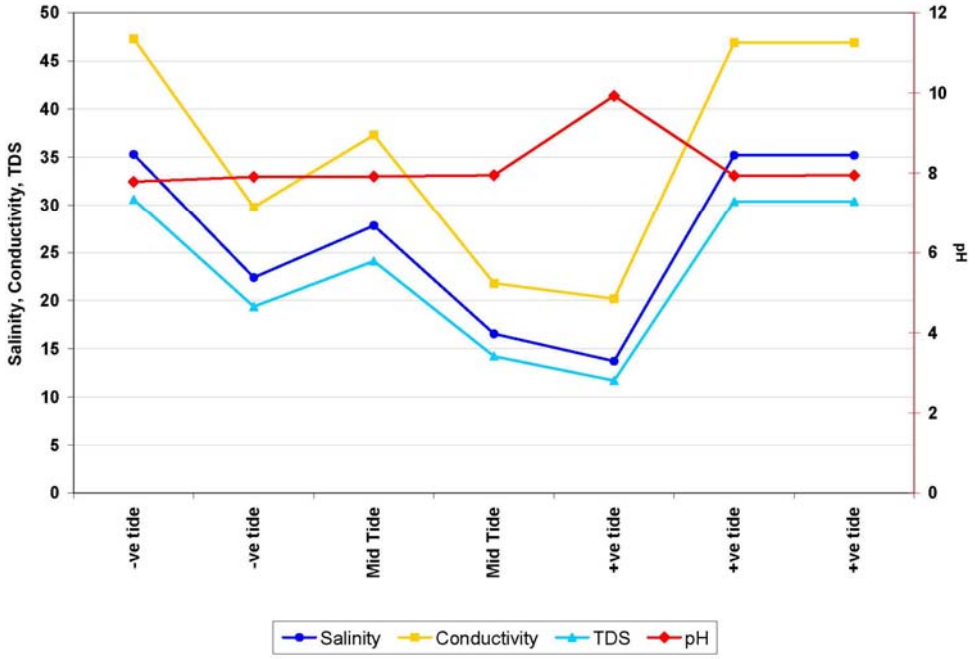


Chart – 7.20 Tide wise pH, salinity, conductivity and TDS of Par water samples

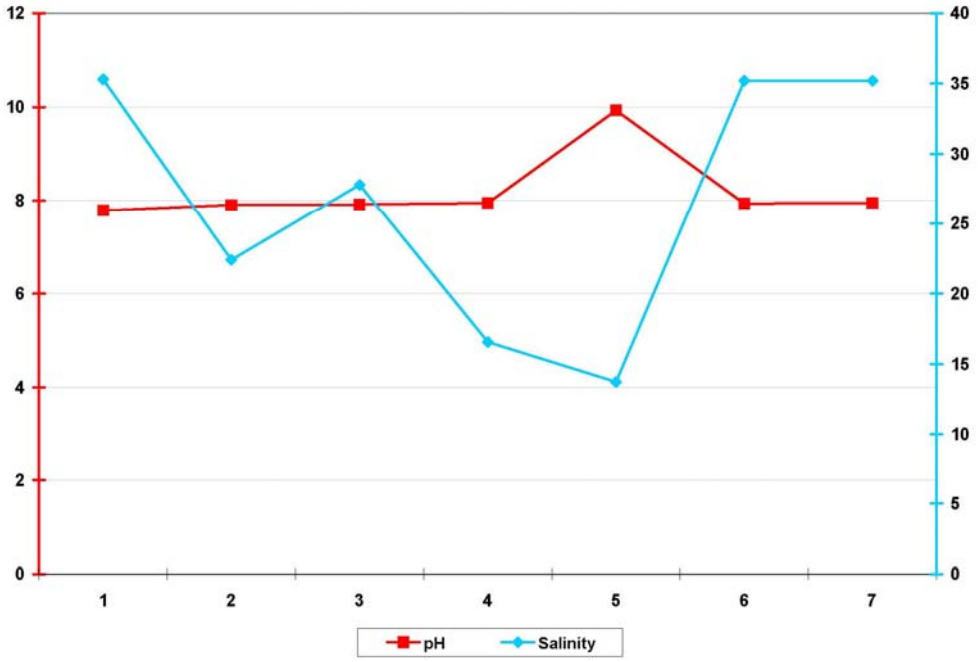


Chart – 7.21 Relationship between pH and salinity of Par water samples

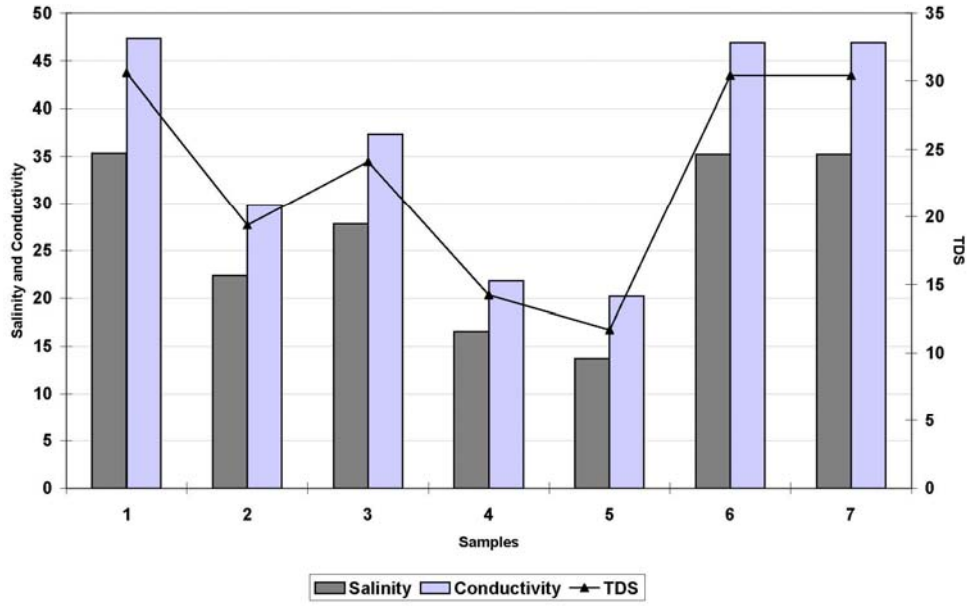


Chart – 7.22 Correlation between salinity, conductivity and TDS of Par water samples

Kolak water properties

Kolak forms one of the smallest estuarine setup of the study area with not even occurrence of a major creek. The sampling here was done obviously from the main channel. Sampling was conducted for two seasons – pre-monsoon and post-monsoon. Four water samples were collected for different prevalent tidal flushing.

Kolak water pH

The pH values of Kolak water samples range from 7.75 to 11.68. The average value is 9.78. It was observed over here that the pH values had changed with the season. They were however not correlated to the changed tidal flushings as not enough sampling over different tidal periods was conducted. With the change of season from pre-monsoon to post-monsoon, the values of pH also increased.

Kolak water Salinity

The salinity of water samples of Kolak River water ranges from 31.2 to 37.3 ppt. The average values come to 34.13 ppt. As observed with the pH values, similarly change in salinity of water samples was observed. However, here the salinity decreased from pre-monsoon to the post-monsoon period. If observations of tidal flushings are considered, then the salinity tends to decrease with the prograding tide, which is quite contrary to the possible trend. However, this was not considered keeping in view that other two samples were not enough to compare and reach such conclusions.

Kolak water Conductivity

The conductivity of Kolak River's water samples ranges from 41 to 49.8 µS. The average values come to 44.85 µS. Change in conductivity of water samples was observed, with the values decreasing over the post-monsoon period from the pre-monsoon readings.

Kolak water TDS

The TDS of water samples of Kolak ranges from 23.78 to 32.2 ppt. The average values come to 28.17 ppt. TDS values of water samples also shows decreasing trend from pre-monsoon to the post-monsoon period.

Sr. No.	Sample Number	Chemical Parameters				
		Tidal influence	pH	Salinity (ppt)	Conductivity (µS)	TDS (ppt)
1	May 2008	Low tide	7.75	37.3	49.8	32.2
2	May 2008	Mid tide	7.95	35.2	46.9	30.4
3	November 2008	+ve tide	11.72	39.2	51	33.3
4	November 2008	+ve tide	11.68	39.80	51.7	33.78

Table 7.40 Tide wise seasonal water properties of Kolak (pH, salinity, conductivity and TDS)

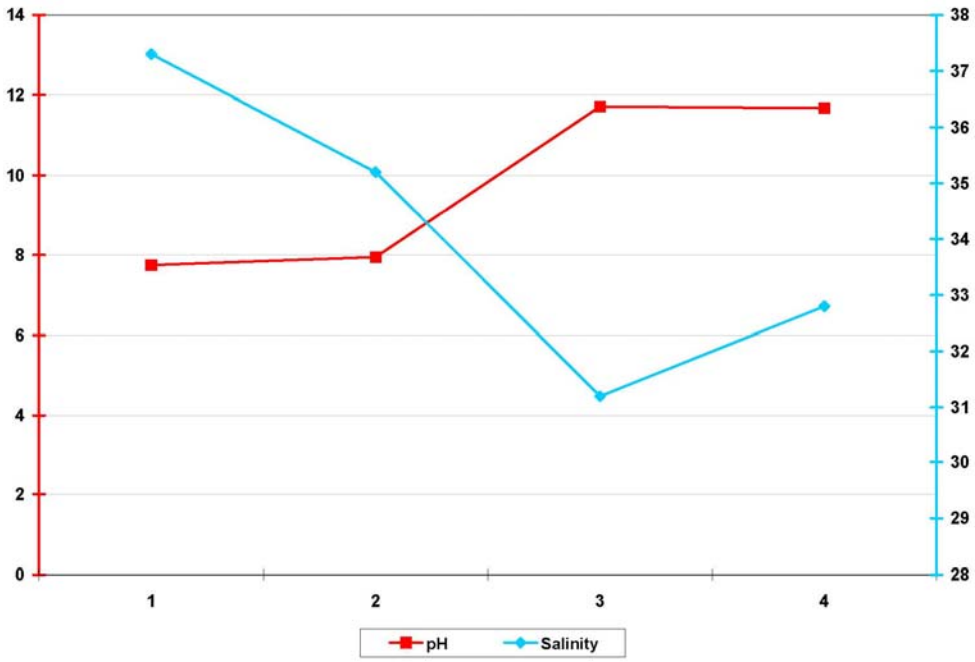


Chart – 7.23 Relationship between pH and salinity of Kolak water samples

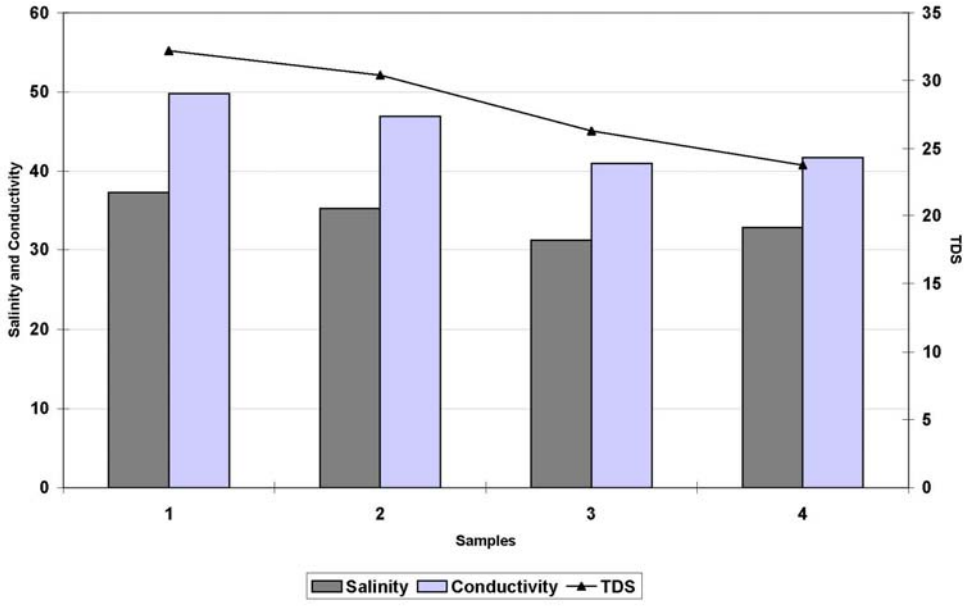


Chart – 7.24 Correlation between salinity, conductivity and TDS of Kolak water samples

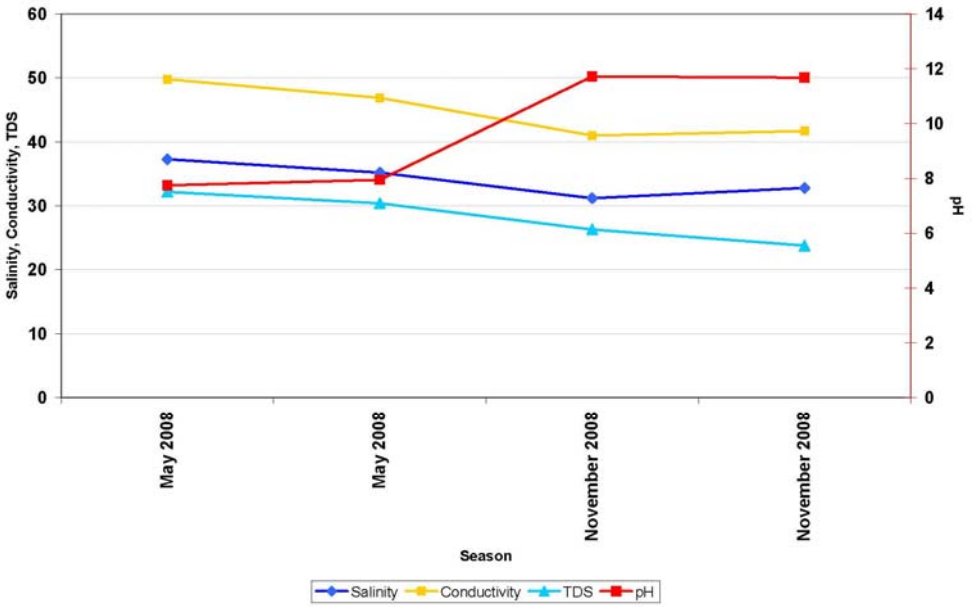


Chart – 7.25 Seasonal variations of pH, salinity, conductivity and TDS of Kolak water samples

For Kolak water samples, no observation was carried out to study the variation in readings of water samples with the change in tidal flushing. pH and salinity showed typical inverse correlation and salinity, conductivity and TDS showed positive correlation with changing simultaneous values. However, it was observed that the pH increase and salinity, conductivity and TDS decreased from pre-monsoon to post-monsoon. This could be because of influx of fresh water post-monsoon which reduced the salinity, conductivity and TDS of the waters of Kolak River (which according to various reports are polluted due to the industries setup on the banks of the river).

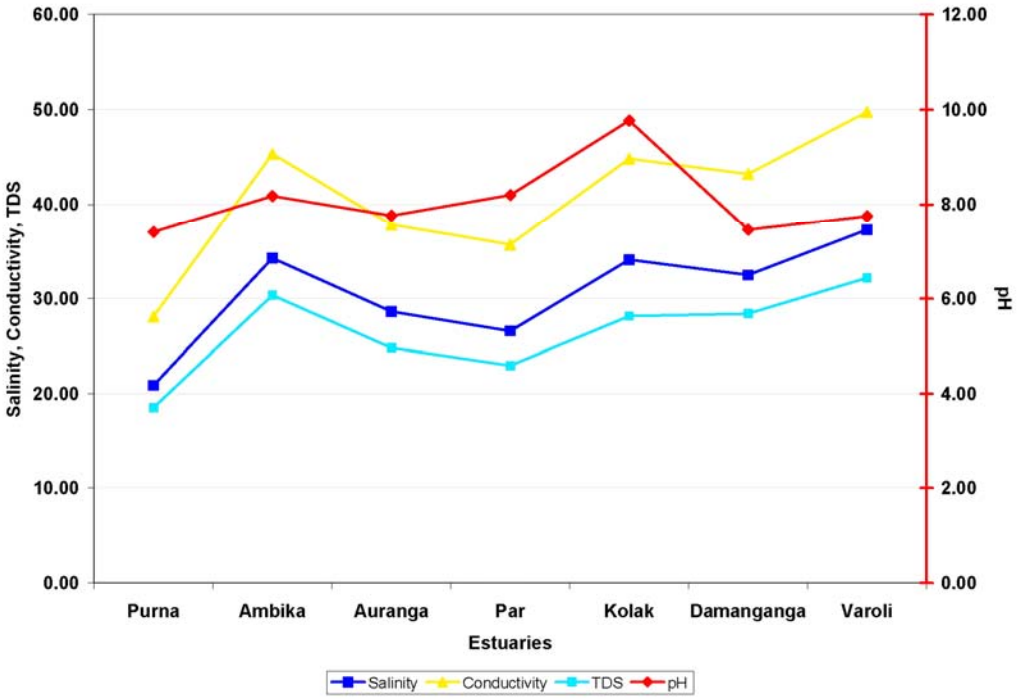


Chart 7.26 Comparative account of water samples of different estuaries

SOIL SAMPLES ANALYSIS

Grain size parameters provide an insight in to the nature and the energy flux of the multi-various transporting agents and their preview of depositional environment. This helps in analyzing various processes effecting erosion and deposition. In addition, soil composition and grain size determines porosity of the soil which ultimately influences soil salinity, water content, and amount of nutrients contained in the soil (clays and silts have higher concentrations of nutrients).

Purna soil properties

Physical characteristic

Twenty one soil samples were collected over a period of two years from Purna estuary. The samples were analysed for grain size as well for the basic physico-chemical properties – pH, salinity and the electrical conductivity.

Sr. No.	Sample Number	Soil Depth (cm)	Physical Parameters			Texture class
			Sand %	Silt %	Clay %	
1	Purna 1	0 - 20	0.24	30	69.76	Clayey silt
2	Purna 2	0 - 20	0.94	53.33	45.72	Clayey silt
3	Purna 3	0 - 20	1.07	43.6	55.33	Clayey silt
4	Purna 4	0 - 20	1.83	42.8	55.37	Clayey silt
5	Purna 5	0 - 20	1.59	36.3	62.11	Clayey silt
6	Purna 6	0 - 20	1.15	19.63	79.21	Clayey silt
7	Purna 7	0 - 20	1.53	51.33	47.14	Silty clay
8	Purna 8	0 - 20	0.38	43.73	55.89	Clayey silt
9	Purna 9	0 - 20	3.08	48.67	48.26	Silty clay
10	Purna 10	0 - 20	4.46	56.6	38.94	Silty clay
11	Purna 11	0 - 20	15.6	47.4	37	Silty clay
12	Purna 12	0 - 20	1.56	50.53	47.91	Silty clay
13	Purna 13	0 - 20	5.26	45.3	49.44	Clayey silt
14	Purna 14	0 - 20	0.21	38.47	61.32	Clayey silt
15	Purna 15	0 - 20	34.47	43.07	22.46	Sandy-silty-clayey

16	Purna 16	0 - 20	0.05	39.37	60.59	Clayey silt
17	Purna 17	0 - 20	0.05	39.37	60.59	Clayey silt
18	Purna 18	0 - 20	2.44	28.63	68.93	Clayey silt
19	Purna 19	0 - 20	14.8	20.67	64.53	Clayey silt
20	Purna 20	0 - 20	18.25	32.57	49.19	Clayey silt
21	Purna 21	0 - 20	45.02	15.7	39.28	Silty sand
	All site average		**7.33**	**39.38**	**53.28**	**Clayey silt**

Table – 7.41 Analysis of physical parameters of soil sample of Purna

The soil samples of Purna mostly fall under clayey silt to silty clay category according to Shepard's classification.

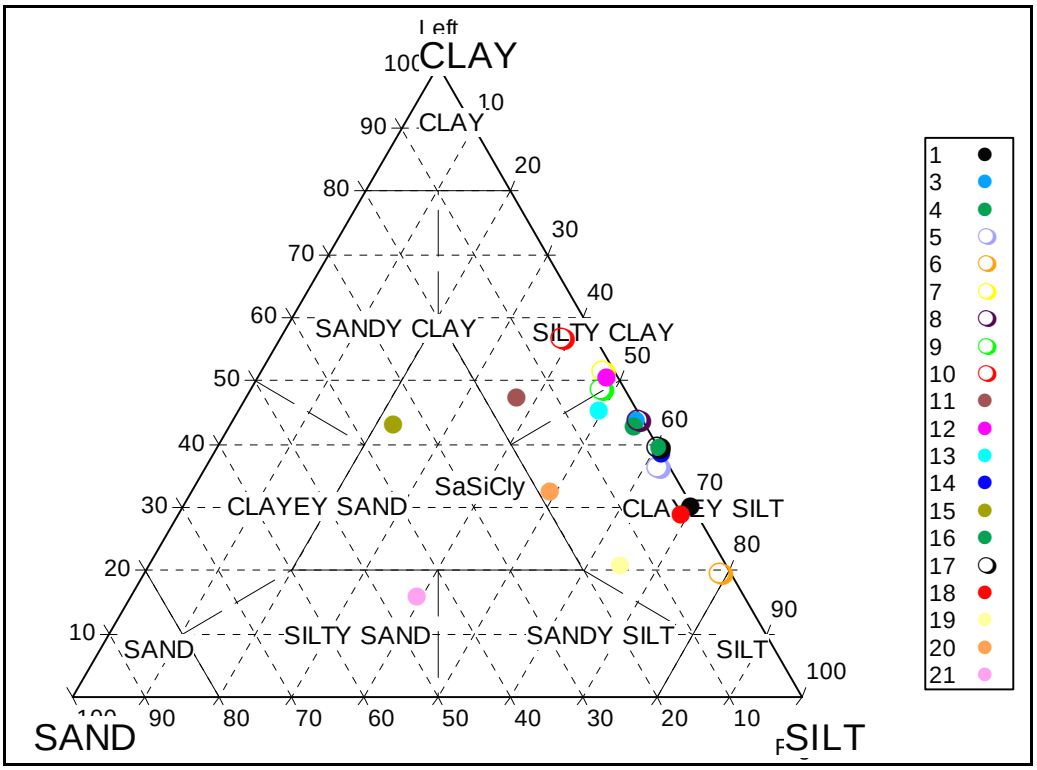


Chart 7.27 Tridraw plot of soil samples of Purna estuary

Chemical parameters

Sr. No.	Sample Number	Chemical Parameters		
		pH	Salinity (ppt)	Conductivity (µS)
1	Purna 1	8.46	10.80	15.22
2	Purna 2	8.44	7.28	10.24
3	Purna 3	8.57	3.46	4.93
4	Purna 4	8.56	5.33	7.59
5	Purna 5	8.41	6.45	9.05
6	Purna 6	8.59	5.53	7.73
7	Purna 7	8.52	8.71	11.60
8	Purna 8	8.58	5.60	8.02
9	Purna 9	8.47	10.16	13.72
10	Purna 10	8.57	6.87	9.51
11	Purna 11	8.70	4.69	6.24
12	Purna 12	8.37	6.79	9.00
13	Purna 13	8.16	6.72	9.16
14	Purna 14	8.13	6.81	9.29
15	Purna 15	8.60	7.84	10.49
16	Purna 16	8.46	11.14	15.33
17	Purna 17	8.62	6.26	8.14
18	Purna 18	8.83	4.56	6.00
19	Purna 19	8.52	8.71	11.60
20	Purna 20	8.88	4.40	5.86
21	Purna 21	8.70	4.71	6.30
All site average		**8.53**	**6.80**	**9.29**

Table – 7.42 Analysis of chemical parameters of soil sample of Purna

Ambika soil properties

Physical characteristic

Eleven soil samples were collected over a period of two years from Ambika estuary. The samples were analyzed for grain size as well for the basic physico-chemical properties – pH, salinity and the electrical conductivity.

Sr. No.	Sample Number	Soil Depth (cm)	Physical Parameters			Texture class
			Sand %	Silt %	Clay %	
1	Ambika 1	0 - 20	0.73	37.67	61.6	Clayey silt
2	Ambika 2	0 - 20	4.33	36.53	59.13	Clayey silt
3	Ambika 3	0 - 20	1.33	29.57	69.1	Clayey silt
4	Ambika 4	0 - 20	4.98	52.87	42.15	Silty clay
5	Ambika 5	0 - 20	4.66	40.37	54.97	Clayey silt
6	Ambika 6	0 - 20	10.34	30.53	59.13	Clayey silt
7	Ambika 7	0 - 20	5.59	22.33	72.08	Clayey silt
8	Ambika 8	0 - 20	17.12	47.07	35.82	Silty clay
9	Ambika 9	0 - 20	8.95	47.87	43.18	Silty clay
10	Ambika 10	0 - 20	4.97	7.87	87.17	Silt
11	Ambika 11	0 - 20	10.37	29.33	60.29	Clayey silt
	All site average		**6.67**	**34.73**	**58.60**	**Clayey silt**

Table – 7.43 Analysis of physical parameters of soil sample of Ambika

The soil samples of Ambika mostly fall under clayey silt category according to Shepard's classification.

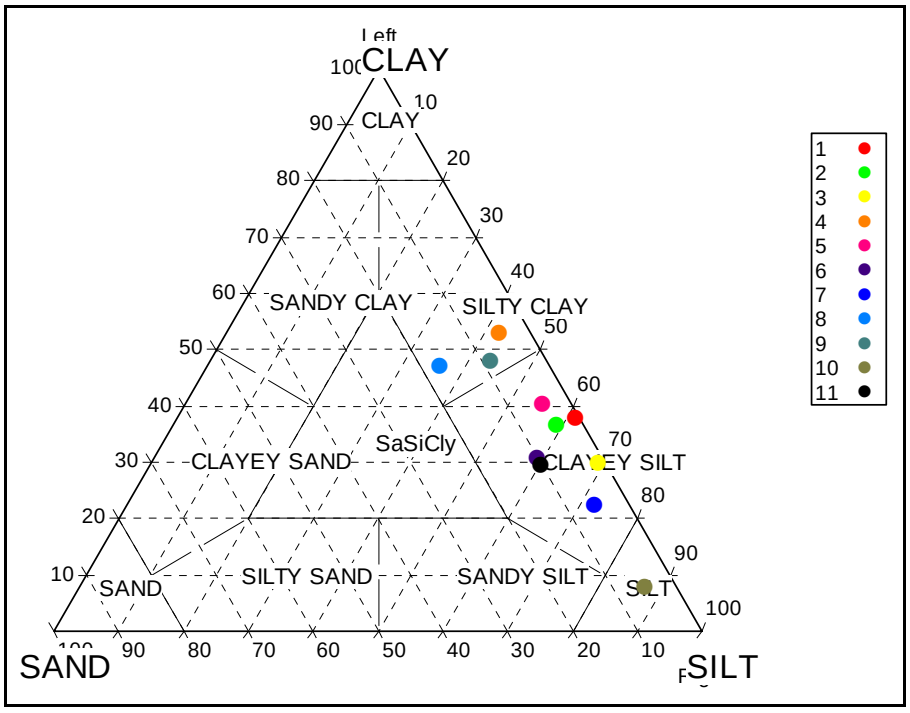


Chart 7.28 Tridraw plot of soil samples of Ambika estuary

Chemical parameters

Sr. No.	Sample Number	Chemical Parameters		
		pH	Salinity (ppt)	Conductivity (µS)
1	Ambika 1	8.39	6.49	9.13
2	Ambika 2	8.60	7.83	10.46
3	Ambika 3	8.80	4.51	6.05
4	Ambika 4	8.51	10.20	13.74
5	Ambika 5	8.58	5.61	8.13
6	Ambika 6	8.46	11.58	15.46
7	Ambika 7	8.46	10.77	15.35
8	Ambika 8	8.68	4.65	6.21
9	Ambika 9	8.15	6.69	9.11
10	Ambika 10	8.55	5.56	7.70
11	Ambika 11	8.44	11.37	15.49
	All site average	**8.51**	**7.75**	**10.62**

Table – 7.44 Analysis of chemical parameters of soil sample of Ambika

Auranga soil properties

Physical characteristic

Six soil samples were collected over a period of two years from Auranga estuary. The samples were analyzed for grain size as well for the basic physico-chemical properties – pH, salinity and the electrical conductivity.

Sr. No.	Sample Number	Soil Depth (cm)	Physical Parameters			Texture class
			Sand %	Silt %	Clay %	
1	Auranga 1	0 - 20	0.47	34.83	64.7	Clayey silt
2	Auranga 2	0 - 20	6.98	44.47	48.56	Clayey silt
3	Auranga 3	0 - 20	4.59	10.33	85.08	Silt
4	Auranga 4	0 - 20	17.2	58.4	24.4	Silt clay
5	Auranga 5	0 - 20	62.46	33.20	4.34	Clayey sand
6	Auranga 6	0 - 20	4.58	29.1	66.32	Clayey silt
	All site average		**16.05**	**35.05**	**48.90**	**Clayey silt - silty**

Table – 7.45 Analysis of physical parameters of soil sample of Auranga

The soil samples of Auranga mostly fall under clayey silt - silty category according to Shepard's classification.

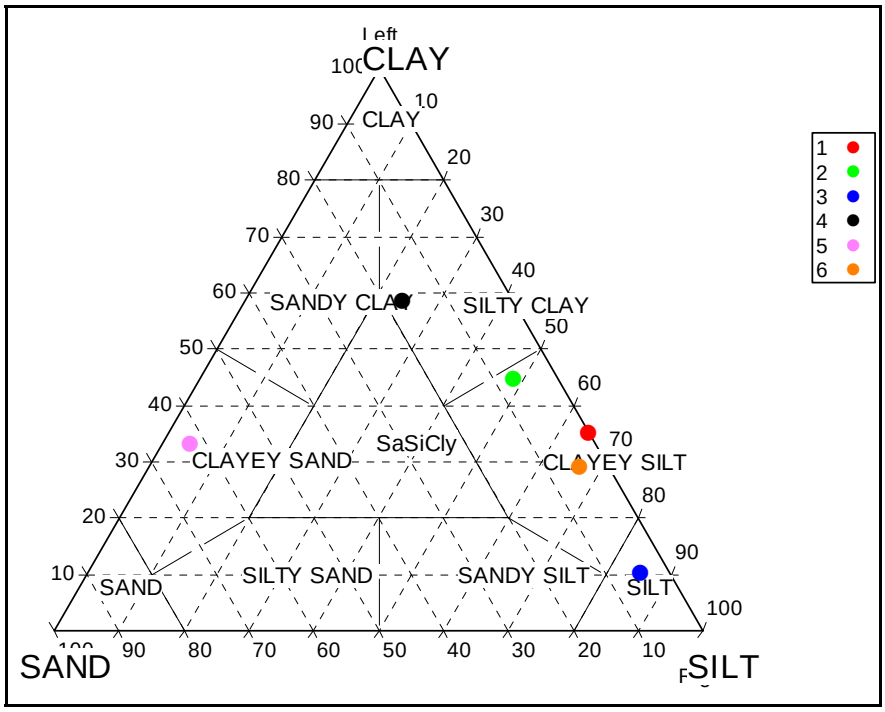


Chart 7.29 Tridraw plot of soil samples of Auranga estuary

Chemical parameters

Sr. No.	Sample Number	Chemical Parameters		
		pH	Salinity (ppt)	Conductivity (µS)
1	Auranga 1	6.03	7.08	8.81
2	Auranga 2	8.41	6.44	11.24
3	Auranga 3	8.57	5.55	7.72
4	Auranga 4	8.18	6.18	8.59
5	Auranga 5	8.93	4.58	5.04
6	Auranga 6	9.73	6.67	8.43
	All site average	**8.31**	**6.08**	**8.30**

Table – 7.46 Analysis of chemical parameters of soil sample of Auranga

Par soil properties

Physical characteristic

Three soil samples were collected over a period of two years from Par estuary. The estuarine setup was small as compared to other estuaries hence the sample collection was also limited and not exhaustive/ infinite as other

estuaries. The samples were analyzed for grain size as well for the basic physico-chemical properties – pH, salinity and the electrical conductivity.

Sr. No.	Sample Number	Soil Depth (cm)	Physical Parameters			Texture class
			Sand %	Silt %	Clay %	
1	Par 1	0 - 20	2.45	36.73	60.81	Clayey silt
2	Par 2	0 - 20	14.78	41.07	44.15	Clayey silt
3	Par 3	0 - 20	1.93	42.87	55.2	Clayey silt
	All site average		**6.39**	**40.22**	**53.39**	**Clayey silt**

Table – 7.47 Analysis of physical parameters of soil sample of Par

The soil samples of Par mostly fall under clayey silt category according to Shepard's classification.

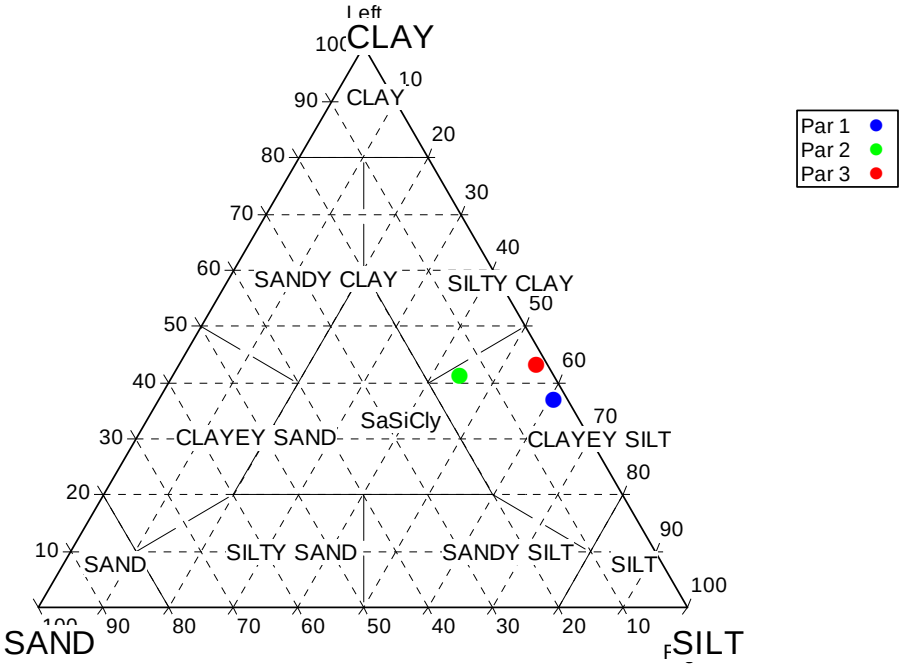


Chart 7.30 Tridraw plot of soil samples of Par estuary

Chemical parameters

Sr. No.	Sample Number	Chemical Parameters		
		pH	Salinity(ppt)	Conductivity (µS)
1	Par 1	8.56	5.33	7.59
2	Par 2	8.59	5.53	7.73
3	Par 3	8.57	3.46	4.93
	All site average	**8.57**	**4.77**	**6.75**

Table – 7.48 Analysis of chemical parameters of soil sample of Par

Kolak soil properties

Physical characteristic

Four soil samples were collected over a period of two years from Kolak estuary. The estuarine setup is quite small as compared to other estuaries hence the sample collection was also limited. The samples were analyzed for grain size as well for the basic physico-chemical properties – pH, salinity and the electrical conductivity.

Sr. No.	Sample Number	Soil Depth (cm)	Physical Parameters			Texture class
			Sand %	Silt %	Clay %	
1	Kolak 1	0 - 20	1.12	29.17	69.71	Clayey silt
2	Kolak 2	0 - 20	0.94	29.23	69.83	Clayey silt
3	Kolak 3	0 - 20	0.31	30.57	69.12	Clayey silt
4	Kolak 4	0 - 20	2.52	32.33	65.15	Clayey silt
	All site average		**1.22**	**30.33**	**68.45**	**Clayey silt**

Table – 7.49 Analysis of physical parameters of soil sample of Kolak

The soil samples of Kolak mostly fall under clayey silt category according to Shepard's classification.

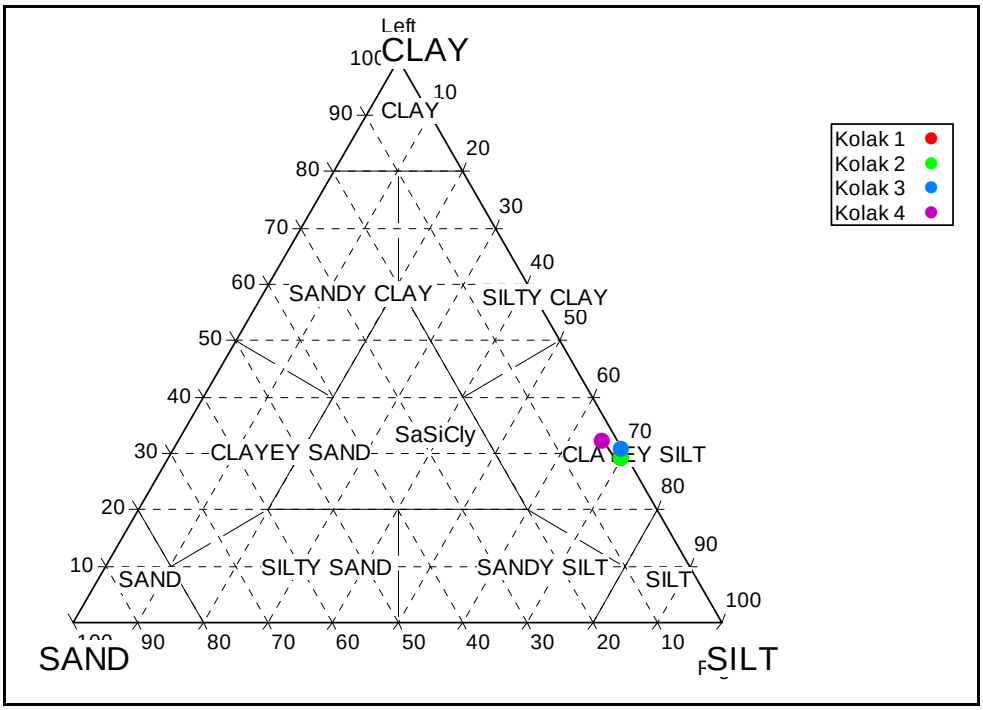


Chart 7.31 Tridraw plot of soil samples of Kolak estuary

Chemical parameters

Sr. No.	Sample Number	Chemical Parameters		
		pH	Salinity (ppt)	Conductivity (µS)
1	Kolak 1	8.44	7.28	10.24
2	Kolak 2	8.41	6.45	9.05
3	Kolak 3	8.58	5.60	8.02
4	Kolak 4	8.46	10.80	15.22
	All site average	**8.47**	**7.53**	**10.63**

Table – 7.50 Analysis of chemical parameters of soil sample of Kolak

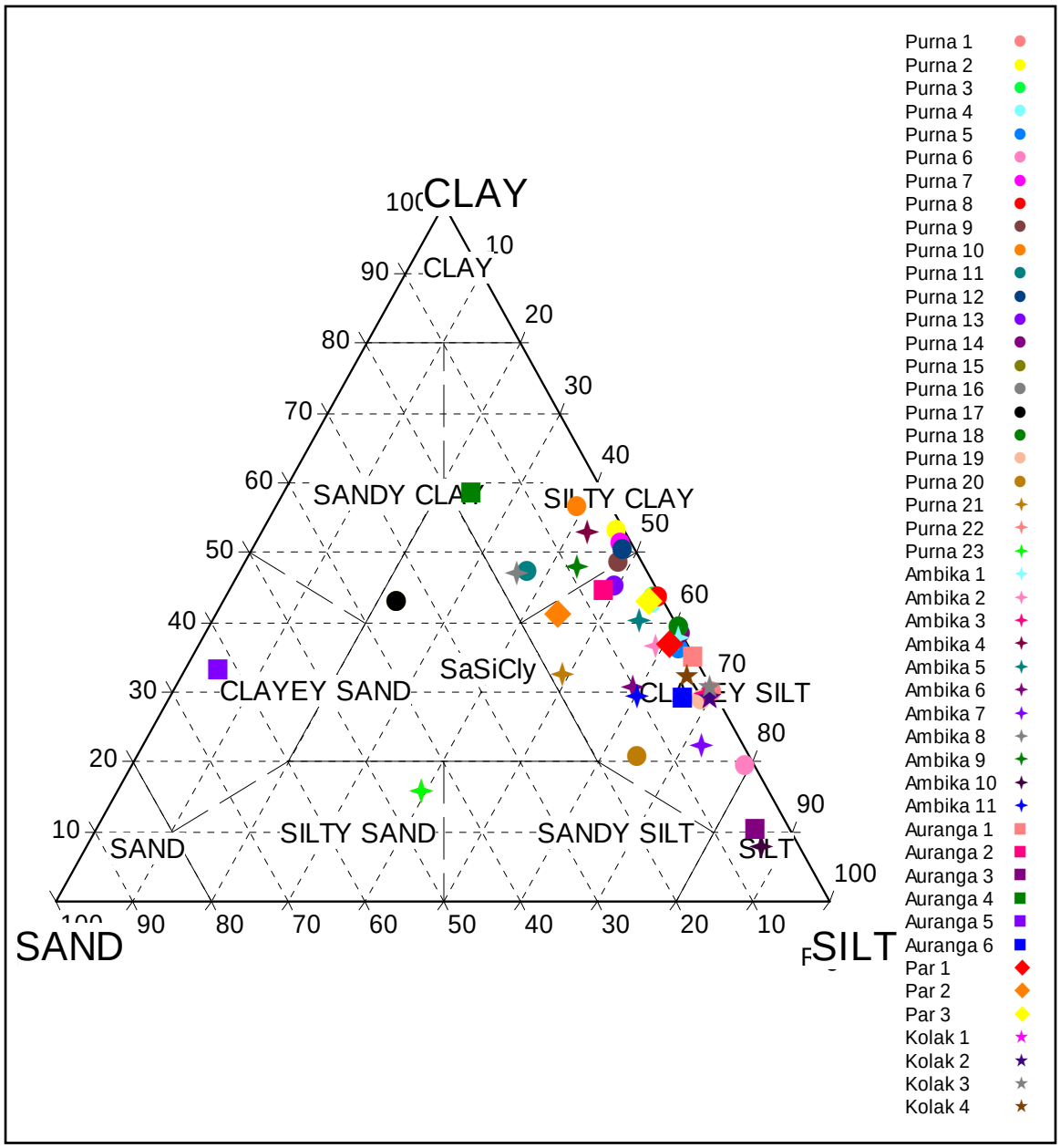


Chart 7.32 Tridraw plot of soil samples of estuaries of south Gujarat

Mangrove physiology, growth and placement can be affected by a variety of variables, including tides, water salinity, soil salinity, soil pH, available nutrients, and soil grain size (Ball and Farquhar, 1984a; Lovelock et al., 2004, 2006). Tides are important because they help determine where mangroves will grow based on how salt tolerant they are. Mangroves grow best in soils with moderate soil salinity of about 25 ppt (English et al. 1997). High salinity in general is often found to be the reason for stunted mangrove growth. High salinity decreases the rate of photosynthesis so with lower salinity and more light the net photosynthesis per unit leaf area increases and growth rate of the mangrove increases (López-Hoffman et al. 2007). Soil pH affects the distribution of mangrove species because each species has a different tolerance for different pH levels (Wakushima et al. 1994) Grain size and composition of soil also affect mangroves. Mangroves tend to grow well in areas where their roots have ample places for attachment and seem to only do well in mud and very fine sand (Cardona and Botero, 1998). In addition, soil composition and grain size determines porosity of the soil which ultimately influences soil salinity, water content, and amount of nutrients contained in the soil (clays and silts have higher concentrations of nutrients).

Electrical conductivity (EC) is found to be lower during post - monsoon and maximal during pre-monsoon. Thus, the influence of atmospheric precipitation on EC and total dissolved solids (TDS) is more pronounced in the mangrove during the monsoon period. The increase in the ionic strength of the

mangrove water during the pre-monsoon periods may be due to less river water input via estuaries due to the construction of dams, aided by evaporation due to the rise in the temperature and relatively less fresh water flow from inland.

Grain size measurement helps in determining the textural and depositional characteristics of the environment. Clay forms the major component of the soil samples of the study area followed by silt and then sand. Mangroves prefer environment with finer particles which helps them sustain and grow.

All these encouraging environmental factors have greatly contributed to the density, areal extent and the diversity of mangroves of study area. However, there are certain threats also posed in form of industrial development and related pollution, increased aquaculture activities, unnecessary erection of ports, etc.

However, these threats are not prevalent at all the estuaries, all at the same time. Mangroves of Mindhola estuary face threats in terms of pollution due to the industrial set-up upstream. The water here is polluted to the extent of corroding the bottom of the boats. The mangroves here thus are restricted to a patch, in spite of large estuarine area. In addition, the threat here is in the face of reclamation of the mudflat land for aquaculture activities at a sewage dumping site.

Mangroves of Purna are jeopardized due to the chopping activities. The fisher-folks here depend on the mangroves for fuel wood as the mudflat area is extensive and most of its part is at a distance from the major towns. In addition, threat is envisioned in the form of proposed port at Vansi – Borsi, which seems unnecessary in the presence of a port at Dholai which is just about 20 - 25 kms away and with another intermediate port in north at Surat, at distance of about 30 – 35 kms.

Mangroves of Ambika estuary not only face threat in form of the Dholai port which is amongst the mangroves, but also ever – increasing aquaculture ponds. Same stands for the mangrove wetland of Auranga estuary, where the aquaculture ponds have been increasing radically, especially from 2001 onwards. However, the encouraging point here is the awareness of the locales on the importance of the mangrove ecosystems. A temple priest at Auranga ensures that the locales conserve the patch of mangrove, albeit small (Shah et. al., 2009).

The mangroves of Par seemed to be recent. The topmost layer of soil here was sandy at many places. Moreover, the mangroves here were shrubby. No apparent threat has been noticed over at the Par estuary at least as of now.

In terms of pollution, mangroves of Kolak and Damanganga face major threat from various industries setup upstream. These industries let out the chemical effluents into the river which ultimately feeds the mangrove ecosystem. The threat due to pollution is so severe here that at many occasions

fishes have been found dead along the banks of river, due to chemical poisoning. Unfortunately, this is not a solitary incident but has been repeating since many years and has been reported in the newspapers as well. (Times of India, Surat, Apr 14, 2011, Indian Express, Surat, Fri Apr 15 2011, Times of India, May 4, 2011)

Dead fish washed on the river banks of Kolak - Occurrence May – 2008

Industries adjacent to the mangrove patches at Kolak

However, the consolation here is the awareness of the local population, especially on the north flank of the Kolak River. The people here are actively involved in the conservation practices and take punitive actions against those who destroy the mangroves. How long the mangroves can withstand the brunt of industrial pollution something which needs to be considered upon.

Awareness and conservation efforts for the mangrove patches at Kolak

Mangroves at river Varoli too are protected by the locals and are guarded fiercely against any unfamiliar being. However, it was observed here that during the dry periods i.e. during summer season the mangrove patches in the upper reaches of the estuarine setup were dry. The estuarine setup here is vast and currently there seems to be no threat from the anthropogenic or the natural causes. However, Varoli estuary is where mangroves like *Aegiceras*

corniculatum and *Lumnitzera racemosa* grow exclusively, upstream. This clearly indicates the favorable environmental conditions governing the estuary.

CHAPTER 8: ENVIRONMENTAL APPRAISAL

Wetlands are often described as “kidneys of the landscape” (Mitsch & Gosselink, 1986). Hydrologic conditions can directly modify or change chemical and physical properties such as nutrient availability, soil salinity, sediment properties and pH. These modifications of the physiochemical environment, in turn, have a direct impact on the biotic response in the wetland (Gosselink & Turner, 1978). When hydrologic conditions in wetlands change even slightly, the biota may respond with massive changes in species composition and richness and in ecosystem productivity. Mangrove ecosystem and its functioning is thus dependent on many factors including the hydrologic regime; geological conditions, etc. Thus, plethora of factors contributes to this habitat which ultimately affects the quality, distribution and species populations of mangroves. Studying them and monitoring these factors over time can give an indication regarding the health of this ecosystem and its sustainability

Mangrove habitats have relatively low levels of species richness compared with other high biomass tropical habitats like rain forests and coral reefs (Ricklefs & Latham, 1993). Despite the relatively low biodiversity, plants in these forests have a broad range of structural and functional attributes which promote their survival and propagation in relatively harsh conditions of the intertidal zone. In this sense, diversity of mangrove plants is not measured in terms of numbers of species, but also in terms of the ability of each species to cope with the wide range of

environmental conditions in utilizing their individual, specialized attributes.

The information of mangrove wetlands of south Gujarat is scarce as well as outdated. Estuary wise assessment was carried out and regional database was generated (chart 8.1) (Table 8.1).

Current work has brought to notice the most diverse patch of mangroves. Overall diversity of mangroves of Gujarat which was reported to be as eight mangrove species have now changed to 10 as two additional mangrove species from south Gujarat region have been discovered – *Lumnitzera racemosa* and *Excoecaria agallocha.* Moreover, biodiversity of mangroves of south Gujarat was never paid attention to. This work has changed that and more focus should be given to study these sustaining patches of south Gujarat.

Moreover, in terms of area, the mangroves are increasing steadily through each passing decade. The FSI data (Anon., 2009) shows increase in mangrove of Gujarat in the recent times, after seeing a decrease due to the impact of cyclone during 1999 (chart 8.2). This increase however can not be translated to the mangroves of south Gujarat, as since, 2003 mangroves of Navsari district do not show any change in terms of areal extent. The mangrove area of Navsari district has remained stable since 2003 with areal extent of 1 sq. km. only. However, Valsad district does show increase in the mangrove area in the recent past with increase in area from 2 sq. km. to 5 sq. km from 2005 to 2007 (chart 8.3). Change in Surat district is mainly due to plantation activities carried by SHELL at Hazira.

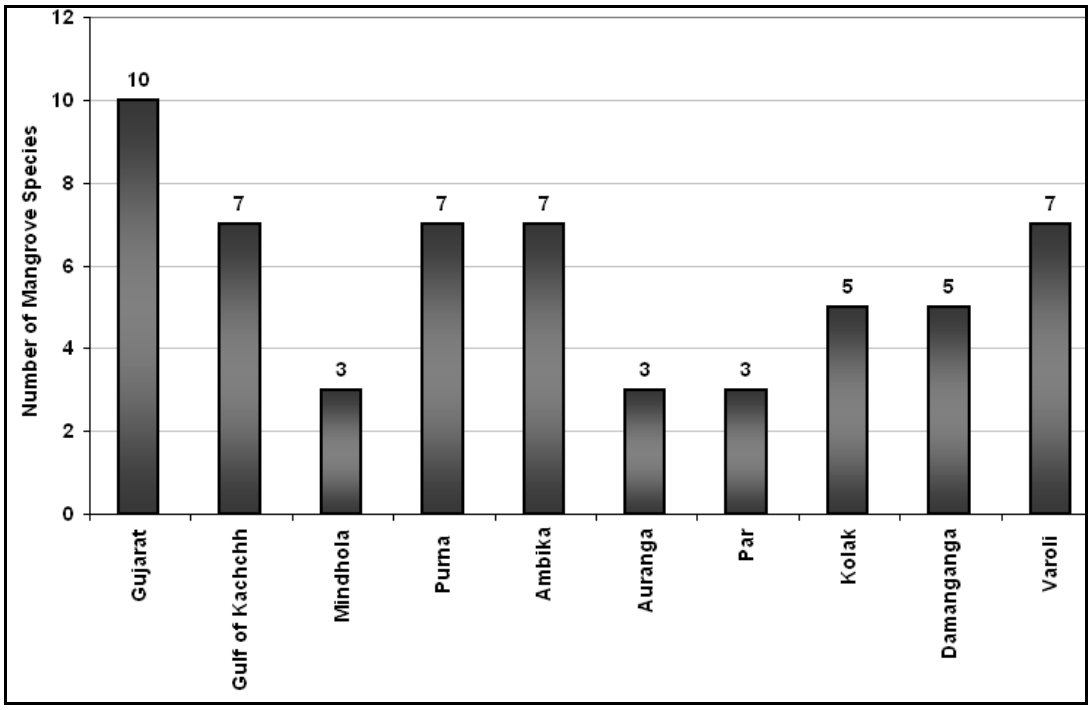


Chart – 8.1 Number of mangrove species across major mangrove patches of Gujarat vs. south Gujarat

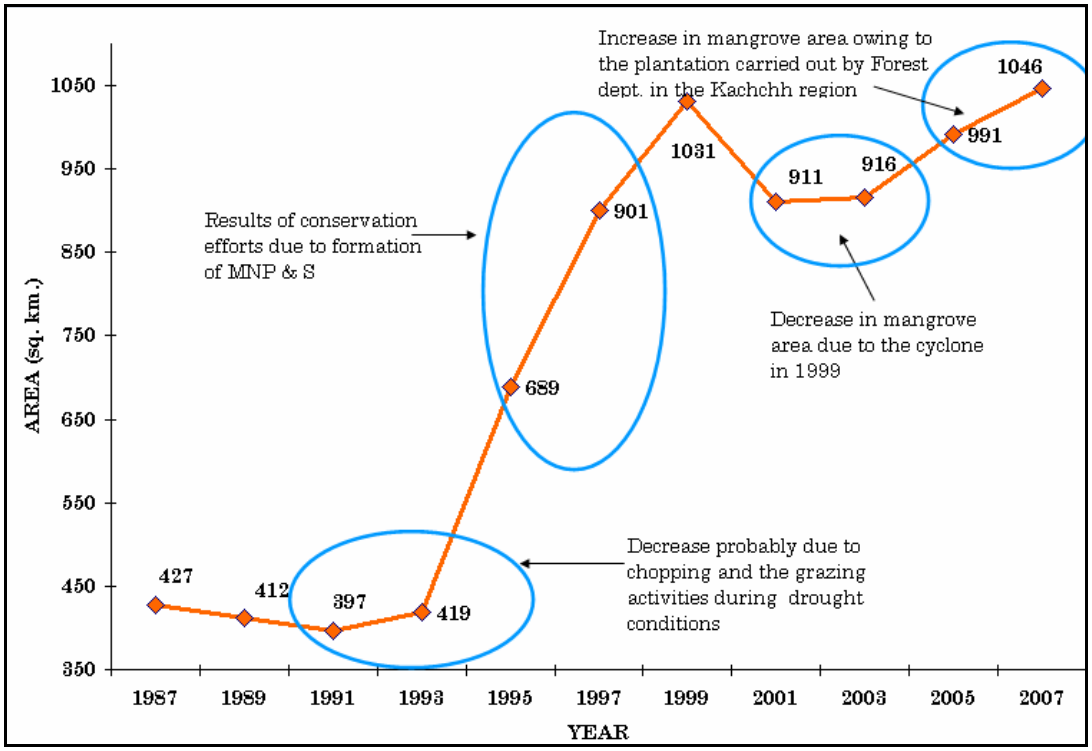


Chart – 8.2 Change in the areal extent of mangroves of Gujarat over 2 decades

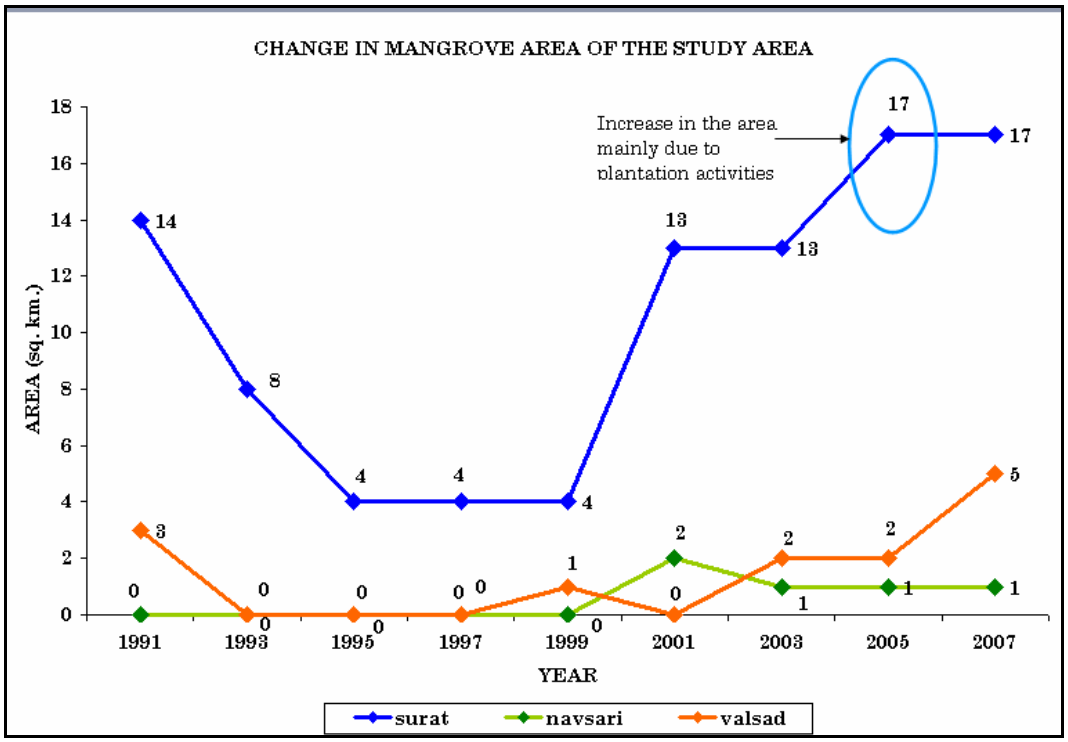


Chart – 8.3 Change in the areal extent of mangroves of south Gujarat over the years

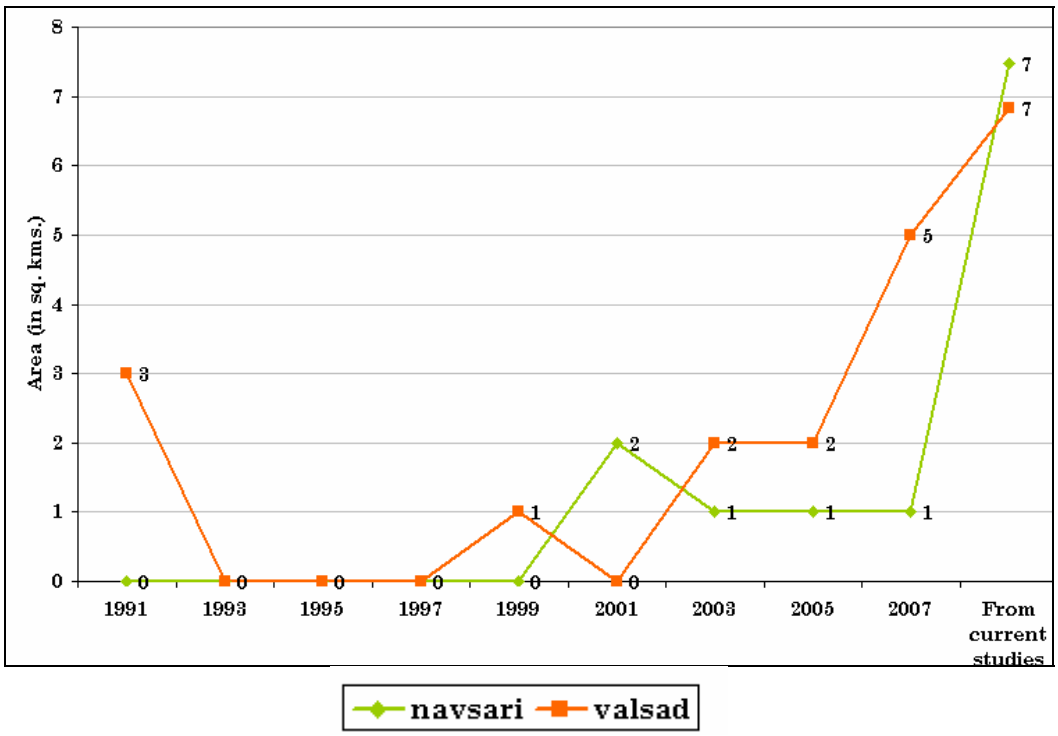


Chart – 8.4 Comparative analysis of area of mangroves of south Gujarat on the basis of current work

However, as a outcome of current work, it can be seen that mangrove area of Navsari district is about 7 sq. km. and that of Valsad district is also 7 sq. km (chart 8.4). However, this area can not be ascribed to any particular year as the satellite data used is from the year 1999 (Damanganga), 2001 (Mindhola, Kolak and Varoli) and 2005 (Purna, Ambika, Auranga and Par). Nevertheless, it definitely shows an increase in the mangroves of south Gujarat. Areal estimates of sparse and dense mangroves in south Gujarat and that of mangroves - estuary wise mangroves have been given in chart 8.5 to chart 8.9.

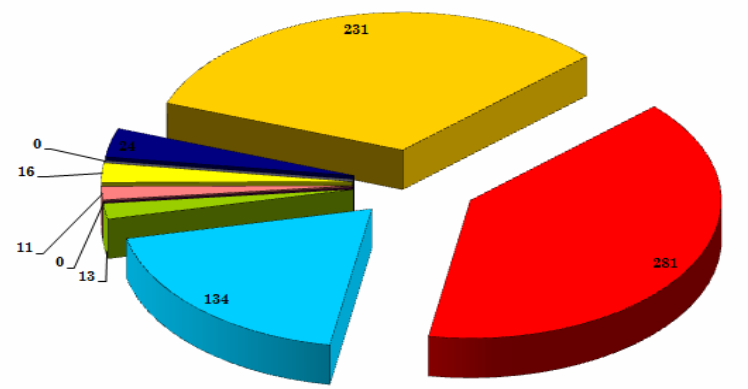


Chart – 8.5 Area of sparse mangroves of south Gujarat (on the basis of current work)

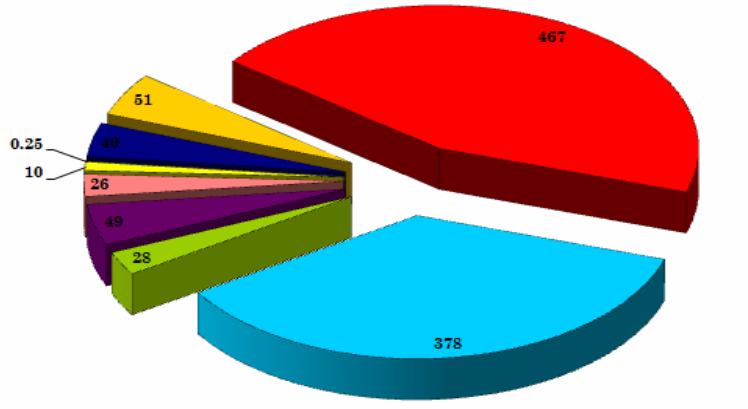


Chart – 8.6 Area of dense mangroves of south Gujarat (on the basis of current work)

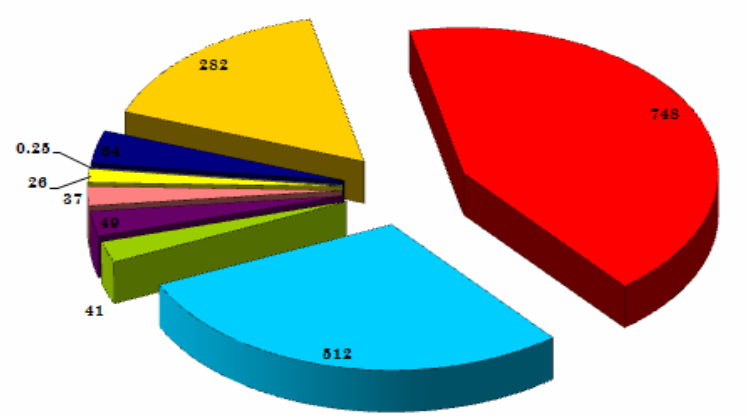


Chart – 8.7 Total area of mangroves of south Gujarat (on the basis of current work)

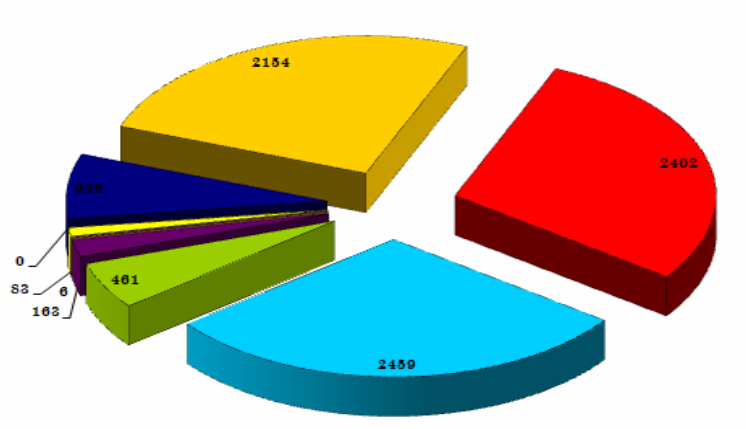


Chart – 8.8 Total area of Salt marsh of south Gujarat (on the basis of current work)

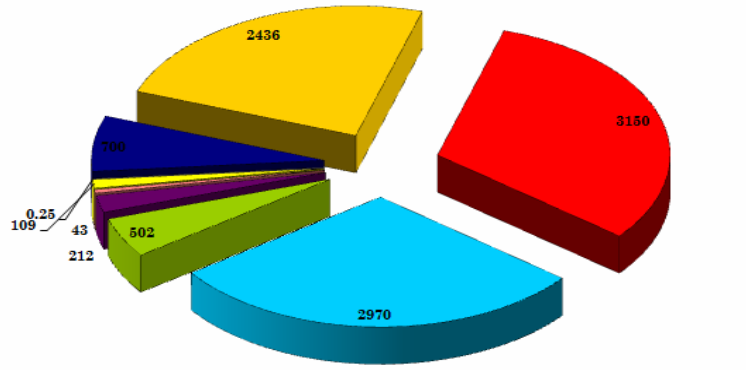


Chart – 8.9 Total area of wetland vegetation of south Gujarat (on the basis of current work)

Mindhola 2001	Purna 2005	Ambika 2005	Auranga 2005	Par 2005
Kolak 2001	Damanganga 1999	Kalu 1999	Varoli 2001	

Interestingly, it is important to mention here, that the increase in the area of mangroves of south Gujarat has been natural. No plantation activities have ever been carried out in the districts of Navsari and Valsad. In Surat, plantation activities were carried out during 2005. However, this plantation is off-the limits of the study area's estuary – Mindhola. Hence, all the diversity and increase in areal extent of the mangroves has been a gradual natural process, without any human intervention. The regeneration of the species is also observed to be good, with many young recruits being observed during the field visits of the study area, suggesting a favorable environment.

Apart from this, the presence of *Porteresia coarctata,* the pioneering species for mangrove wetlands indicate these mangrove formations are of recent origin. It was found growing mainly on the fringes of channel bars. It is believed to startup the accretion process which is later on accelerated by the mangrove species. Same has been backed by the evidences from mapping the SOI toposheet, and subsequent satellite images, where not a single estuary has shown presence of mangroves. However, eventually formation of channel bars and simultaneous mangrove habitat expansion is observed, especially in case of Purna, Ambika and Auranga estuary.

This might also be the reason of the dominance of *Avicennia marina* and indicative presence of other species such as *Rhizophora mucronata, Ceriops tagal, Bruguiera cylindrica and Lumnitzera racemosa* as this species do not tolerate the various governing factors with ease as much as that of *Avicennia marina.*

Sr. No.	Mangroves Genus	As per Singh (2006)		SPECIES RECORDED FROM SOUTH GUJARAT (CURRENT WORK)								
		Gujarat	Gulf of Kachchh	Overall record from Sguj	Mind-hola	Pur-na	Ambi-ka	Aura-nga	Par	Kolak	Daman ganga	Varoli
	Family: Avicenniaceae											
1	Avicennia alba Blume	P	P	X	X	X	X	X	X	X	X	X
2	Avicennia marina var. marina (Forsk.) Vierh.	P	P	P	P	P	P	P	P	P	P	P
3	Avicennia officinalis L.	P	P	P	X	X	X	X	X	X	P	P
	Family: Sonneratiaceae											
4	Sonneratia apetala Buch. Ham.	P	X	P	P	P	P	P	P	P	P	P
	Family: Rhizophoraceae											
5	Ceriops tagal (Perr.) C.B. Roinson	P	P	P	X	P	P	X	X	P	X	X
6	Rhizophora mucronata Poir.	P	P	P	X	P	P	X	X	X	X	X
7	Rhizophora apiculata Bl.	Extinct										
8	Bruguiera gymnorrhiza (L) Lamk.	Extinct										
9	Bruguiera cylindrica (L) Blume. (Reported Extinct earlier)	X	X	P	X	P	P	X	X	X	X	X
	Family: Myrsinaceae											
10	Aegiceras corniculatum (L.) Blanco	P	P	P	X	P	P	X	X	P	P	P
	Family: Acanthaceae											
11	Acanthus ilicifolius L.	P	P	P	P	P	P	P	P	P	P	P
	Family: Euphorbiaceae											
12	Exoecaria agallocha L. (Reported for first time)	Not reported	Not reported	P	X	X	X	X	X	X	X	P
	Family: Combretaceae											
13	Lumnitzera racemosa Willd. (Reported for first time)	Not reported	Not reported	P	X	X	X	X	X	X	X	P
TOTAL NO. OF SPECIES		**8**	**7**	**10**	**3**	**7**	**7**	**3**	**3**	**5**	**5**	**7**

Table – 8.1 List of species of mangroves of Gujarat (on the basis of current work)

It is worthwhile mentioning here the participation by the local community, which ensures protection to the mangrove patches of the mangrove wetlands, especially Kolak, Auranga and Varoli estuary.

Aquaculture ponds are constructed over the mudflats at Auranga; which provide with the economy to the local people. Increase in these aquaculture ponds can be observed in the given maps. Due to the increase in aquaculture ponds, there is threat to the mangroves as the mudflat area is limited and never enough for the development. Foreseeing this, the priest at Auranga estuary has educated the villagers about the importance of mangroves and thus great measures are been taken for their conservation. The mangroves remain undisturbed and the construction of new aquaculture ponds is done away from the mangrove patch, to ensure protection.

At Kolak estuary, the village head has placed boards in the mangrove patch which says that 'chopping of mangroves is an illegal act and a punishable offence'. At Varoli too, the head of the village keeps a check on people going to mangrove patches, fearing they will chopped in no time and taken over for various industrial activities.

Such practices should be supported and implemented to make certain that such an important ecosystem is safeguarded against all the detrimental factors, be it wrath of the nature or human interferences.

The values of soil and water samples obtained from the current studies of south Gujarat were compared with the observations of the values of other mangrove patches of Gujarat (Mundra, Jakhau, Kori creek)

(unpublished data) and with those values obtained by other researches for mangrove patches of Gujarat and India as well (chart 8.10).

It was found that the pH values of water of South Gujarat mangrove shows not much difference in values when compared with those of waters of mangroves of Gulf of Kachchh and western mangrove region.

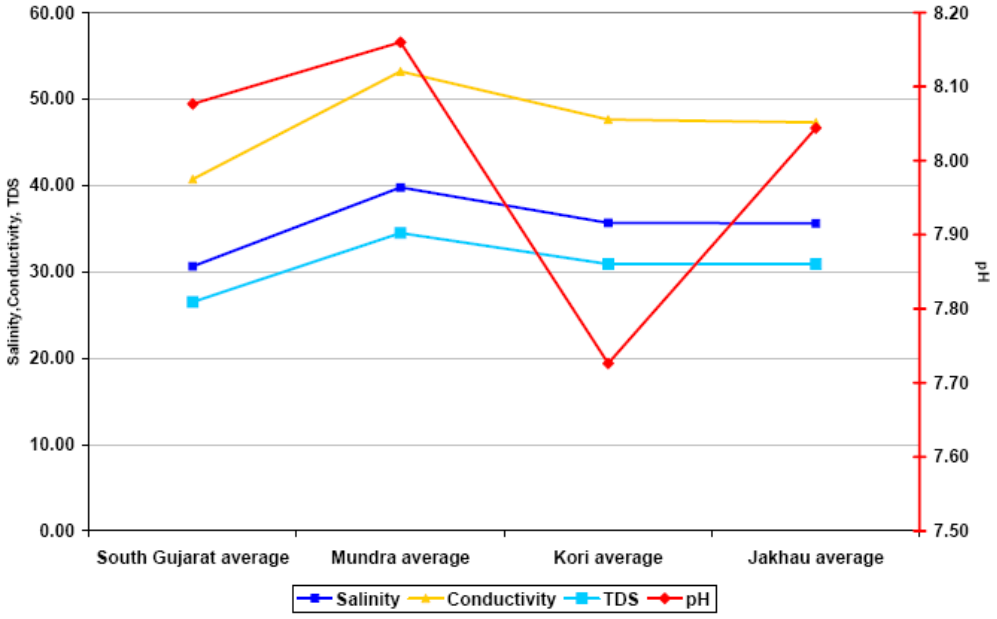


Chart – 8.10 Total area of wetland vegetation of south Gujarat Comparative analysis of water samples of mangrove areas of Gujarat

However, the salinity values of water of south Gujarat are relatively low when compared with values of mangrove patches of Gujarat and not only that, the salinity values are very low when compared to other mangrove patches of India (Manori creek – Mumbai, Sunderbans, Pichavaram). This can be largely attributed to the higher rainfall and the presence of perennial rivers. This is one of the possible reasons of higher diversity of mangroves found in south Gujarat (chart 8.11).

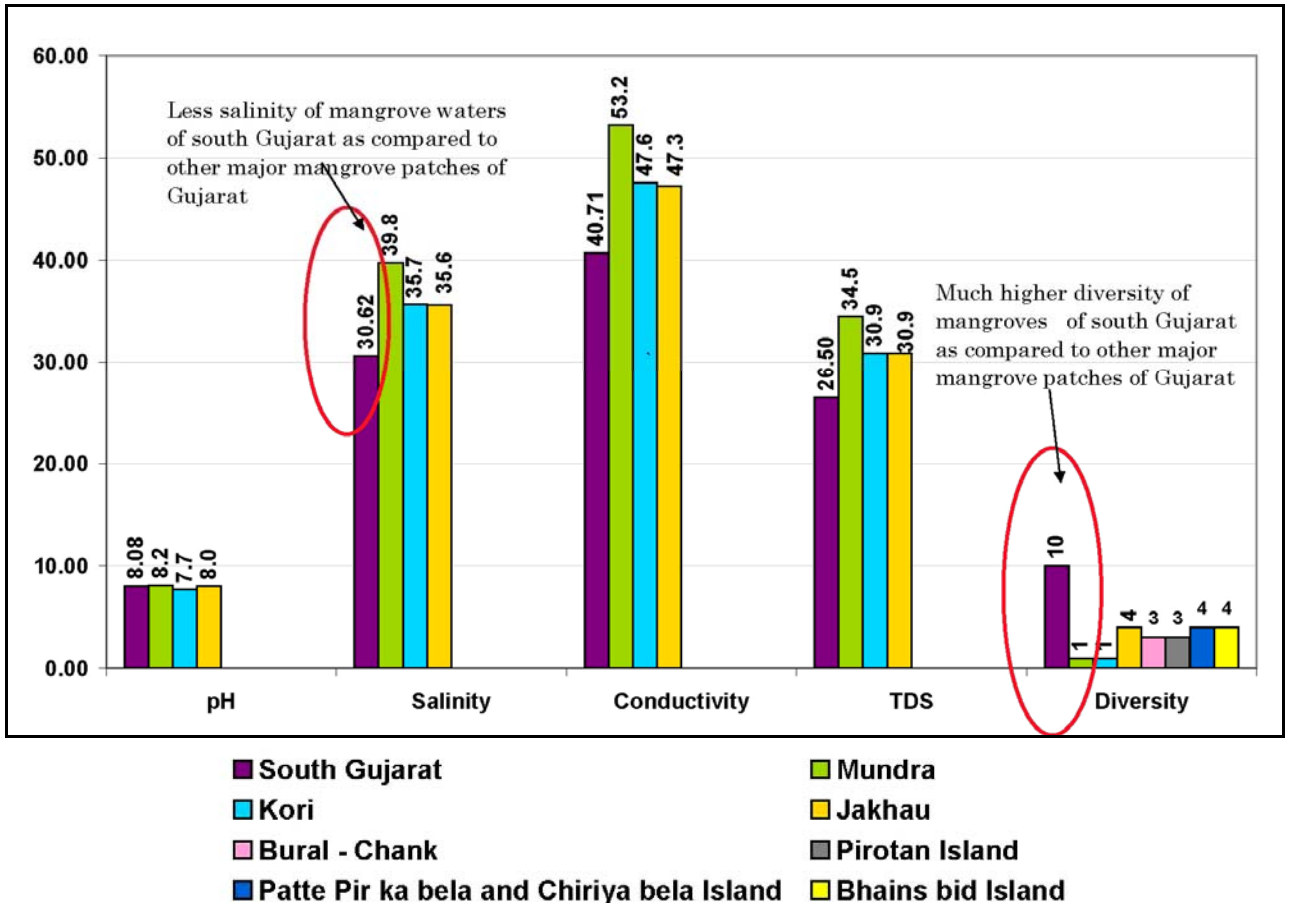


Chart – 8.11 Mangrove diversity of major patches of Gujarat

Despite the threats in face of aquaculture ponds, industrial pollution, chopping of mangroves, mangroves of south Gujarat are increasing in number. The diversity of mangroves attests that the environmental conditions of south Gujarat region are quite favorable as compared to the other areas of Gujarat and so is proved by the environmental studies of mangrove wetlands of south Gujarat as well.

The areal extent of mangroves in south Gujarat has chance of further increase. The salt marsh patches are extensive and same can be used for plantation of mangrove species. However, it is imperative that plantation is not mono-specific, but to increase the diversity of mangroves in south Gujarat. In addition, mangrove plantation can be carried out on the still barren mudflats to negated erosion processes.

Summing up the overall scenario of mangroves of south Gujarat against the governing factors as well as the threats posed by various factors – natural and anthropogenic, the mangroves of this area have been sustaining well so far. However, all these threats could specially affect those species which are already limited in number and restricted to a patch – like *Lumnitzera racemosa* and *Excoecaria agallocha*. For this, better management practices and conservatory approach needs to be implemented.

To conserve something, protect something, a feeling of ownership is must. Environment is a set of the circumstances that surround an individual or a community. Moreover, it is important to remember that it largely affects

the growth and development of an individual or a community and the social and cultural aspects such as ethics, economics aesthetics etc which ultimately affect the behavior of ***Homo sapiens*** (Keller, 1985).

With the prevalent knowledge of the benefits of mangrove ecosystems and their vulnerability and degradation, measures need to be undertaken in order to reverse the overall trend of declining mangrove species.

Efforts should be made to conserve the biodiversity found in wetlands. The first step in conservation of biodiversity is to assess the diversity of natural resources present and identify those, which are important and most irreplaceable (Groombridge & Jenkins 1998). This was the single most important task of this thesis – bringing out the diversity of mangrove wetlands of south Gujarat. The mangrove diversity of south Gujarat is now rich then the other mangrove patches of Gujarat. This, as proved is responsible to the conducive hydrological factors, which reduces the salinity, allowing mangroves to grow in the suitable environment.

Moreover, if we can't ensure enough protection then we can employ the alternative approach which could be to leave the habitats in their natural state so as not to detract from their potential in the enrichment of coastal waters and in the stabilization of the shoreline and river banks.

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"Environmental appraisal of Mangrove Wetlands between Mindhola and Varoli estuary (South Gujarat) using Remote Sensing"

Thesis submitted to

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Geology

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Coastal zone is a broad transitional area wherein the Mangrove ecosystems in-habitat. This system is influenced by many systems and processes such as the tidal system, the marine and sedimentary processes and it reflects in the environment and the geomorphology of the coastal zone.

Mangrove trees and shrubs grown in this transitionary environment of tropical and subtropical rivers and coastlines in many parts of the world. They thrive at the interface of land and are very well adapted to this environment and have immense ecological, economic and societal importance. This transitional habitat harbors varied life forms, making it one of the most productive ecosystems. This makes it a preferable habitat for the coastal avi-fauna and fishes. Mudflats and salt marshes also form breeding and feeding grounds for many avi-fauna species. Mangroves also impart immense ecological stability to the system. They protect coasts, mitigating the effect of wave activity. Mangroves are also significant as they help in accretion of sediments. Mangroves are unique because they grow along low-lying tropical and occasionally subtropical coastal areas, along the margins of estuaries, deltas, coastal lagoons, and brackish tidal waters in general where no other plant species can possibly survive.

There are many factors which influence this unique ecosystem. They are usually governed by local climate, salinity, geomorphology, waves and currents and tidal inundations to state major of them. Salinity plays a vital role in the distribution of mangrove species, their productivity and the growth of mangrove forests and changes in salinity are normally controlled

by climate, hydrology, rainfall, topography and tidal flooding. Geomorphological processes are also closely related to ecological processes. Processes affecting geomorphology are influenced by the substrate and the biota (plants and animals) growing on it. Coastal vegetations can cause more rapid deposition as a result of slowing down the velocity of the water flow and has an ability to modify the estuarine morphodynamics.

However, with so much complexity, mangrove systems have often proven difficult to be studied. Remote sensing proves to be an excellent tool in studying such complex and dynamic systems, as it offers a medium to study the area, without coming in direct contact of the area

Mangroves occur in all the tropical countries. Global mangrove coverage is approximately 18 million which forms just about 0.45% of the world forests and woodlands. Mangroves of South and Southeast Asia form world's most extensive and diverse mangrove system comprising 41.4 % of global mangroves. Mangroves in India are distributed along all the coastal states. Eastern coast of India harbors more mangroves then the western coast. The State of Art Report on Mangroves report by the MoEF, GOI gives an estimate of mangroves of India of 2007 to be 4,639 km ^{2} in the coastal states and Union territories.

Gujarat state is the western-most state of India and has the longest coastline of the country, of about 1600 km, harboring approximately 1.046 sq. km of mangroves supporting the second largest block of tidal forests of India. Mangroves in Gujarat are mostly confined to a) Indus deltaic region i.e. Kori creek and Sir Creek area, b) The Gulf of Kachchh, and c) The Gulf

of Cambay. Major work on the mangroves in Gujarat had been carried out by agencies such as the State Forest Department, Space Applications Centre (SAC, Indian Space Research Organization, Ahmedabad), and Gujarat Ecological Education and Research Foundation (Gandhinagar). Some of the more recent workers in this area are the Maharaja Sayajirao University, Gujarat Ecological Commission (GEC), and Gujarat Institute of Desert Ecology (GUIDE). However, most of the work has been restricted to the Gulf of Kachchh and to a small extent the other regions of Kachchh district, emphasizing mainly on the species diversity and their extent. 11 mangrove species were reported from Gujarat out of which 3 are believed to be extinct.

The coastal wetlands of south Gujarat were always believed to be devoid of mangroves or at times marked by presence of the salt marsh, with some reports of mangroves being present at one of the wetlands. Earlier workers suggested that the coastal wetlands of south Gujarat harbor mangroves. However this information was not adequate as only the locations were mentioned without pointing to the diversity of the entire area. Diversity of mangroves of south Gujarat was never worked out by anyone except for suggestions of presence of mangroves. They have remained largely uninvestigated, except for areas of Umargaon creek and Valsad. However, here too precise information on mangrove distribution and diversity for any estuarine area in south Gujarat is lacking.

Study on mangroves of south Gujarat was never conducted in details. Also the environmental parameters which govern the mangrove ecosystems

have not been studied to a greater extent for mangroves of Gujarat as well. The ever-changing geomorphological processes also interact in a dynamic way with the mangrove ecosystem.

Keeping this in view and the lack of data for the mangroves of south Gujarat, it was decided to take up the current work and thus study the mangrove diversity of unexplored mangrove wetlands of south Gujarat – that of rivers Mindhola, Purna. Ambika, Auranga, Par, Kolak, Damanganga, Kalu and Varoli with an emphasis on its diversity which is one of the best environmental indicator, by systematic ground surveys, coupled with remote sensing studies to bring out the density and zonation of mangroves as well and the environmental parameters - the water and soil properties.

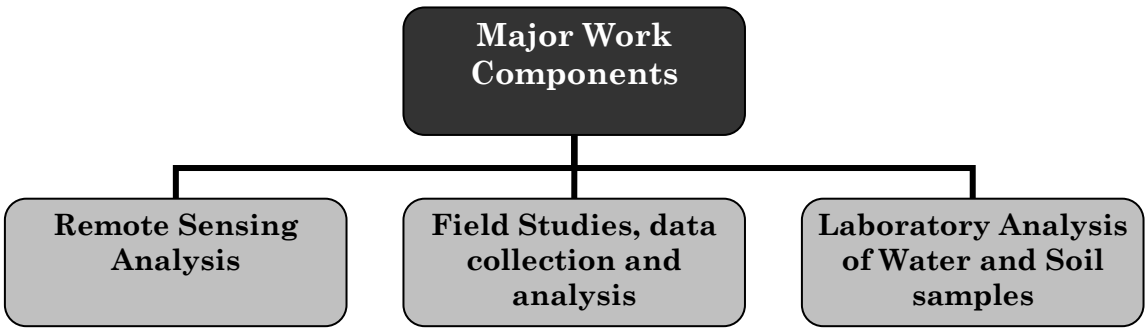
The current work is thus an outcome of study of mangrove diversity of an un-explored estuarine area of rivers Mindhola, Purna, Ambika, Auranga, Par, Kolak, Damanganga, Kalu and Varoli; which have been investigated with emphasis on mangrove diversity, by systematic ground surveys, coupled with remote sensing studies to bring out the density and zonation of mangroves as well.

The study was undertaken to fulfil the following objectives –

- Generating base line information for the mangroves of coastal wetlands of south Gujarat
- Mapping the mangrove habitats and area occupied by the mangroves
- Mapping the diversity and major mangrove communities

- Detecting change in the mangrove habitat during from the earliest date to the recent most available data for Purna and Ambika – Auranga's estuarine setup
- Mapping the geomorphological changes
- Physico-chemical influences on the mangrove *environs*

An approach was developed to study the diversity of the area, map the mangrove habitats and major communities and also to get an insight about the environmental condition of the mangrove ecosystems thriving in this location and that how they have changed over a period of time. The methodology was broadly divided over remote sensing, field studies and lab analysis. Detailed work under each was carried out.



The remote sensing technology offers a cost-effective method of extending limited field areas to map large areas of mangroves. Remote sensing data provide a means to extend the knowledge of a small area *(a patch)* to a larger region *(entire wetland)* and, therefore, appears to be well suited to the analysis of mangrove ecosystems.

Remote sensing analysis was carried out to achieve the following outputs –

1. Coastal Wetland Maps,
2. Mangrove wetland maps,
3. Maps depicting change in the study area
4. Coastal geomorphology map

Field studies were conducted as ground data forms a foundation for any environmental study. It was more important here as little was known about the mangroves of the study area. An inventory of the mangrove vegetation and associated flora growing in the area was made on the basis of ground surveys. Also training sites for supervised classification were identified through the field studies. Soil and water samples for analysis of the environmental parameters were collected during the field surveys and were analyzed in the laboratory later on. Field surveys were carried through the years 2006-2008 for the pre-monsoon and post-monsoon seasons.

Lab studies were conducted to study the soil and water samples which included studying the pH, salinity and particle size, as they form the major governing factors for the growth of mangroves.

Environmental appraisal

Mangrove ecosystem and its functioning is depends on many factors which include the hydrological conditions, geological conditions, anthropogenic influence, etc.

The rainfall in south Gujarat is abundant and this region is also flushed by the numerous perennial and seasonal rivers. As a result, mangroves have found conducive environment. The high rainfall and fresh water input keeps and salinity in check. Also the estuarine setup formed here offers a protected environment to the mangroves. This affects the over-all diversity and density of mangrove species.

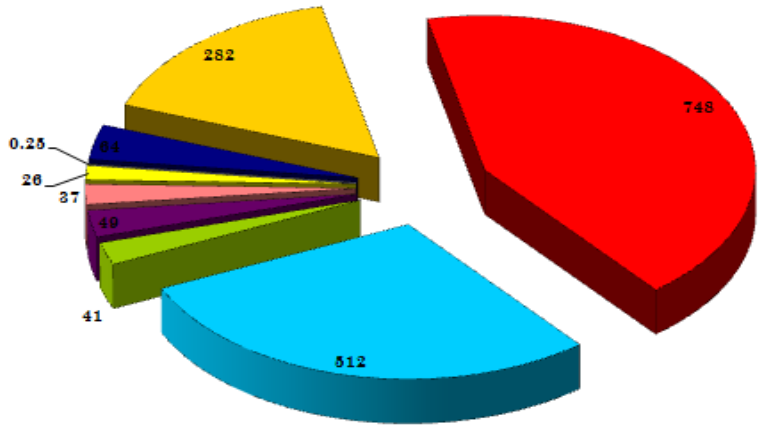
Mangrove habitats have relatively low levels of species richness compared with other tropical habitats. Diversity of mangrove plants is not measured in terms of numbers of species, but also in terms of the ability of each species to cope with the wide range of environmental conditions in utilizing their individual, specialized attributes.

As the information of mangrove wetlands of south Gujarat was scarce, estuary wise assessment was carried out and regional database was generated for mangrove wetlands of south Gujarat.

The current work has brought the mangrove diversity of south Gujarat as 10 species, with Purna and Varoli estuary harboring the maximum number of mangroves 6 and 8 respectively, making them the most diverse patch of mangroves of Gujarat. Overall diversity of mangroves of Gujarat which was reported to be as 8 mangrove species have now increased to 10 as two new mangrove species from south Gujarat region have been discovered – *Lumnitzera racemosa* and *Excoecaria agallocha.*

The area of mangroves of south Gujarat also might contribute to the overall area of mangroves of Gujarat. Through current work the overall area of the mangroves of study area was found to be about 7 sq. km.

Navsari district and about 7 sq. km for that of Valsad district as well. However, this area can not be ascribed to any particular year as the satellite data used is from the year 1999 (Damanganga), 2001 (Mindhola, Kolak and Varoli) and 2005 (Purna, Ambika, Auranga and Par). Nevertheless, it definitely shows an increase in the mangroves of south Gujarat.



Total area of mangroves of south Gujarat (on the basis of current work)

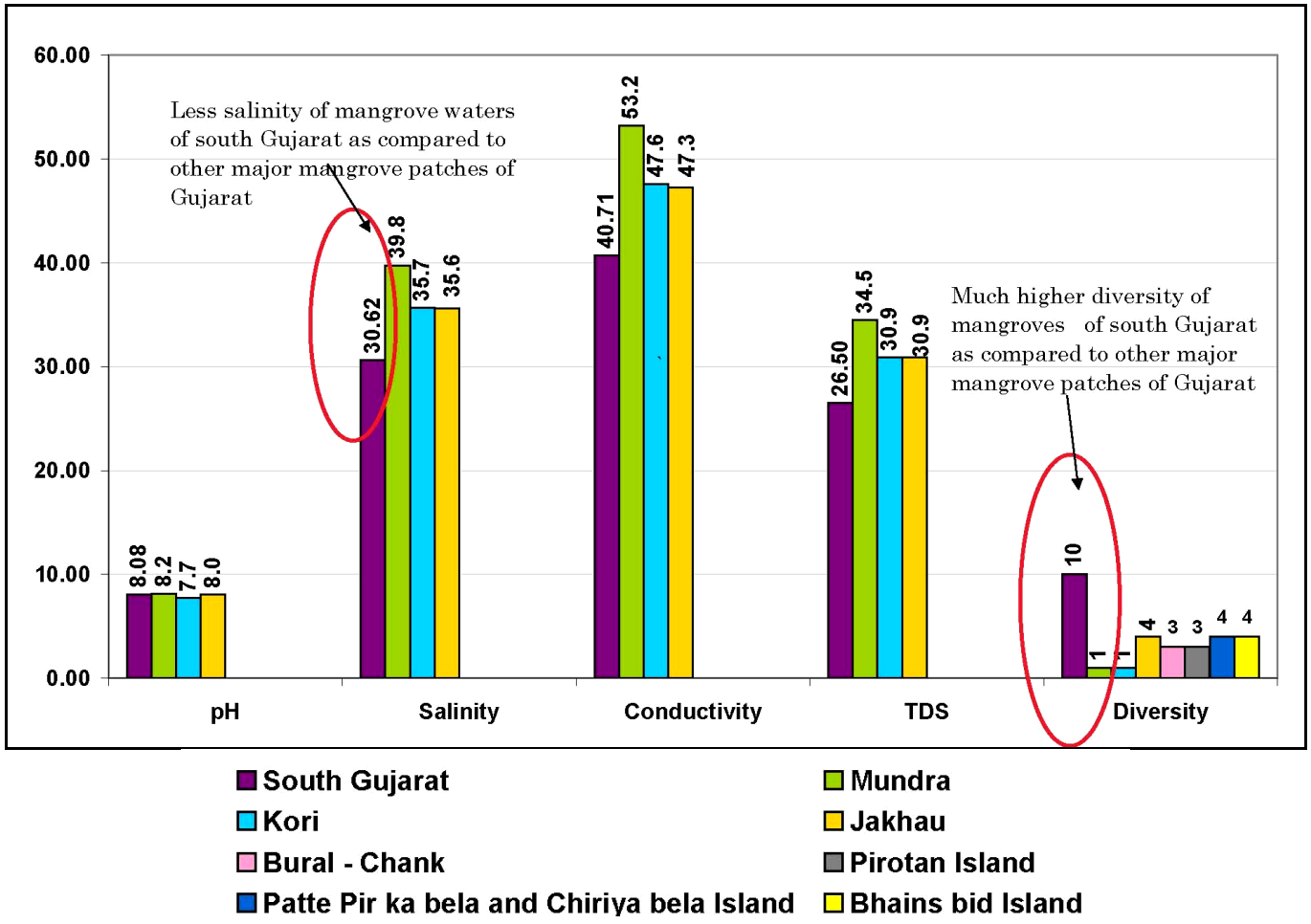
Also this increase in the area and more number of mangroves in terms of diversity has been a natural process as no plantation activities have ever been carried out in the districts of Navsari and Valsad. The mangrove species are regenerating well, suggesting a favorable environment.

The values of soil and water samples obtained from the current studies of south Gujarat were compared with the observations of the values of other mangrove patches of Gujarat and India as well. The salinity values

of water of south Gujarat are relatively low when compared with values of mangrove patches of Gujarat and not only that, the salinity values are very low when compared to other mangrove patches of India (Manori creek – Mumbai, Sunderbans, Pichavaram). This can be largely attributed to the higher rainfall and the presence of perennial rivers. This is one of the possible reasons of higher diversity of mangroves found in south Gujarat.

Flip side is however the constant increase in the aquaculture ponds, especially over the mudflats at Auranga. Due to the increase in aquaculture ponds, there is threat to the mangroves

However, the participation of local community is commendable which has ensured protection to the mangrove patches of Auranga, Kolak and Varoli estuary. Such practices should be supported and implemented to make certain that such an important ecosystem is safeguarded against all the detrimental factors.


60.00
50.00
40.00
30.00
20.00
10.00
0.00
Less salinity of mangrove waters of south Gujarat as compared to other major mangrove patches of Gujarat
Much higher diversity of mangroves of south Gujarat as compared to other major mangrove patches of Gujarat
8.08
8.2
7.7
8.0
30.62
39.8
35.7
35.6
40.71
53.2
47.6
47.3
26.50
34.5
30.9
30.9
10
1
1
4
3
3
4
4
pH
Salinity
Conductivity
TDS
Diversity
South Gujarat
Mundra
Kori
Jakhau
Bural - Chank
Pirotan Island
Patte Pir ka bela and Chiriya bela Island
Bhains bid Island

Summing up the overall scenario of mangroves of south Gujarat - the mangrove diversity of south Gujarat is now rich then the other mangrove patches of Gujarat. This, as proved is responsible to the conducive hydrological factors, which reduces the salinity, allowing mangroves to grow in the suitable environment. However, there are threats posed by various factors – natural and anthropogenic. Nevertheless, the mangroves of this area have been sustaining well so far. Conversely, all these threats could specially affect those species which are already limited in number and restricted to a patch – like *Lumnitzera racemosa* and *Excoecaria agallocha*. For this, better management practices and conservatory approach needs to be implemented.

Further efforts needs to be taken to conserve the biodiversity of south Gujarat wetlands. As the first step in conservation of biodiversity is to assess the diversity of natural resources present and identify those, which are important and most irreplaceable, this was the single most important task of this thesis – bringing out the diversity of mangrove wetlands of south Gujarat, while appraising the environmental characters that govern it. This work can form basis for further conservation works and analysis.