Chapter 4 Methodology

The coastal zone is a dynamic, scarce and vulnerable territory, where natural, economic, demographic, social and environmental aspects work together. With increase in the population, pressure on coastal zone in general and on coastal resources in particular is rising (Nayak, 2010). This can cause rapid decline in the quality of coastal zone, if no initiation is taken to manage and conserve this vital coastal as well as terrestrial ecosystems.

Since coastal changes occur temporally from few seconds to geological time scale and spatially from millimeter to thousands of kilometer, a method which can provide data on spatial-temporal scales is required (Maiti and Bhattacharya, 2011). Space-borne remote sensing is one of the best techniques as it provides a synoptic, repetitive and regional view of the coastal area (Bhavsar, 1983; Gower, 1996; Hasselmann *et al.*, 1996; Irish and White, 1998; White and El Asmar, 1999; Lafon *et al.*, 2004). The technique has been found to be very useful in generating baseline inventory of coastal wetlands, coral reef, mangrove, monitoring of protected areas, selecting sites for brackish water aquaculture, detecting shoreline changes, studying coastal geomorphology, estimating suspended sediment concentration and assessing impact of engineering structures on suspended sediment patterns (Nayak, 2004). This technique has become a useful tool and has scientific value for the study of human-environment interaction especially in case of land use and land cover changes (Dale *et al.*, 1993; Satyanarayana *et al.*, 2001; Codjoe, 2007). Satellite remote sensing in conjunction with geographic information system have become efficient methods for analysis of land use changes and coastal vegetation. The effectiveness of remote sensing technique in studying land use land cover changes and coastal vegetation has already been discussed earlier.

Conventional ground surveys as well as geospatial techniques have been used in the current study. The geospatial tools were mainly used for mapping coastal land use land cover and coastal geomorphology. The listing of coastal vegetation was accomplished through field surveys. The methodology was thus broadly divided into geospatial analysis, field excursions and lab analysis. The major tasks undertaken under each head has been described briefly in the form of flow chart given in Figure 4.1.

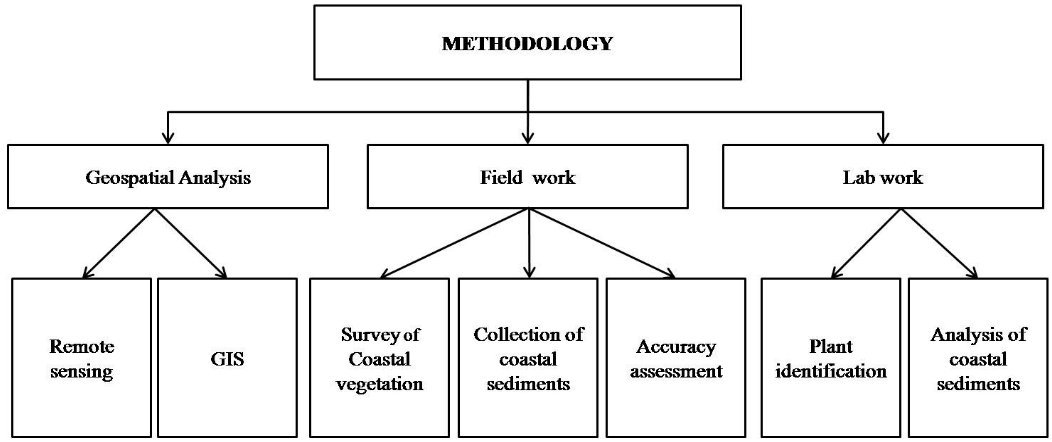


Figure 4.1 Graphical representation of methodology

4.1 GEOSPATIAL ANALYSIS

This included remote sensing analysis and geographical Information system (GIS) analysis. Maps were prepared using remote sensing analysis which were then incorporated into GIS to undertake change studies.

4.1.1 REMOTE SENSING

Satellite remote sensing techniques have proved to be of immense value for preparing accurate land use/land cover maps and monitoring changes at regular intervals of time. In case of inaccessible area, this is the only method of obtaining the data on a cost and time effective basis (Rao *et al.*, 1996). Hence, application of remotely sensed data for coastal zone study has increased and became an important branch of coastal studies especially in the field of change detection (Collins and Moon, 1979; Robinson, 2004). This technique has been used to prepare coastal land use land cover maps and coastal geomorphology maps. An outline of the steps involved has been depicted in Figure 4.2.

4.1.1.1 Image Acquisition Step

Data used:

In present investigation data over a period of more than 30 years was used. Two different types of data sets, satellite images and base map (topographic sheets) were used to bring out changes in the coastal area.

4.1.1.1.1 Base maps:

The Survey of India (SOI) provides maps showing locations of town, villages, their topography, administrative boundary, transport network (road, railway etc.) links, locations of streams, canals, water features, forest and brief idea about the vegetation and land use pattern. A map providing these details is called as a base map. These maps are prepared by SOI, on a scale of 1:250,000 or 1:50,000 scale. To identify map

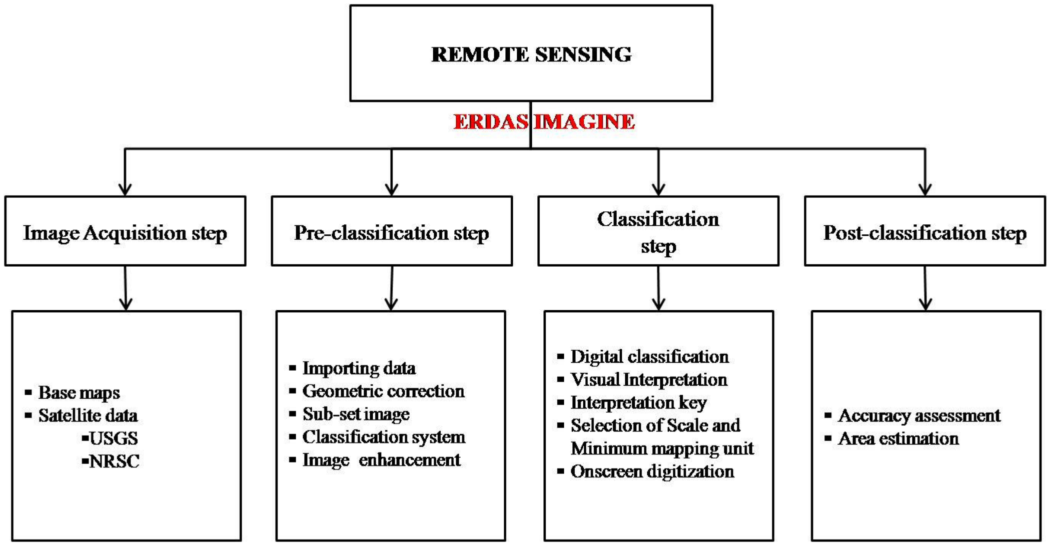


Figure 4.2 Graphical representation of Remote sensing part

of a particular area, a map numbering system has been adopted by SOI. Under this numbering system, the present study area falls under 46 B and 46 C. A total 9 different topographic sheets viz. 46B/8, 46B/12, 46B/16, 46C/9, 46C/10, 46C/11, 46C/13, 46C/14 and 46C/15 covering the three coastal talukas were used. Two series of topographic sheets were available of the study area which were surveyed in the years 1880's and 1970's. The 1970's topographic sheets were used, as resolution of 1880's data was much coarser.

4.1.1.1.2 Satellite data:

Satellite images provide detailed, accurate, cost effective and up-to-date information with respect to different vegetation types and land uses (Forkuor and Cofie, 2011).

A. *Criterion for data selection*:

In case of change detection studies, it is important to use same or similar sensor, with similar resolution characteristics (same radiometric and spatial resolution data) and with anniversary or very close to anniversary of acquisition dates (Deng *et al.*, 2008). As the span of the study was large, the earliest satellite data had characteristics which were the best available at that time even though they were different from the later ones. Efforts were made to aquire data belonging to the same season over the different years.

One of the major factors affecting the selection of the satellite image in the coastal area was the cloud cover. In the coastal area, high humidity content makes it difficult to obtain the cloud free image and thus reduces the number of available images (Green *et al.*, 2000).

The tide condition is another limiting factor in the selection of satellite image of coastal area. In case of high tide condition, the water column tends to modify or reduce the signatures reflected from the coastal zone and may cause error in the interpretation of the coastal features (Green *et al.*, 2000; Shah, 2004). During the low tide condition, it is easy to demarcate the land-water boundary, low waterline, high waterline, mangrove and other vegetation as the entire coastal wetland get exposed. Hence, the images with low tide conditions were preferred over the high tide images. In the present study, all the satellite images showed low tide condition. They however had small variations in tidal conditions.

B. *Satellite Data used*:

Historical data was acquired from the Landsat satellite with Multi-Spectral Scanner (MSS) and Thematic Mapper (TM) sensors. Whereas for the recent satellite data, Indian remote sensing satellite (IRS) IRS 1C (LISS III), IRS 1D (LISS III) and IRS P6 (LISS III) were used. Besides this multispectral data, panchromatic images of Cartosat-1 (Mono, PAN-F) were used for specific areas. The characteristic of the different data sets is given in Table 4.1 and details of the satellite images used in the present study are given in Table 4.2.

C. *Image Procurement*:

The data for Landsat MSS and Landsat TM was downloaded from the United States Geological Survey (USGS) website (http://glovis.usgs.gov/) in compressed TIFF format. Whereas data for (the satellite images of) Indian remote sensing satellites (IRS 1C, 1D, P6 and Cartosat-1) was procured from the National Remote Sensing Center (NRSC), Hyderabad. The data was received on CDs (CD-ROM).

Satellite	Sensor	Radiometric Resolution	Spatial Resolution	Spectral Resolution		Temporal Resolution
Landsat 3	MSS	6 bits		5 Bands		18 days
			Landsat 3	MSS	6 bits	
			79 m	*Band 5	0.6-0.7 µm	
			79 m	*Band 6	0.7-0.8 µm	
			79 m	*Band 7	0.8-1.1 µm	
			240 m	Band 8	10.4-12.6 µm	

Satellite	Sensor	Radiometric Resolution	Spatial Resolution	Spectral Resolution		Temporal Resolution
Landsat 5	TM	8 bits		7 Bands		16days
			30 m	Band 1	0.45-0.52 µm	
			30 m	*Band 2	0.52-0.60 µm	
			30 m	*Band 3	0.63-0.69 µm	
			30 m	*Band 4	0.76-0.90 µm	
			30 m	*Band 5	1.55-1.75 µm	
			120 m	Band 6	10.4-12.5 µm	
			30 m	Band 7	2.08-2.35 µm	
IRS 1 C	LISS III	7 Bits		4 Bands		24 Days
			23.5 m	*Band 2	0.52-0.59 µm	
			23.5 m	*Band 3	0.62-0.68 µm	
			23.5 m	*Band 4	0.77-0.86 µm	
			70.5 m	*Band 5	1.55-1.70 µm	
IRS 1D	LISS III	7 Bits		4 Bands		25 Days
			23.5 m	*Band 2	0.52-0.59 µm	
			23.5 m	*Band 3	0.62-0.68 µm	
			23.5 m	*Band 4	0.77-0.86 µm	
			70.5 m	*Band 5	1.55-1.70 µm	
IRS P6 or Resourcesat-1	LISS III			4 Bands		24 Days
		7 bits	23.5 m	*Band 2	0.52-0.59 µm	
			23.5 m	*Band 3	0.62-0.68 µm	
			23.5 m	*Band 4	0.77-0.86 µm	
		10 bits	23.5 m	*Band 5	1.55-1.70 µm	
IRS P5 or Cartosat-1	PAN-F (Mono)	10 bits	2.5 m	*Panchromatic Band	0.5-0.85 µm	5 days Programmable

Table 4.1 Characteristics of different satellite data used in present study (Collected from various sources (Jensen, 2005; Anon, 2004b; Anon, 2006c))

Note: * indicates bands used in the present study

Taluka	Satellite/ Sensor	Path/ Row	Date of Acquisition	Tidal condition
Jambusar	Landsat 3 MSS	159/045	16th October,1978	Low tide
	Landsat 5 TM	148/045	20th March, 2000	Low tide
	IRS P6 LISS III	93/57	21st January, 2012	Low tide
Vagra	Landsat 3 MSS	159/045	16th October,1978	Low tide
	Landsat 5 TM	148/045	12th January, 1987	Low tide
	IRS 1 C LISS III	93/57	09th April, 1997	Low tide
	IRS 1D LISS III	93/57	05th April, 2001	Low tide
	IRS P6 LISS III	93/57	08th February, 2004	Low tide

Taluka	Satellite/ Sensor	Path/ Row	Date of Acquisition	Tidal condition
	IRS P6 LISS III	93/57	21st January, 2012	Low tide
	Cartosat-1 (Mono) PAN-F	509/296	17th February, 2012	Low tide
	Cartosat-1 (Mono) PAN-F	509/297	17th February, 2012	Low tide
	Landsat 3 MSS	159/045	16th October,1978	Low tide
	Landsat 5 TM	148/045	12th January, 1987	Low tide
Aliabet	IRS 1C LISS III	93/57	09th April, 1997	Low tide
	IRS 1D LISS III	93/57	05th April, 2001	Low tide
	IRS P6 LISS III	93/57	08th February, 2004	Low tide
	IRS P6 LISS III	93/57	21st January, 2012	Low tide
	Landsat 3 MSS	159/045	16th October,1978	Low tide
	Landsat 5 TM	148/045	12th January, 1987	Low tide
Hansot	IRS 1C LISS III	93/57	09th April, 1997	Low tide
	IRS P6 LISS III	93/57	08th February, 2004	Low tide
	IRS P6 LISS III	93/57	21st January, 2012	Low tide

Table 4.2 Details of satellite images used in present study

D. *Software and Hardware Used*:

Hardware: HP xw4300 series workstation having 64 bit and Intel Pentium Dual core PC computers having 32 bit display colour monitors were used to store and process the digital data. Both the systems had Windows XP operating system.

Software: ERDAS Imagine (versions 8.5 and 9.1) image processing software were used in the present study for processing and analysing the digital remote sensing data.

4.1.1.2 Pre-Classification Step

This was a preparatory phase for analysis which includes importing the data into the software, geographical referencing and the correction or compensation of systematic error in the image and thereby improving quality of image.

4.1.1.2.1 Data importation:

The data which was downloaded from USGS website was first decompressed and then imported band wise in to the software. In case of CDs, the data was first of all transferred to workstation and later imported in the software for further processing of the data. This data was either in raw (generic binary) format or in Geotiff format. In case of generic binary format the data was stored in band sequential (BSQ) Format. In this step, data was converted in to viewable two dimensional raster.

***Selection of bands for image*:**

In the present study, this step was done for the images acquired by MSS and TM sensors. These sensors had 5 and 7 spectral bands respectively, all of which were not required for the current study. Hence, based on the objective of the study, four bands for both MSS and TM sensors were selected. The band selected for MSS were band 4 (0.5-0.6 µm), band 5 (0.6-0.7 µm), band 6 (0.7-0.8 µm) and band 7 (0.8-1.1 µm) whereas for TM were band 2 (Green: 0.52-0.60 µm), band 3 (Red: 0.63-0.69 µm), band 4 (Near Infra red: 0.76-0.90 µm) and band 5 (Short wave Infra red: 1.55-1.75 µm) respectively. These bands were imported in to the software and then layer-staked to form a single, composite image.

4.1.1.2.2 Geometric correction:

The next important step in image preprocessing is "Geometric correction". The data received had geometric information which was not very accurate. Hence to get better accuracy as well as to give similar projection information to all the data sets geometric correction was carried out. Geometric correction was done using image to image rectification. The satellite image of year 1997 was used as base image which was georeferenced with base map (Survey of India Topographic maps). The base map possesses the Geographic Lat/Long projection and spheroid and datum as Modified Everest. The satellite image was also transformed in to the same projection, spheroid and datum. The ground control points (GCPs) were selected in the image and matched with the Survey of India topographical maps. The GCPs selected in the images were mostly manmade features and not natural features such as vegetation or water bodies, as they could have variation over time. At least 30 ground control points were selected and were equally distributed in the image. Most of the GCPs were selected on land surface as it was difficult to get these points on the coast or in the gulf area. Once, the GCPs were selected, a second order polynomial equation was run to transform the geometry of image data from the original file system to the selected map projection. The accuracy of the polynomial transformation was assessed by calculating the Root Mean Square (RMS) error for each GCP. This was $\leq$ 0.5 pixel for the 1997 year image. This was followed by resampling of the image using the nearest neighbour method.

As computation of area statistics was very important, the base image was reprojected in to polyconic projection and Everest as spheroid and datum. A similar method was followed by Shah (2004), Chauhan (2007) and Bhatt (2013). This satellite image of year 1997 was used as base image to georeference all the other satellite images. Each of these images was superimposed on the base map in order to check the accuracy of geometric correction. RMS error for all the satellite images was $\leq$ 0.6 pixel. This means that the error in geometric correction varied from about 30 m in the MSS data to about 15 m for TM and LISS III data.

4.1.1.2.3 Subset image:

Each satellite captures an image based on its swath width. This results in a large size image, of which only a small part is generally required for image analysis. Therefore, to minimize computer storage, time and effort, one of the first tasks is to prepare subsets. It is a process wherein small portion of large image was selected to show only the region of interest (Campbell, 1996). In the present study, the taluka boundaries obtained from the SOI and SAC were selected to subset the images.

4.1.1.2.4 Classification system:

The data captured by the remote sensing sensors and stored in the form of satellite image has to be interpreted to bring out the meaningful information. Image analysis or image interpretation is the procedure that enables the image interpreter to relate geographic patterns on the ground to their appearance on the image. It is fundamentally a process based on the perception of image interpreter about the object or phenomena (George, 2007). The first need is to have a Classification system based on which the image is subjected to the image enhancements techniques (optional step) and then followed by image classification (Campbell, 1996; Strickland, 2002).

Classification:

Classification is a process of identification of various categories and grouping them in to various classes based on their similarities and differences. The classification system used in the present land use study was developed at SAC (Space Application Centre) and has been given as annexure 4.1 (Nayak *et al.*, 1992). They had classified different land use land cover classes up to third level. It is important to mention here that, as few additional land use categories were observed in the image as well as on the ground, hence, necessary modifications were incorporated in the classification system. For mapping coastal geomorphology, the classification system for coastal mapping developed at SAC, Ahmedabad was used in this study (Nayak *et al*., 1992). The detailed classification system is outlined in annexure 4.2. In both the classification systems, the classes were delineated using the nature of landforms, the degree of exposure during different tidal conditions, material of landforms, the nature of vegetation, the spectral behaviours of the classes and associated factors, if any. In case of vegetation, the classification in to very dense, dense, moderately dense, sparse or degraded was based on the visual appreciation and spectral behaviour of the density as seen on the imagery.

***Land use land cover categories observed in present study area*:**

Out of the several categories listed in the classification system, following categories were observed in present study area. They are accompanied by a brief description of their characteristics in the area under study.

Wetlands (Coastal): Wetlands are located between the marine and terrestrial ecosystems, were dominated by the influence of water and played a significant role in maintaining the ecological balance between both biotic / abiotic components in the coastal and inland environment (Anon, 2010a).

Mud flats: Mud flats are coastal wetlands that formed by deposition of mud by either tides or by river. They are a characteristic feature of low energy coasts. Based on their inundation during tidal condition they were divided into sub-tidal, inter-tidal and high-tidal mud flats (Davies, 1972). Based on the presence or absence of vegetation they were classified as barren or vegetated.

Sub-tidal mudflat: This area which got exposed only during the lowest of low tides.

Inter-tidal mudflats: This comprised of the area between the high water line and low water line that was inundated by tidal water on most days. It comprised of the fine grained silt and clay of fluvial-marine nature. Other sources of sediments were the erosion of the cliffs. The mangrove vegetation was mostly found in the inter-tidal mud flat.

High-tidal mudflats: They were located near the high water line and had a low frequency of tidal inundation. The vegetation on it mostly included salt marsh vegetation or scrub vegetation.

Shoals: A shoal was a somewhat linear landform located within or extending into a water body. It was typically composed of sand, silt or pebbles and developed in shallow waters where a stream or ocean current promoted the deposition of granular material.

Mangroves: They are considered to be one of the most important coastal vegetation types with great ecological as well as economical significance. These plants grew most luxuriantly in the inter-tidal mudflats and along the creek. Stunted mangroves were also found on the high tidal mudflats.

Salt marsh vegetation: They generally grew on high-tidal mud flat. Salt marshes were mixture of halophytes (Salt loving) plants and wetland adapted plants (where the fresh water inlet lowered the salt to the point where the not-so-salt-tolerant plants could survive).

Porteresia coarctata: This is a perennial halophytic wild grass. It generally grew on the newly formed alluvial mudflats and acted as pioneer species in the succession process of mangrove colonization.

Water bodies: Water body class included rivers, lakes, ponds, water logged areas, canals, reservoirs/tanks etc.

River: The present study area was drained by few perennial rivers such as Mahi, Dhadhar, Narmada and Kim.

Creek: A narrow inlet of sea water in tidal mudflats. The creek was a natural feature and was modified as per the hydrodynamics of the area. But in the recent years, the sprawling saltpan as well as aquaculture industry had modified the creek network by creating a large number of artificial creeks to bring sea water. They also served as a way for the villagers to get to their villages in high tide as well as providing a safe place for parking their boats.

Pond: It was an inland body of standing water, either natural or man-made and was mainly utilized for the storage of the fresh water.

Canal: It was a linear man made feature for transport of water for agricultural activities. But at a few places, the canal had silted up on account of poor mainatainance and served as a site of growth for wetland vegetation.

Waterlogged area: Waterlogged areas were the places which showed water logging during the rainy season and became dry on the onset of the dry season. During the wet season freshwater vegetation would completely cover the area and some or a complete part of it would later be used for agricultural activity.

Barren/waste land: The land area which was not utilized for any specific purpose and was generally non-vegetated was considered as Barren land.

Built-up land: This mainly included habitation, habitation with vegetation, industrial area and transportation like road, jetty.

Habitation and Habitation with vegetation: This included areas under habitation and habitation with vegetation categories. Generally, habitation was associated with vegetation but at a few urban places like Hansot, Jambusar it was possible to separate pure patch of habitation.

Industrial area: This category included area of land which was used for any industrial activity.

Transportation: This category basically included roads, railways, port, jetty, airport etc. Only those roads that were wide enough to be identified as polygons were mapped. The transportation category was associated with the habitation and industrial category and an increased in any of the two categories resulted in better transportation facilities.

Agricultural land: This comprised of land associated with agricultural activity. Kharif season was important for agriculture and during this period mainly cotton, rice, Pigeon pea, black gram (Urad), millet, sesame, maize, etc. crops were cultivated. During Rabi season crops like wheat, sorghum, gram, sugarcane and vegetables were cultivated. At a few locations during summer groundnut, rice, maize, sugarcane and vegetables were cultivated in the area.

Forest: In Vagra taluka the forest category was located only on the western side of Luhara village and on the northern side of Dahej village. At both these location the area was a designated "Reserved Forest". The area has seen large scale changes during the course of the study.

Other features: This included aquaculture ponds, salt pans, sea wall, oil well, brick kiln etc.

Aquaculture pond: These were sites where brackish water aquaculture was carried out for the cultivation of prawns. This category had come into existence in the latter part of the study and was generally concencetrated in areas to the south of Narmada.

Salt pan: The salt pan industry was one of the earliest industrial categories that could be easily deciphered from satellite images. It generally occupied the high-tidal mudflat region.

Seawall: This was a linear, artificial structure constructed parallel to the shoreline for providing protection against the coastal erosion. Due to serious erosional activity at few locations in the study area, sea walls had been constructed for protection. They were delineated mainly based on field evidence.

Oil well: The study area has been an important petroleum producing region of the state and showed the presence of structures associated with the petroleum industry. These structures included oil wells as well as gas gathering stations (GGS). A regular rectangular shape associated with a circular or rectangular pond was the key characteristics important at the time of identification of this category. Figure 4.3 illustrates how this category appeared in LISS III as well as Cartosat imagery.

Brick kiln: As per classification system given by Nayak *et al.*, (1992), this category was grouped under "barren land" category. But as it was associated with a specific type of industry, it was considered as a separate category. A distinct colour, a polygonal outline and its association with a water body were the features based on which it could be identified on satellite images (Figure 4.3).

Scrub: Nayak *et al.*, (1992) had grouped this category under the wetland category. But as it was found both in coastal wetlands as well as in land areas, it was grouped under other features. This was a plant community characterized by shrubby vegetation which also included a few grasses and herbs. The areas were heavily dominated by *Prosopis juliflora*. Its capability to grow in almost any of environmental condition found in the study area supported its ubiquitous nature.

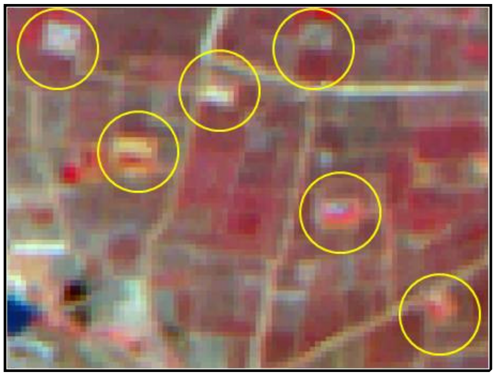
A few of these above mentioned categories are shown in Plates 4.1, 4.2 and 4.3.

4.1.1.2.5 Image enhancement:

This technique was applied for increasing human interpretability and thereby improving the ability to derive meaningful information from remotely sensed images. As several image enhancement steps alter the original numeric data of pixel, it was applied only for analog (visual) image classification (Campbell, 1996). This step was performed only for the image of the year 1987 where histogram equalization was carried out.

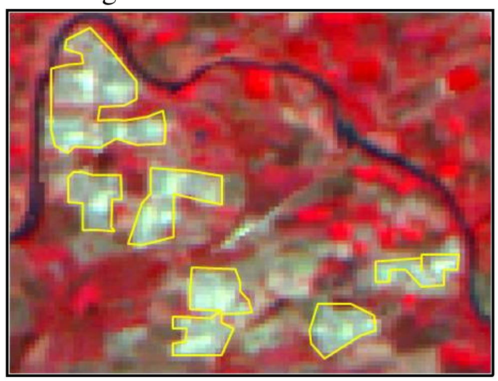
4.1.1.3 Classification Step

Classification of an image is the process of identifying image pixels with similar properties, organizing them in to groups and assigning labels to those groups. The end



Identification of oil well from IRS P6, LISS III satellite image

Identification of oil well from Cartosat-1 satellite image



Identification of brick kiln from IRS P6, LISS III satellite image

Figure 4.3 Characteristics of oil wells and brick kilns in satellite image

product of this step was a map of habitats or other features of interest, based on which we (user) can make deductions about habitat (or any feature) and could meet our goals.

There are basically two different ways for extracting features from the satellite images: 1) Digital Classification and 2) Onscreen visual interpretation.

4.1.1.3.1 Digital classification:

In the digital classification method, the software needs user inputs such as number of classes, standard deviation, mean digital number (DN) value, variance, threshold value etc. to carry out the classification (Nayak and Behera, 2009). This kind of classification worked well for spectrally homogenous areas (Chauhan, 2007). It involved either automated statistical clustering of image data (unsupervised classification) or statistical clustering defined by the user (supervised classification) (Green *et al.*, 2000). In unsupervised classification, the computer automatically classified the pixels in an image in to a number of classes (defined by the user) on the

Barren mudflat at Kavi (Jambusar)

Vegetated mudflat at Ankalwa (Hansot)

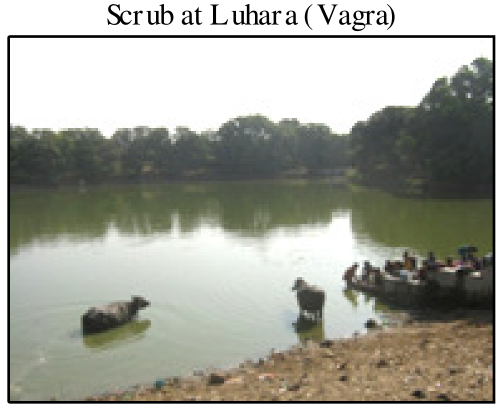
Salt pan industry and its expansion in mudflat area at Paniyadra (Vagra)

Mangrove and salt marsh vegetation at Ankalwa (Hansot)

Salt marsh vegetation at Dhamrad (Hansot)

Scrub at Luhara (Vagra)

Creek dissecting vegetated mudflat at Dahej (Vagra)



Pond at Degam (Jambusar)

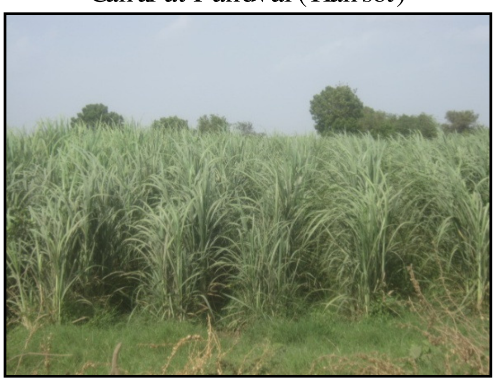
Plate 4.1 Various land use land cover categories observed in present study


River at Chanchwel (Vagra)


Waterlogged area in north of Muller (Vagra)


Canal at Pandvai (Hansot)


Dried canal at Kadodara (Vagra)


Agricultural land at Mothia (Hansot)


Agricultural land at Gandhar (Vagra)


Fallow land at Bhensali (Vagra)


Habitation with vegetation at Rohid (Hansot)

Plate 4.2 Various land use land cover categories observed in present study


Industries at Ambheta (Vagra)


Industry (ship building yard) at Kaladara (Vagra)


Jetty at Lakhigam (Vagra)


Brick kiln industry at Obha (Hansot)


Oil well at Gandhar (Vagra)


Oil well (Gas Gathering Station(GGS)) at Muller (Vagra)


Salt pan industry at Nada (Jambusar)


Aquaculture industry at Kanthiajal (Hansot)

Plate 4.3 Various land use land cover categories observed in present study

basis of spectral similarity. A map prepared by this method, was useful in planning the field survey wherein we don't require prior field knowledge (Green *et al.*, 2000). In the present study, Aliabet which was a relatively homogenous area was subjected to unsupervised classification. In unsupervised classification, firstly an area of interest (AOI) was demarcated for Aliabet area and was subtracted from the satellite image. This subset of Aliabet was used further to carry out unsupervised classification. This was accomplished by classifying each of the satellite images in to 80 classes. This was followed by labeling of each class which was then recoded. In unsupervised classification method sometimes spectrally very similar, but with different land use classes might classified wrongly as same category. Such errors were removed by contextual editing steps. This involved the conversion of raster image to vector format and then correction of polygon which was misclassified in unsupervised classification by changing its code to the correct one.

4.1.1.3.2 Visual interpretation:

For heterogeneous region, where a large number of categories had quite different or sometimes very similar spectral characteristics, digital classification was not recommended (Yang and Lo, 2002; Chauhan and Nayak, 2005). A problem observed especially in mapping of land use features, where the spectral signature of a single land use category may correspond to two or more spectrally similar, but different land use categories. For example: the category of habitation with vegetation may possess tree crown, buildings/ houses (rooftops), lawns etc. In such cases, digital classification would classify each different spectral region as separate category and may lead to misclassification (Campbell, 1987). A human interpreter could however readily recognize this complex pattern. Hence, visual interpretation or analog (visual) interpretation technique has been considered to be better technique for the land use land cover classification (Coppin *et al.*, 2002; Robertson and King, 2011). Visual interpretation involved use of different elements such as colour (tone or hue), texture, shape, size, shadow, pattern, association, height etc for discrimination of different features. In present investigation, Jambusar, Vagra and Hansot were heterogeneous areas. Hence, onscreen visual interpretation was used for extracting units of land use land cover and geomorphology from the image. After having knowledge of these visual elements, the next important step in visual image analysis was (1) to prepare image interpretation key, (2) to define scale of interpretation and (3) to select minimum mapping unit for demarcation of various features.

4.1.1.3.3 Preparation of interpretation key:

An interpretation key is the criteria for identification of an object with interpretation elements (George, 2007). It helped in identifying thematic classes from the image based on their characteristics features. The interpretation key used here was an elimination key wherein the interpreter proceeded step by step through a series of choices such as light tone, dark tone, smooth texture, rough texture etc., so by the successive elimination the object was identified. For the present study, the interpretation key was based on Nayak *et al.*, (1992) with necessary modifications. The detailed key has been depicted in annexure 4.3.

4.1.1.3.4 Selection of scale and minimum mapping unit:

***Scale*:**

Scale is a prerequisite at the time of image interpretation as it affects the understanding of various features encoded in the image. The choice of an appropriate scale depends on level of information desired, method of analysis to be used, spatial resolution of data and on the expected use of map (George, 2007). Generally 1:250,000 scale maps were used for planning purpose at the district level whereas 1:8000/4000 was required for implementation of activities at the field level (George, 2007). As it was decided to follow the third level of classification in the present study, a much finer mapping resolution was required. In the present study, 1: 15,000 scale was used for visualizing and delineating various land use land cover and geomorphological units. At this unit finer detail required for mapping up to the third level could be easily identified from the satellite image.

***Minimum mapping unit*:**

Minimum Mapping Unit (MMU) is the smallest size areal entity to be mapped as a discrete area (George, 2007). Based on the scale selected for present study, the minimum mapping unit decided was 0.15 ha. So, the polygons less than this unit were not mapped in land use as well as geomorphological maps.

4.1.1.3.5 Onscreen digitization:

After this, the main task in image analysis was to delineate boundaries for various feature of interest. This was achieved by using mouse driven cursor on a computer screen. Onscreen digitization technique was carried out using ERDAS IMAGINE (Version 8.5 and 9.1) software. In this step, different land use land cover categories and geomrphological categories were demarcated separately for preparing land use land cover map and geomorphological map respectively. After digitization, the vector layer was cleaned (a process of building the polygons and removing the dangle lines), followed by coding (a process wherein code was given to each of the digitized feature). After coding, symbology was generated in which a distinct colour was given to various classes of the 1st and 2nd level. For the categories of the third level classification, only different shades were selected for the allotted colours.

This exercise was first carried out for the year 2004 which was used as pre-field map. The various categories were verified on ground during the field visits and necessary modifications were incorporated.

4.1.1.4 Post Classification Step

In this step classified land use land cover maps and geomorphology maps were subjected for accuracy assessment and area estimation.

4.1.1.4.1 Accuracy assessment:

Accuracy defines "correctness". It measures the agreement between a standard assumed to be correct and a classified image of unknown quality (Campbell, 1996). The classification accuracy referred to correspondence between the class label and the 'true' class, which was defined as what was observed on the ground during field surveys. In other words, it gave an idea about how much of the class labeled as category 'habitation' on a classified image was actually 'habitation' in situ (in field). This was the most important step for a map generated from any remote sensing data.

To calculate the accuracy of a classified image, the field data of each and every pixel was required, which was not practically feasible. The accuracy assessment was carried out using the procedure prescribed by Congalton (1991). More than 100 points were randomly plotted on the classified maps using the image processing software. The plotting of point was stratified by excluding water and agriculture category. The accuracy of map was determined from the error matrix.

Error Matrix: It is a square array of rows and column in which row and column represents one habitat category of the classification. Each cell contains the number of sampling sites (pixels or group of pixels) assigned to a particular category. In this table, each column represented the reference data (collected from field data and assumed to be true) and the rows indicated classification generated from the remote sensing data.

There were several statistical methods to measure the accuracy of classification of which overall accuracy and Kappa coefficient are commonly used

(Yang and Lo, 2002; Shah, 2004; Yang and Liu, 2005; Chauhan, 2007; Bhatt, 2013; Rojas *et al.*, 2013).

***Overall accuracy*:**

It was the most common way of describing the accuracy for the whole map across all categories. It was considered to describe the overall degree of agreement in the error matrix. The equation used to derive the overall accuracy is given below (Congalton, 1991). The following relation was used to derive the overall accuracy

$$Overall\ accuracy = \frac{N_{dc}}{T}$$

Where,

N_{dc} = Total number of correctly classified points (diagonal points) and

T = Total number of points used for accuracy assessment

***Kappa analysis*:**

It is a discrete multivariate statistical technique used to assess classification accuracy from an error matrix. Kappa analysis generates Kappa coefficient that had a value range from 0 to 1 and would be less than overall accuracy unless the classification was exceptionally good (Green *et al.*, 2000). The value of K expressed the proportionate reduction in error generated by a classification process compared with the error of a completely random classification. The formula used to calculate its value is given below (Congalton, 1991).

$$Kappa\ coefficient, K = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r}(X_{i+} \times X_{+i})}{N^2 - \sum_{i=1}^{r} X_{i+} \times X_{+i}}$$

Where,

r = Total number of rows (i.e. classes) in a matrix

X_{ii} = Total number of points in row i and column i

X_{i+} = Marginal total in row i

X_{+i} = Marginal total in column i and

N = Total number of points used for accuracy assessment.

This was followed by calculation of areal extensions of various categories.

4.1.1.4.2 Area estimation:

The area of each class or category in the different maps generetated during the study was extracted from the attribute table of vector map using ERDAS Imagine software.

4.1.2 GIS ANALYSIS

GIS is a system of hardware, software and procedures designed to facilitate the management, analysis, modeling and representation of the geo-referenced digital data (Iyengar, 1998; Seifi and Sepasian, 2011). It is a very important tool in mapping, monitoring and assessing the changes in coastal environment (Ramachandran *et al.*, 1998; Dahdouh-Guebas *et al.*, 2002). Here, GIS was used in order to bring out changes in the various land-use and land cover categories.

4.1.2.1 Change Detection

Change detection is a process of identifying differences in the state of an object or phenomena by observing it at different times (Singh, 1989). Change detection involves use of multi temporal datasets to quantify the changes over a period of time. Remotely sensed satellite data, with its repetitive coverage, short interval of time and consistent image quality has found increased application in change detection studies (Jayappa *et al.*, 2006; Shalaby and Tateishi, 2007; Kamusoko and Aniya, 2009; Alqurashi and Kumar, 2013). Its application especially in the field of coastal zone had increased during the last two decades (Jayappa *et al.*, 2006). Several researchers have developed procedures of land cover change detection using digital data. These procedures of change detection are grouped under two different approaches (1) comparative analysis of independently produced classification for different dates (post classification comparison) and (2) simultaneous analysis of multi-temporal data (pre classification comparison) (Singh, 1989).

In the present exercise, the different satellite imageries with different resolutions were used to study changes in land use land cover pattern of the area. In the post-classification comparison, two dates of imagery were independently classified and registered. Then, an algorithm was employed to bring out the pixels with a change in the classification between the two dates. In addition, selective grouping of classification allowed analysts to observe any subset of changes which might be of interest. It provided a complete matrix of change direction, "from-to analysis" i.e. information about the initial (t_1) and final (t_2) land use or land cover type. It provided information on the changes in areal extent and spatial distribution of land use /cover. The accuracy of such procedures exclusively depended on the accuracy of each of the independent classification used in the analysis. In this case, errors if present in the classification would be compounded in the change detection process and reduce the final accuracy (Alqurashi and Kumar, 2013). Thus, a great deal of time and expertise is required for the performance of post-classification comparison (Alqurashi and Kumar, 2013). The post-classification change detection approach was employed in the current study using the method described by Shah (2004). The analysis was carried out between the earliest and the latest datasets along with one intermediate date.

The change detection was carried out using ESRI's ArcInfo (User 7.2.1) software. The whole procedure was involved four major steps. These steps have been described below.

1. **Merging of Vector Layers:** This step involved the merging of sptatial information of the two dates in the form of vector data. This was accomplished by using the "union" command which formed a new dataset by joining the two vector datasets and had information of both the data sets.
2. **Dissolving polygons:** The above process results in a large numbers of polygons which have an area less than 1500 m^2. The polygons less than this area were merged with the neighbouring polygons with which they shared their longest boundary.
3. **Identification of change categories:** Information from both the datasets were used to create an item in the polygon attribute table (.PAT) of the newly formed dataset. This was used to define the "from-to" categories as well as no change categories.
4. **Defining output legend (Map composition):** The number of output classes in each of the change detection analysis was very large. To represent all this change in the change detection map would create complex representation and decrease the clarity of the map. Hence, mapping of change detection was restricted only to the mangrove and industrial area categories only.

Later, statistics and change detection maps were compiled to express the specific nature of the changes between the dates of imagery.

4.1.3 INFORMATION REPRESENTATION

The information derived from the satellite images and GIS analysis were summarized as thematic maps, statistics and graphs.

Besides this statistical parameter such as Pearson's correlation coefficient was used to find out correlation among various coastal wetland categories and land categories. To represent this data, correlation matrix was prepared for the coastal wetland and land categories.

4.2 FIELD STUDY

Field survey is an essential element in mapping using satellite images. It is required to identify the habitats present in the study area, to record locations of habitat for multispectral image classification and to obtain the independent reference data to test the accuracy of the resulting habitat maps.

In the present study, the field surveys were carried out with the following objectives:

1. To make an inventory of the coastal vegetation growing in the area
2. To study the phyto-sociology of the mangrove vegetation
3. To collect the soil samples from the coastal wetland
4. To verify the doubtful areas (in the image interpretation)
5. To estimate accuracy of thematic maps

Field surveys were carried from March 2009 - May 2015 during the pre-monsoon and post-monsoon seasons. Details of area visited during this time span has been given in Table 4.3. In the gulf environment, where the tidal amplitudes are very high it was not feasible to work during the high tide conditions. For this reason, the ground surveys were carried out mainly during the low tide conditions. Besides this, the soft sandy or muddy terrain makes it more difficult to work in this terrain. Hence, a proper time period (i.e. 6th-10th day from the full moon or no moon day) was selected to carry out the field work in the coastal area. These days were selected for field surveys as during this time work was possible from the morning to evening and the tidal amplitudes were also lower. During the field work precise geographic co-ordinates of the various locations and field features were collected with help of Magellan eXplorist 210 GPS. The overview of this field survey component is given in Figure 4.4.

Taluka	Period of Field work	Sites
Jambusar	May 2011	Sarod, Isanpura (Jamdi), Devla
	June 2012	Kamboi, Degam, Asarsa, Tankari
	November 2012	Kamboi, Degam, Isanpura, Devla, Asarsa, Tankari
	May 2015	Nada, Neja, Sarod
Vagra	March 2009	Chanchwel, Muller, Gandhar, Paniyadra, Padariya, Dahej
	May 2009	Bhensali, Kaladara, Vengani
	May 2011	Gandhar, Muller, Trankal, Ambhej, Sayakha, Bhersam
	June 2012 June 2012	Aliabet Kaladara, Suwa, Ambheta, Lakhiagam, Luhara, Dahej
	October 2012	North of Muller, Gandhar, along coast of Aladra, Padriya

Taluka	Period of Field work	Sites
	October 2014	Aliabet
	March 2013	Kaladara, Suwa, Ambheta, Aliabet
Hansot	May 2011	Katpur, Kanthiajal, Rohid, Digas
	April 2012	Balota, Elav
	June 2012	North of Mothia and Dhamrad
	November 2012	Katpur, Wamleshwar, Kanthiajal, Ankalwa
	October 2014	Ankalwa, Kanthiajal, Katpur

Table 4.3 Details of field visits carried out in present study

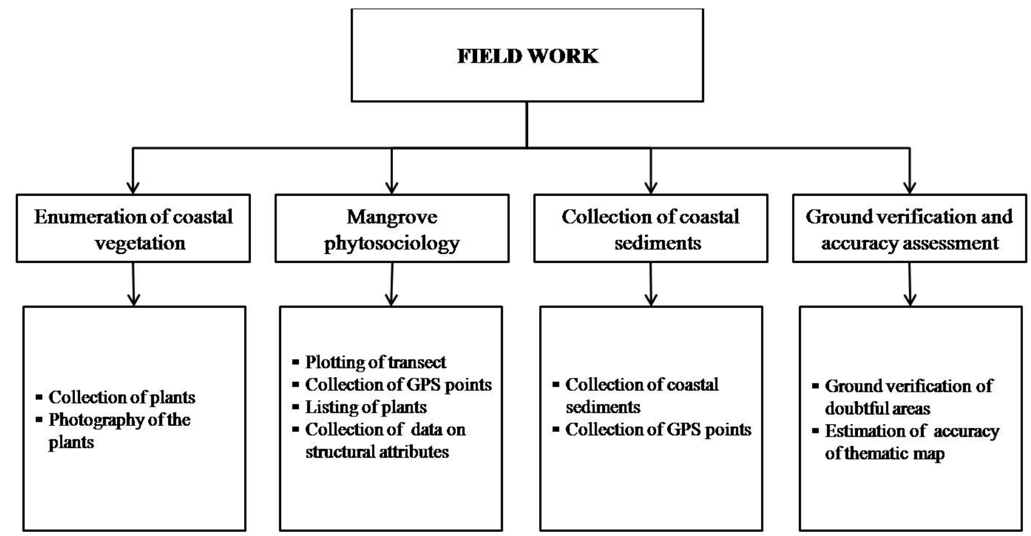


Figure 4.4 Overview of the field survey

4.2.1 SURVEY OF COASTAL VEGETATION

4.2.1.1 Enumeration of Coastal Vegetation

To prepare an inventory on the coastal vegetation of the study area, villages along the coast were visited. Most of the coastal villagers (>80%) were visited and coastal as well as land areas 500 m from the high water line were surveyed. Field photographs of the plants were taken and then the plants were collected and pressed. They were brought to the laboratory and identified with help of different flora. The identification was confirmed by experts. A list of species growing in the coastal area of Bharuch District was prepared taluka-wise. To compare the diversity of the vegetation in the different talukas the Sorenson's index of similarity was used. Sorensen Index of similarity is generally used to compare the species composition of two different vegetation units (Sorensen, 1948; Diamond and Smeins, 1984; Snyder and Boss, 2002; Wernberg *et al.*, 2011). It is the ratio of the number of shared species to the average number of total species in two communities (Chuang, 2012). The index is mathematically depicted below.

$$Similarity\ index = \frac{2A}{B + C}$$

Where,

A = Total Number of species in both sites, B = Number of species in first site and C= Number of species in second site

4.2.1.2 Mangrove Phytosociology

Forest phytosociological studies are very important in determining the forest structure and its composition. It is a study of vegetation and its internal "social" relationships (Vidyasagaran *et al.*, 2011). It involves not only classifications of plant communities but also analysis of their structure, composition, successional relationship, relationship with environmental factors, as well as comparison of different communities (Fujiwara, 1987). In the present exercise, structural characteristics of mangroves were studied using the Point- Centred Quarter Method (PCQM). It is a plot-less (Cottam and Curtis, 1956; Snedakar and Snedakar, 1984; Martins, 1991) method which provides good accuracy (Dahdouh-Guebas and Koedam, 2006) and allows relatively rapid forestry survey which is an important factor when working in the mangrove tidal ecosystem (Neukermans *et al.*, 2008).

The sampling was done by taking transects from landward side to the seaward side i.e. in direction perpendicular to the coast. For each mangrove plot, based on the accessibility of an area, a transect line of minimum 100 meters was laid out. GPS (Global Positioning System) locations were recorded at the beginning; middle and endpoints of transect line. At each sampling point, four quarters were established by perpendicular lines on the transect direction. In each quarter, an individual tree closest to the sample point was identified (Figure 4.5) and their structural attributes such as height, circumference and distance from sample point were recorded in the data sheet. The same procedure was followed at the interval of every 10 meter as suggested by Cottam and Curtis in 1956 and Cintrón and Schaeffer Novelli (1984).

This exercise was carried out to determine variables such as tree density (stems/0.1 ha.), basal area, absolute frequency (% composition), relative frequency (% composition) and relative density (% composition). The formulas of all the above mentioned parameters are given below (Snedakar and Snedakar, 1984).

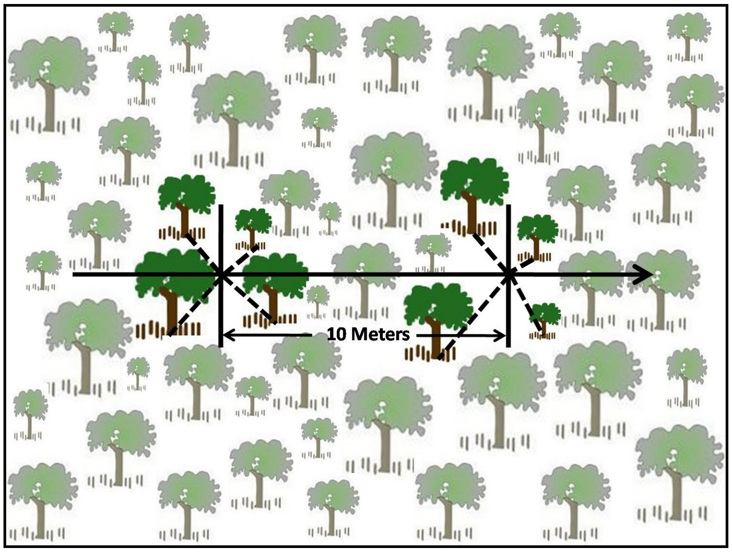


Figure 4.5 Graphical representation of PCQM Method

Complexity index is used to illustrate structural development or complexity of vegetation in a stand (Bosire *et al.*, 2014). The collected data was used to calculate complexity index using the method followed by Holdridge *et al.*, (1971). This index was an integrative measure that combined information on several parameters like number of species, stand density, basal area and height. The formula used to calculate complexity index is given below.

Where,

s = Number of species, d = Stand density, h = Mean height and BA = Basal area.

In addition to this, several other statistical parameters were used to analyse the phytosociological data that was collected. Pearson's correlation coefficient was used to show correlation among structural attributes such as distance (between two plants), diameter and height parameters. Fisher's test (F-test) was used to know the significance of variation in above mentioned structural attributes for mangrove stand of Jamdi and Devla of Jambusar taluka and Katpur and Kanthiajal stands of Hansot taluka. ANOVA was carried out to evaluate the overall variation in height, distance and diameter across the five sites.

4.2.2 COLLECTION OF COASTAL SEDIMENTS

Substrate characteristics (edaphic factor) are some of the most important parameters that affect the plant growth (Boto, 1984). The type of soil and its chemical states are in turn affected by factors such as topography, tidal and riverine sedimentation pattern, climate, tidal range and long-term sea level changes (Perera and Amarasinghe, 2014). Therefore, it is necessary to analyze the physico-chemical properties of coastal sediments in order to understand the distribution of coastal vegetation.

Collection of sediments was done from coastal wetland area by random sampling. The collection procedure suggested by Kathiresan (2010) and Bhatt (2013) were followed and has been described below. The collected samples were then processed in the laboratory. GPS location for each sample was collected.

<u>Procedure for the collection of the soil sample:</u>

- An area of 15 x 15 cm was selected.
- The top 10-15cm surface layer of the soil was removed with help of trowel.
- Soil sample was collected in a polythene bag, labeled with a sticker and were brought to laboratory for further analysis.

4.2.3 GROUND VERIFICATION AND ACCURACY ASSESSMENT

4.2.3.1 Ground Verification

It is an important step wherein observations found in the field were matched with attributes found in remotely sensed images. It was important in identifying new categories as well as checking doubtful areas (sites whose interpretation/identification was unclear). These sites were verified on the ground and necessary corrections were incorporated in the thematic maps.

4.2.3.2 Estimation of Thematic Map's Accuracy

It is necessary to evaluate the accuracy of map by comparing the categories on the classified images with the present condition on the (areas of known identity on) ground. Here, to ensure that all habitats are adequately represented by field data, a stratified random sampling strategy as suggested by Congalton (1991) and followed by Shah (2004) and Bhatt (2013) was adopted. All the possible points were visited on the ground and the error matrix was generated.

4.3 LAB WORK

Lab work mainly comprised of plant identification and the analysis of sediments. Steps involved in plant identification have been discussed earlier in this chapter. The sediments collected from the coast were analysed for several parameters. These different physico-chemical parameters included grain size analysis, pH, electrical conductivity (EC), salinity and soil organic carbon (OC).

PROTOCOL FOR SOIL SAMPLE ANALYSIS

In the coastal environments, the variation in the physical and chemical composition of soil is one of the major reasons for occurrence or limitation of a particular type of vegetation (Boto, 1984). Hence, it is necessary to study the physical and chemical composition of the coastal sediments.

4.3.1 PREPROCESSING STEP FOR SEDIMENT SAMPLE

- After collection, soil samples were brought to laboratory. In laboratory, the samples were removed from polythene bags and kept on filter paper in the form of small lumps. The samples were allowed to dry under room temperature.

- The dried samples were mixed properly and by the coning and quatering method as described by Bhatt 2013 subsamples were obtained. This was then analysed further for various parameters.

4.3.2 PREPARATION OF THE SOIL SUSPENSION FOR THE DETERMINATION OF pH, EC AND SALINITY

- Soil suspensions were prepared with proper water and soil ratio. In present study, 1:5 ratio (i.e. 10gm of soil: 50 ml of distilled water) was followed which was the most preferred and accepted ratio (Jackson, 1967; Angela *et al.*, 2008; Li *et al.*, 2010). 10 gm of air-dried soil was taken in a 100ml of beaker. To this 50 ml of distilled water was added and stirred vigorously at the interval of 15 minute for an hour. After this the sample was ready for the analysis. It is important to note here that, for pH, the entire soil suspension was used where as for electrical conductivity and salinity, the supernatant (the upper clear water) was used. Hence, for all the samples first, pH was estimated and then the other parameters were estimated.

- pH, electrical conductivity (EC) and salinity were measured using Microprocessor Soil Analysis Kit Model no. 1160 (Electronic India).

4.3.3 ORGANIC CARBON

The wet oxidation method given by Walkley and Black (1934) was used for the estimating the amount of organic carbon in the soil sample.

4.3.4 GRAIN SIZE

Particle size or grain size analysis is one of the most important physical determinations of soil (McManus, 1988; Poppe *et al.*, 2000; Watson *et al.*, 2013). It is a measurement of the size distribution of individual particles in a soil sample. The particle or grain size analysis is also known as granulometric analysis. In the present study, as the most of the samples contained finer sediments, the pipette method given by Folk (1974) was used.

Statistical parameters such as graphic mean size, inclusive standard deviation, graphic skewness and kurtosis were calculated from the data generated from grain size analysis. The graphic method given by Folk and Ward (1957) was used for the calculations. Equations used for the calculation of graphic mean size, inclusive standard deviation, graphic skewness and kurtosis are given below. The method given by folk (1974) was used to derive values of phi (ϕ) required for these statistical parameters.

Graphic Mean (M_z): It was a measure of central tendency. This was the best graphic measure for calculating average size of sediment.

$$M_z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

Inclusive Graphic Standard Deviation (σ_1): It measured the uniformity or sorting. Sorting was a measure of the "spread" of a curve about the mean size. It gave an idea about the size ranges of materials that were present in the sample.

$$\sigma_1 = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

Skewness (Sk_1): This parameter gave idea about the asymmetry of a curve as well as the sign i.e. whether the curve had an asymmetrical tail to the left or to the right of the modal class. It is calculated by the formula given below.

$$Sk_1 = \frac{(\phi 16 + \phi 84) - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{(\phi 5 + \phi 95) - 2\phi 50}{2(\phi 95 - \phi 5)}$$

Kurtosis (K_G): It gave an idea about the "peakedness" of a curve. It was quantitative measure of the departure from normality and measured the ratio between sorting in the "tails" of the curve to sorting in the central portion. Graphic kurtosis is defined as:

$$K_G = \frac{\phi 95 - \phi 5}{2.44\ (\phi 75 - \phi 25)}$$

To know correlation of different grain size (silt, clay and sand), pH, electrical conductivity, salinity and organic carbon, Pearson's Correlation coefficient was calculated. Based on these values, a correlation matrix was generated which showed correlation among these above mentioned parameters. The variation in the chemical parameters such as pH, electrical conductivity (EC), salinity and organic carbon across various sites of Jambusar, Vagra and Hansot talukas were analysed using ANOVA.