Chapter 1

Introduction

The coast, occurring between land and sea, is dynamic in nature. It changes gradually by sequences of hydrodynamic changes (e.g., river cycles, sea level rise, etc.) and geomorphological changes (e.g., barrier island formation, spit development, etc.), and suddenly and rapidly by seismic and storm events (Scott, 2005). For integrated coastal zone management and its future sustainability, understanding of this dynamic nature is important. Several earlier workers have attempted to interpret coastal changes in different modes, namely, as interrelationship between different coastal parameters (Hayes, 1972; Hails, 1974; Kukal, 1990; Cowell et al., 1995), by qualitative assessment of form and processes (Cooper et al., 2001; Woodroffe, 2002), and by quantification of sediment budget (Young and Ashford, 2006). In recent years, Remote Sensing and Geographic Information System (GIS) techniques have been widely used for studying various coastal aspects (Cracknell, 1982; Bhavsar, 1983; Jensen, 1986; Bonham-Carter, 1994; Gower, 1996; Hasselmann et al., 1996; Irish and White, 1998; Saraf and Choudhury, 1998; White and El Asmar, 1999; Hanamgond and Mitra, 2010; Erdogan and Kuter, 2010; Sener et al., 2010). This is because of the synoptic as well as repetitive coverage of the earth by satellites. Further, data from inaccessible areas of the earth can be obtained by air-borne and space-borne sensors. In recent years, use of satellite images for surveying nearshore areas has become popular due to their synoptic coverage, cost-effectiveness and repetitive data acquisition capabilities. In marine operations, they have an added advantage of safe mode of data acquisition vis-à-vis the conventional hazardous and costly data acquisition techniques (CETN-VI-17, 1985). Using remote sensing techniques, a broad range of marine applications have been successfully achieved in different case studies, such as, time series analysis (Kraus and Rosati, 1997; White and El Asmar, 1999; Lafon, et al., 2002, 2004); estimation of longshore transport (Hasselmann, et al., 1996; Fedor and Bown, 1982); shoreline determination (Douglas and Crowell, 2000; Ryu et al., 2002; Yamano et al., 2006); identification of relative changes among coastal units (Siddiqui and Maajid, 2004; Jantunen and Raitala, 1984); extraction of topographic and bathymetric information (CETN-VI-6, 1990; Irish and White, 1998; and Lafon, 2002) and integrated coastal zone management (Nayak et al., 1996; White and El Asmar, 1999). Besides satellite data, aerial photographs will also be used for detailed study over some selected regions. Further, these two techniques are also advantageous, due to their cost-effectiveness, reduction in manual error and absence of subjective approach of conventional field techniques.

1.1. Literature Survey

Coastal change is defined as the mutual adjustment of the topography and fluid dynamics against sediment transport (Wright and Thom, 1977). The relative positions, extents and geometries of different coastal change units, reflecting the topographic changes in an area are the manifestation of this mutual adjustment. The development of morphodynamics study has undergone through several approaches: starting from the status of essentially descriptive (Woodroffe, 2002), empirically based discipline (McBride, et al., 2007; Kraus and Soares, 2004; CEM-II-6, 2002; FitzGerald et al., 2000), understanding the interrelationship between different coastal parameters (Kukal, 1990; Hails, 1974; Hayes, 1972). It has progressively moved towards predictive and quantitative assessment, in order to understand why, when, and how much of the coastal change has taken place. It is now focused towards quantitative interpretation of coastal hazard, sediment budget analysis (Young and Ashford, 2006), and coastal morphodynamics (Irish and White, 1998) using advanced technologies, such as, LiDAR (Gibeaut, 2003) and continuous video observation (Almar, et al., 2008; Lippmann and Holman, 1989) with the aim of integrated coastal zone management. This progress has been made with the development of mathematical modeling of some key geomorphological features. Though the hydrodynamic parameters (e.g. wave propagation, wave breaking, wave-current interactions) of the coastal region are crucial in quantifying and explaining fluvial hydrodynamics, and integrated study of river and coastal morphodynamics turns out to be an useful exercise. Cellular models of complex systems are sometimes formulated based on a strikingly simplified picture. This activity has led to substantial improvements in the understanding of the physical processes controlling the mechanics of coastal forms as well as leading to prediction of the morphology of the coastal region using complex models.

Time and space based, deterministic, sequential and probabilistic models have evolved to facilitate these studies (Cowell et al., 1995; and Cooper et al., 2001). However, due to changing weather conditions and lack of long term high resolution data, the traditional deterministic prediction with single model is scientifically unsound (Southgate et al., 2000); while sequential models are complex in nature and focus on short term relatively localized-scale predictions (Cooper et al., 2001). Further, running of the same model for the different sequences of time may introduce exaggeration of small errors. On the other hand, a probabilistic approach, based on empirical observations and statistical records over a span of time, can be a viable option. In this regard, satellite images are important as these provide a synoptic, repetitive as well as regional view of the coastal data (Bhavsar, 1983; Gower, 1996; Hasselmann et al., 1996; Irish and White, 1998; White and El Asmar, 1999; and Lafon et al., 2004). Moreover, inaccessible areas, for field data collections can be easily viewed in a single date satellite image. The stochastic forcing (e.g., storms) of sediment motion in the coastal region along with intrinsic unpredictable character of some morphodynamics systems, which are characterized by nonlinear dynamics, have posed a new challenge to long-term prediction of morphological changes. Remote sensing techniques, such as, video monitoring system, LIDAR mapping etc, are valuable tools to obtain precise information about coastal morphology required to test the available models. Due to these advantages, coastal change studies from space became an important branch of coastal studies (Robinson, 2004 and 2005; Collins, et al., 1979).

Since coastal changes occur temporally from instantaneous to geological scale, and spatially from millimeter scale to thousands of kilometer scale, choosing spatial-temporal scales are important. Most of the previous work on coastal change studies considered large scale aerial photographs as historical data sets (Fryer et al., 1994), as they were available much before the availability of satellite imageries. However, in situations where aerial photographs are not available, earliest satellite sensor, Landsat Multi Spectral Scanner (MSS) can be used as a source of historical data.

1.2. Spatial -temporal scale and influencing factors

Coastal change is a complex process involving global, regional and local factors. Media and popular interest have focused on global climate change which may be leading to eustatic sea level rise. Almost all natural changes are related to short-term or long-term periodic effects, such as, global lunar nodal cycle (Gratiot et al., 2008; Jeuken et al., 2003), climatic-solar periodicities (Hiremath and Mandi, 2004; Moselti and Purga, 1991), El Nino and other global meteorological phenomena (Revell and Marra, 2002), river discharge and salinity variations (Chamarthi and Shree Ram, 2009) etc. Many of which are not clearly defined. Anthropogenic factors complicate the natural changes. Separating shoreline changes into component parts, e.g., recession associated with global climate change, changes in relative sea level, long-term and short-term cycles, and episodic events, a complete understanding of the global and regional climatology, regional geology, anthropomorphic influences and coastal processes are required to understand. Broad varieties of time and spatial scales of natural and human-induced factors or forcing are responsible for coastal evolution. These can exhibit spatially and temporally uniform or fluctuating motions of significant magnitude. Therefore, these motions need to be considered to understand coastal evolution. In this regard, consideration of temporal and spatial scales of geologic and oceanographic phenomena is important. The published Shore-Protection Manual (SPM, 1984) indicates a broader range of such phenomena (Fig. 1.1). From largest spatial and temporal scale of continental glaciers upto smallest scale of bedform movement, the graph highlights various types of influencing factors.

In the present study, since observations were based on satellite imageries, a much smaller spatial-temporal range has been considered. The red box inside the graph indicates that range. Within this range, following influencing factors or geomorphological phenomenon can be explained: cultural influence, seasonal beach cycle, volcanic eruptions, cliff erosion, river delta cycle (Walker et al., 2008), seas level change (Thom and Cowell, 2005), and part of tropical storms etc. The dates of the chosen satellite imagery vary from 1973 to 2009. The observations were divided into three temporal and three spatial scales, as discussed below.

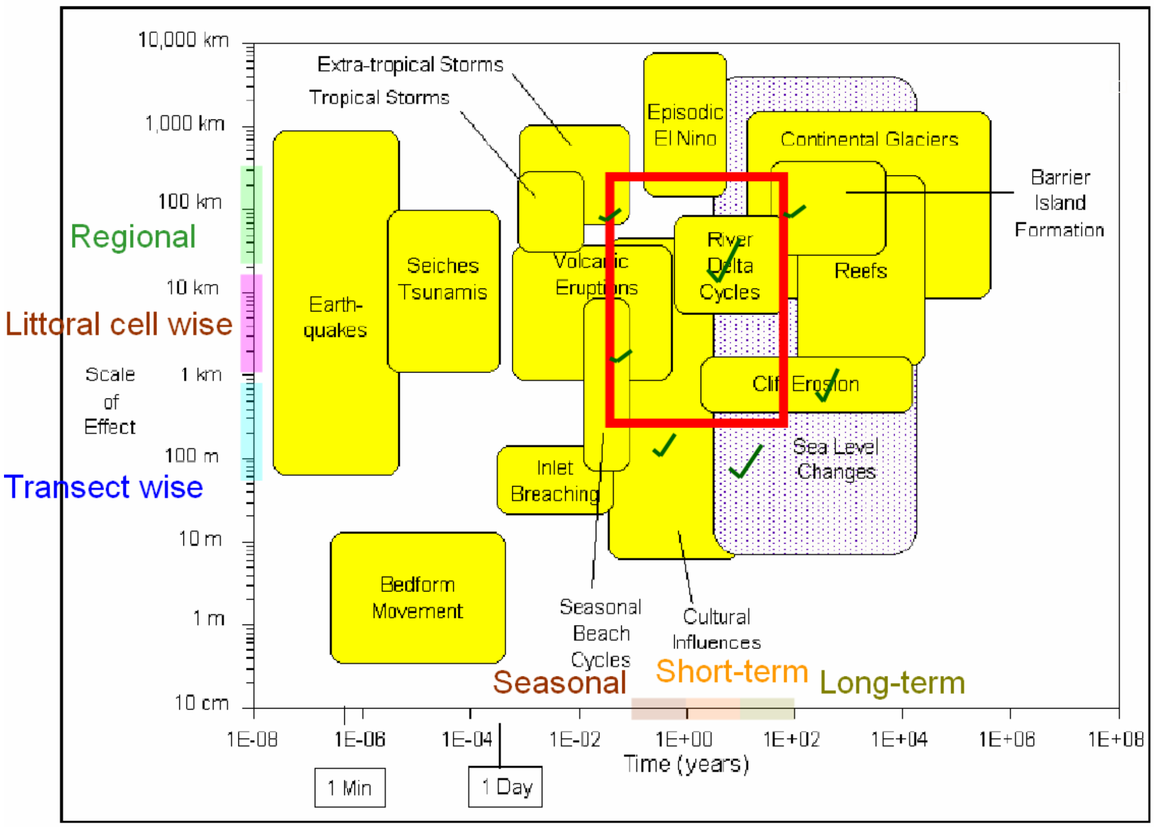

Figure 1.1: Temporal and spatial scales of geologic and oceanographic phenomena. Red box indicates the limit of present study. (Modified after SPM, 1986)

1.2.1. Spatial scale

The coastal morphology is the manifestation of a non-linear dynamical system. The spatial and functional complexities of the coastal tract system are being referred to as the level of 'physiographic units', such as, river delta, beach barrier, coastal inlet, backbarrier system (lagoon, bay or estuary), chenier plain, washover, etc. However, beyond such regional considerations a detailed scale study can be carried out, such as, at medium scale for 'Littoral cells' and at comparatively higher resolution scale for 'transects'. In this study, spatial scale has been sub-divided into three categories: regional scale (upto 113 km), littoral cell (5 km to 10 km), and transect (100 m to 1 km).

1.2.2. Temporal scale

Shoreline position fluctuates in a variety of time scales, and this behaviour introduces many difficulties while reconstructing different coastal trends. Variability in the coastline position may be the response to a single factor or a combination of them. Understanding the reasons for the fluctuations is important, in order to design appropriate mitigating interventions. Short- and long-term relative sea-level changes also control shoreline movement. The supply of sand determines how shoreline changes at a particular location. For different settings, such as, whether a beach is sheltered from waves, or adjacent to a tidal or storm channel, or next to a jetty or seawall, effects are also different. To understand and predict the coastal change, it is important to distinguish between long-term, short-term, and episodic coastal changes and their causes. Therefore, in the present study, a variety of time scales (seasonal, short-term and long-term) has been considered for understanding and predicting shoreline changes.

1.2.2.1. Seasonal: It concerns periodic fluctuations in the dynamic behaviour of a beach on the time scale of seasons. This seasonality, however, is not universal due to regional and/or temporal inter-seasonal variations in wave climate.

1.2.2.2. Short-term: The short-term or inter-annual scale variability can be measured from the dataset covering 10 years of measurements. It gives a good basis for determining typical changes at the inter-annual scale as well as seasonal variability. Furthermore, since the temporal resolution is studied on pre and post-monsoon basis, the effects of storm events can be reliably assessed. All measurement criteria discussed above refer to the shoreline proxy of land-water boundary.

1.2.2.3. Long-term: Shoreline variability and mobility on long-term or decadal scales is investigated over a period of 30 years.

1.3. Objectives

The present study was undertaken with the following five fold objectives:

i) Identification and mapping of different geomorphological and anthropogenic features

ii) Compartmentalization of the coastal stretch under investigation into littoral cells and selection of transects in each cell.

iii) Identification of shorelines and calculation of shoreline change rates over different periods (long-term, short-term and seasonal) for prediction of future shoreline positions.

iv) Formulation of a three-unit (viz., land, wetland and water) based approach for coastal change studies and validation of results with conventional beach profiling.

v) Corroboration of long-term, short-term, and seasonal coastal changes with different influencing factors.

1.4. Methodology

The following steps have been adopted to achieve the above mentioned objectives.

- Multi-temporal satellite data ranging from 1973 to 2009 of different sensor characteristics, namely, Landsat MSS, TM, ETM+ and ASTER were acquired. All imageries were georeferenced with UTM projection of zone number 45N.
- Shoreline positions during different dates were determined from different imageries and archived in vector format within same GIS platform.
- The coastal stretch under investigation was subdivided into seven littoral cells, based on natural boundaries. Transects, perpendicular to the reference shorelines, were selected at equal intervals. Shoreline change rates were estimated by applying Linear Regression (LR) method.
- The predictions and cross-validations of shoreline positions were carried out transect-wise, littoral cell wise, and regionally.
- Multi-date satellite imageries were classified into three coastal units, viz., land, wetland and water using supervised classification technique.
- Mutual changes between these coastal units were identified in terms of five coastal change units, namely, ‘land accreted’, ‘wetland accreted’, ‘land replaced by wetland’, ‘wetland replaced by water’, and ‘land replaced by water’.
- Beach profile surveys were conducted during three consecutive seasonal periods (post-monsoon 2008, pre-monsoon 2009 and post-monsoon 2009).
- Derived five coastal change units were superimposed on the beach profiles, in order to find the elevation change between any two consecutive seasons corresponding to each change unit.
- Based on seasonal three-unit based coastal change study and beach profile data, sediment budget estimation for different littoral cells have been carried out.

- Field surveys were carried out with global positioning system (GPS) to serve three important aspects: (a) positional accuracy of studied satellite imageries, (b) to map geomorphological and anthropogenic features with geographic co-ordinates, and (c) to record and store the geographic co-ordinates of all beach profiles.

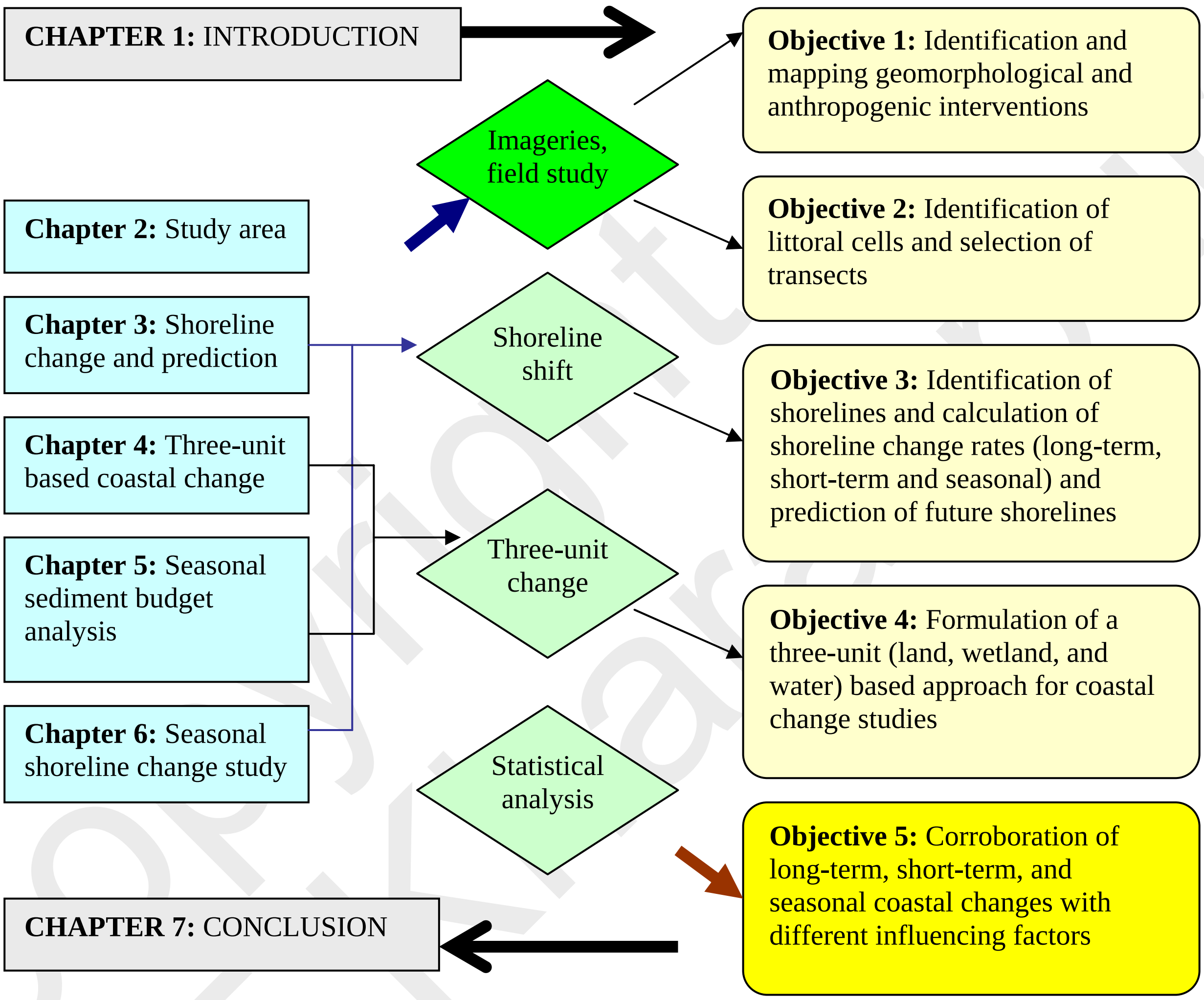

Figure 1.2: Flow chart showing integration of different chapters, adopted methodologies and assigned objectives

The chapter-wise interlinking of the objectives and various methodologies is demonstrated by a flow chart (Fig. 1.2). As shown in Fig. 1.2, three columns with different colours indicate three main components of this Thesis, viz., Chapters (blue), Methodologies (green) and Objectives (yellow). Within this flowchart, using different arrows, the integration between these columns is demonstrated. First and last long bold arrows (black) indicate respectively that Chapter 1 proposes different objectives of this study, and Chapter 7 integrates the accomplishments of different objectives. Further, one short bold arrow (blue) indicate that all six chapters utilize first methodology (imagery and field study); while the other short bold arrow (brown) show the integration of all the methodologies toward realization of the last objective (5). Different statistical tools, such as, Normal distribution, Regression analysis, RMSE analysis, Error matrix, one to one data correlation etc. have been used. Chapters 3 and 6 utilize second methodology (shoreline shift), whereas Chapters 4 and 5 utilize the third methodology (three-unit based change study). Though Chapters 3 and 4 follow different methodologies (shoreline shift and three-unit change respectively), but they show similar results of long-term changes. In the same way, Chapters 5 and 6 show similar results of seasonal changes though using two different methodologies.

1.5. Organization of the Thesis

The present study has been presented in seven chapters. The brief discussions of these presentations in the Thesis is given below

Chapter 1 introduces the present study through a literature review of earlier approaches of coastal change study and their suitability, spatial and temporal considerations for analysis and suitability of the present study within present coastal setup. Demonstrating a brief outline of the suitable methodology, the objectives of the present research has been also discussed in this chapter.

Chapter 2 discusses the division of the study area into littoral cells, based on natural boundaries and the results of analyses and interpretations of satellite imageries and field observations. Geomorphology and anthropogenic interventions have been documented in each of the littoral cells.

Chapter 3 describes the methodology adopted for determination of shoreline change. Satellite derived shorelines have been analyzed along different transects to quantify shoreline change rate by Linear Regression method. The littoral cell-wise statistical summary of long-term (30 years, 1973 to 2003) shoreline change rate has been described here.

Chapter 4 gives detailed outline of the newly proposed methodology, namely, three-unit based coastal change detection. Using this technique, the coastal changes have been categorized into five different change units. Subsequently, a long-term coastal change (1973 to 2000) has been determined and verified using field evidences of geomorphological changes. Suitability of the adopted methodology in the study of three different aspects of coastal zone management, viz., sediment budget analysis, morphodynamic study and coastal hazard zonation has been discussed.

Chapter 5 considers three-unit based coastal change study undertaken during three consecutive seasons: post-monsoon 2008 to pre-monsoon 2009, and pre-monsoon 2009 to post-monsoon 2009. Several beach profiles were considered and results of analysis corroborated with coastal change units in order to estimate sediment budget during periods of recovery and devastation.

Chapter 6 estimates shore line changes for short-term interval of ten years (1999 to 2009) for pre- and post monsoon seasons separately along transect-wise, littoral cell-wise and regional. The results were corroborated with change of weather, seasonal anomaly of rainfall and storm occurrences. Finally, overall short-term shoreline change rates have been derived from this chapter. This chapter also discusses the short-term interval (10 year) changes from 1970 onwards, which have been corroborated with global nodal variation of tides.

Chapter 7 combines and summarizes all the above mentioned Chapters (from 1 to 6). The fulfillment of each objectives of the Thesis is explained. The conclusions derived from the present study are listed in this chapter. Probable scopes of future work, related to this study are also added.