Introduction
Chapter 1
INTRODUCTION

1.1 Beach

The zone of unconsolidated material that extends landward from the low water line to the place where there is a marked change in material or physiographic form or to the line of permanent vegetation (usually the effective limit of storm waves) is defined as beach. The seaward limit of a beach, unless otherwise specified, is the mean low water line. A beach includes foreshore and backshore (Shore Protection Manual, 1984). Beaches usually slope gently toward the body of water they border and the beach face has a concave shape. They extend landward from the low water line to the point where there is a distinct change in material (as in a line of vegetation) or in land features (as in a cliff). Shore is a word used as synonymous to beach.

Shoreline is an imaginary line which demarcates the land and water and it is a dynamic one. It is defined as the intersection of a specified plane of water with the shore or beach (e.g., the high water shoreline would be the intersection of the plane of mean high water with the shore or beach) (Shore Protection Manual, 1984). Shoreline definition is more complex and it should consider both temporal and spatial sense. Shoreline is a dynamic feature and this boundary is of importance to coastal engineers and scientists.

1.1.1 Beach morphology

A vertical section of the beach which is called beach profile is presented in Fig.1.1. Some of the terminologies associated with the beach and beach profile are reproduced below from Shore Protection Manual (1984).

**Backshore:** That zone of the shore or beach lying between the foreshore and the coastline and acted upon by waves only during severe storms, especially when combined with exceptionally high water.

**Bar:** A submerged or emerged embankment of sand, gravel or other unconsolidated material built on the seafloor in shallow water by waves and currents.

**Berm crest:** The seaward limit of berm
**Berm**: A nearly horizontal part of the beach or backshore formed by the deposit of material by wave action.

**Foreshore**: The part of the shore lying between the crest of the seaward berm and the ordinary low water mark, that is ordinarily traversed by the uprush and backrush of the waves as the tides rise and fall.

**Nearshore**: The region seaward of the shore (from approximately the step at the base of the surf zone) extending offshore to the toe of the shoreface.

**Surf zone**: The area between the outermost breaker and the limit of high tide level.

**Swash zone**: The portion of the beach face alternately covered by the uprush of the wave swash and exposed by the backwash.

![Diagram of coastal zones](image)

*Fig. 1.1 A schematic diagram showing the different zones of the coast (Shore Protection Manual, 1984)*

The terminologies ‘erosion’ and ‘accretion’ are used to describe beach profile changes over a period of time. Whenever there is a build-up of material in a temporal frame, the beach is said to accrete. Alternatively when there is loss of sediment from the beach, it is said to erode.

Another method of describing beach morphological changes is in terms of the advance or retreat of shoreline. An advance of shoreline is indicative of accretion while retreat is indicative of erosion.
Erosion/accretion or shoreline change can be both short-term and long-term depending on the time scale. Along the west coast of India, seasonal (short-term) erosion occurs during the southwest monsoon. This eroded beach is normally rebuilt during the fair weather period resulting in no net erosion or accretion over a period of one year. However, in some sectors of the coastline net erosion or accretion occurs on a longer time scale, mostly due to human interventions.

1.2 Causative Factors for Beach Morphological Changes

The processes affecting beach morphological changes can be broadly classified into (i) natural and (ii) man-made. A brief discussion of the causative factors is given in the following sections.

1.2.1 Natural factors

1.2.1.1 Waves

Waves are the principal source of input energy into the coastal zone. They comprise of the ‘sea’ which is generated locally and the swells that propagate into the area from other areas, where they are generated. In deep water, the water particle motion of waves is confined to the vicinity of the surface. As a consequence, the water particle velocity and pressure fluctuation are non-existent near the bottom. Therefore, neither bottom undulation nor bottom roughness appreciably affects the wave motion in deep waters. But in shallow waters, contrary to this, the waves undergo transformation under the influence of the bottom slope/steepness, bed characteristics, coastal structures, etc. Some of the important shallow water wave transformation processes are listed below.

Shoaling: As waves move into shallow water, the group velocity slightly increases and then decreases with decreasing water depth. Where group velocity increases wave crests move further apart leading to a reduction in wave height. Decreasing group velocity occurs for most of the nearshore region so that wave crests move closer together and wave heights increase. This process is called wave shoaling. If waves are incident normal to the beach with almost straight and parallel bottom contours, change in the wave profile is solely due to the change in water depth.
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**Refraction:** A gradient in the wave celerity occurs along the crest of a wave moving at an angle to underwater contours because that part of the wave in deeper water is moving faster than the part in shallow water. This variation causes the wave crest to bend toward alignment with the contours. Such a kinematic process of wave transformation is referred to as wave refraction (Fig. 1.2). Refraction depends on the relation of water depth to wave length. Refraction coupled with shoaling, determines the wave height in any particular water depth for a given set of incident deep water wave. The change of direction of waves results in convergence or divergence of wave energy. Refraction therefore has a significant effect on the distribution of wave height and wave energy along a coast. This variation of energy is responsible for the beach morphological changes along the coastline.

![Fig. 1.2 Refraction of waves in the areas of (a) canyons (b) headland (Shore Protection Manual, 1984)](image)

**Diffraction:** Waves can propagate into a sheltered basin, such as into the lee of a breakwater. This phenomenon of diffusion or transverse flow of wave energy is called wave diffraction. In diffraction, transfer of energy takes place laterally along a wave crest (Fig. 1.3).

### 1.2.1.2 Nearshore currents

Nearshore currents are responsible for sediment transport in the nearshore. The circulations as a result of waves breaking in the nearshore decide the sediment distribution in the nearshore area. The nearshore circulation system consists of longshore currents and a cell circulation system of rip currents.
Longshore transport is an important mechanism of sediment transport caused by longshore currents that flow parallel to the coast in the surf zone. Longshore currents are generated by the longshore component of waves that obliquely approach the shoreline. The direction of longshore transport is related to the wave direction. Longshore current velocity depends mainly on two factors viz. angle between wave crest and the shoreline and breaker wave height. The longshore current velocity varies both across the surf zone and in the longshore direction. The volume of longshore sediment transport depends on five parameters: the breaker height, wave period, breaker angle with local shoreline, alongshore current velocity and the surf zone width. Rip currents are currents that flow perpendicular to the shoreline and are caused by water moving down slope (away from beach) as a result of wave setup (Fig. 1.4). Rip currents are fed by a system of longshore currents. The slow mass transport, the feeding longshore currents and the rip currents taken together form a cell circulation system in the nearshore zone.

Fig. 1.3 Wave diffraction (Shore Protection Manual, 1984)
1.2.1.3 Winds and wind-induced currents

Wind can influence the beach profile changes in two ways, directly by being a vehicle for transport of sand to and fro the beach and indirectly by influencing the hydrodynamic processes, which are the main vehicles of sediment transport in the nearshore environment. On beaches where strong seasonal wind blows, sand transport by wind is an important mechanism contributing to beach changes. If the wind speed at certain elevation reaches a critical value, sand grains on a loose sand surface begin to move. Once movement begins, winds of the same or higher speed can move the sand grains and cause their flow continuously to the downwind side. After the sand grain rises from the surface, it is acted on by the forces of gravity and force due to the wind (drag force), and when the force of gravity exceeds the drag force, the sand grain falls. In addition to this, direct effect of wind can cause onshore transport of sediments by influencing the hydrodynamic processes. Depending on the wind direction with respect to the shoreline, the wind can cause a seaward movement of the surface waters compensated by a landward near bottom current or a piling up of surface waters on the shore accompanied by an offshore undertow. In the former case accretions of the shore result while the latter leads to erosion. With offshore winds, the advancing waves tend to be reduced in height by the head winds, so that the waves reaching the shore are of lower steepness, resulting in beach accretion.

Fig. 1.4 Nearshore circulation systems (after Komar, 1976)
1.2.1.4 River/Estuary inputs

River/estuary may be a source of sediments depending upon the characteristics of the hinterland. Elevation, the types of rock, density of vegetation and the climate are the important factors determining the sediment supply. Damming of rivers has severely affected input of sediments from rivers. There are two distinct approaches to estimate the sediment supplied to the beach by the river. The first involves empirical correlation between the sediment supply, the drainage area of the river basin and the effective annual precipitation. The second approach is that of estimating the sand transport from measurements of the river discharge or velocity, by using appropriate mathematical formulations (Beer, 1998).

1.2.1.5 Geomorphologic factors

Geomorphology of coastal area may alter the positions of shoreline, which leads to erosion as well as accretion. The shoreline orientation depends on the geomorphology of the coastline. The natural geomorphologic features are bay, headland, cliff, rocky terrain, sand dunes, barrier beach etc. The nearshore processes become more complex because of the presence of these geomorphologic features. The presence of headlands and bay may change wave energy pattern in the nearshore area. Also, alongshore transport may be blocked by the presence of headland and it may cause accretion in the up-drift side and erosion in the down-drift side of the inlet.

1.2.1.6 Cliff erosion

Cliff erosion is an important source of sediments in some coastal areas. During storms, erosion of cliff occurs due to the hydrostatic pressure exerted by the waves. Rock type, orientations of rock formation, jointing and bedding pattern and wave exposure are some of the important factors that affect the sea cliff erosion by waves. In addition to wave action, ice wedging and rain-wash also contribute to sea cliff erosion. Cliff erosion rate can be determined by field surveys or by comparing aerial photos. Earlier, the principal source of sediment to any coast was rivers. But due to human interferences such as construction of dams, such sources get reduced and the principal source becomes erosion of adjacent shore and sea cliffs. Backshore erosion is a significant source where older coastal deposits, which contain a large fraction of sand, get eroded.
1.2.1.7 Sea level change

Due to global warming, the sea level is rising. Though the global sea level rise in the past one century is of the order of 10 to 20 cm, it is expected to increase exponentially in the coming century and is likely to be of the order of 1 m over next 100 to 150 years. Sea-level rise causes the wave to progress/move to higher levels and thereby permitting larger waves to reach coast, through deepening of near-shore waters. Thus the sea level rise is expected to cause a significant retreat of the shoreline further hinterland. According to Unnikrishnan et al. (2006), the average rise in sea level in Indian coastline is 1.2 mm/year. The projected rise in sea level for the Indian coastline in the next century is around 50 cm and this in turn is expected to cause considerable retreat of the Indian shoreline.

1.2.2 Human-induced activities

Human-induced activities can cause shoreline changes. The civilization and instability of the coastline are very much linked. Man made structures in the coastline will alter/disturb the natural process. The hydrodynamic condition and sediment transport pattern may change due to man-made interventions leading to erosional or accretional processes. The existence of such instabilities, whether human induced or naturally occurring, whether sudden or spread over a long time, whether catastrophic or predictable do immensely affect the living stock of both humans and associated living forms. Some of the important human interventions that can cause beach morphological changes are listed below.

1.2.2.1 Coastal structures

Coastal structures are of different types. While some are intended for shore protection, some others are built to facilitate harbours or other developmental activities. These structures by interfering with the natural coastal processes affect the beach morphology. A few of the coastal structures commonly seen along our coasts are listed below:

Seawalls: Seawalls are massive coastal structures constructed parallel to the shoreline mainly to protect the land adjoining the shoreline from wave action. The constructions of this massive structure alter natural processes of the beach and have some
disadvantages also. Seawalls are less effective in preventing shoreline retreat. They do not protect the shore in front of them. Long-shore sediment transport will lead to toe erosion. The access to beach is affected. A major problem normally encountered in seawall protected coasts is the erosion observed in one end or both the ends of the seawall which usually is called as the “end effect”.

**Groin:** Groins are finger like structures usually perpendicular to the shoreline extending to the sea. Groins are classified as permeable or impermeable, high or low, fixed or adjustable. T-groin is the latest type which is intended to trap the sediment transported offshore. Groins are usually constructed in groups called groin fields. Their primary purpose is to trap littoral drift and thereby retard erosion of the shore by depositing the sediments in between the groin walls. But erosion is likely to occur on the downstream end or lee side. Transitional groins where the length of the groins tapers down towards the ends of the groin field are nowadays being built as an alternative to reduce erosion at the end.

**Breakwater:** Breakwaters are structures built offshore to dissipate the energy of incoming waves. Breakwaters may be either fixed or floating: the choice depends on normal water depth and tidal range. The disadvantages of breakwaters are its massive nature, negative impact on scenery and are not suitable for tourist spots. On rare occasions breakwaters reflect or diffract wave energy in destructive ways or lead to concentration of waves in local hot spots. Erosion problems and the scouring effects of the misdirected energy lead to the loss of beach/coastline and damage the structures.

Submerged breakwater is a breakwater with its top below the still water level. When waves strike this breakwater, part of the wave energy is reflected seaward and the remaining energy is largely dissipated in a breaker. This is further transmitted shoreward as a multiple crest system, or as a simple wave system. Permeable submerged breakwater is another variant of submerged breakwater which is partially permeable allowing the waves to pass through it.

**1.2.2.2 Beach sand mining**

Mining of beach material is done in many parts of the coast. This material is
sometimes mined for the mineral it contains in some locations. In other places it is used for construction purposes. It is a direct loss, which can lead to erosion of the beach.

1.2.2.3 Reduction of sediment supply to the coastal zone

Reduction of sediment supply to the coastal waters can affect the beach morphology. In some areas the transport of sediment to the coast by rivers forms the major source of material to the coast. Dams constructed on these rivers not only trap the sediments but also reduce peak flood flows, thereby reducing the sediment supply to the coast. Dredging, leading to reclamation in many cases, is another activity which takes away sediment from the coastal environment.

1.3 Methods for Estimation of Beach Morphological Changes

1.3.1 Beach profile measurements

The most accurate method of estimating shoreline change is by measurement of beach profiles by level and staff method. A shoreline can be compiled by interpolating between a series of discrete shore-normal beach profiles (Boak and Turner, 2005). Such beach profiling at regular time intervals can give accurate estimates of seasonal, annual and long-term shoreline change. However, the recourse to this method is constrained due to the exorbitant cost involved.

1.3.2 Aerial photography

Shoreline can be extracted from aerial photographs, preferably of scale 1:15,000 or more. Aerial photography is an old method and it provide good spatial coverage of the coast (Dollan et al., 1983). By definition, the ‘‘shoreline’’ obtained from aerial photography is based on a visually discernible feature. This method has some drawbacks like distortion, which includes both radial and relief distortion, depending on the tilt and pitch of the aircraft, and scale variations caused by changes in altitude along a flight line (Anders and Byrnes, 1991). Modern technique of photogrammetry allows a digitally scanned pair of aerial photos to be converted into a three-dimensional digital terrain model and a georectified orthophoto (Hapke and Richmod, 2000; Overton and Fisher, 1996). The aerial photography is the most common data source for determining past shoreline positions. The extraction using this technique of
mapping has to pass by two processes (Gibeaut et al., 2001). The first is to identify the shoreline and trace from the photograph, and the second is transfer on to a map with a common cartographic base.

1.3.3 Field survey using Global Positioning System (GPS)

Beach morphology can be mapped using GPS (Global Positioning System) and it is a more recent method of mapping shoreline. It is used to map shoreline positions as well as beach characteristics (berm, vegetation, scarp, etc.). While the hand held GPS can be used for the mapping, the accuracy of the mapping can be considerably enhanced by using Kinematic Differential GPS. The GPS survey can be effectively used to map the shoreline poison at regular time interval. The short-term as well as long-term shoreline change can be easily derived from the GPS surveyed data. This method is more accurate than aerial photography (Pajak and Leatherman, 2002).

1.3.4 Satellite remote sensing

Shoreline change can be monitored using satellite images. Images can be geo-referenced from base maps using GIS software and shoreline mapped. The advent of high resolution satellite sensors has increased the accuracy of this method in recent times. The advantage of this method is the high receptivity of the satellite data which enable the mapping of shoreline changes at a cheaper cost when compared to any other method.

1.3.5 Airborne Light Detection and Ranging Technology (LIDAR)

Airborne LIDAR surveys can be used for shoreline monitoring and it has the ability to cover hundreds of kilometers of coast in a relatively short period (Stockdon et al., 2002). This technique obtains highly accurate and detailed topographic measurements of the beach and hinterland. LIDAR can acquire data with vertical precision from 8 to 15cm and data-point less than 1m. From these data, a shoreline may be extracted for use in shoreline change analyses (Gibeaut et al., 2001). Tidal datum-based shorelines, such as MHW, can then be found by fitting a function to cross-shore profiles of LIDAR data. This data source is generally limited in its temporal and spatial availability because of high cost. The main advantage of LIDAR data is that it can be used to obtain a large coverage within a short period of time.
1.3.6 Video Imaging

Continuous monitoring of beach can be carried out by installing a video camera at a higher level overlooking the beach. By connecting the installed camera to a computer, the images at programmed intervals can be captured. By using appropriate image processing software, the shoreline or any other littoral environmental parameter can be derived. The advantage of this method is the facility to monitor shoreline changes in micro time scale.

1.3.7 Modelling

Basically there are two types of models viz. physical models and numerical models. The physical models are advantageous in correctly reproducing physical behavior. However, they have certain limitations like selecting the appropriate scale and the high cost. Hence numerical models have become more and more popular.

Fig. 1.5 New N-Line model and comparisons of beach change models in term of spatial and temporal scales (Hanson and Kraus, 1991a)
Numerical modelling is a powerful tool in understanding physical systems. It facilitates study of plan shape or profile changes particularly where both time and spatial scales are large. Numerical models are preferred not only due to the progressively increasing maturity of our knowledge in coastal processes, but also due to the advanced capacities of computer power for coastal morphological models (de Vriend, 1998; Komar, 1998). A classification of beach change prediction models by temporal and spatial scales as summarised by Hanson and Krauss (1991) is reproduced in Fig. 1.5

1.3.7.1 Advantages of numerical modeling

Numerical modelling is a powerful tool for study of physical systems. The models are able to examine systems to unravel the complexity of the multiple processes that may occur simultaneously. The beach and nearshore processes are very complex. Hence it is possible to understand and predict the behaviour of beach in response to hydrodynamic conditions by using numerical models. Beach erosion problem can be managed effectively by prudent use of numerical models. Designing of coastal structures and assessment of their environmental impact can be carried out effectively. The quantitative prediction of loss of beach material is one of the paramount tasks of coastal engineers. Numerical model helps to predict beach evolution quantitatively and the results can be used for many applications like estimating the quantity of beach nourishment, study of both long term and short term changes, etc.

Numerical model also has certain limitations. Most of the numerical models are based on large number of geological and oceanographic assumptions. Model assumptions should be examined collectively also in isolation. No numerical model can be an ideal representation of actual field conditions. There is a need for a theoretical re-examination of mathematical models used to predict any physical system (Robert Thieler et al., 2000).

1.4 Background of Present Investigation

The south-west coast of India is notable for severe erosion observed all along the coast during the southwest monsoon. While the beach is rebuilt in most of the sectors during the ensuing fair weather period, there are certain sectors of the coast which are not rebuilt fully or partially even during the fair weather period. Such sectors of the
coast are said to be eroding on a long term basis. Muthalapozhi, north of Trivandrum, Valiazhikkal, north of Kayamkulam are examples of critically eroding coasts. In many of these cases man-made activities are the major contributing factors for the observed erosion.

Studies on beach morphological changes along the Indian coastline are mostly field based which are very laborious. Of late shoreline change studies using remote sensing techniques are also available. However, development of predictive capabilities, in spite of its immense application in coastal engineering and coastal zone management, has not received the due attention. Though there have been some isolated efforts towards development of predictive capability they were not successful. Even the commercially available models and free software that are available have not been calibrated/validated for our coast. The present investigation is undertaken in this context and aims at development of numerical model for prediction of long-term and short-term beach morphological changes using indigenously developed model instead of commercial available models which are very expensive.

1.5 Objectives

The investigation has been taken up with the following aim and objectives:

- Study the wave characteristics and beach processes of a few selected sites of SW coast of India
- Develop a profile change model to predict short-term profile changes due to episodic events
- Develop a shoreline change model to predict the long-term changes in the shoreline
- Apply these models for different coastal locations

1.6 Thesis structure

The thesis has been presented in 7 chapters including this introductory chapter.
The exhaustive literature review carried out is presented in the Chapter 2. The beach morphological change models are classified into two based on the time scale criterion: profile change (short-term) and shoreline change (long-term) models.

Chapter 3 describes the development of numerical models to predict short-term profile changes and long-term shoreline changes. To predict long-term shoreline change, a numerical model based on the approach of Kraus and Harikai (1983) is developed. Beach profile change model has been developed based on the concepts of Larson and Krauss (1989).

Chapter 4 describes the field measurements and collation of secondary data carried out in connection with the investigation for different coastal locations of the SW coast of India. The locations selected for study are Adimalathura, Valiathura, Muthalapozhi, Kayamkulam, Trikkunnapuzha, Mararikkulam and Calicut. The data on waves, beach profiles, littoral environmental characteristics and sediment characteristics have provided insight into beach morphodynamics at these locations in response to different forcing factors.

The processes of calibration/validation of the models utilising data from different locations are covered in Chapter 5. The chapter also deals with the performance assessment of the models by statistical and graphical methods in addition to comparison with a commercial model.

Chapter 6 presents the results of applications of the models for different coastal locations of the southwest coast of India. The Shoreline Change model is used to predict shoreline changes over a five year period at two locations of the south-west coast of India. The Profile Change model is used to predict profile changes in a couple of cases of episodic events.

Chapter 7 presents the summary and conclusions of the work. Recommendations for future work also are presented.