BACKSHORE MORPHOLOGY AND STRATIFICATION: FROM AKSHI TO REVDANDA COAST, MAHARASHTRA.

A THESIS SUBMITTED TO
TILAK MAHARASHTRA VIDYAPEETH, PUNE
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BY

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CERTIFICATE OF THE SUPERVISOR

It is certified that work entitled **Backshore Morphology And Stratification: From Akshi To Revdanda Coast, Maharashtra** is an original research work done by **Debolina GuhaThakurta** under my supervision for the degree of Doctor of Philosophy in Geography to be awarded by Tilak Maharashtra Vidyapeeth, Pune.

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I **Debolina GuhaThakurta** am the Ph.D. scholar of the Tilak Maharashtra Vidyapeeth in Geography. Thesis entitled **Backshore Morphology And Stratification: From Akshi To Revdanda Coast, Maharashtra** under the supervision of Dr Shrikant N. Karlekar, solemnly affirm that the thesis submitted by me is my own work. I have not copied it from any source. I have gone through extensive review of literature of the related published / unpublished research works and the use of such references made has been acknowledged in my thesis. The title and the content of research are original. I understand that, in case of any complaint especially plagiarism, regarding my Ph.D. research from any party, I have to go through the enquiry procedure as decided by the Vidyapeeth at any point of time. I understand that, if my Ph.D. thesis (or part of it) is found duplicate at any point of time, my research degree will be withdrawn and in such circumstances, I will be solely responsible and liable for any consequences arising thereby. I will not hold the TMV, Pune responsible and liable in any case.

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ABSTRACT

The coastal region of the state of Maharashtra has a unique physiography. This region is called Konkan and comprises of plateaus, plains and hills. It consists of rocks mainly of igneous origin in the northern section, with patches of alluvial deposits in the plains. It is a 500 kilometers stretch of land, running North-South along the western boundary of Maharashtra. It shows a distinct physiographic uniqueness from the rest of the state.

From a physiographic point of view, on the basis of lithology and rock structure, Konkan is divided into:

North Konkan is basaltic in nature and runs from Dahanu to Revas. The major land facet by which it is characterized comprises of forested hills and plateaus. The minor narrow plains border the river channels. The entire area is lying on Deccan trap and the courses of rivers indicate a clear control of lineaments.

Middle Konkan is known for its planation surfaces. Forested residual hill and palaeogeomorphic features are prominent in this region. Many evidences of such physiography are witnessed from Revas to Shrivardhan. Basalt is the common rock type. However, laterites are also found in this area.

South Konkan shows granite as a main rock type. . Laterites are also found here in plateau section but are deeply entrenched by rivers. It is the longest stretch between Shrivardhan to Vengurla.

On the basis of **tidal incursion**, Konkan is divided into

1. Macrotidal coast (Between **>3.5m and >2m**)
2. Mesotidal coast (Between **3.5mto 2m and 2m to 1.5m**)
3. Microtidal coast (Between **<2m and <1.5m**)

Strictly speaking about the coastal climate, the major characteristics as observed by Karlekar (2017) enable us to know that there is marked seasonal change in every coastal parameter. The most crucial factor which is prominent here includes

the wind direction and speed that show a definite trend from north to south which in turn affects the wave.

The wind and wave speed also changes locally due to indentation of the coastline. Seasonal variation is also witnessed in the wind-wave spectrum. Waves become steeper and higher near the shore in monsoon than in fair weather.

During the fair weather, the beach is accretional, which means both the foreshore and backshore are clearly seen and wide berms are developed. In the monsoon, the beach experiences heavy erosion which results into steep sloping foreshore only, while the backshore remains relatively flat.

Height of the wave also varies seasonally. Monsoon experiences wave height of as high as 5meters, than in fair weather when the height does not exceed more than 2meters.

The long shore currents are south-eastwards in monsoon and move with an average velocity of 30to40cm/s. In fair weather they are north- north westwards and have a velocity of 8to20cm/s.

It has been reported that Maharashtra coast experiences negligible annual long shore sediment net transport and the direction of annual net transport is towards south (Kunte et al 2001).

The Konkan coast experiences semi diurnal tides with a tidal range that varies from less than 2 m to more than 3.5 m.

All along the coast the shoreline is broken by frequent headlands and promontories, which are the sites of sea cliffs, beautiful sandy pocket beaches, drowned river valleys, small tidal inlets, river creeks. Several features are present along the Maharashtra coast, but the land facets that define the coastal morphology of Konkan are:

- Beaches
- Sandbars and spits
- Coastal dunes
- Sea cliffs and shore platforms

- Sea caves
- Littoral terraces
- Estuaries and creeks
- Tidal mudflats

A wave deposited accumulation of sediment which predominantly comprises of sand and shingles on the sea shore is termed as the beach. It is a part of foreshore in the coastal system which lies between the modal wave base and upper swash limit. They are influenced by tides, nature of sediment supply, winds and biota in coastal waters.

The beach system includes sub aerial beaches, surf zone, near shore zone, inner continental shelf. Every beach has its own spatiotemporal dimension. Gravity plays an important role in formation of the beach.

Shape of a beach highly depends on the nature of wave and the characteristics of the sediment carried by the waves. Beaches represent a special case of coastal system in that they exist where sand is accumulated from the same processes that strip away rocky and sedimentary material. Catastrophic events such as tsunamis, hurricanes and storm surges accelerate beach erosion, potentially carrying away the entire sand load.

Human activities also accelerate the erosion of beaches. Gradual evolution of beaches comes from long shore drift.

Often back-beach and backshore are mistakenly considered synonymous. However, there is quite a subtle difference between these two terminologies. The back-beach usually refers to the back portion of the beach sector, in the profile till the seaward edge of the dune. Whereas, the backshore is the landward extension of the foreshore between the swash limit and the landward edge of dune or other landforms like terraces

The backshore is that part or zone of a beach profile which extends landward from the sloping foreshore to a point of either vegetation development or a change of physiography, e.g. a sea cliff or a dune field or the limit of vegetation colonization.

The backshore area of a beach extends from the limit of high water foam lines to dunes or any other landward costal features, if present.

There should be presence of a lot of sediment supply and aeolian transfer to have a prominent backshore. Relatively it is higher than surrounding beach area. Vegetation cover is present here which lead to the stabilization of the dunes and other backshore features.

This area is dotted with depositional features and belongs to the older timeline hence materials found here are well sorted and medium to coarser in nature. Aeolian activity is prominent here apart from any storm episodes, when storm surges reaches backshore and contributes to the depositional properties of the area.

Human interference such as agricultural activities and settlement deform the original morphology of the area in many places.

Some major features found in backshore include:

- **Berms** are generally a mound or rise of swash deposited sediment of sand/or gravel/shingle at the end of the beach sector or tidal zone. They are prominent in wide flat beaches as they correspond to the fair weather. Berms are insignificant to absent during monsoon as the beaches go through erosion.

- **Dunes** are large, shore-parallel, linear accumulation of sand which are formed when the wind carries sediment landward from the beach and deposits where an obstruction hinders their further transport. The pre requisites of dune formation are a large amount of sediment to be present for transport and a prominent aeolian action to carry the sediment. The basic process of dune formation is interaction between sand transported by wind and vegetation cover which characterizes coastal dunes (Pethick 1984). Coastal dunes generally exist in wide zone bordering the high tide mark and extend landward. This zone of sand can have a relatively straight forward morphology running parallel to the shoreline and separated from each other by marked ridges or valleys, and some have extremely complicated morphology developed as complex dune ridges orthogonal to the coast

- **Palaeodune** is an older dune or a dune that exists from an earlier coastal system and satisfies the criteria of its distance from the shore. Commonly a palaeodune is accompanied by a marine terrace. It signifies a drop in sea level.

- **Littoral Terraces** is a relatively flat, gently inclined surface of marine origin mostly an old abrasion platform which is away from the present wave activity. It lies above the current sea level and occupies backshore area bordering beaches or banks of the shoreline sectors of tidal inlets. A littoral terrace is an emergent coastal landform. They are raised above the shoreline by a relative fall in the sea level.

- **Mudflats** are the low lying area around the tidal channels of estuaries and creek are called tidal flats or mudflats due to their sediment composition. The areas are dominated by tides and very devoid of any major wave action and thus accumulation of mud takes place.

The backshore of this area is thus dominated by aeolian transfer and deposition. The seasonal changes play a very important role in shaping the beach sector by erosion and accretion in monsoon and fair weather respectively. Extending landward, the backshore is wide, flat fronted and a little concave with insignificant berms, some stabilized low dunes and an extensive terrace which has currently been turned to agricultural land and settlement owing to its flat and fertile nature

The area of investigation lies between 18°33’ N/ 72°55’ East and 18°38’N/ 72°53’ E on the Middle Konkan region of Maharashtra coast. It covers a length of about 10 kilometers. It has a unique geology of coastal alluvium. The spring tide range along the coastal stretch is 2.5 m and the neap tide range is 1.8meters. The average beach width is around 100 m. it comprises of low dunes not exceeding the height of 1.5meters.

Like most beaches of Konkan, beaches of the study area are also dissipative in nature and are very vulnerable to seasonal changes. Most of the littoral terraces are turned into agricultural fields owing to their fine and fertile soil. Some of the terraces are used for roads and settlements. Mudflats owe their existence to the presence of the creeks, especially in Nagaon in north and the Paulo creek in the middle. Due to high wave action mudflat is significant near Kundalika creek in couth near Revdanda. Berms are only prominent in northern sector near Akshi and decreases as we go south. Human interference is found more towards south of the Paulo creek. Creepers like ipomeas are evident on top of the dunes that helped them being stabilized. Trees like coconut and arecanut are abundant in the area, whereas, the stabilization of the dune sector has been done by planting casuarina trees due to government intervention of declaring them as reserve forest.

With the help of SRTM data regional cross profiles were drawn and with the help of Google earth imageries geomorphic map of the study area has been made showing all the major and minor features present in the area.

Apart from mapping the backshore along with its components with the help of dumpy level survey, sediment samples were taken for a better understanding of the nature and origin of the area. After plotting the surveyed points, four major land facets were identified in every profile namely: beaches, berms, dunes and littoral terraces.

The samples that were collected underwent mechanical sieving to determine their size frequency occurrences, post which they were plotted in the probability graph.

The grain-size analysis of the sediment samples usually provides the size frequency spectrum in terms of weight or volume present in a specific size interval. Plotting of the results of single sample analysis on a probability paper no doubt enables us to know about the sediment distribution properties such as mean, median, standard deviation, skewness and kurtosis but it also helps in the identification of processes by which the sediment is deposited. Certain process cannot be interpreted directly from ordinary statistical techniques. This is the advantage of using probability plots especially when it comes to beach and dune sediment samples. In order to identify different processes, segments on probability curve, should be studied separately. Identification of such process segments helps in improving the interpretation of the process dominant in the deposition of the said segment.

Three common segments were identified by Moss (1963), on probability plot. Two of these are tails and another is the middle portion of the curve. Tanner (2009) designated these segments as "coarse tail", "central segment", and "fine tail". Important hydrodynamic and process changes could be identified no matter from where the samples are selected, either from the beach or back-beach.

The cumulative sand grain weight against size of the fine tail on the probability plot corresponds to the sediment load carried in suspension. The coarser tail is considered to represent the movement by surface creep and the central segment, the movement of saltation.

The sediment profiles in this area gave a distinctive picture of the dune development. The wireframe 3D model of dune sector in the study area shows the dune development in the backshore. Both east-west (along) and north-south (across) profiles are also shown separately to understand the effect of wind movement Dune development in the backshore is thus the resultant function of wind direction and sand deposition. The dune formation takes place along and across the dune zone. These trends and features produced like blowouts and inter-dunal areas could be ascertained from wireframe models and their rotation. The difference between the first and second derivative is precision. Both calculate and bring forth the non-discernable patterns in the study area.

Dune stratigraphy is the preservation of sediments and processes that formed the sediment layers, which can provide a chronological history of depositional sequence. The area being dotted with low dissected dunes, studying them in continuity posed a problem. The exposed facies of the dune segment were identified and studied in four places.

Since most of the fore dunes are eroded, it was not possible to study the continuum of each facies deposited in the dune. An attempt was made to reconstruct the stratigraphy of shore parallel foredune from the exposed dune sections.

All these facies give a confused and haphazard pattern of dune sand deposition and its erosion or removal. The overall stabilization is relatively chaotic including diagonal, horizontal, wavy, bioturbation bedding. The upper section of dunes is sparsely vegetated. The dune stratigraphy exposed also suggests the fact that earlier dunes were also covered by sparred vegetation.

According to Short (2000), the stratigraphy provides information on earlier sediment types and depth and amount of disturbance. Thickness of strata, facies type and lamination of the beddings are all indicators of the processes that were responsible for dune development.

The sediment samples collected from the dunes enabled us to know about the origin of the dunes and their evolution. Cumulative sediment weight of sediment was plotted in probability graph to understand each of their contribution in dune sector. Apart from some minor anomalies, the sediment of dune sector was justified in terms of their location and evolution.

Beyond dunes, at the edge of backshore are found terraces, which are extended up to estuary or tidal channel. It is a coastal landform that acts as a barrier between sea and the older coastal landform or mainland bedrock (Short, 2000). Thus a barrier is defined as a shore parallel and sub-aerial accumulation of detrital sediment formed by waves, tides and aeolian processes.

It constitutes a sequence of landforms that vary in age, lithology and form. Akshi-Revdanda coast thus identified as a barrier system consisting of modern beach, berm, modern and palaeo dunes, strand plains in the form of terraces and segment of tidal inlets. The system is attached to mainland through littoral terraces and banks of tidal inlets.

It is basically a barrier between sea and older mainland landforms separated now by partially, filled tidal channels stretching from Akshi in North to Revdanda in South.

The extent of land units reveal that it belongs to an older period. The maximum area of 5.9 sq km is covered by the terraces which indicate that the area belongs to an earlier coastal system. Back dune is the second most extensive feature covering around 3.1sq km situated near the southern mudflat of Revdanda. The presence of a long estuary along the backdune signifies that the area belong to a barrier island system.

The sedimentation found in a 3meter thick section in Paolo creek, that gives a clear idea about the sequence of sedimentation in the study area. The strata of silt and fine grained sand lumps which are generally found in beach and dune sector were seen here as lithified layer, implying that the area is a part of earlier Holocene coastal system.

Sedimentation must have taken place in mid Holocene period in the area. This barrier system is backed by tidal creek and bordered by mangrove swamp deposit. It also comprises of associated tidal inlet deposits, beach derived aeolian dunes and littoral terraces.

The field evidence gathered from sediment deposition sequence exposed in Paulo creek and other small inlets and foredune stratigraphy clearly suggest that the system is formed as a result of landward processes, both of which include aeolian transport and upward accretion of sand.

The haphazard pattern of dune deposition and erosion indicates that the barrier is established during mid to late Holocene and prograde due to falling sea level. This barrier system is attached to mainland and adjusted to falling sea level in late Holocene. The beach sediments, tidal inlet sediments and the dune stratigraphy exposed in the area all suggests their evolution with reference to earlier higher sea level in early Holocene.

From all field and sedimentary evidences the beach-dune-terrace and tidal inlet barrier system appears to be a “regressive barrier” formed earlier under “regressive sea” condition.

CHAPTER ONE

INTRODUCTION

A. THE BEACH AND THE BACKSHORE

The Backshore is the landward extension of the foreshore and is referred to the entire area which directly or indirectly is associated with present and past beach mechanism. It is the area that initiates itself from the point where the beach (the tidal inundation zone) ends.

Backshore is the zone between swash limit and the landward edge of a dune or other landforms (such as terraces). It is mainly influenced by the aeolian sand action and thus dune formation is very prominent in this region. The backshore is both one of the most intensively used and scientifically neglected parts of beach system (Hesp, 2000).

Most of the studies along the Indian coasts till date describe the major beach processes and their foreshore and/or near-shore effects. Backshore still remains a bit of a geographically and geomorphologically overlooked region. It is not only important from an earth-science view; as it can tell us about both past trends through palaeogeomorphic evidences and the present coastal-inland interactive mechanism; but also from an anthropogenic angle due to severe human interference and the economic activities associated with it..

Beach:

A wave deposited accumulation of sediment on the sea shore is termed as the beach. It generally lies between the modal wave base and upper swash limit (Karlekar 2017). Beaches occur on all sedimentary shorelines that have been exposed to waves and are one of the most dynamic physical systems on Earth. They are influenced by tides, nature of sediment supply, winds and biota in coastal waters. The beach is a system that includes sub aerial beaches, surf zone, near shore zone, inner continental shelf. Every beach has its own spatio temporal dimension.

Tides on the coast are non essential though ubiquitous component of many beaches. Tides continuously shift the shoreline horizontally and vertically. This shoreline mobility shifts the swash, surf and wave shoaling zone.

Biota contributes to the calcareous material such as shells, algae skeletons, sea grasses and sea weeds. These are incorporated in beach sands as carbonate sands and organic detritus. The sediment characteristics and morphodynamics of beaches are generally controlled by specific wave and tidal environment related to season.

Most beaches are built by gravity waves that are sea and swell waves and they determine the overall gradient of the beaches. The tides are ubiquitous component of many beaches. They however do contribute substantially to beach morphology. Wider, low gradient, featureless beaches are normally produced in the areas of high tidal range.

The shape of a beach depends on whether or not the waves are constructive or destructive, and whether the material is sand or shingle. Constructive waves move material up the beach while destructive waves move the material down the beach. On sandy beaches, the backwash of the waves removes material forming a gently sloping beach. On shingle beaches the swash is dissipated because the large particle size allows percolation, so the backwash is not very powerful, and the beach remains steep. Cusps and horns form where incoming waves divide, depositing sand as horns and scouring out sand to form cusps (Karlekar 2017).

Beaches represent a special case of coastal system in that they exist where sand is accumulated from the same processes that strip away rocky and sedimentary material. Catastrophic events such as tsunamis, hurricanes and storm surges accelerate beach erosion, potentially carrying away the entire sand load. Human activities also accelerate the erosion of beaches.

The gradual evolution of beaches often comes from the interaction of longshore drift, a wave-driven process by which sediments move along a beach shore, and other sources of erosion or accretion.

The beach profile is typically divided into two sectors: (Fig. 1.1)

1) Seaward relatively steep sloping foreshore.

2) Landward nearly horizontal backshore (Karlekar 2017).

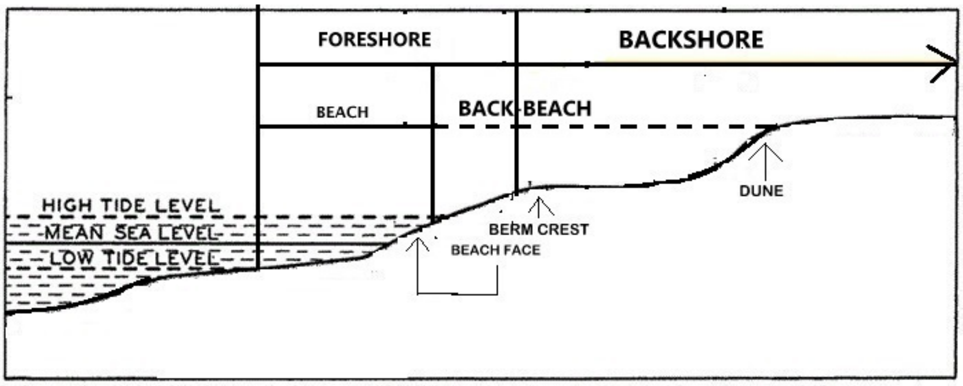

Fig.1.1: A general beach profile

Beach profile has two completely different pictures depending on the weather condition at a given point of time. During the fair weather, the beach is accretional, which means both the foreshore and backshore are clearly seen and wide berms are developed. In the monsoon, the beach experiences heavy erosion which results into steep sloping foreshore only, while the backshore remains relatively flat (Fig1.2).

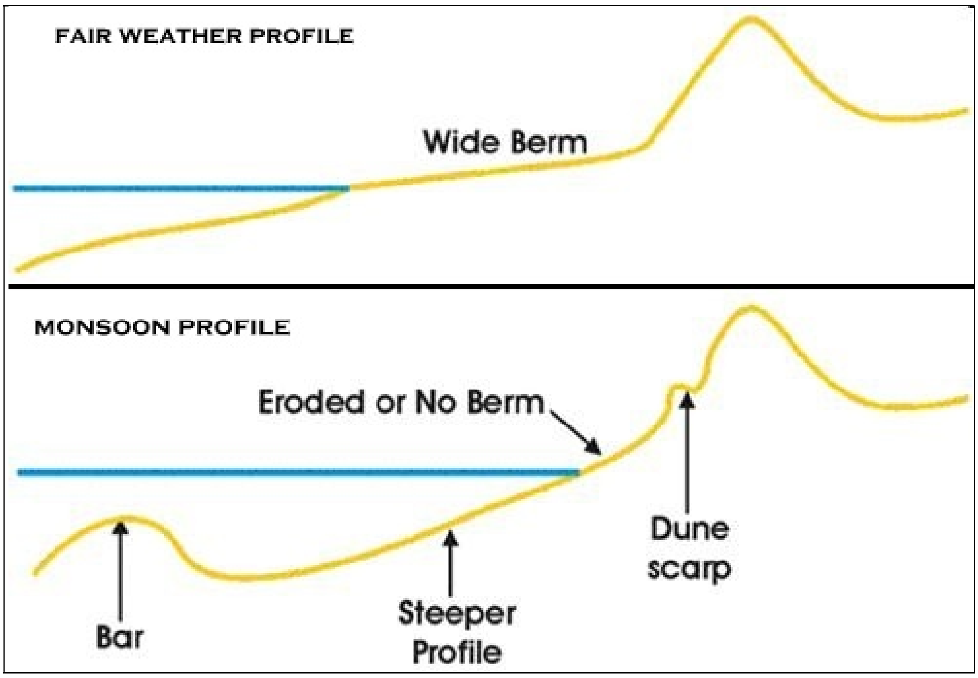

Fig 1.2: A general view of the seasonal change in the gradient of the beach profile

The erosion dominates the monsoon, while the deposition takes place during the fair weather. A cyclical cut and fill pattern prevails especially on the Indian coasts. Much sediment is transported to the nearshore zone, along and perpendicular to the shore which results in the active erosion of the steep slope during monsoon season. During the fair weather period the sediments are again deposited re building the beach.

The beach face is the zone of most active change. It is the sloping portion of the beach dominated by wave swash and backwash. Its inclination varies greatly depending upon significant grain size and wave energy. Shingle beaches have steeper gradient due to coarse grains and high degree of percolation. Sandy beaches have surface backwash and hence relatively smoother gradient. The offshore area extends from the low tide mark seaward beyond the wave breaking zone (Karlekar 2017).

The gradual evolution of the beach often comes from the interaction of long-shore drift, a wave driven process by which sediment move along a beach shore, and other sources of erosion (Karlekar 2017).

In addition to these major types, various subtypes of beaches are developed according to the type of sediments and their sizes.

Pocket beach is usually a small beach in between two headlands and their length does not exceed more than 5 km. on the Konkan coast.

Storm beach is the beach affected by only storm surges and the resultant effect is that the beach has a very steep gradient with coarser materials.

Shingle beach is the beach armored with pebbles and small stones. They generally have a steep slope as well because of the low power of the backwash as the porous coarse grains allow the water to easily flow through them during swash. However these are not much witnessed along the coast of Maharashtra.

Mud beach occurs on the coast which is predominantly composed of clay or silt. The mud beaches are generally found in the sheltered area with less wave action but dominated by macro-tidal environment and are common in the outflow areas within estuaries.

Backshore:

The backshore is that part or zone of a beach profile which extends landward from the sloping foreshore to a point of either vegetation development or a change of physiography, e.g. a sea cliff or a dune field or the limit of vegetation colonization. The backshore area of a beach extends from the limit of high water foam lines to dunes or any other landward costal features, if present. It is only affected by waves during exceptional high tides or severe storms (Fig:1.3).

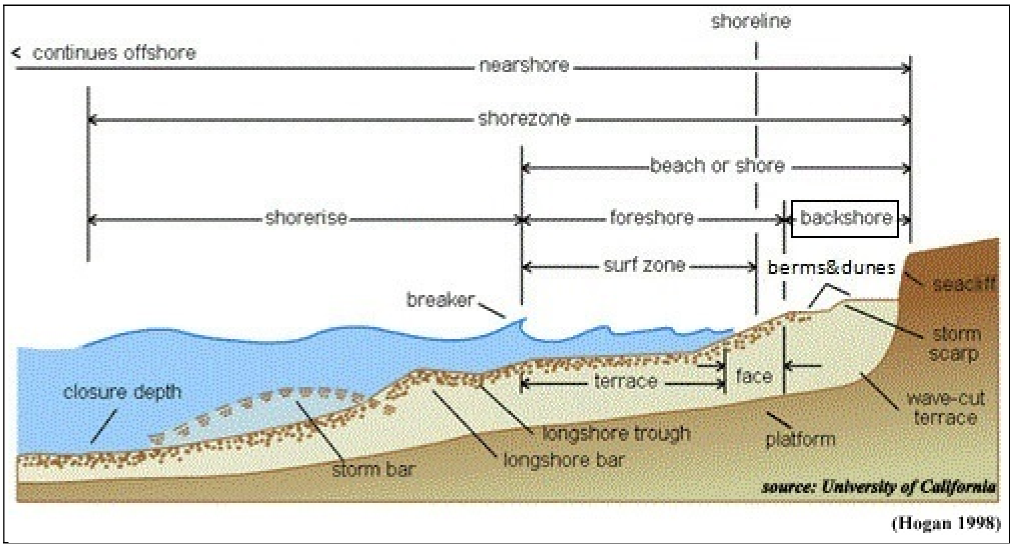

Fig: 1.3: Beach and backshore

Sediments in this area are well-sorted and well-rounded. Their grain sizes are mainly coarse sand and medium sand, which are larger than that in littoral barrier dune. The sedimentary structures include parallel bedding and low-angle cross-bedding.

The backshore is dry under normal conditions. It is often characterized by berms and is without vegetation. The backshore is only exposed to waves under extreme events such as highest high tide and storm surge.

A nearly horizontal shore parallel berm is formed on the backshore due to the landward transport of the coarsest fraction of the beach material by the wave up rush. Sometimes several berms are found on backshore zone and in some cases no berm is developed. During dry periods berms are often formed across openings of minor streams and lagoons.

The landward limit of the backshore is given by the base of sea cliffs, the landward end of coastal dunes, or the limit of vegetation colonization. It is considered that these locations coincide with the upper limit of the swash of storm waves. Since the magnitude of waves during each storm event differs considerably, it is anticipated that the stability of the backshore limit is not secure and that its height can also vary (Takeda 1997).

The foreshore tends to be firm in its lower parts and soft on its upper margin. The backshore is generally softer than the lower foreshore but often firmer than the upper foreshore. The difference between lower foreshore and backshore deposits can be explained by differences in moisture content (Kindle, 1936). Lower foreshore deposits are saturated with water during most stages of the tide, and sandy lower foreshores generally retain significant fluid at low tide when the deposit is exposed. Backshore deposits are less frequently subjected to wave swash and consequently tend to be dry. The capillary effect of water in the voids between grains on the exposed lower foreshore tends to act as a cohesive agent binding the grains together (Sallenger, 1982).

The beach and the backshore: Beach width is important in determining the fetch which is critical for determining the volume of sand delivered across the backshore and to dunes. Beach morphology is important because the greater the morphological variability, the more likely that wind velocity variations take place across the backshore.

Beach mobility is important because the greater the beach mobility, the greater the morphological variation. The latter affects the fetch such that the beach width is at times quite narrow and at limes quite wide. It is also important because alternating episodes of cut and fill result in varying beach morphologies. Modal dissipative beaches have maximum potential of aeolian sediment transport. Reflective beaches have minimal potential of aeolian sediment transport, and intermediate beaches range from relatively high potential at the dissipative end to low potential at the reflective end.

There is a distinct seasonality to the spatial definition of the backshore, due to summer to winter changes in high tide levels as well as storm patterns. In these cases the floral and faunal composition of the backshore also varies among seasons (Hogan 1998).

The foreshore and the backshore are the most sensitive and critical coastal zones from an ecological and environmental as well as a social, economic and developmental point of view. The space of the foreshore is delimited by nature itself (Fig: 1.3). The foreshore is the zone which is wet by the tides and waves. In contrast, the backshore is the terrestrial zone added to the foreshore which is defined as having a breadth of up to 50 meters from the upper limit of the foreshore to serve communication between land and sea and vice versa (Brebbia et al, 1998). As spatial zones, the foreshore and the backshore are organically and functionally linked. There can be no backshore without a foreshore. It is the functionally public space necessary for enjoying the environmental and social benefits and for providing free access to foreshore. Foreshore sediments are usually finer, better sorted, and more negatively skewed than backshore sediments (Cheing-Tung Lee, 2013).

Often back-beach and backshore are mistakenly considered synonymous. However, there is quite a subtle difference between these two terminologies. The back-beach usually refers to the back portion of the beach sector, in the profile till the seaward edge of the dune. Whereas, the backshore is the landward extension of the foreshore between the swash limit and the landward edge of dune or other landforms like terraces.

Some general aspects of the backshore are: (Fig: 1.4)

- It is relatively at a higher elevation than rest of the beach area.
- The region is prominent in aeolian sand transport.
- It is dotted with depositional sand features.
- Moderate to thick vegetation cover is witnessed, which helps in the formation of the backshore features and in stabilizing the area as well.
- The area normally experiences anthropogenic activities and thus tremendously modified and altered.

Most of the beach profiles concentrate on the foreshore morphologies. The following diagram stresses on the features found prominently in the backshore (Fig:1.4). It has been illustrated on the basis of data, which are analyzed from the toposheet, collected during field work, and Google earth imageries.

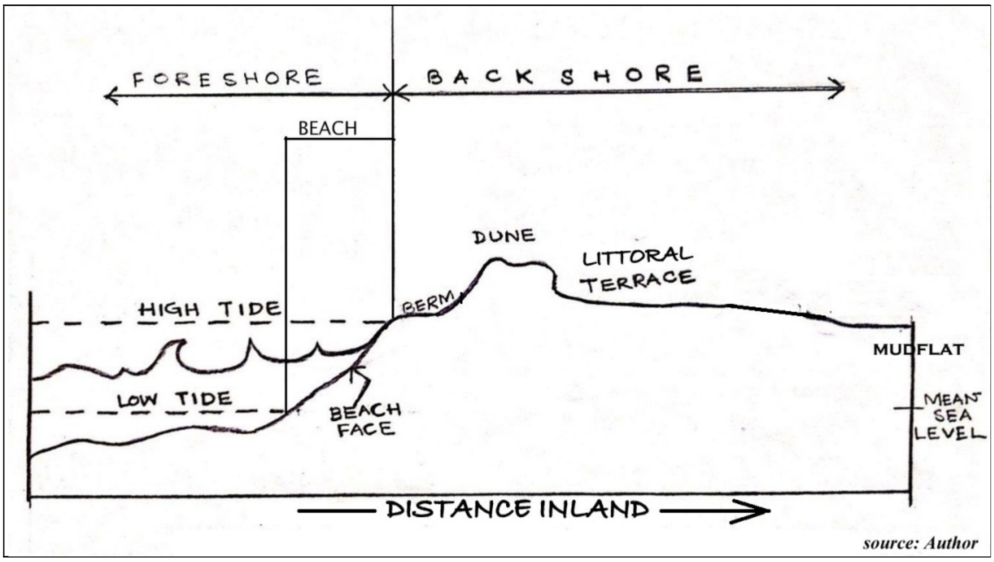

Fig: 1.4- The backshore morphology

According to Hesp (2000), the existence and extent of backshore depends on:

Beach types -> Backshore morphologies are more noticeable in sandy beaches than rocky beaches due to availability of aeolian transportable materials.

Beach status -> A stable beach will have more of stabilized features than any accelerated or decelerated beach. Thus the status of a beach, in turn, enables the status of the backshore as well.

Monthly tidal inundation levels -> The presence or absence of certain backshore features depends upon the tidal inundation level. Features like berms are rare to absent in micro-tidal beaches.

Sand supply -> The formation of any feature depends upon the supply of the similar material. The availability of uninterrupted sand supply is a major pre-requisite of a prominent backshore.

Some major features found in backshore include (Fig 1.4):

- Berms
- Dunes
- Littoral Terraces
- Palaeodunes (according to the physiography and its distance inland, from the coast)

- Mudflats (in case of the presence of a creek or an estuary or found in an area which is sheltered from the wind driven waves (Karlekar, 1993)).

Berms:

This is a mound or rise of swash deposited sediment of sand/or gravel/shingle at the end of the beach sector or tidal zone, generally with a gentle back-slope termination at the foot of the subsequent physical feature of the backshore especially a dune or a ridge. Sediments and morphodynamics of berms are controlled by specific wave and tidal environment.

Well-developed berms are the characteristics of fair weather period. They are transformed from narrow to no berm scenario during monsoon. Early studies (Bagnold, 1940; Bascom, 1953) have suggested that berm height increases with increasing wave height, though this may not be evident in the field where tidal fluctuations and varying wave conditions make it more difficult to extricate this influence from among a number of others. Some work has also suggested that berm height increases with increasing grain size and certainly the height of gravel and cobble berms appear to be higher for given wave conditions (Bascom, 1953). Their nature is complicated by the fact that an increase in wave height is often accompanied by increased wave and wind set-up, which leads to erosion and flattening of the berm. Berms may be very pronounced in case of low energy microtidal and mesotidal intermediate beaches and high energy intermediate beaches, and always absent on dissipative beaches. They can occur as a single well define landforms or as a sequence of obliquely stacked features.

Dunes:

A very prominent and immediate feature landward of the beach is the dune which is a large, shore-parallel, linear accumulation of sand. They are formed when the wind carries sediment landward from the beach and deposits where an obstruction hinders their further transport. Beach and dune environments are strongly coupled and mutually adjusted (Sherman and Bauer 1993). **Dunes** developed on backshore are the major landforms formed from sand deposits that have been blown off the beach.

Where sufficient sand is deposited and dries in the intertidal zone (area between the high and low tide marks) it is then transported by saltation by the blowing wind. Sand dunes only form where the rate of beach building (deposition) is greater than erosion (positive sediment budget). When the dried sand reaches the top of the beach it can be trapped by debris such as driftwood, dead seaweed or rocks and pebbles. If the sand is not eroded again it may become colonized by small plants, or trap other windblown debris, increasing its size and thus trapping even more sand. The first dunes to form are known as embryo dunes. They contain species such as marram grass. These species survive by growing upwards through accumulating windblown sand. These plants add organic matter to the dunes making the dunes more hospitable for plants that later grow. These dunes tend to grow to around 1m.

The next stage in the sequence of sand dune development is the formation of fore dunes or yellow dunes. These are initially yellow but darken as organic material adds humus to the soil. These dunes remain slightly alkaline.

Fore dunes tend to grow to around 5m in height and around 20% of the sand is exposed. Very little moisture exists in this area.

The next stage is the formation of grey dunes and dune ridges. At this stage the dunes are more fixed. The soil becomes increasingly acidic as more humus forms which in turn increases water retention. This allows new species of plants to thrive e.g. creeping ipomoea and sphinifex. Less than 10% of the sand is exposed on these dunes which tend to be between 8-10m high.

As sand dunes become colonized with vegetation roots stabilize the sand and hold it together. The sediment in dunes tend to be fine to medium sand that is quite well sorted (Karlekar 2017). The vegetation cover stabilizes the dune. Others devoid of vegetation show signs of active movements. Coastal dunes tend to merge with each other as their zone of existence is very narrow.

The basic process of dune formation is interaction between sand transported by wind and vegetation cover which characterizes coastal dunes (Pethick 1984).

Coastal dunes generally exist in wide zone bordering the high tide mark and extend landward. This zone of sand can have a relatively straight forward morphology running parallel to the shoreline and separated from each other by marked ridges or valleys, and some have extremely complicated morphology developed as complex dune ridges orthogonal to the coast. Dune ridges may vary in height from 1m to 2m to 20m to 30m. They act as a buffer to extreme wave and wind condition. Dunes also replenish the nearshore and the beach after a storm episode.

A variety of coastal sand dunes is a major phenomenon observed in backshore zone. They are different from any other coastal landforms as they are mainly the result of the interaction between sand transport by wind and the vegetation cover of the area thus differing them from desert counterparts. Moreover, unlike the desert dunes, coastal dunes have a steep windward slope and gentle leeward slope.

The ideal condition for the growth of a dune is a gentle gradient beach with large tidal range providing wide expanses of sand which dry at low tide. These conditions are normally found in macro tidal environment where tidal range is more than 4m.

According to Pethick (1984), there is a definite dune sequence in every dune system. The oldest dune ridges remains farthest from the coast and are usually parabolic in nature and exhibit dune slack (low-lying area between dunes which are flooded seasonally). These are fronted by back dunes with number of blowouts. They are usually intact. Several settlements are evident in this part of the dune zone.

Parallel to these another dune line that borders the backdune is relatively younger and nearer to the sea. It is characterized by incipient blowouts at number of places. The seaward section is characterized as the fore dune ridge that is mostly modern. It is more or less intact. This is fronted by small embryo dunes that are highly unstable and temporary.

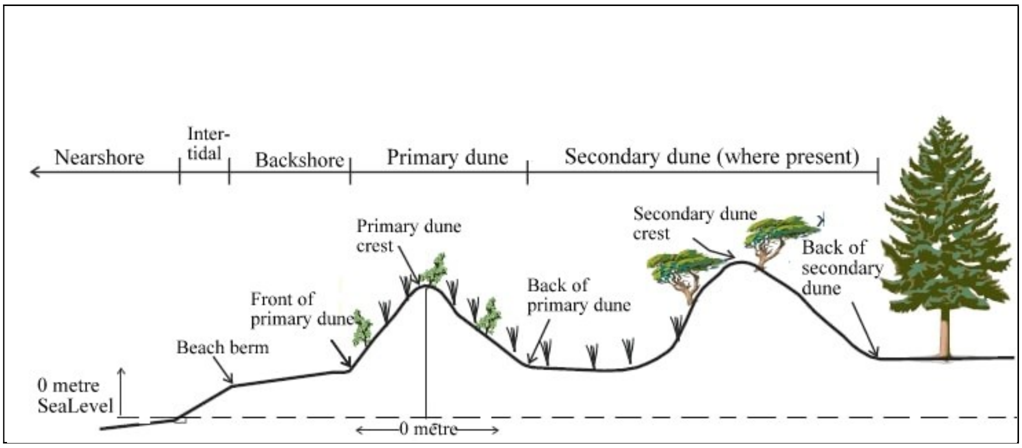

Fig: 1.5- Dune system

According to Goldsmith 1989, coastal dune formation is episodic and variable in location, style and extent of development related to the interaction of terrestrial, atmospheric, and near-shore ocean systems. In humid coastal regions, vegetation plays a significant role in dune development. On some tropical beaches where they are expected, they may not be present at all because although formation of dune depends on variety of factor, they depend essentially on the abstraction of sand from the source on the beach (Davies 1978).

The extent of vegetation cover on the foredune influences its effectiveness in trapping sand (Hesp 2000). The vegetation cover on the dunes also shows zonation of species. The foredune generally have binding grasses and herbs, and the back dunes have shrubs and trees. To reduce dune erosion and to protect the agricultural area in the backshore, trees are planted along the foredunes. This initiative taken by the government is known as protected forestry, which is very prominent mainly along the Konkan coast of India.

The variety of dunes on Indian coast is either purely erosional or transgressive in nature (that which has been formed by transgressing a prior feature like parabolic dune)

Blowouts are also found in coastal environment. Most author define a blowout as a saucer, cup or trough shaped depression formed by wind erosion on a pre existing sand deposit. The adjoining accumulation of sand, the depositional lobe, derived from the depression and possibly other sources, is normally considered part of the dune (Glenn, 1979; Carter et all., 1990)

Blowout morphology is highly variable. They are either semi circular saucer type depression or elongated trough shaped having deeper depression floor and steeper lateral walls or slope. The initial shape, size, location of a blowout depends on the width and height of a dune and vegetation cover present on it.

Palaeodunes:

A dune is called a palaeodune if it satisfies the criteria of its distance from the shore. Several lithified and transgressional dunes are old in nature in their morphology but not considered as palaeo in nature. Commonly a palaeodune is accompanied by a marine terrace. It signifies a drop in sea level which changed the marine climate and initiated into a new shoreline and dunes. Palaeodunes are mostly covered by settlements and roads.

Littoral Terraces:

A littoral terrace is a relatively flat, gently inclined surface of marine origin mostly an old abrasion platform which is away from the present wave activity. It lies above the current sea level and occupies backshore area bordering beaches or banks of the shoreline sectors of tidal inlets. A littoral terrace is an emergent coastal landform. They are raised above the shoreline by a relative fall in the sea level.

Around the world, a combination of tectonic coastal uplift and sea-level fluctuations have resulted in the formation of such marine terraces. A marine terrace commonly retains a shoreline angle between the marine abrasion platform and the associated palaeo sea-cliff. The shoreline angle represents the maximum shoreline of a transgression and therefore a palaeo-sea level (Wikipedia).

The littoral terrace usually has a gradient between 1°–5° depending on the former tidal range with, commonly, a linear to concave profile. The width is quite variable and is controlled by palaeo coastal configuration. Older terraces are covered by marine and/or alluvial or colluvial materials while the uppermost terrace levels usually are less well preserved. The terraces can be covered by a wide variety of sediments with complex histories and different ages.

It is believed that the terrace gradient increases with tidal range and decreases with rock resistance. In addition, the relationship between terrace width and the strength of the rock is inverse and higher rates of uplift and subsidence as well as a higher slope of the hinterland increases the number of terraces formed during a certain time (Trenhaile 1987, Woodroffe 2002). Erosion caused by incisive streams play an important role in the degradation of these terraces.

The morphostratigraphic approach is generally used to study the chronological sequence of terraces found in the region. It is used in the regions of marine regression where altitude is the most important criterion to distinguish coast lines of different ages. Moreover, individual marine terraces can be correlated based on their size and continuity. The lithostratigraphic approach uses typical sequences of sediment and rock strata to prove sea level fluctuations on the basis of an alternation of terrestrial and marine sediments or littoral and shallow marine sediments (Reading 1996).

The distribution and sediment sequence of Holocene littoral terraces is a fundamental tool for the reconstruction of palaeogeography and neo-tectonic evolution of any backshore area (Karlekar, 2017, In Press). The distribution of terraces is indicative of raised shorelines and is usually linked to Holocene sea levels in the area. Their evolution from early to late Holocene can be inferred from their relative locations and elevations on the coast and one can identify the palaeo-shorelines planimetrically. Marine and transitional sedimentary deposits can be identified and used to reconstruct the sequence of sedimentation.

According to Karlekar (2017 in press) littoral terraces on Konkan and Goa coast are flat, reliefless wide to narrow sectors bordering the creeks and estuaries or occurring directly back of the beaches and dunes. In majority of the cases they are related to the recent higher sea level in the area. Their gentle seaward gradient and the sandy silty sediment cover suggest their marine origin. The landward margins of these terraces are irregular and also suggest the configuration of ancient coastline when the sea was slightly higher. They help in the identification of limit of the ancient bays or other tidal inlets in the area

The terraces assume importance mainly in the hilly coastal sectors where they are well preserved. The landward portion of these terraces show a surface cover of hill slope wash and weathered material brought from nearby hills. This is the most important land facet on Konkan and Goa coast as regards its flatness and supportive capacity of the land.

Mudflats:

The muddy low lying area around the tidal channels of estuaries and creek are called tidal flats or mudflats due to their sediment composition. The areas are dominated by tides and very devoid of any major wave action. Tidal flats are classified on the basis of their sedimentary characteristics, hydrography, tidal range or geomorphological setting (Woodroffe 2002). Saline inter-tidal mudflat within tidal inlets especially the estuaries are the prime areas of sedimentation of Konkan coast.

B. THE KONKAN COAST

A 650 km long coastline (720 km long including estuarine and creek coast) and a narrow coastal plain stretching from north to south along the western boundary, is a distinct physiographic region of Maharashtra (Fig. 1.6) in India. The region is traditionally known as Konkan and is a land of plateaus, plains and hills. It is separated from upland Maharashtra by a west-facing escarpment of Sahyadri Mountains or Western Ghats.

Konkan extends from Damanganga River in the north to Terekhol River in the south. The width of this coastal belt is not uniform and varies from 40 to 50 km all along the region. Administratively it comprises of Palghar, Thane, Raigad, Ratnagiri and Sindhudurg districts and Mumbai.

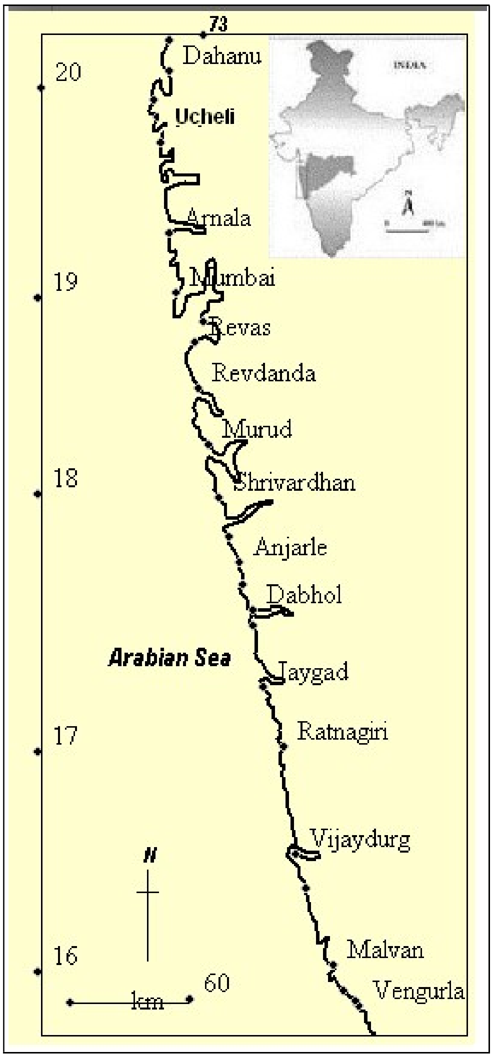

Fig. 1.6- Konkan coast

Physiographic divisions of Konkan region:

On the basis of certain characters like lithology, geomorphic configuration, nature of hinterland and climate, Konkan region of Maharashtra can be divided (Fig 1.7) in to North Konkan, Middle Konkan and South Konkan. (Dikshit1986, Karlekar 2017). Following are the main features of these sectors according to Karlekar (2017).

1. **North Konkan,**
2. **Middle Konkan and**
3. **South Konkan.**

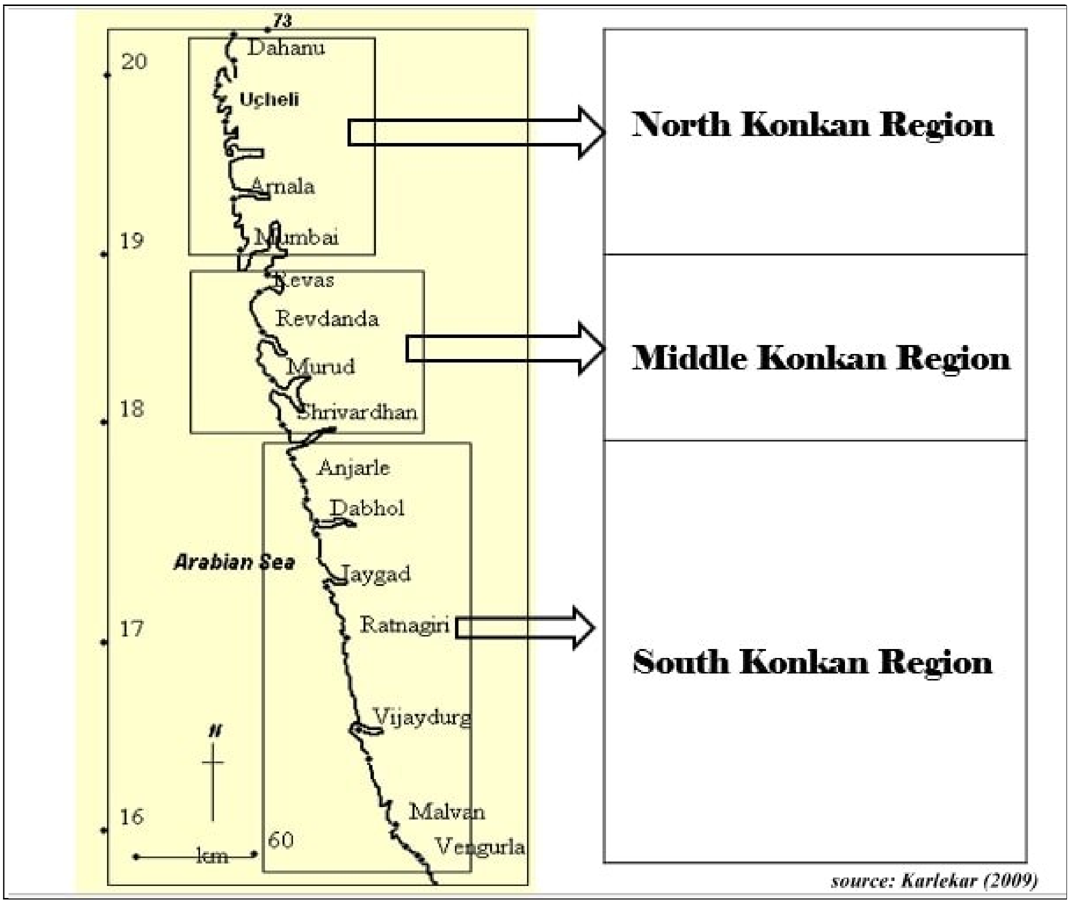

Fig: 1.7 Sectors of Konkan region

North Konkan: The coastal belt from Bordi, Dahanu to Karanja (Fig.1.7) is included in this sector. The region is mainly characterized by forested hills and a small plateau of a height of about 350-m ASL. The drainage network comprises of rivers like Surya, Tansa, Vaitarna and Prinjal, Ulhas, Kalu and Bhatsai. Courses of rivers like Vaitarana clearly indicate a control of lineaments. Narrow plains invariably border the river channels. Ulhas plain, covered by brown silt, is according to Dikshit (1986) a marine planation surface in early quaternary. North-south oriented, forested coastal hill range is an important feature of North Konkan. The entire region is an area covered by the Deccan Trap rocks with intertrappean beds. North Konkan receives an annual rainfall of 1500 mm and more.

Middle Konkan: The coastal belt from Karanja to Shrivardhan can be identified as Middle Konkan. This region also comprises of forested hills but it is relatively more flat. Amba, Kundalika, kal, and Savitri are the main rivers and show a distinct control of lineaments. The central part of the east - west belt of this area is hilly with height ranging from 300 m to 500 m. Basalt is the major lithological formation in the area. The study area of this research work lies in this coastal sector.

South Konkan: This is the longest stretch of Konkan between Shrivardhan and Vengurla, covered by thick laterites that have molded the personality of the region when compared to North and Middle Konkan. Barren lateritic plateaus, deeply entrenched river channels and the piedmont plains at the foot of the Sahyadrian escarpment are the significant land facets, which reflect the impact of lithology (Karlekar, 1981). The plateau is 150- 200 m high and the cover of laterite is 8 to 12 m thick. Vashshthi, Shastri, Kajavi, Muchkundi, Arjuna, Vaghotan, Gad and Karli are the major rivers in the area.

DIVISIONS OF COASTAL SECTOR

On the basis of the impact of tidal incursion and the tidal range in spring and neap, Konkan can be divided into macro, meso and micro tidal regions. Table 1.2 gives the classification of Konkan based on these aspects. According to Karlekar (2017) on the basis of the impact of tidal incursion and tidal range at neap and spring tide, Konkan can be also be divided into;

1. Macrotidal coast
2. Mesotidal coast
3. Microtidal coast

Regions	Coastal Stretch	Major Rock Component	Major Identified Facets	Tidal Range
North Konkan	Dahanu to Revas	Basaltic	Forested hills and Plateaus	>3.5 meters (**Spring Tide Range**) >2meters (**Neap Tide Range**)
Middle Konkan	Revas to Shrivardhan	Basaltic and Lateritic	Relatively flat forested or residual hills also referred as Planation surfaces. Presence of palaeo-features	3.5 meters to 2meters (**Spring Tide Range**) 2meters to <1.5 meters (**Neap Tide Range**)
South Konkan	Shrivardhan to Vengurla	Lateritic and Granitic	Barren Lateritic plateau deeply entrenched by rivers.	<2meters (**Spring Tide Range**) <1.5meters (**Neap Tide Range**)

source: Karlekar (2009)

Table: 1.1 Major components in all the three divisions of Konkan region

Stretch	Macrotidal Coast Dahanu to Revas	Mesotidal Coast Revas to Ratnagiri	Microtidal Coast Ratnagiri to Vengurla
Spring tide range	**>3.5 m**	**3.5 to 2 m**	**< 2 m**
Neap tide range	**> 2 m**	**2 to 1.5 m**	**< 1.5 m**
tidal Incursion	**40 km**	**25 km**	**20 km**

source: Karlekar (2017)

Table: 1.2 Tidal characteristics in all three divisions of the Konkan region

Coastal Climate:

Following are the major characteristics of coastal climate are observed according to Karlekar (2017).

1. Wind direction and wind speed on this coast show definite trends from north to south**.** It is found that the waves are westerly in pre monsoon period on middle and south Konkan coast and north westerly on northern coast with a speed varying between 3 and 8 knots.

2. The south Konkan experiences winds of 5 to 11 knots in this period. Monsoon is a period of westerly to south westerly waves with a speed exceeding 10 knots along major part of Konkan coast.

3. The wave approaches and the wind speeds can change locally due to considerable refraction as the waves approach the indented shoreline. Waves become steeper near the shore especially during monsoon

4. Wave heights do not normally exceed 2 m in fair weather (October to May). In monsoon (June to September) waves exceeding 5 m height are seen, especially along south Konkan coast. Long period waves, with a wave period of 10 to 12 seconds, dominate fair weather season. In monsoon, wave period decreases from 3 to 6 seconds.

5. The breaker zone near the shore is about 200 m wide from June to September and very high breakers are produced in this period. Wave breakers in monsoon are of spilling and plunging type.

6. In fair weather breakers are characterized by low, surging or collapsing waves. The surf zone produced in monsoon is more than 200 m wide and considerably reduces to less than 25 m in fair weather (Karlekar2014, Karlekar & Rajaguru 2012).

7. The long shore currents are south-eastwards in monsoon and move with an average velocity of 30to40cm/s. In fair weather they are north- north westwards and have a velocity of 8to20cm/s.

8. The direction and the velocity of the long shore currents changes locally and they are mainly influenced by the local coastal configuration.

9. It has been reported that Maharashtra coast experiences negligible annual long shore sediment net transport and the direction of annual net transport is towards south (Kunte et al 2001).

10. The Konkan coast experiences semi diurnal tides with a tidal range that varies from less than 2 m to more than 3.5 m. The tidal range gradually increases from south to north i.e. from 1.5 m at Vengurla to 5.4 m at Valsad.

Landforms of the Konkan coast:

Karlekar (2017) gives a detailed account of major landforms found on this coast. All along the coast the shoreline is broken by frequent headlands and promontories, which are the sites of sea cliffs, beautiful sandy pocket beaches, drowned river valleys, small tidal inlets, river creeks and creek lets. These land facets have contributed immensely to distinctiveness of the Konkan coast.

The Beaches

Konkan is dotted with innumerable, small, sandy pocket beaches. Sandy beaches dominate the shoreline, but there are few mud beaches also. The sediment characteristics and the morphodynamics of these beaches are controlled mainly by specific wave and tide environment related to seasons and tidal range. Wide beaches with a well-developed berm and beach face are characteristic of fair weather period. The swash-aligned beaches on Konkan coast are crescentric beaches.

Sandbars and Spits

Konkan is also endowed with long, beautiful sandbars and spits, which are essentially the sandy beaches attached to the main land at one end. They are usually drifts aligned, in that they are built parallel to the line of maximum drift. The building of beach abruptly ends where coastline followed by littoral currents, turns landward, at the entrance of tidal inlets. Spits produced by the combination of drift and tide invariably show features of tidal and drift dynamics, as the bed forms. A few spits end in one or more hooks.

The Coastal Dunes

This is a well-marked and distinct feature of this coast. On the backside of many beaches embryo dunes and primary dunes with characteristic wind ripples and parallel ridges of secondary dunes can be easily recognized. There is a great variability as regards their morphology, orientation and the degree of preservation.

The Sea Cliffs and Shore Platforms

Impressive sea cliffs shore and rock platforms characterize the rocky coast of Konkan. These features are usually found along joints, cracks and other weaker sections of the rocky headlands. Cliffing is the dominant process on this coast. The shore platforms at the foot of the cliffs are also a striking feature in Konkan. Their average width rarely exceeds 30 m. The platforms are intertidal and are shaped by abrasion and water layer weathering.

The Sea Caves

The caves on this coast are developed in basalts, granites as well as laterites. They show a significant variation in their depth, height and overall form. Most of the caves are typical examples of abandoned caves fronted by shore platforms. Caves at few places in the area are fronted by long narrow and deep Geos which are produced along the weaker zones. Caves found at some height are relatively narrow and small and insignificant as compared to those developed near the foot of the cliff.

Littoral Terraces

Narrow, flat terraces are seen in backshore areas all along the coastline. These terraces are small, elongated and usually parallel to the coast. Their height varies from 3 m to 7 m above sea level. They either stretch between two streams to north and south or are confined to regions surrounded by hill slopes. The morphology, shape and the configuration of these terraces undoubtedly points to their marine origin and defunct nature due to a slight drop in sea level.

Estuaries and Creeks

The estuaries and creeks on this coast are distinct especially due to their tidal and fresh water regime. They also exhibit a complex pattern of sediment input.

The Tidal Mud Flats

Saline intertidal mud flats within tidal inlets especially the estuaries are the prime areas of sedimentation on Konkan coast. The Tidal mud Flat deposits on the ancient high tidal flats are covered under coastal alluvium. In the intertidal zone thick tidal mud is found on the surface, especially along the present high water line. During ebb, an extensive area of intertidal zone is exposed and one can see mud, sand and sandy mud everywhere in the inlet regions.

C. THE STUDY AREA

The area of investigation lies between 18°33' N/ 72°55' East and 18°38'N/ 72°53' E on the Middle Konkan region of Maharashtra coast (Fig. 1.8). It covers a 10 km long beach sector from Akshi in the north to Revdanda to the south along the Arabian Sea coast. The spring tide range along the coastal stretch is 2.5 m and the neap tide range is 1.8meters. The average beach width is around 100 m.(Table 1.3).

The back shore behind the beach varies in width and character. The sands on back beach are generally fine grained and well sorted compared to beach face. The backshore is the area of the shoreline above the high water or high tide mark. Permanent vegetation, sand dunes and a berm (flat upper beach) are the main features found in back beach region of study area. The foreshore extends from the low water line to limit of wave up rush at high water.

EXTENT	18°33' N/ 72°55' E to 18°38'N/ 72°53' E
LENGTH	10 km

BEACH WIDTH (AVERAGE)	100m	
WIDTH OF BACKSHORE(AVERAGE)	150m	
TIDAL RANGE	**SPRING TIDE**	**NEAP TIDE**
	2.5m	1.8m
COASTAL FEATURES WITH THEIR AVERAGE DIMENSIONS	Area of beach – 0.1 sq.km. Area of fore and back dune –7.4 sq.km. Area of northern mudflats (near Akshi)- 1.6sq.km. Area of southern mudflats (near Revdanda)– 3.1 sq.km. Length of estuarine channel –7.7 km. Area of terrace –5.9 sq.km.	
ALTITUDE VARIATIONS (E-W)	0 m to 1.5 m	
GEOLOGY	Coastal alluvium	
UNIQUE COASTAL IDENTIFICATION	Coastal barrier	

Table 1.3: Parameters of the study area

Satellite imageries are one of the biggest sources of primary data these days. The Google earth image displays the various land facets seen in the study area.

They are listed below in table: 1.4 and shown in fig: 1.9.

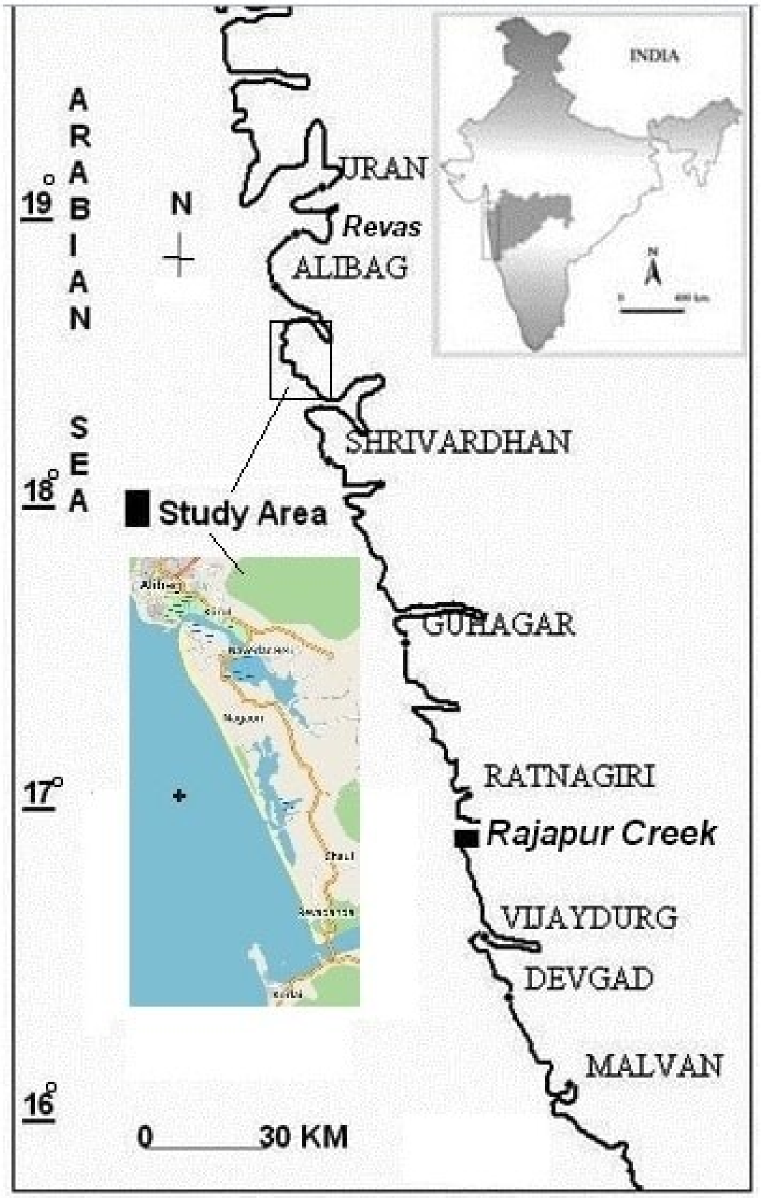

Fig: 1.8 Study area

Fig: 1.9 Google earth imageries showing major land facets of study area

Inset 1: (Akshi area)

- Beach
- Settlements
- Mudflats in Nagaon creek
- Plantation (coconuts, arecanuts etc.)

Inset 2: (Bagmala area)

- Beach
- Settlement
- Paulo creek
- Tidal inlets in the creek
- Mudflats on the creek bank
- Agricultural fields

Inset3: (Revdanda area)

- Beach
- Fort
- Plantation
- Agricultural fields
- Settlements
- Roads
- Northern bank of Kundalika creek

Table: 1.4 List of the major land facets found in the study area

The geomorphic map of the study area (Fig. 1.10) shows the various land facets observed in the Google image.

The plantation area occupies the major proportion of the study area. Trees like coconut and arecanut are abundant in the area, whereas, the stabilization of the dune sector has been done by planting casuarina trees. Most of the streets and terraces are covered under the plantation canopy. The next feature of aerial significance is the terraces. Most of these are turned into agricultural fields owing to their fine and fertile soil. Some of the terraces are used for roads and settlements. There runs an extensive beach along the study area which narrows down a little in the middle and is drained by Paulo creek. Mudflats owe their existence to the presence of the creeks, especially in Nagaon in north and the Paulo creek in the middle. Several tidal channels are also seen which are submerged during the high tide and monsoon and dry up in fair weather. Berms are only prominent in northern sector near Akshi and decreases as we go south. Human interference is found more towards south of the Paulo creek.

Fig 1.11 shows the SRTM terrain view of the study area. The regional cross profiles obtained from this view give an idea of the changing nature of terrain from north to south.

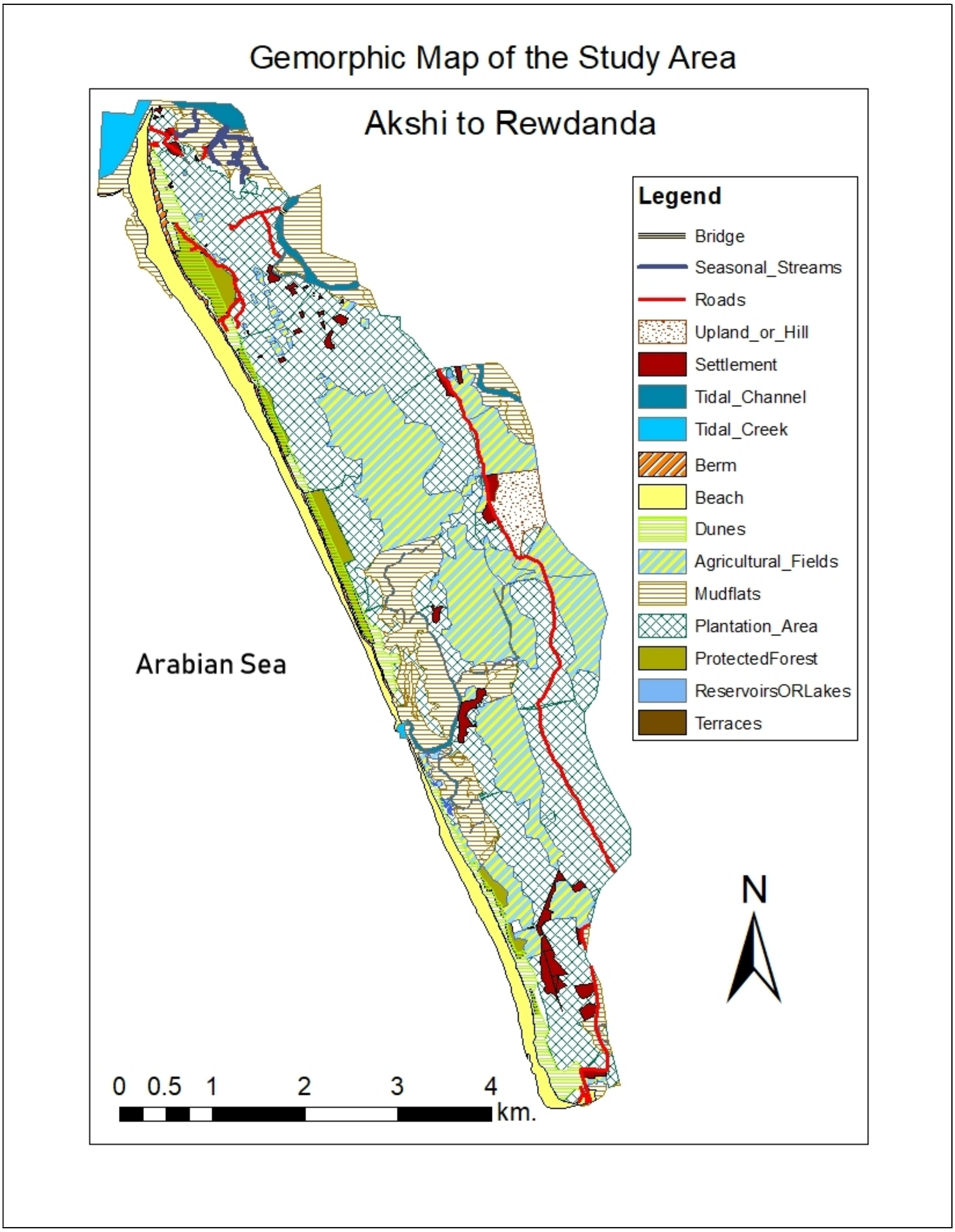

Fig: 1.10 Geomorphic map of the study area

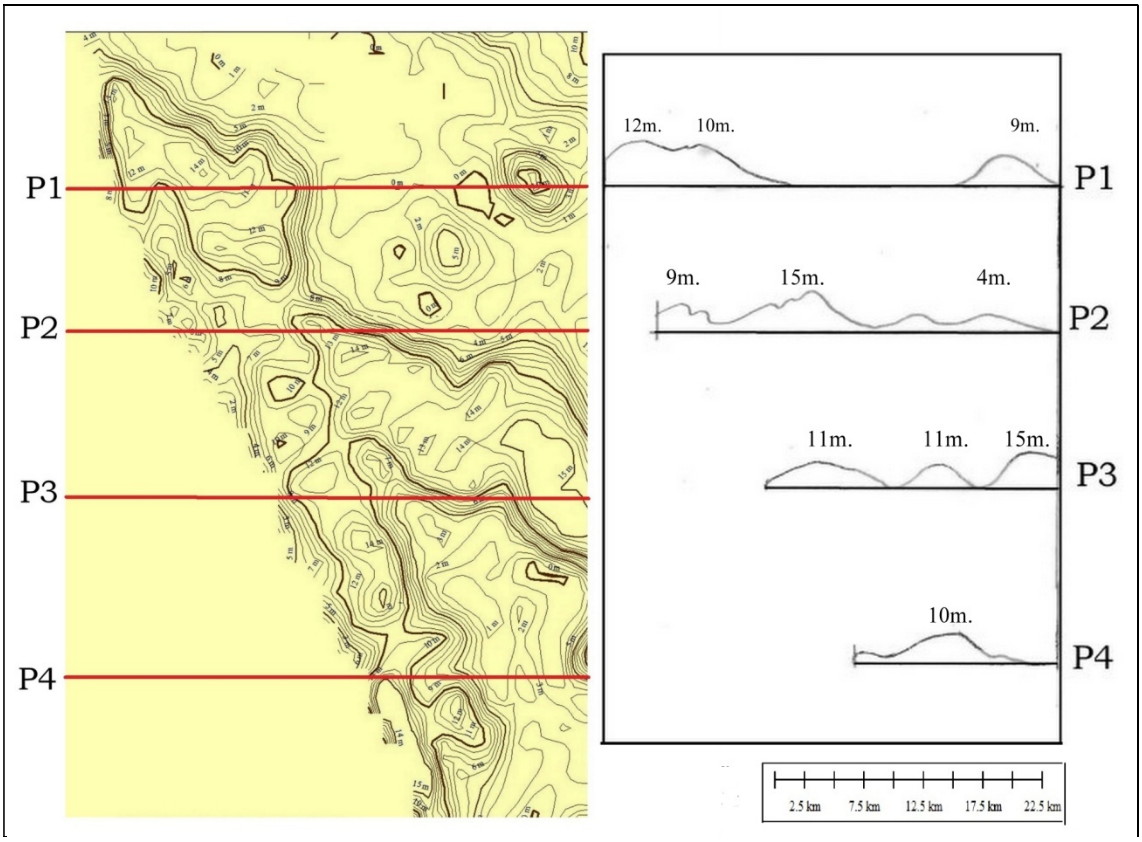

Fig: 1.11 Cross sectional profiles from SRTM data of the study area

Four major morphological facets that are witnessed in the backshore of the study area:

- **Beach**
- **Berms**
- **Dunes**
- **Littoral Terraces**.

BEACH

Berm formation at the end of beach face

BERMS

DUNES

LITTORAL TERRECES

D. BARRIER SYSTEM

The barrier is defined as a shore parallel and sub-aerial accumulation of detrital sediment formed by waves, tides and aeolian processes. It constitutes a sequence of landforms that vary in age, lithology and form. It is a coastal landform that acts as a barrier between sea and the older coastal landform or mainland bedrock (Short, 2000).

The seaward margin of barriers is usually formed by beaches. The barrier system incorporates the beach, berm, dunes, terraces and strand plains and even tidal inlets.

Barriers always have some degree of mainland attachment and they can be stable, transgressive or regressive in nature (Short 2000, Davis 1994, Roy et al 1995).

The expansion of barrier islands is related to sand supply, sea level history, and the wave and current regime. If a continued sediment supply, stable sea level, and low to moderate subsidence continues, barriers prograde seaward. A reduction in sediment supply, rise in sea level or a high rate of subsidence will result in landward migration of barriers and reduction in size. Over time, the barrier island may increase in horizontal extent from these processes. As barriers are built forward, dune ridges are built inside the beach. These ridges may become covered with vegetation and stabilized at levels above the beach. If the beach continues to build seaward, a new dune ridge may form closer to the new shoreline, and this in turn becomes stabilized; thus a series of ridges may develop (Biggs 1978). The seaward side of a barrier system receives similar wave and tide forces as described for beach, dune and shoreface environments and the system is usually tide or wave dominated.

Barrier system elements:

The major sedimentary environments of a barrier system are the beach, dunes, marshes, tidal flats. Six interactive sedimentary environments in a barrier island system are generally identified:

- the mainland,
- a back-barrier lagoon/creek,
- barrier island,

- inlets,
- barrier platform, and
- the shoreface

Each element has distinct morphology and sediment patterns within the barrier island system which in turn can be wave or tide dominated.

The study area comprising of Beach, Backshore, Dunes and Terraces is basically a **Barrier system** (Short, 2000). This barrier system appears to have formed as a result of some type of landward transport and upward accretion of sands (Davis, 1994).

Akshi-Revdanda coast is basically a barrier system consisting of modern beach, berm, modern and palaeo dunes, strand plains in the form of terraces and segment of tidal inlets (fig:1.12).

The system is attached to mainland through littoral terraces and banks of tidal inlets. It is regressive in nature produced by fall in sea level in mid to late Holocene. The sediments in this barrier system have been deposited by the waves, tides and aeolian processes in the regressive period.

From the study of dunes and terraces it appears that this barrier system was established during the marine transgression in mid Holocene and since then, due to heavy sediment supply, the regression of sea level continued to prograde seaward.

A gentle gradient of substrate, easy availability of sediments and mixed tide-wave environment have been conclusive for the formation of this barrier. Enough accommodation space must have initially produced shoreface beach, aeolian sand, and the dunes at swash deposits of the berm.

The Holocene sea levels have resulted in barrier formation close to present sea level. The deposits of littoral terraces are in all probability Holocene barrier deposits. This barrier system is backed by tidal creek and bordered by mangrove swamp deposit. It also comprises of associated tidal inlet deposits, beach derived aeolian dunes and littoral terraces.

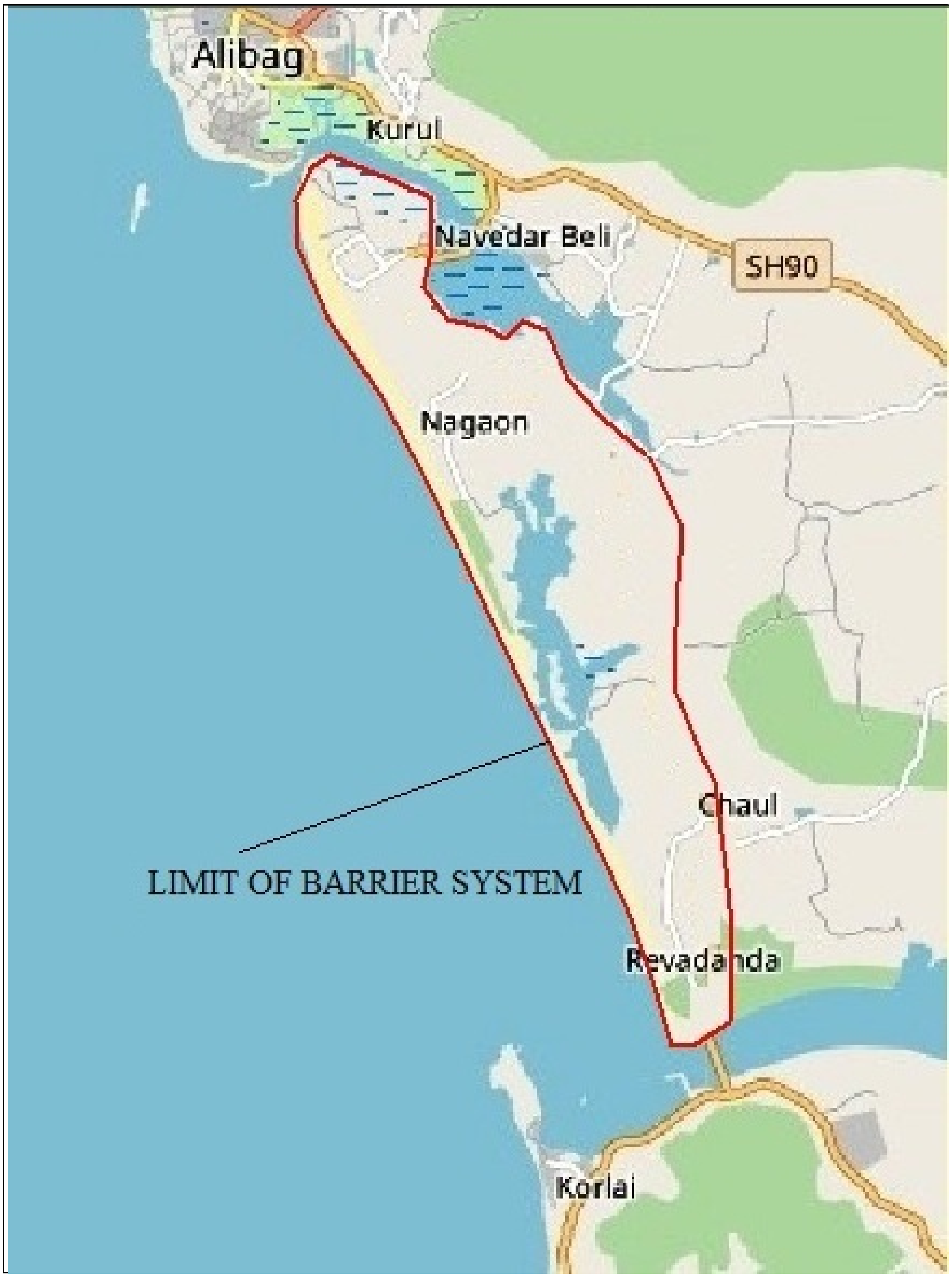

Fig: 1.12 The barrier system

CHAPTER TWO

THE LITERATURE REVIEW

The available literature pertaining to the definition and characteristics of backshore, coastal dunes and dune stratigraphy as well as terraces was surveyed and studied carefully in context of the present research topic. Following is the brief account of the survey.

According to Hesp, "Backshore is the zone between the swash limit (sometimes the berm crest) and the seaward edge of a dune or other landform (e.g a cliff)."It is the zone that is episodically impacted by both swash and aeolian sand transport and thus critical to dune formation. On the other hand, backshore is also defined as, a nearly flat terrace like area, slopes slightly toward leeward and is commonly much broader than the foreshore which in normal condition is a sub-aerial feature (Davis, 1982). Surprisingly, the backshore is intensively used yet scientifically neglected part of the beach system (Hesp, 2000). Presence and extent of backshore depends upon various factors. A.D.Short demarcated various factors like, beach type, beach width, and medium to long term beach status. However, monthly inundation level and sand supply are two other major factors. The relationship between the formation of the backshore coastal dune and aeolian sand transport in sub-aerial environment has been tried to explain in various attempts by Bagnold (1941), White (1979), and Kawamura (1951).

According to Michael Hogan 1998, most of the organisms inhabiting the backshore are terrestrial in nature, most of whom have made incursions from the proximate upland habitat. Although the biodiversity of the backshore is much higher than that of the very demanding environment of the foreshore, there are a much smaller number of species that inhabit backshores compared to more upland habitats. This outcome flows from the trickiness of life in the windswept habitat where the dry sands are ever-shifting, and saline soils are prevalent.

Backshore microclimate is a significant determinant of organism diversity on the backshore. Except for mangrove covered backshores in the tropics, the lack of shade cover and exposure to intense sunlight is also a constraint to life. (While most mangrove species thrive on foreshores, there are a number of mangrove species and palms that covet backshore tropical habitats) However, for the very reason that few species are found on the backshore, the populations of those well adapted to backshores can be very large, being devoid of serious competitors.

According to Guimarães PV (2016) the backshore zone is transitional environment strongly affected by ocean, air and sand movements. On dissipative beaches, the formation of ephemeral dunes over the backshore zone plays significant contribution in the beach morphodynamics and sediment budget. The coastline orientation relative to the dominant winds and the dissipative morphological beach state favors the aeolian sand transport towards the backshore. Prevailing winds increase sand transportation to the backshore, resulting in the formation of dunes. Precipitation inhibits aeolian transport and ephemeral dune formation and thus maintains the existing morphologies during strong winds, provided the storm surge is not too high.

Detailed textural analyses in a carbonate foreshore-backshore coastal environment in Hawaii indicated distinct differences in mean, sorting, skewness, and percent of fines between zones and within zones, Cheing-Tung Lee, (2013). As a group, foreshore sediments were finer, better sorted, and more negatively skewed than backshore sediments. This pattern was thought to reflect the decoupling of the foreshore source population by swash-backwash and aeolian processes. Spatial variations in texture within the foreshore were also observed, and this led to the subdivision of the foreshore into three zones based on observed textural variations– lower foreshore, mid-foreshore, and upper foreshore. Traditional bivariate plots of textural parameters for the foreshore and backshore samples indicated that this approach alone would not be useful in distinguishing sub environments in paleosequence studies.

The systematic components of spatial variation in texture over a beach foreshore-backshore-dune complex can be identified using trend surface analysis according to Greenwood Brian (1978) . Variability across the foreshore is a function of the vector of sediment movement and reflects both orthogonal and shore-parallel transport processes. In the dune zone, textural variability reflects local topographically controlled environments, source sediments and a temporal factor. The decreasing mean size, increased sorting and decreasing negative skewness from a low water to high water mark are correlated with changes in the linear segments of the cumulative size-frequency curve: a decrease in the coarse traction population is matched by an increase in the major saltation populations. The distinction between wave-laid and wind-laid deposits is also reflected in the segments of the cumulative curve: the latter lack the coarser component but has a distinctly fine tail. Greater spatial homogeneity of textural characteristics is present in the dune sediments but distinct trends in size frequency statistics reflect the variability in a dominant saltation population, the lack of a coarse traction population, and the presence of a fine suspension population dictated by localized transport mechanisms.

The anthropogenic activities in the backshore destroy the natural physiography. Woodroffe (2002) described the interference as the tourism and resort cycle. Poor coordination amongst officials, engineers, planners, and coastal geomorphologists is also a major obstacle in coastal management (Karlekar, 2009).

The Konkan beaches undergo seasonal changes, in addition to daily changes. The berm and beach face are prominent during the low, flat swell waves, during fair weather; whereas, high, steep, storm waves during the monsoon reduced the berm and beach face (Karlekar, 1997). The coastal sector is characterized by headland, pocket beaches, tidal inlet, and shoreline terraces. The area is also known for its hills with height ranging from 300m to 500m ASL. Dikshit (1990), identifies most of the hills as planation surfaces.

The available record of general sea level fluctuation on Konkan coast are more or less of general character, but a relative chronology of sea level event is still awaited (Karlekar,2000). Neo-tectonic activity along this coast has been studied by many, but there is a general agreement over a higher sea level around 3000 YBP along this coast (Thakurdesai and Karlekar, 2014)

Morphodynamic models of the coastal landforms can simulate the coast in both 2-dimensionas and 3-dimensions with the help of 3D GIS modeling. Satellite images and mapping, emphasized the geomorphic significance.

Theoretically speaking, beaches are the depositional units along the coastline in between low water mark and high water mark line. They are the product of the wave interaction with a sandy bed at the shoreline. The beach interaction zone generally extends upto the limit of swash action. To give a more precise morphological definition of the beach is more difficult. Considering any beach profile can be said that a beach profile extends from low water of spring tides to the upper limit of the wave action (Pethick 1984).

There is a considerable amount of variability in sandy beaches which is a result of a wave environment along the Konkan coast. The major differences in grain size reflect differences in wave energy. Tides are the important driving factor in the meso and micro tidal beaches in the north of the Konkan coast. Decrease in the velocity of tidal current at ebb, results in the sediment deposition in swash zone. The flood tide current on the contrary induce erosion and cutting of beach profile (Karlekar, 2009). According to Davies 1977, swash aligned beaches in this coast are found along indented and irregular stretches. In some case they are transformed into drift aligned beaches in monsoon. On fine sandy beaches, the quantum of swash and backwash is more or less equal due to restricted percolation. However in coarse sandy and gravel beaches the percolation of swash wave is more effective. The sediments of Konkan beaches are subjected to reworking every year by aeolian, biological and coastal processes. The sea beaches are most unlikely of landforms to be found facing the open sea (Pethick 1984). The secret of their geomorphic existence lie in the very fact that they are made up of only loose sand. They can adjust their shapes in accordance to near shore wave energy. The beach can very easily maintain its dynamic equilibrium. The beaches respond quite sensitively to changes in local environment.

One of the classifications of the beaches are on the basis of energy level and divided in two groups, namely winter and summer profile is synonymous with fair weather and storm profile or dissipative or reflective beaches.

Early researchers identified the relationship between beach slope and grain size (BEB, 1933; Meyers, 1933; Bagnold, 1940; Bascom, 1951, Johnson, 1956). King (1972) expressed these results in a sensitivity graph (Fig.7.1) which showed how beach slope decreases with decreasing grain size and increasing wave energy. King (1972) reported on numerous beach profile form a variety of beaches in Britain, France, the USA as well as laboratory experiments. The beaches included those with a wide, low gradient, smooth profile which she attributed to large tide range and high waves (see section 8.6.2); to those with 'submarine' bars which were found in enclosed tide less seas exposed to steep waves; with crescentic bars for which she had no satisfactory explanation; and ridges and runnels which occurred on some fetch limited, high tide range beaches. King also reported on the temporal variation on many of these profiles, which depending on seasonal wave action could either be regular (seasonal) or erratic. Finally, she attributed beach cut and offshore bar migration to the occurrence of higher, steeper waves, and beach accretion to lower, flatter waves. While King correctly linked certain profile types with salient environmental conditions, and beach change with dominant processes, there was no clear relationship between the seemingly wide range of beach profiles and the nature and scale of their response.

Coastal dunes are different from their desert counterparts. Unlike the desert dunes, they have a steep windward side and a gentle leeward side. Moreover, availability of vegetation cover plays a very important role here (J.Pethick, 2000). On narrow sandy beaches with width not more than 50m, the dunes are low and inconspicuous. The dune zones assumes certain amount of significance only on wide sandy beaches where they form extensive dune system (Karlekar, 1997).

Sherman and Lyons (1994) noted the basic transport model in the dune formation, that includes;

-Wind-field is steady and uniform.

-Surface is flat, horizontal, and unobstructed.

-The sediments are sand, non-cohesive, clean, and dry.

-Transport tales place via saltation in a layer that is in equilibrium with the wind-field.

The coastal dunes are characterized into several different types by different geomorphologists as shown below.

Embryo dunes Foredunes	Pethick(1984)

Dune slacks Old dune ridges	
Foredunes Incipient and Established dunes Shadow dunes Parabolic dunes Nebkha/coppie dunes Transgressive dune fields	Hesp(2000)
Primary dunes Free and Impeded dunes Secondary Dunes Transgressive and Remnant dunes Lithified dunes	J.L.Davis(1977)
Foredunes U-shaped/parabolic dunes Blowouts Barchans/crescent shaped dunes Transverse dunes Longitudinal dunes Attached dunes	Smith(1954)

According to Takeda Ichirou (1997) the seaward limit of dune grass colonies is characterized by a specific topographic break in the beach profile. It was found that this position rarely shifted during the two-year survey period, although many storms of different magnitude occurred and that the position corresponded almost completely to the landward limit of beach change due to waves. Therefore the position can be used as the landward limit of the backshore, which was fairly stable. This stability suggests that there is no significant difference in the up rush limit of waves in each storm event. This is probably due to the lack of significant temporal fluctuations in breaker height at the shoreline during storm.

The barrier literature has traditionally been dominated by one form of barrier, the barrier island comprising six elements: the mainland, back-barrier lagoon, inlet and inlet deltas, barrier island, barrier platform and shoreface (Oertel, 1985). Barrier islands, however, represent one end member in a spectrum of barrier types. In one direction barrier islands grade, with increasing tide range and/or decreasing wave height into mixed wave-tide dominated barrier islands and inlets and finally into tide dominated coastal flats. In the other direction, as the distance between the Bather Island and mainland decreases due to increasing substrate gradient, the barrier may be partially or completely joined to the mainland as a barrier (Hayes, 1994).

Discussion on the origin of barriers dates back to de Beaumont (1845) who favored barrier emergence through upward-shoaling of shallow sand bars. Later Gilbert (1885) working around Lake Bonneville, proposed that barriers evolve as spits from longshore drift. McGee (1890) favored the drowning of coastal ridges as a mechanism for barrier development. Subsequent to this early work there was little progress made on barriers until the 1960's when US workers began re-evaluating bather models. First Hoyt (1967) favored drowning, while Otvos (1970) favored an emergent bar, and Schwartz (1971) argued for multiple causalities, and supported all three modes under certain conditions.

However, it was not until the use of vibrocoring that more robust models emerged. Swift (1975) and Field and Duane (1976), utilizing vibrocoring results, favored onshore barrier migration during rising sea level. This model was further supported by Rampino and Sanders (1980) who found some barrier remnants were left behind on the shelf, and Niederoda et at (1985) who also found evidence for onshore migration. Subsequently there has been a considerable body of field evidence (e.g. Leatherman, 1979b; Roy et at, 1995) to support the conclusion reached by Davis (1994) that 'most (barriers) appear to form as a result of some type of landward transport and upward accretion of sands'.

There is now common agreement that barriers form at sea level on suitable substrates by the action of waves (and tides). Most barrier models now contain these elements (e.g. Hayes and Davis, 1984, Otvos, 1985), while some also include sediment supply (e.g. Boyd et at, 1992) and relative sea level (e.g. Penland et al., 1985; Roy et al. 1995). There is also agreement that during the last Post-glacial marine transgression many low sea level barriers were eroded, truncated and reworked into new transgressive barriers, with some remnants left on the shelf (e.g. Roy et at, 1995).

CHAPTER THREE

METHODOLOGY

A. AIM AND OBJECTIVES

Aim of this work is to study the nature of the backshore morphology and stratification of dune in the study area.

To achieve this, following **objectives** were set**:**

~To ascertain the limit of backshore

~To identify various features of backshore

~ To assess the morphology and sedimentology of these features.

~ To evaluate the area as a barrier system.

Field components	Laboratory Components
1. Leveling survey using Dumpy level. 2. Positioning survey using GPS 3. Field confirmation and delimitation of the features identified in toposheet. 4. Collection of sediment samples 5. Identification and study of dune stratigraphy.	1. Plotting the Dumpy Level readings and the GPS points to ascertain terrain levels. 1. Contour levels were obtained from SRTM data and regional profiles were drawn. 2. Preparation of geomorphic map of the study area. 3. Analysis, characterization and plotting of sediment parameters. 4. Analysis and re-creation of the dune stratigraphy in the area.

Table: 3.1 Methodology

B. FIELD COMPONENT

Morphological features in the study area were ascertained by carrying out dumpy level survey of the backshore region. The entire area of 10km was covered in total of 9profiles.

All the locations of the profiles are shown in the map of the study area (Fig.:3.1). Contour levels of the region were also obtained from SRTM data and regional profiles were made and shown in the earlier chapter (Fig: 1.11).

Sediment samples were collected along each profile at specific distance. The sites from where these samples were collected are shown in the following map of the study area (Fig: 3.2).

The field component also comprised of the identification and measurement of dunes and dune stratigraphy. The stratigraphy of the foredunes was exposed at four locations which were studied in details as shown in fig 3.3. The facies exposed were measured and mapped. The sections were used to reconstruct the stratigraphy of dunes all along the study sector.

C. LABORATORY COMPONENT

On the basis of leveling survey, the cross sectional profiles were plotted for all the study area. The facets such as berms, dunes, terraces were identified and shown on profiles. The terrain profiles were also constructed from the SRTM generated contour maps.

The sediment samples collected were mechanically sieved to get the proportion of sediments in different sizes. The distribution parameters such as mean, mode, median etc were calculated. The result obtained were also used to know the amount of sediment moving by the process of surface creep, saltation and suspension and their role in formation of dunes in the study area.

The geomorphic map of the area was prepared on the basis of measurements and Google earth image of the area (Fig 1.10).

As observed in the field, different physical features were colour coded and digitized as separate layers in the geomorphic map for the better understanding of their location in the field.

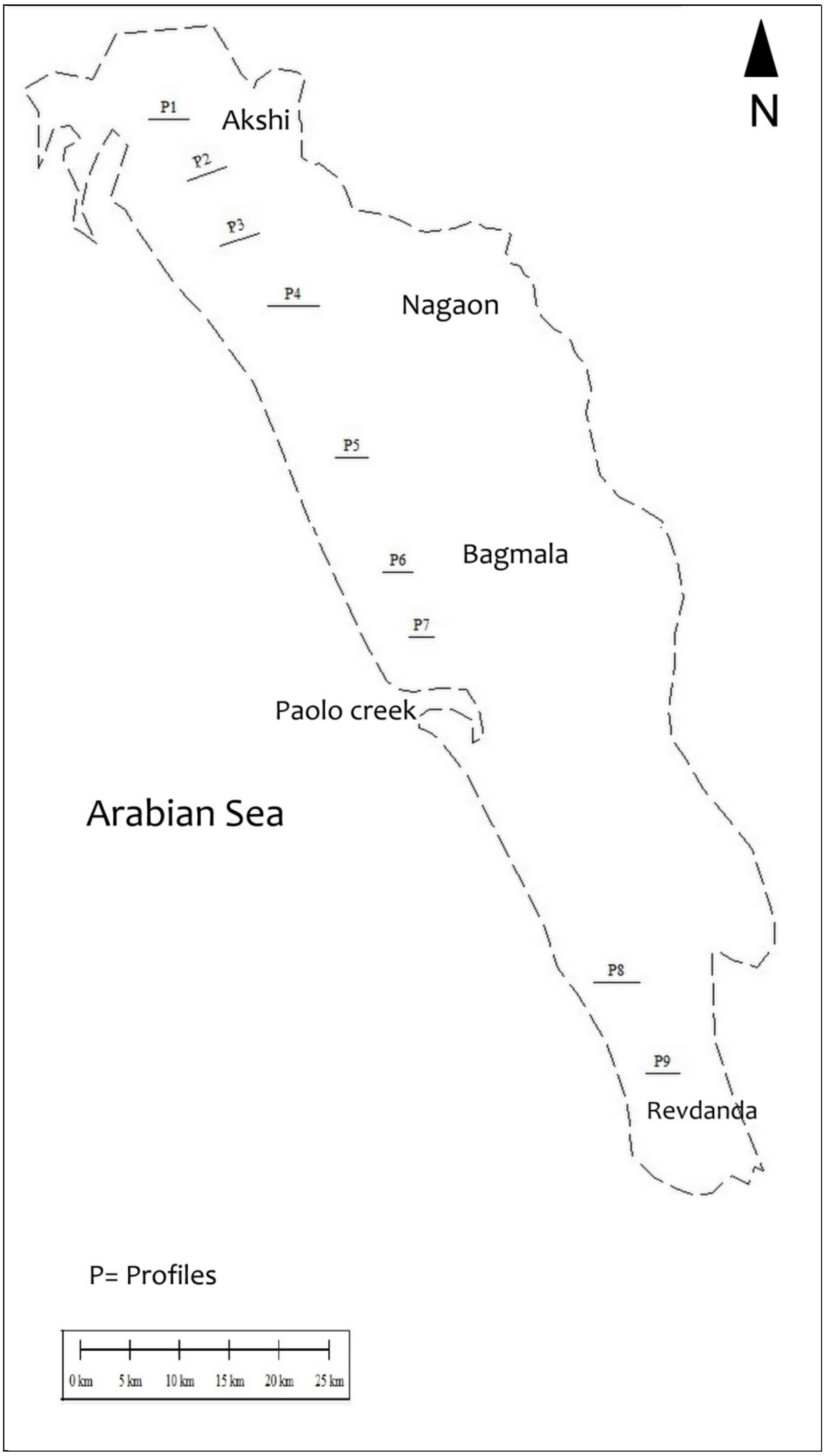

Fig: 3.1 Location of backshore profiles leveled by dumpy level

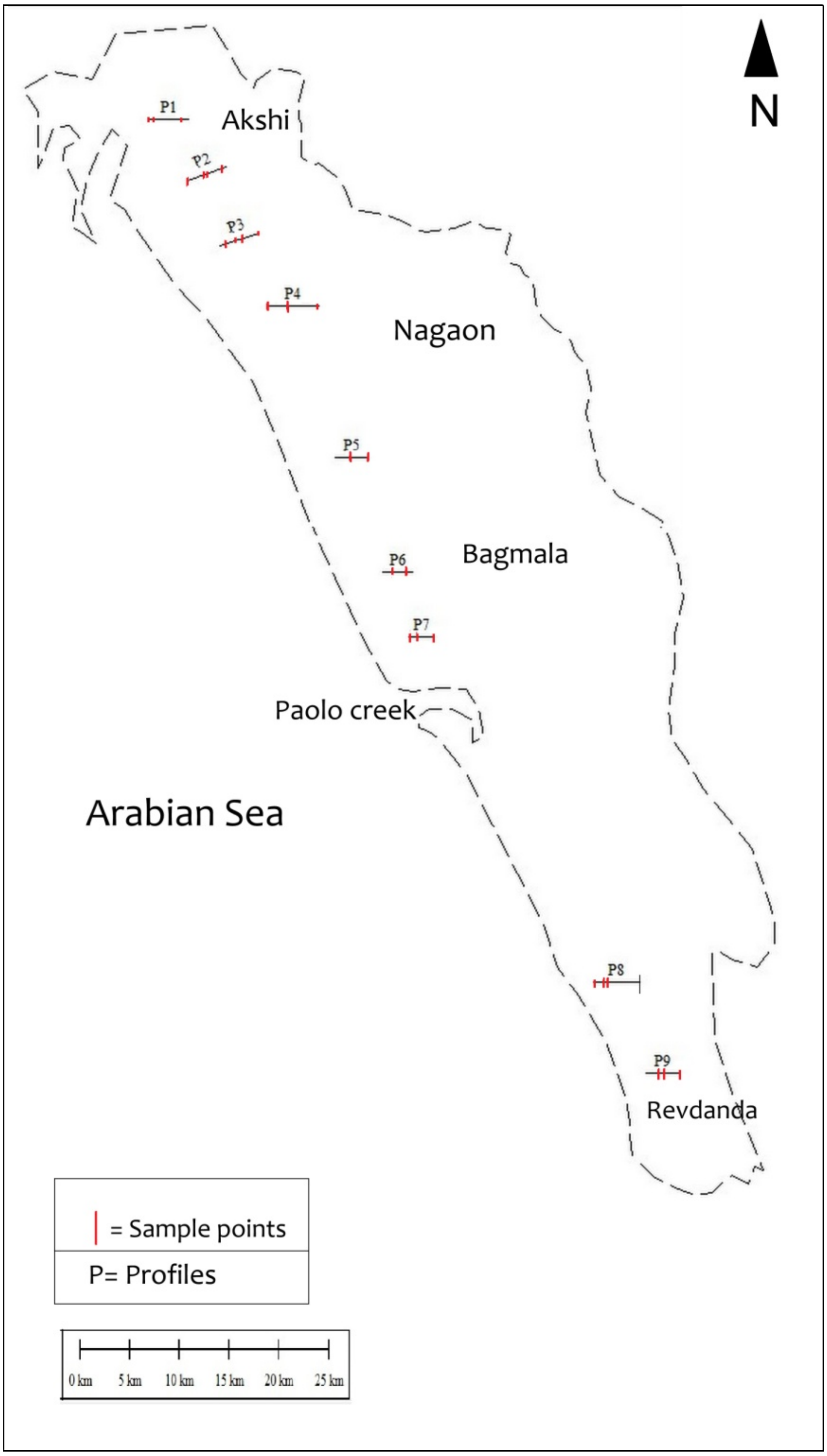

Fig: 3.2 Location of sample points on beach profiles

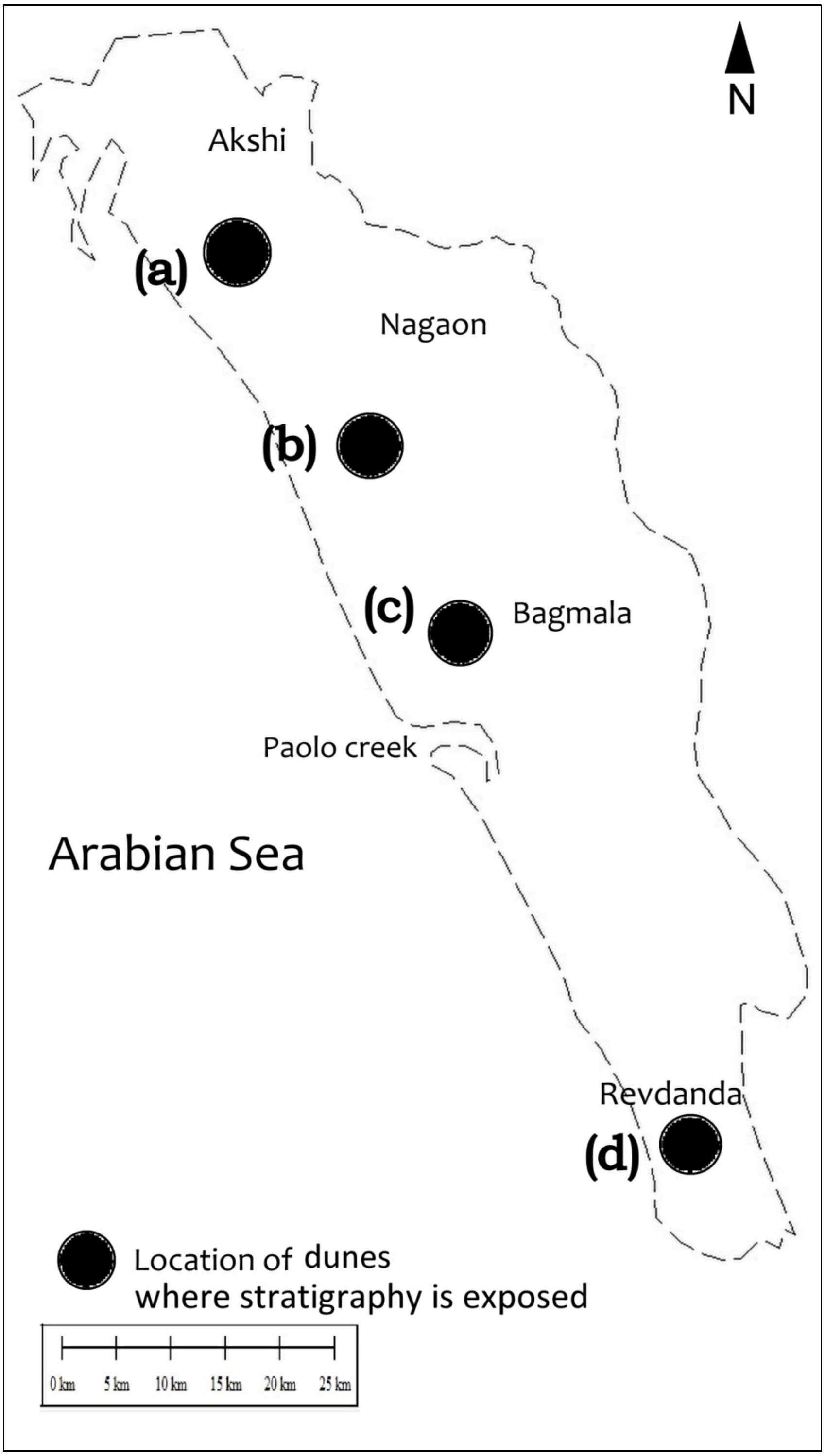

Fig:3.3 Dune Stratigraphy sites

CHAPTER FOUR

ANALYSIS AND INTERPRETATION

A. PROFILING OF BEACH AND BACKSHORE

a. The beach

In order to understand the nature of the backshore, one must study the beach which forms an integral part of foreshore-backshore system. The study of beach component was carried out by collecting information on beach width, swash zone width, wave height, wave period, longshore currents and tidal cycle (Table: 4.1). The nature of monsoon and fair weather beach sediments was learnt by the grain size analysis of sand samples that were collected at various locations along leveled beach profiles.

LENGTH	10km	
WIDTH	100m	
SWASH WIDTH	100m	
SURF ZONE WIDTH	60m	
AVERAGE SLOPE	1.6°	
TIDAL RANGE	Spring tide	Neap tide
	2.5m	1.8m
BREAKER DISTANCE FROM COAST	4km	
BREAKER WIDTH	240m	
WAVE HEIGHT	Monsoon	Fair weather
	3m to 3.5m	1m to 2m
WAVE PERIOD	Fair weather- 10 sec to 12sec Monsoon- 4sec to 6sec	

Table: 4.1 The beach parameters (*Source: Karlekar 1993, 2014, 2017)*

A total of 8 profiles were taken along 10km stretch of coast in monsoon and post-monsoon season (Fig 4.1).

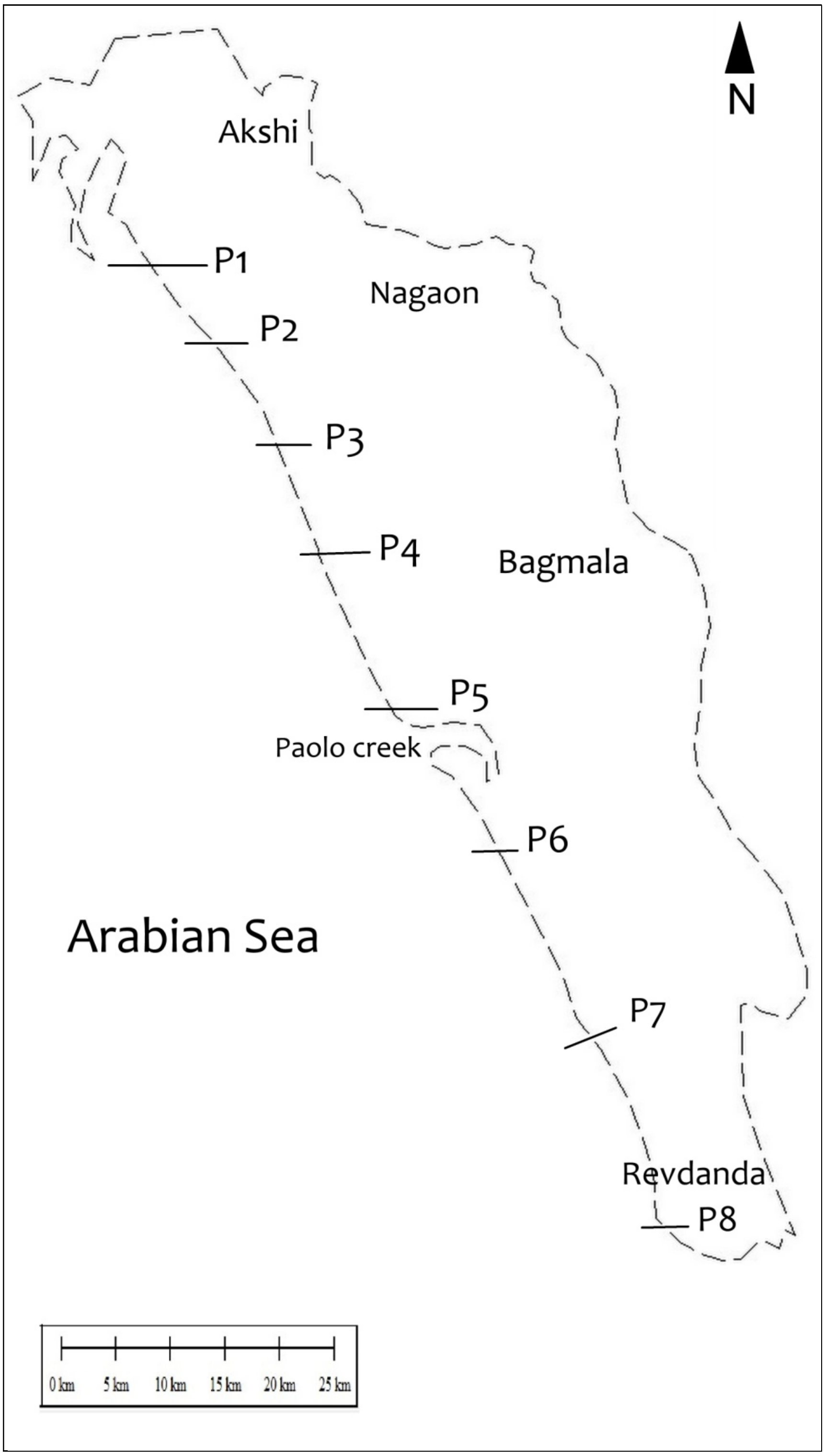

Fig: 4.1 Location of Beach profiles

The beaches on the Konkan coast are known for their dissipative nature. In the monsoon they experience high level of erosion. As the beach sediments are taken away by the stormy waves of the monsoon, the gradient gradually increases, making the beaches steep. On the other hand during post monsoon, the waves are depositional and the beach gradient gradually decreases making it gentle. The beach profiles in the study area were leveled using dumpy level in monsoon and post monsoon season (Fig: 4.2). The blue lines in the graph shows the monsoon profile, which indicates that the beaches are narrow with a steeper gradient since erosional action of waves remains prominent. Redlines in the graph indicate post monsoon profiles which show a gentler beach gradient because of the depositional action of the waves.

Ten km long beach in the study area is a wave dominated beach characterized by spring tide range of 2.5 m and neap tide range of 1.8 m. The average breaker width in near shore zone is about 60 m. The swash width is to the tune of 100 m. The 150 m wide beach is classified as a Dissipative beach (Karlekar, 2014) with an average slope of 1.8 deg.

All beaches usually are by definition dominated by waves and composed of fine to coarse textured sediments. Wave dominance on this beach is all along its length from north to south. Likewise beach sediments are dominated by fine to medium sand. The sandy beach enjoys macro tidal environment (Tidal range > 2m). The three beach zones of shoaling, surf and swash are assumed to be stationary, with minimal horizontal and vertical tidal movement.

The Beach profile:

The simplest expression of any beach is its cross-sectional profile. The beach profile records the height, width, slope and volume of a beach, while sequential profiles record changes either through time, or alongshore.

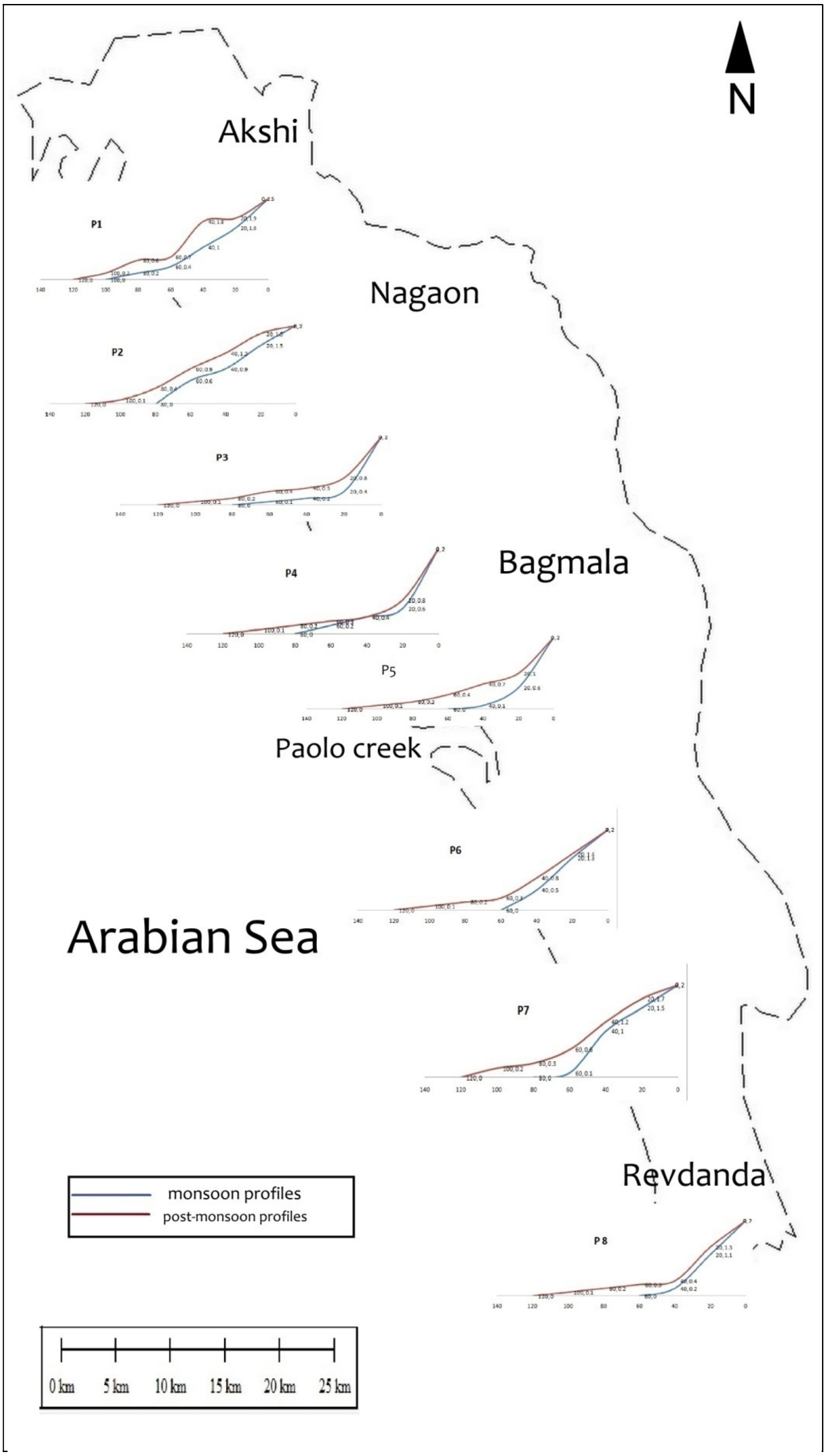

Fig:4.2 Profiles of beach sector along the study area

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Sequential beach profiles (cut and fill):

In order to link 'fair weather and monsoon ' beach profile, observations of the transition from one type of beach profile to the other is required. A distinct seasonal pattern with cut during higher monsoon waves, forming an offshore bar, and a fair weather beach fill with a relatively gentle slope , produced by lower swell waves is clearly observed (Fig 4.3) on this beach. This beach behavior is a function of wave climate in monsoon and fair weather season. Such monsoon cut and post and pre monsoon fill behavior is observed on beaches of west coast of India.

It was found that beach change in the study area was driven entirely by waves and consisted of an erosion and accretion sequence. According to Sonu and James (1973) such beach cycles usually are Markovian with each step in the sequence being dependent on the pervious beach profile as well as wave conditions. Markov models offer an objective and quantitative method of assessing beach changes.

For this beach a probabilistic first order model based on surveyed profile data was employed. This could describe and predict transitions of beach from cut to fill profiles in monsoon and fair weather seasons. Cut and fill equilibrium profiles were obtained from the sequence determined by using Markov chain analysis.

Beach level (m)	Beach fill levels in fair weather (m)	Beach cut levels in Monsoon (m)
<0.5	0.6	0.5
0.5 – 1	1.15	0.85
1 – 1.5	2.44	1.56
1.5 – 2	2.1	1.9
>2	2.53	2.47

Table: 4.2 Beach levels

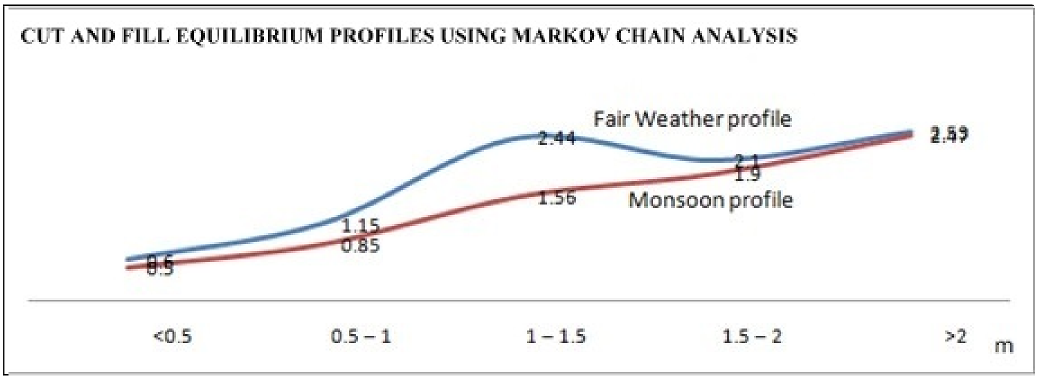

Fig: 4.3 Beach cut and fill sequence

While two dimensional beach changes is a useful indicator of gross beach behavior, it does not acknowledge the inherent three dimensional behaviors of beaches and their surf zones (Short 2000). Increasing wave height and decreasing wave period and grain size usually favor development of dissipative beaches. Based on these parameters, Karlekar (2014) classifies this beach as a dissipative beach.

Dissipative beaches normally represent the high energy end of the beach spectrum. These beaches are characterized by wide low gradient surf zones across which spilling breakers dissipate their energy, hence the name dissipative. Because of the requirement of persistent high waves only a few, high energy beaches with fine sand are modally dissipative (Short 2000). They have been reported on the coasts of Maharashtra (Karlekar 2014).

Dissipative beach in the study area is characterized by a wide(107 m), low gradient(1.8 Deg) swash zone(100 m), that extends from the foot of the dune to the low tide zone, and is more than 120 m wide at low tide, with the fine compacted sand (Karlekar,2014). The swash zone is usually flat and featureless, apart from occasional widely spaced cusps on the high tide beach, and backwash induced ripple features across the low tide beach. The surf zone is usually between 50 and 60 meters wide and contains at least two subdued shore parallel bars and troughs. The dune face, beach, shoreline, troughs and bars are parallel and with minimal long shore variation in morphology.

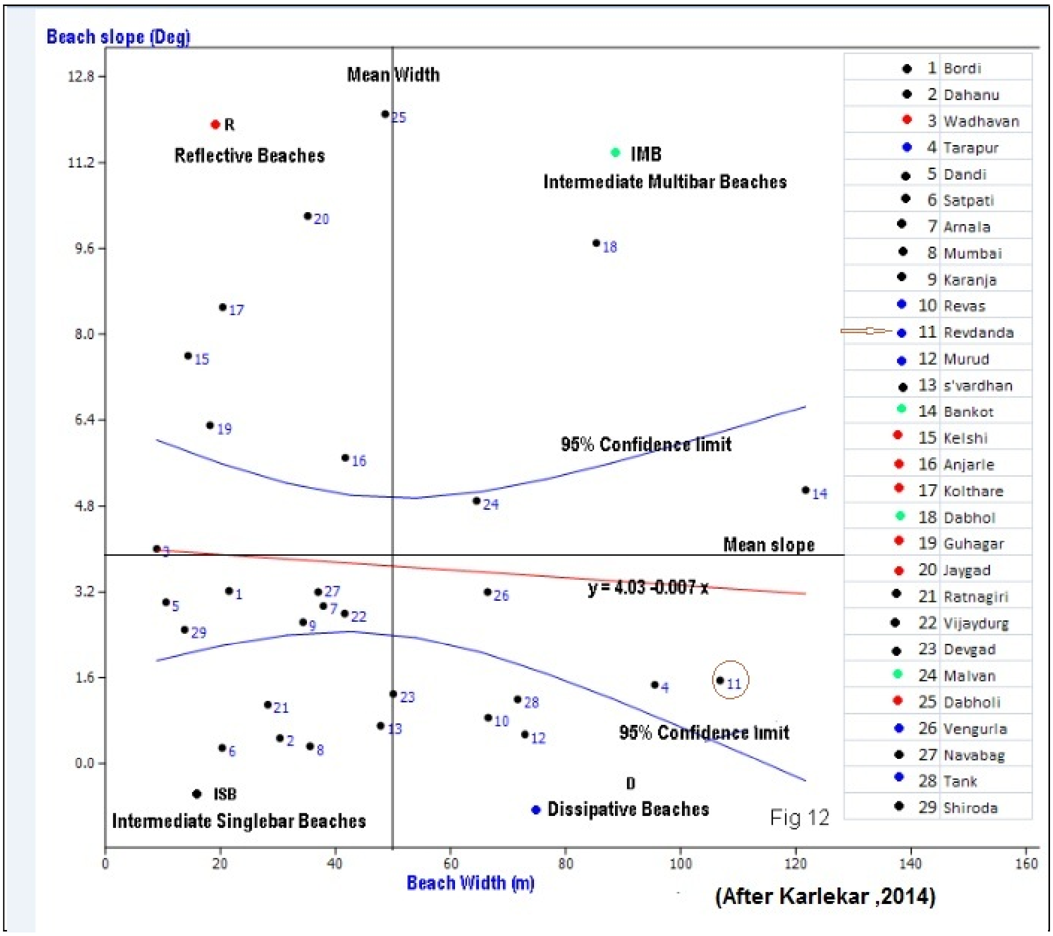

Fig: 4.3 Types and nature of beaches along the Konkan coast

Wave breaking in offshore area begins as high, steep spilling breakers over a broad 240 m wide breaker zone (Karlekar, 2014). Currents are driven by both the spilling breakers and long waves. Incident waves gradually decay towards the beach. During oblique waves in monsoon, long shore currents are strong due to the large energy dissipation.

The fine beach sand produces a wide, low gradient beach, with the high tide swash reaching to the back of the beach. A reduction in the near shore slope resulting in incident wave dissipation could be easily observed.

This Dissipative beach tends to have a relatively stable morphology. It exhibits minimal shoreline change. This can be attributed to a number of factors. (Short and Hesp, 1982, Short, 1983). First, the fine low gradient profile is less susceptible to change compared to steeper, coarser profiles. Second, the beach is suited to high storm waves, and consequently experiences little erosion during storm events. Third, coupled with this is the fact that the beach accommodates higher waves by causing them to break further seaward on the gentle near shore slope thereby dissipating the energy over a wider surf zone. Fourth, the greater dissipation in turn increases the elevation of wave set-up which accommodates the greater inshore volume of water. There is minimal long shore variation, which minimizes the need for spatial or temporal readjustment. Such conditions have resulted in a situation where the topography is in a state of equilibrium with the hydrodynamics, and the morphology relatively stable (Fig: 4.3).

Beach sediments are characterized by very fine sand due to continuous wave action which smoothen the particles. Apart from some rocky beaches, Konkan contains mostly of sandy beaches, the study area being of no exception. It is very evident from the table, that the samples belong to the beach sector due to the high proportion of **very fine sand**. The only two exceptional values were seen in the samples taken from the third profile and the last profile near Revdanda. The reason for the increased proportion of **medium sand** near third profile was the ongoing construction along the dune section that lead to the mixing of building materials with the beach sediment; whereas, near Revdanda the higher proportion of medium sand is due to two reasons:

i) Mixing of both fluvial and marine sediment takes place in the Kundalika creek.
ii) The south west direction of the waves let the sediment to deposit in the first obstruction which happens to be the Revdanda coast.

The result of grain size analysis of the samples collected from the beach are shown in table 4.4

PROFILE	SAMPLE	MEAN	SORTING	SKEWNESS	KURTOSIS	COARSE SAND%	MEDIUM SAND%	FINE SAND%	VERY FINE SAND%
N 1	1	3.44	0.47	-0.53	1.48	1.6	3.8	4	90.6
2	1	3.31	0.46	-0.02	1.4	2.1	3.5	9.1	85.3
3	1	3.19	0.47	-0.04	0.95	22.8	40.3	13.9	23
	2	3.49	0.36	-0.48	2.43	0.6	3.4	16	80
4	1	3.44	0.61	-0.64	2.17	0.9	2.6	4	92.5
	2	3.44	0.37	-0.47	1.05	2.9	8.2	3.1	85.7
5	1	3.47	0.36	-0.45	1.02	1	1.4	4.3	93.3
	2	3.43	0.51	-0.59	1.72	2.1	4.6	4.5	88.7
6	1	3.32	0.75	-0.62	1.72	4.6	7.9	7.4	80.2
7	1	3.47	0.37	-0.46	1.05	0.9	1.6	5	91.8
	2	3.37	0.52	-0.09	1.2	1.9	3.8	7.4	86.8
8	1	3.09	0.9	-0.63	0.86	1.2	18	18.4	62.4
	2	2.27	0.99	-0.28	0.96	10.5	38.8	26.2	24.4
S	3	1.93	1.22	-0.15	0.89	22.8	40.3	13.9	23

Table: 4.4 Result of analysis of sediments from beach profiles

The linear trend surface analysis for the mean sediment size reveals that the general tendency of the sediment value during monsoon is on the medium to finer side due to the extensive mixing, while during the post monsoon the sediments are finer in nature (Fig:4.5).

The **trend surface** analysis equation for **Monsoon** beach sediment size:

Z= 1.30 - .0008X - .001Y (EV 40 %)

The **trend surface** analysis equation for **Post-monsoon** beach sediments size:

Z= -1.43 +.013X+.0006Y (EV 70%)

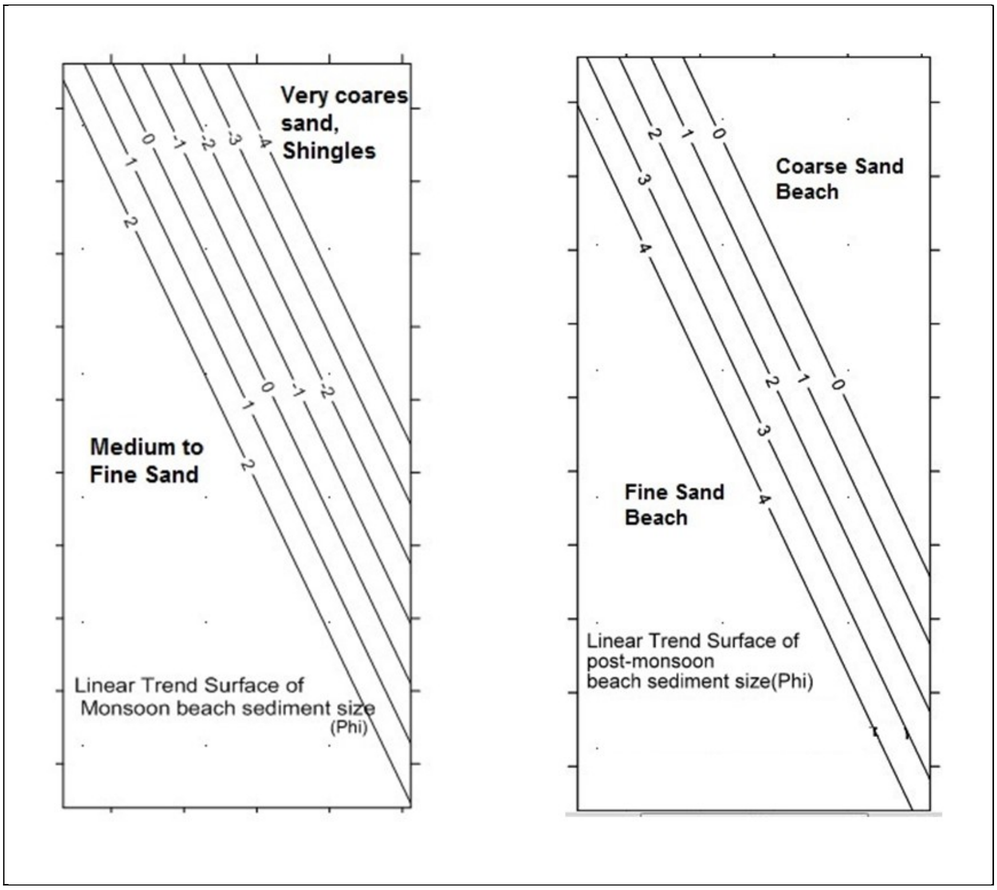

Fig: 4.5 Linear trend surface analysis of beach sediments

Isoline maps prepared for beach levels and slopes on the basis of the mean sediment size values, for both monsoon and fair weather seasons, showed a drastic difference (Fig:4.6, 4.7 respectively).

During pre monsoon the beaches experience alternate erosion and accretion and have maximum growth. With the development of berms and wide foreshore, the beach is very wide and extensive in nature. On contrary in the monsoon season, the beach level reduces to minimum slope due to storm surges and high wave activities.

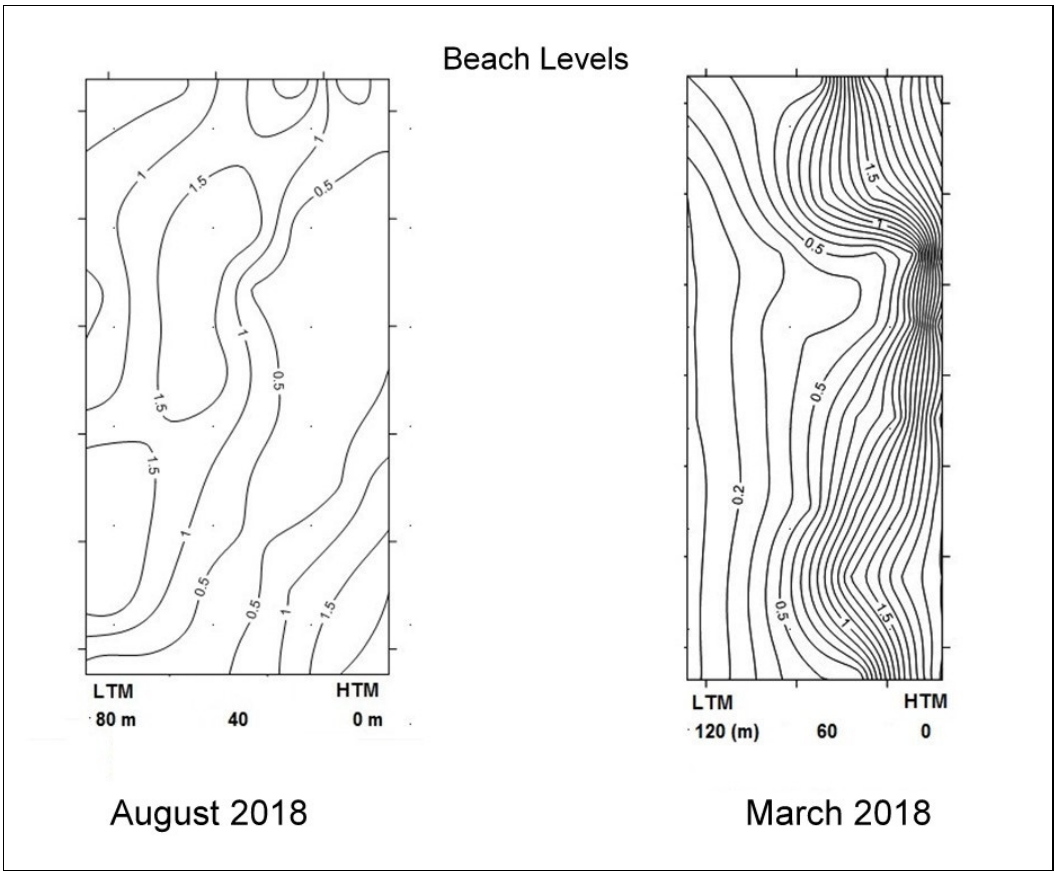

Fig: 4.6 Beach level contours

The beach slope can be studied as a function of sediment size. During south west monsoon, beach experiences maximum erosion with narrow foreshore and concave beach slope. Due to high wind velocity present near the Kundalika creek and increased amount of mixing, the mean sediment size is higher in the southern part from the rest of it. Thus the slope across the beach remains more or less same with an exception of Revdanda. On the other hand the beach experiences replenishment during the post monsoon season with medium to fine sand. The slope scenarios also showed a more consistent and a gentler slope all across and along the beach (Fig:4.8).

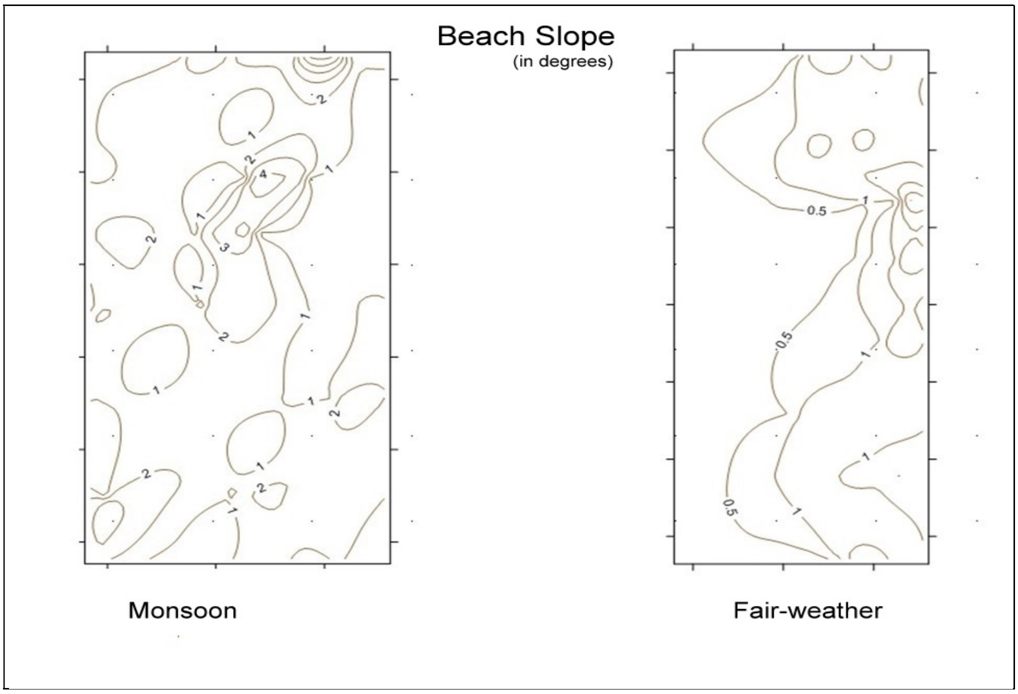

Fig: 4.7 Beach slope contours

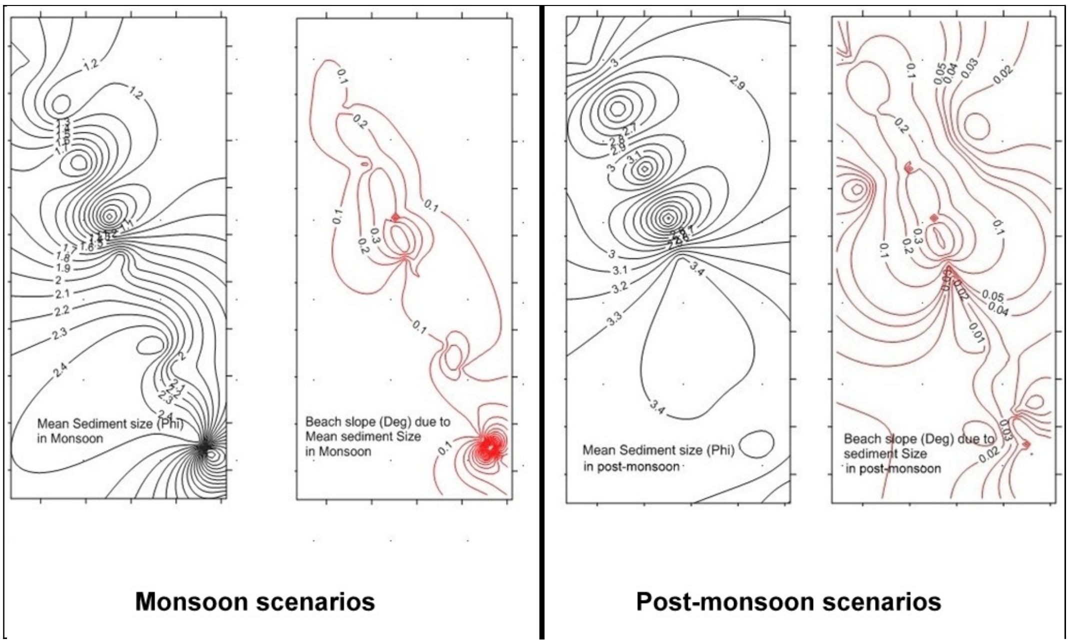

Fig: 4.8 Contours depicting relationship between mean sediment size and beach slope

b. The backshore

The various segment of backshore morphology were ascertained by carrying out profile leveling using dumpy level. The north-south extent of about 10km length was covered in 9 profiles. The location of these profiles is shown in fig 4.9.

The berm, dunes and terraces are the major segment of the backshore in study area. Necessary samples were collected from relevant locations along each profile and were subsequently analyzed by mechanical sieving. The results are given in table 4.3, and the profiles are discussed in the following paragraphs.

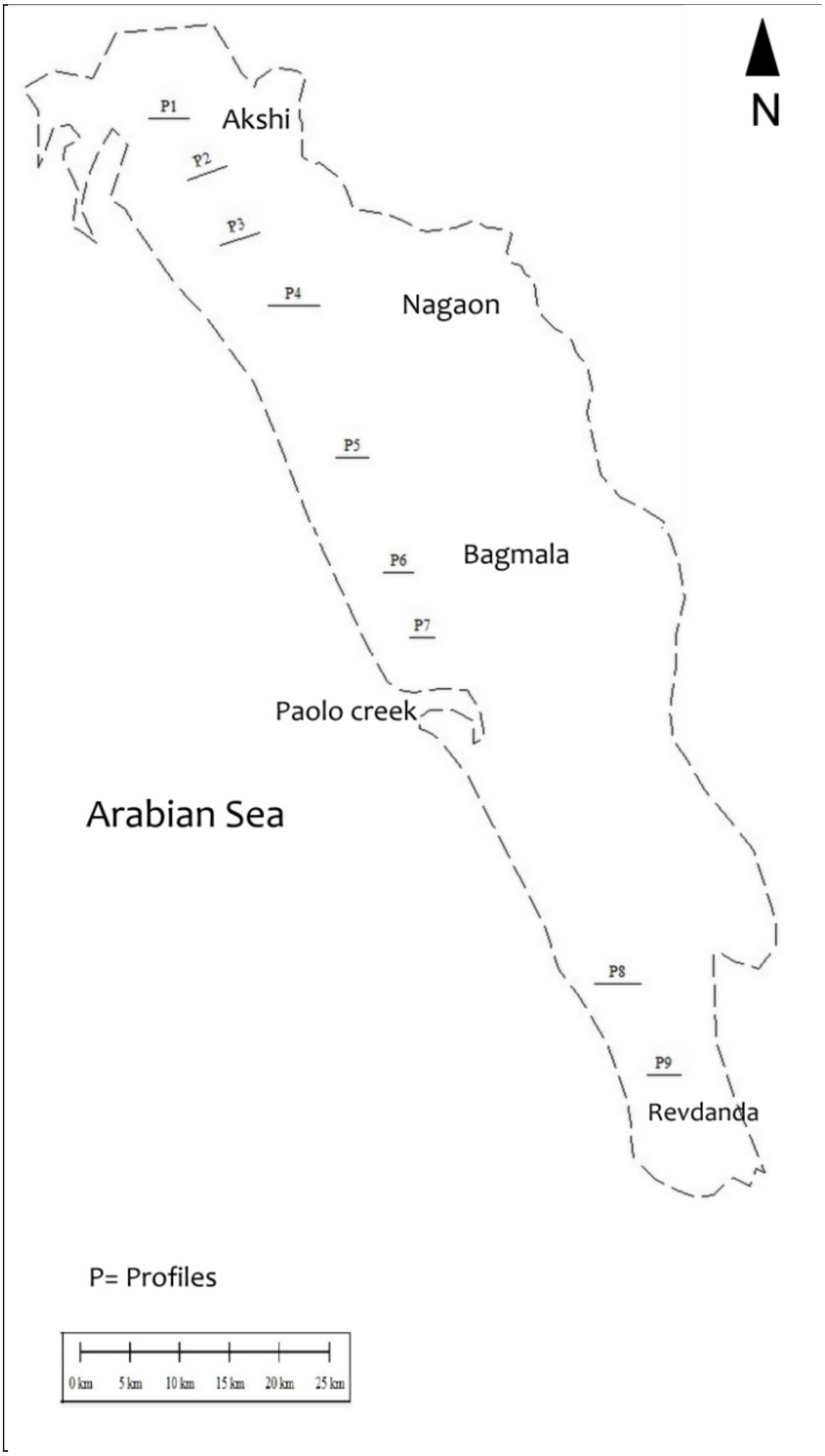

Fig: 4.9 Location of backshore profiles

PROFILE	SAMPLE	DISTANCE FROM THE BEACH(BERM LINE)	MEAN SEDIMENT SIZE(phi)	SandType	SORTING(phi)	Type	SKEWNESS	Type	KURTOSIS	Type	MEDIAN D50	Type
1	1	15.05	3.3	very fine	0.5	well	-0.12	coarse	1.3	lepto	3.31	LE
	2	38.25	3.49	very fine	0.61	moderately well	-0.15	coarse	1.88	very lepto	3.45	LE
	3	71.39	2.04	fine	1.16	poorly	-0.3	coarse	0.92	meso	2.28	LE
2	1	4	1.85	medium	1.2	poorly	0.47	very fine	0.68	platy	1.36	LE
	2	132.35	0.92	coarse	1.08	poorly	0.57	very fine	1.05	meso	0.57	LE
	3	137.7	2.57	very fine	1.22	poorly	-0.55	very coarse	1.19	lepto	3.06	LE
	4	153.46	2.29	fine	1.3	poorly	-0.51	very coarse	0.67	platy	2.81	LE
3	1	23.93	1.56	medium	1.35	poorly	0.12	fine	0.5	very platy	1.49	LE
	2	55.39	0.85	coarse	1.01	poorly	0.63	very fine	0.94	meso	0.47	LE
	3	75.78	3.43	very fine	0.43	well	0.05	symmetrical	1.2	lepto	3.39	LE
	4	119.98	0.69	coarse	1.03	poorly	0.94	very fine	1.31	lepto	0.07	LE
4	1	27.57	3.1	very fine	1.05	poorly	-0.73	very coarse	1.65	very lepto	3.64	LE
	2	148.3	1.63	medium	1.44	poorly	0.17	fine	0.5	very platy	1.5	LE
5	1	18.44	3.19	very fine	0.7	moderately well	-0.24	coarse	1.81	very lepto	3.25	LP
	2	150.84	1.74	medium	1.32	poorly	0.74	very fine	0.56	very platy	0.43	LP
6	1	18.03	1.9	medium	1.48	poorly	-0.17	coarse	0.68	platy	2.19	LE
	2	55.28	1.94	medium	1.29	poorly	-0.21	coarse	0.79	platy	2.19	LE
7	1	9.3	2.25	very fine	1.28	poorly	-0.66	very coarse	0.76	platy	3.02	LE
	2	26.01	1.6	medium	0.63	moderately well	0.09	symmetrical	1.24	lepto	1.56	LE
	3	65.87	1.63	medium	1.41	poorly	0.07	symmetrical	0.54	very platy	1.66	LE
8	1	11.5	3.07	very fine	0.45	well	-0.11	coarse	1.44	lepto	3.11	LE
	2	25	3.19	very fine	0.42	well	0.02	symmetrical	1.45	lepto	3.16	LE
	3	29.1	2.89	fine	0.56	moderately well	-0.36	very coarse	1.18	lepto	3.03	LE
	4	35.8	2.69	fine	0.65	moderately well	-0.03	symmetrical	0.97	meso	2.7	LE
9	1	33.63	3.26	very fine	0.45	well	0.07	symmetrical	1.25	lepto	3.22	LE
	2	46.03	3.14	very fine	0.56	moderately well	-0.17	coarse	1.33	lepto	3.18	LE
	3	131.34	2.58	fine	1.31	poorly	-0.48	very coarse	1.34	lepto	3.04	LE

Table:4.5 Results of the mechanical sieving of the sediment samples collected from the profiles

The dumpy level points were plotted in excel sheet as the following:

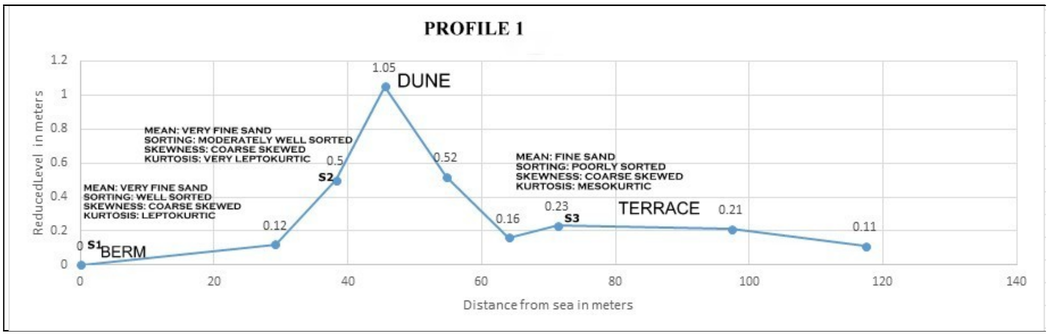

Fig: 4.10.1

The northern most backshore profile near Akshi showed the presence of berm with well sorted and very fine sand. Sediments on the dune sector comprise of fine sand with moderate sorting. The sand on the leeward side of the primary dune is poorly sorted. The terrace section of the profile is covered by windblown fine sand. Sorting here is very poor because sediment here is mostly of mixed origin.

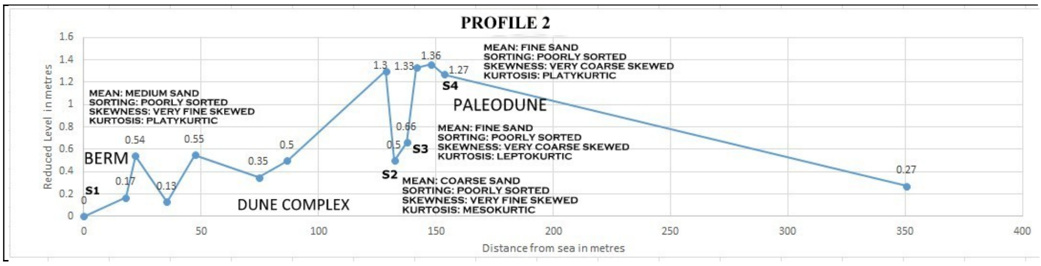

Fig: 4.10.2

To the south of Akshi lie the second and perhaps the most complex region of study area. Here the berm is prominent enough with a height of about 54cm. Berm here is completely independent of any beach influence. The fine sand deposition is generally the result of suspended materials and produced by wind moving from beach to dune and further, while the coarser material creeps and accumulates near the foot of the dune. A complex dune structure is here with a proper primary dune, an inter-dunal area and a back dune followed by a terrace which was evident by the drop in the elevation. The sediment analysis shows that the sediment is of fine nature on and around dunes, but sorting is very poor in both inter-dunal area and area beyond that. The very coarse skewed material proves that the back dune sediment is essentially mixed in character.

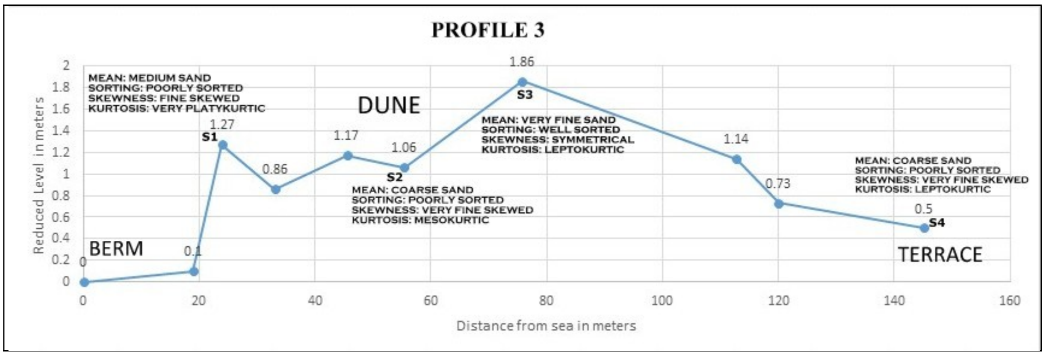

Fig: 4.10.3

At the site of third profile, severe construction is going on leading to the mixing of sediments and construction materials. Cover of medium sand was found on top of the dune where generally the fine material is expected. That is because of the mixing of construction materials with the wind blown beach sediments. Berm here is not as prominent as to collect sediment samples; there were mostly beach materials in the berm region. For most part of the dunes, the sediments were coarser in nature. On the top of the dune section which is a little far from all the building activity, very fine sand is found following a drop in the terrain level leading to the adjoining terrace bordered by a tidal channel..

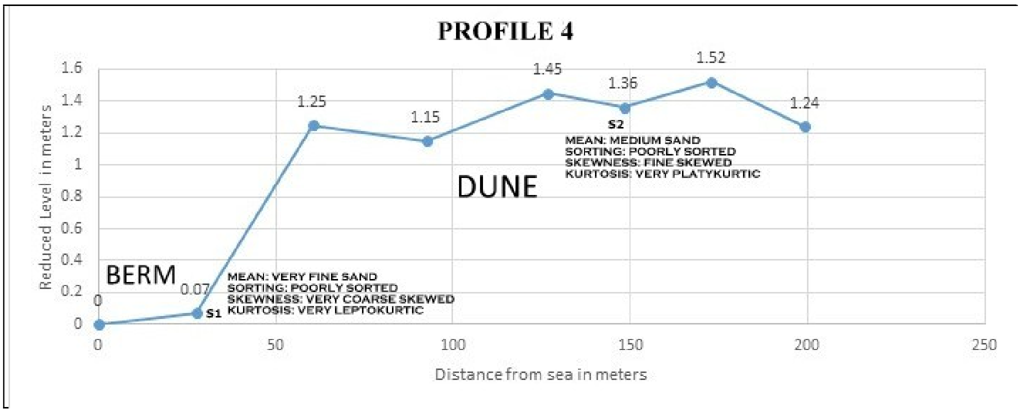

Fig: 4.10.4

At the location of profile 4, the backshore is much disturbed. Berm structure is very prominent however. It is covered by very fine sand which is poorly sorted at the foot of the dune. The dune zone is completely modified by building of roads and shops.

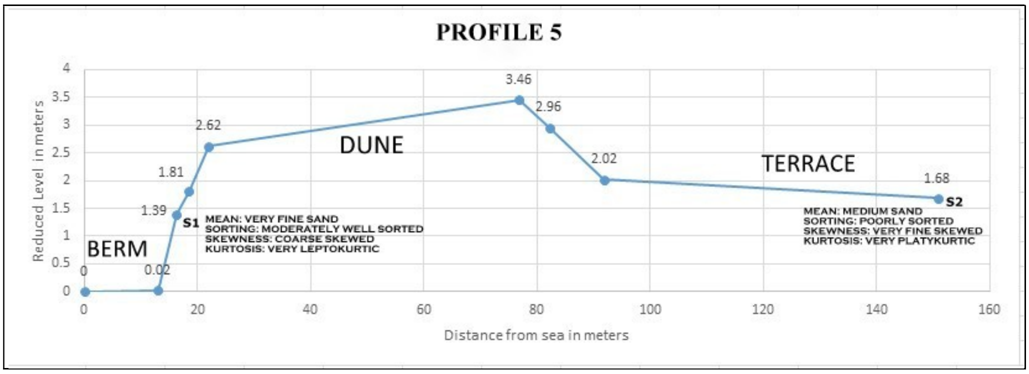

Fig: 4.10.5

The fifth profile was again seen to be in a proper shape as the dune is protected by trees and was protected by the anti-erosional wall. Berm is not much prominent here since the material of the wall intruded the berm sector. The dune has very fine aeolian sand which is moderately sorted. Not much change in sediment is evident on the dune. The dune is backed by the drop in elevation and presence of a littoral terrace. The terrace is used for the construction of the houses in the settlement.

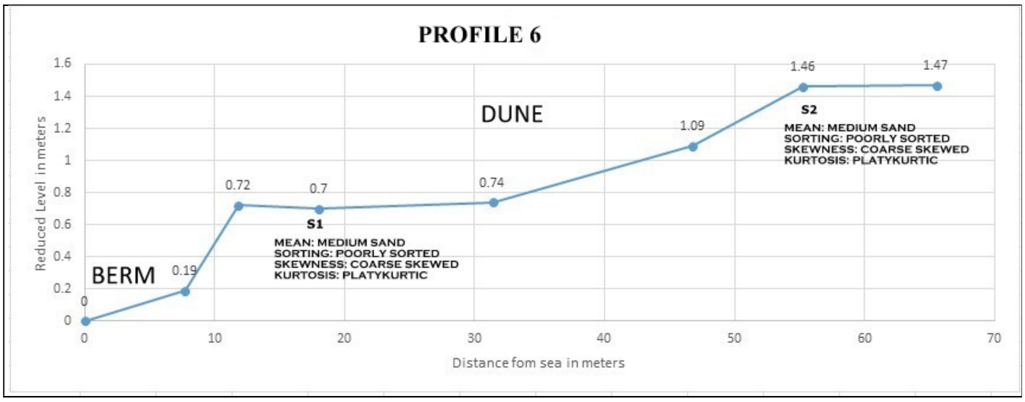

Fig: 4.10.6

The sixth profile has a similar topographic situation like in profile number four. Berm, however, is not much prominent due to the presence of the concrete materials getting mixed from the anti erosional wall. Due to the presence of the anti-erosional wall, dune is protected and thus one can see an extensive stretch of dune zone. The terrace or the back dune area is not fully exposed due to the constructional activities.

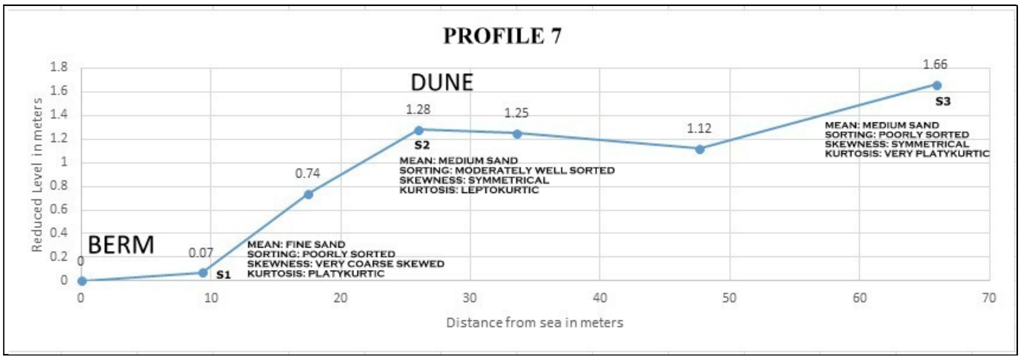

Fig: 4.10.7

A proper berm and dune is seen near the site of profile number 7. Beyond that the morphology is disturbed by anthropogenic activities. Sediment here comprises of fine sand around the berm area. Apart from that, as we go up the dune, the sorting index suggests mixing of beach material with older sediments.

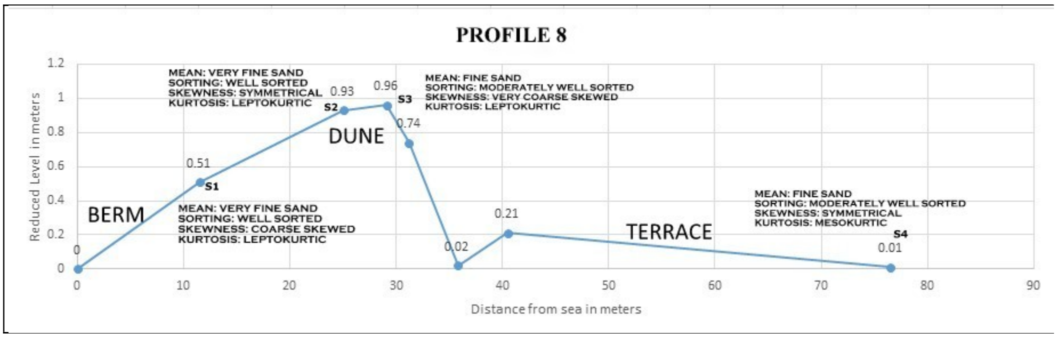

Fig: 4.10.8

Profile 8 lies near the south of Paulo creek and the profile is covered by the presence of vegetation on the backshore, especially ipomoea. Berm here is not prominent. However, dune is well preserved with well sorted fine sediment material. Terrace is present beyond the dune but it is mostly reclaimed for building settlements.

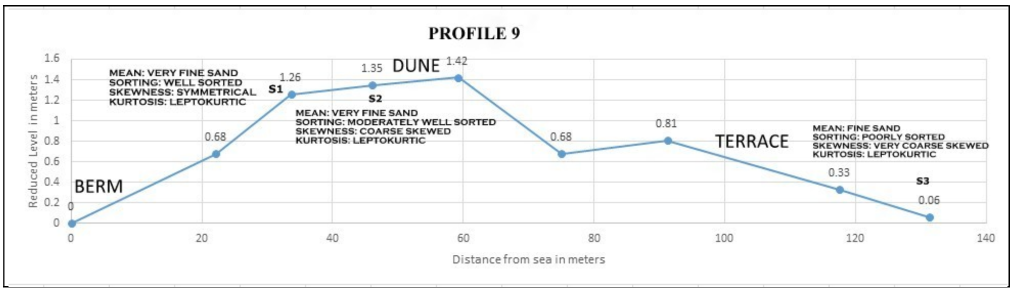

Fig: 4.10.9

Very low dune, almost absent berm section and terrace being used for paddy cultivation are the three essential components that describe the backshore which lies south of Paulo creek and mostly around Revdanda. Dunes are covered by well sorted fine sand. The littoral terrace comprises of both windblown recent sediment and older sand, and hence sediment sorting here is poor in nature.

The wireframe 3D model of dune sector in the study area shows the dune development in the backshore. Both east-west (along) and north-south (across) profiles are also shown separately to understand the effect of wind movement (Fig: 4.11). The along and across diagram help to establish a relation between the wind movement and the pattern of sand deposited. The dune sector in the area is a result of wind blowing orthogonal to the beach as well as along north-south direction. Change in dune formation is seen when both along and across profiles are read separately. Features like blowouts or inter-dunal areas gets effected as the wind changes its direction.

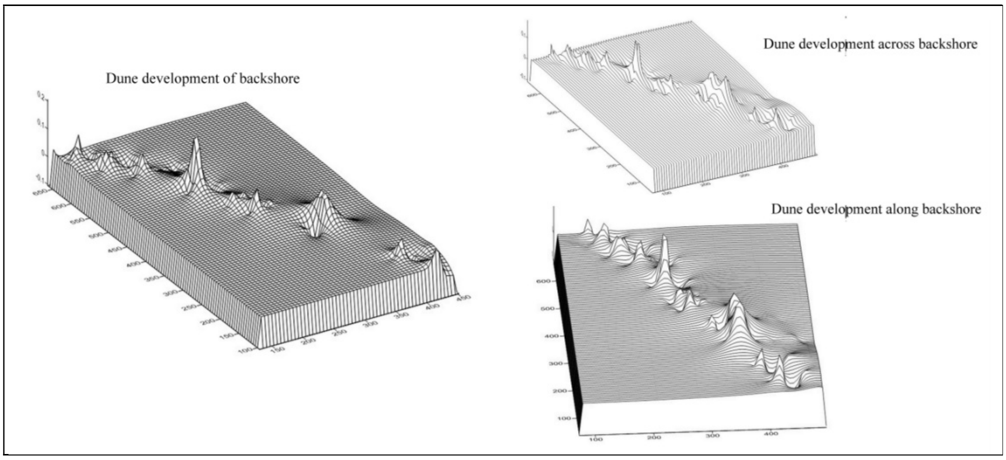

Fig: 4.11 Wireframe model of dune development

The contour map of dune elevation along with the first and second derivatives shows that the majority of the study area is dotted by low level dunes which are the characteristics of Konkan coast; however, in the northern section of the study area shows considerable dune heights in compare to southern section due to less anthropogenic activities. Southern zone of the study area is more prone to anthropogenic processes that effected the development of the dunes (Fig 4.11.1).

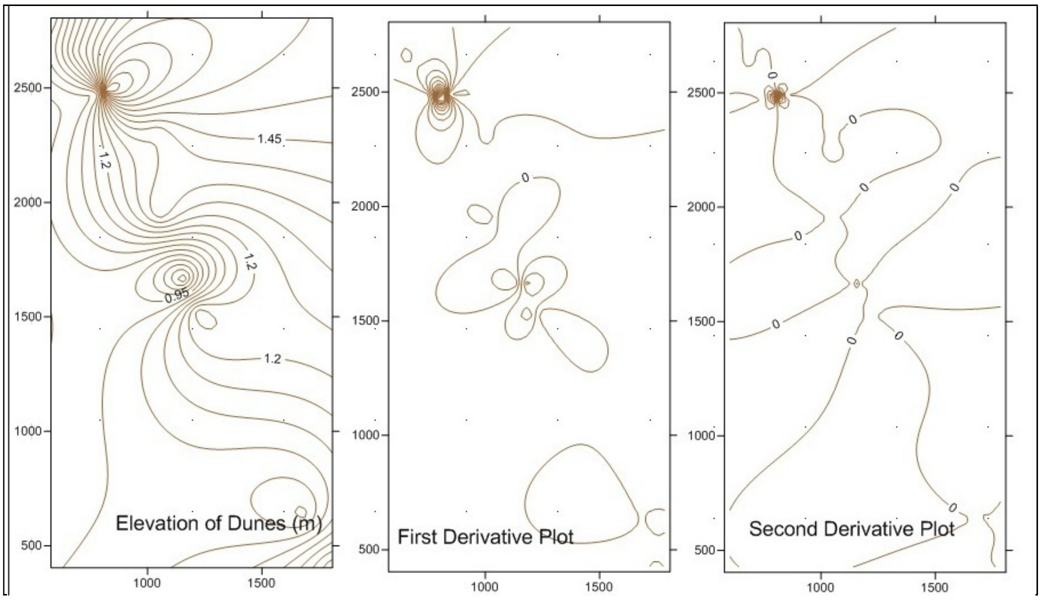

Fig: 4.11.1 Dune elevation contours

The directional derivatives of the dune elevation and their wireframe 3D models convincingly elaborate the micro changes that are difficult to identify in the field. The wireframe helps in keeping the height value constant at each intersection of the XY value whereas the directional derivatives provide us with the information about the rate of change of slope of a specified surface at a given direction. The difference between the first and second derivative is precision. Both calculate and bring forth the non-discernable patterns in the study area (Fig: 4.11.2). The first and second derivative of dune development shows different patterns in both across and along the beach that was not seen in the earlier diagram.

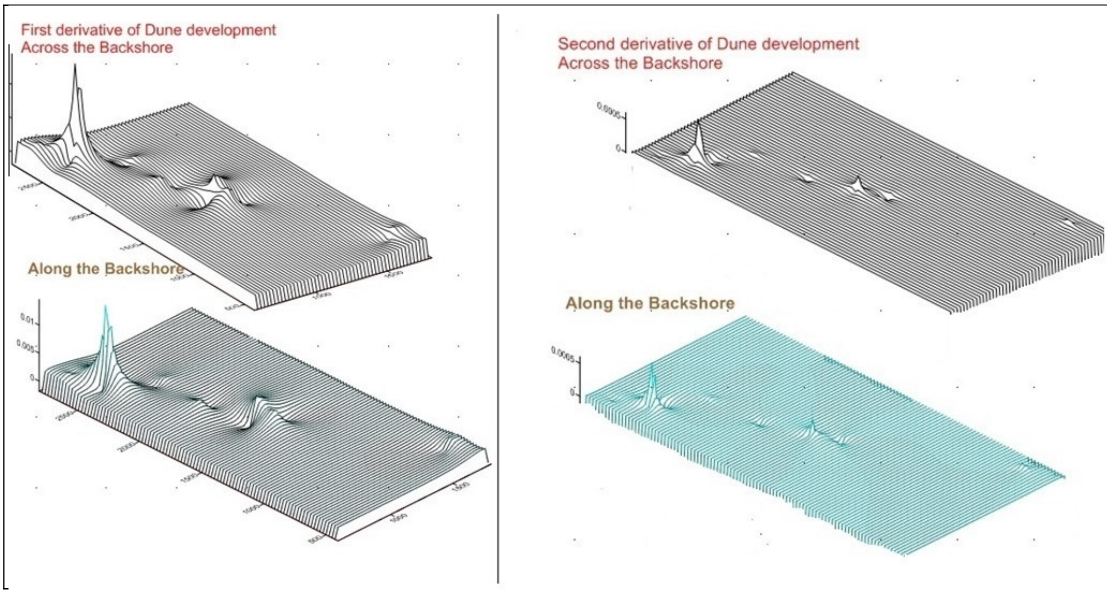

Fig: 4.11.2 Derivative wireframe diagram of dunes to identify the non-discernible features

B. SEDIMENT ANALYSIS: NATURE AND MOVEMENT

The difference in grain texture and size helps in formation of distinct environmentally sensitive sediment population. A number of theoretical and empirical experimental attempts have been made to quantify the grain transport rate, mostly by using sheer wind velocity measurement or sediment traps.

However, for many size distributions, the complicated nature of data makes a graphical display always helpful. Taking that into consideration, for the current study we used probability graph to show the size frequency spectrum in term of weight in a specific size interval because it can be used in identifying the distinctive inflections. It also help us to know about separate component where mixing is suspected.

A probability plot is graph that can be used to evaluate the fit of a distribution of the data, estimate percentages, and compare different sample distributions. It is useful for any method of sampling that utilizes some form of random selection

The advantage of the probability curve is that it creates an estimated cumulative distribution from the samples by plotting the value of each observation against its estimated cumulative occurrences.

The scales are transformed so that the fitted distribution forms a straight line. A good distribution fit is one where the observations are near the fitted line. It also helps us in estimating internal sorting.

Such profiles are drawn for the entire backshore area between North and South end. A break or change in plot signifies the change in the grain size leading to the change in the movement pattern. The weight of the sediment and their percentage contribution in a particular process became prominent when they were measured separately within each segment between the breaks in the profile, from the probability plot.

All the values from the graph, for a single segment, were collected and statistically analyzed; which gave us the mean, median, standard deviation (sorting), skewness and kurtosis for that particular segment. Such quantitative analysis is done for all the probability plots. The segment wise statistical calculations let us know about a particular process that is going on in that region.

Samples collected from near the berm face showed completely different numeric figures than the ones collected from further landward of the backshore. The numerical evidence itself spoke about the morphological features from where the samples are collected. Field truthing with the dumpy level data only confirmed what already we knew from the quantitative analysis of the sediment samples.

Representative probability plots for four samples were collected from beach limit (S1) berms, (S2) dune face, (S3) dune, and (S4) terrace (Fig 4.12).

The grain-size analysis of the sediment samples usually provides the size frequency spectrum in terms of weight or volume present in a specific size interval. Plotting of the results of single sample analysis on a probability paper no doubt enables us to know about the sediment distribution properties such as mean, median, standard deviation, skewness and kurtosis but it also helps in the identification of processes by which the sediment is deposited.

Certain process cannot be interpreted directly from ordinary statistical techniques. This is the advantage of using probability plots especially when it comes to beach and dune sediment samples. In order to identify different processes, segments on probability curve, should be studied separately. Identification of such process segments helps in improving the interpretation of the process dominant in the deposition of the said segment.

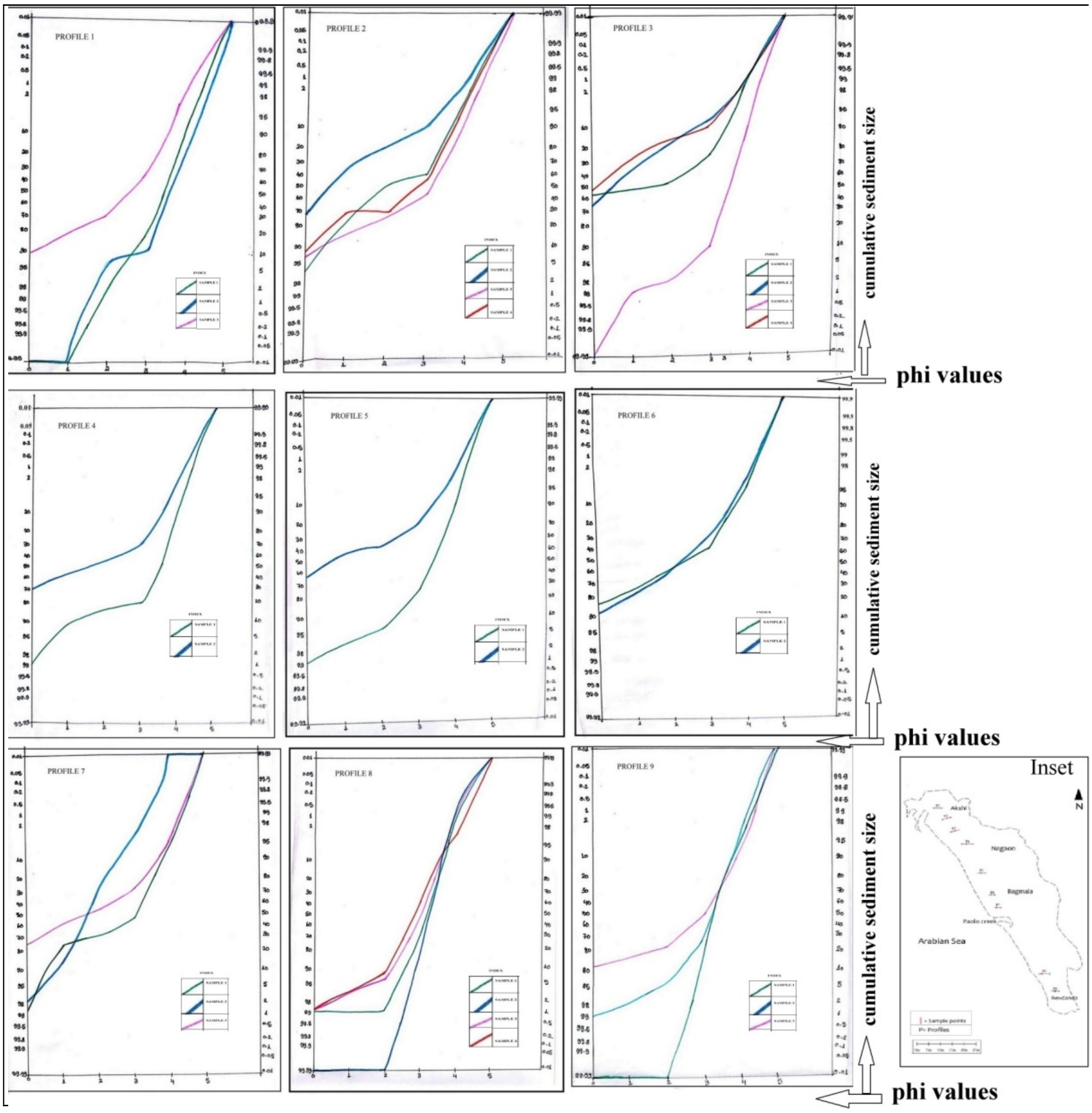

Fig: 4.12 Sediment movement analyses of the backshore profiles

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Three common segments were identified by Moss (1962-63), on probability plot. Two of these are tails and another is the middle portion of the curve. Tanner (2009) designated these segments as “coarse tail”, “central segment”, and “fine tail”.

Important hydrodynamic and process changes could be identified no matter from where the samples are selected from the beach or back-beach. The cumulative sand grain weight against size of the fine tail on the probability plot corresponds to the sediment load carried in suspension. The coarser tail is considered to represent the movement by surface creep, the central segment represents the movement of saltation, and the fine tail is considered as the movement of suspension. They show the north to south variations in the amount of sand moving by the process of saltation, surface creep and suspension respectively (Table 4.6).

SAMPLES	SURCFACE CREEP(%)	SALTATION(%)	SUSPENSION(%)
PROFILE 1			
SAMPLE 1	0	19	81
SAMPLE 2	7	3	90
SAMPLE 3	30	38	32
PROFILE 2			
SAMPLE 1	52	10	38
SAMPLE 2	66	24	10
SAMPLE 3	16	28	56
SAMPLE 4	29	27	44
PROFILE 3			
SAMPLE 1	52	22	26
SAMPLE 2	63	29	8
SAMPLE 3	1	7	92
SAMPLE 4	84	6	10
PROFILE 4			
SAMPLE 1	9	11	80
SAMPLE 2	45	25	30
PROFILE 5			
SAMPLE 1	6	19	75
SAMPLE 2	63	19	18
PROFILE 6			
SAMPLE 1	63	33	4
SAMPLE 2	72	25	3
PROFILE 7			
SAMPLE 1	27	19	53
SAMPLE 2	71	29	0
SAMPLE 3	53	42	5
PROFILE 8			
SAMPLE 1	1	98	1
SAMPLE 2	0	99	1
SAMPLE 3	6	93	1
SAMPLE 4	8	82	10
PROFILE 9			
SAMPLE 1	0	19	81
SAMPLE 2	5	22	73
SAMPLE 3	21	26	53

Table: 4.6 Percentage sediment movements

Process wise sand deposition in dune zone could be thus ascertained by using probability graph prepared to show the sand distribution in various size classes and coarse tail, fine tail and central segment proportion indicative of surface creep, suspension and saltation respectively.

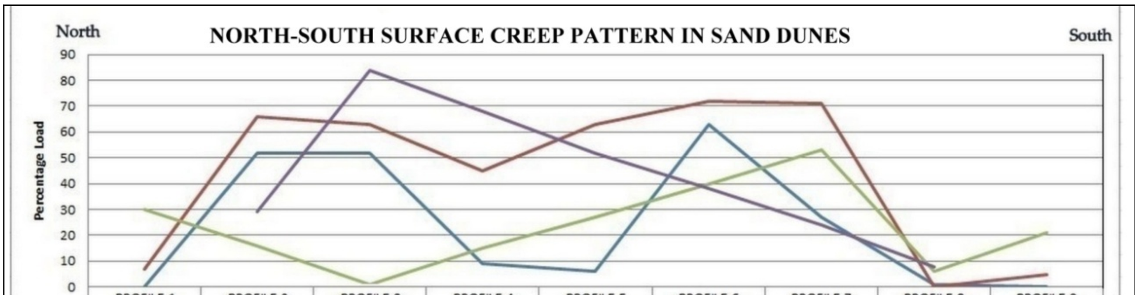
The results were plotted to show the north south variation in the amount of sand deposited by these processes.

The amount of sand deposited in the dune sector mainly by process of surface creep in more than 50%. It slowly decreases in inland direction. The volume of sand deposited by surface creep is more to the north than to south. It is least in the terrace region around profile number 8.

Saltation seems important only around 8^{th} profile where the volume of deposit is as high as 99%. It appears that it is not very significant in dune development in the area.

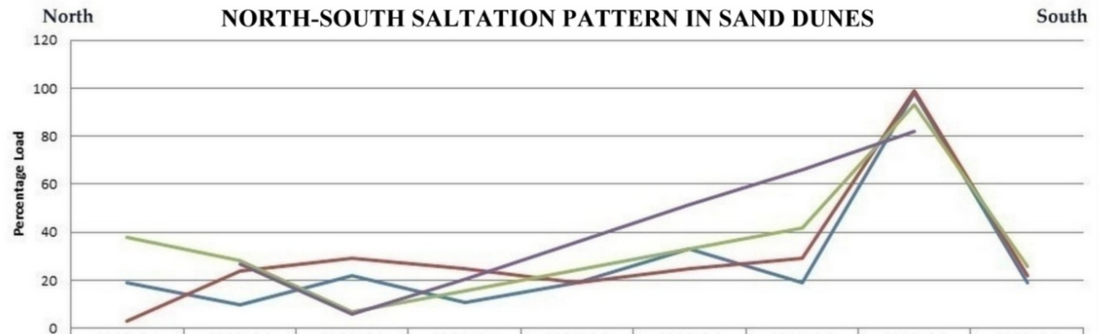
Suspension is by far the most important process. It can be seen that both northern and southern ends of dune sector are built by sand moved by suspension. The process is not very conspicuous in central part around Paulo creek.

The contours of the process movements (Fig: 4.14) significantly show that there is an inverse relationship between surface creep and saltation. While surface creep and suspension contribute in the process of dune development, saltation on the other hand has a negligible contribution.



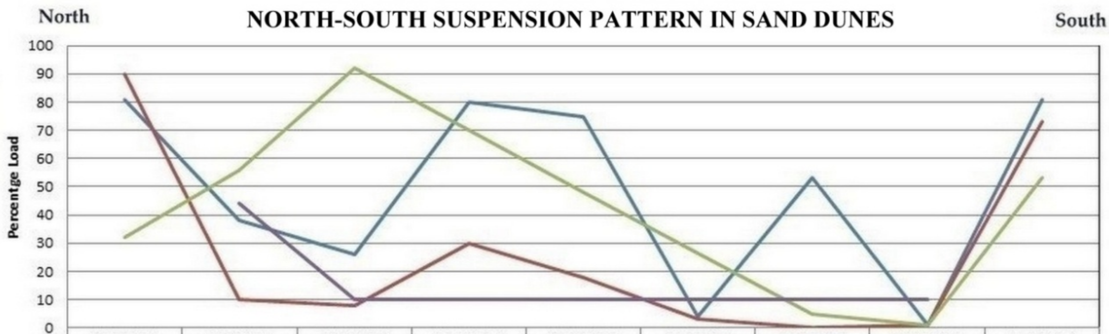
	PROFILE 1	PROFILE 2	PROFILE 3	PROFILE 4	PROFILE 5	PROFILE 6	PROFILE 7	PROFILE 8	PROFILE 9
s1	0	52	52	9	6	63	27	1	0
s2	7	66	63	45	63	72	71	0	5
s3	30	16	1				53	6	21
s4		29	84					8	

Percentage sand moved by surface creep



	PROFILE 1	PROFILE 2	PROFILE 3	PROFILE 4	PROFILE 5	PROFILE 6	PROFILE 7	PROFILE 8	PROFILE 9
s1	19	10	22	11	19	33	19	98	19
s2	3	24	29	25	19	25	29	99	22
s3	38	28	7				42	93	26
s4		27	6					82	

Percentage sand moved by saltation



	PROFILE 1	PROFILE 2	PROFILE 3	PROFILE 4	PROFILE 5	PROFILE 6	PROFILE 7	PROFILE 8	PROFILE 9
s1	81	38	26	80	75	4	53	1	81
s2	90	10	8	30	18	3	0	1	73
s3	32	56	92				5	1	53
s4		44	10					10	

Percentage sand moved by suspenion

Table: 4.7 Process wise sediment movement

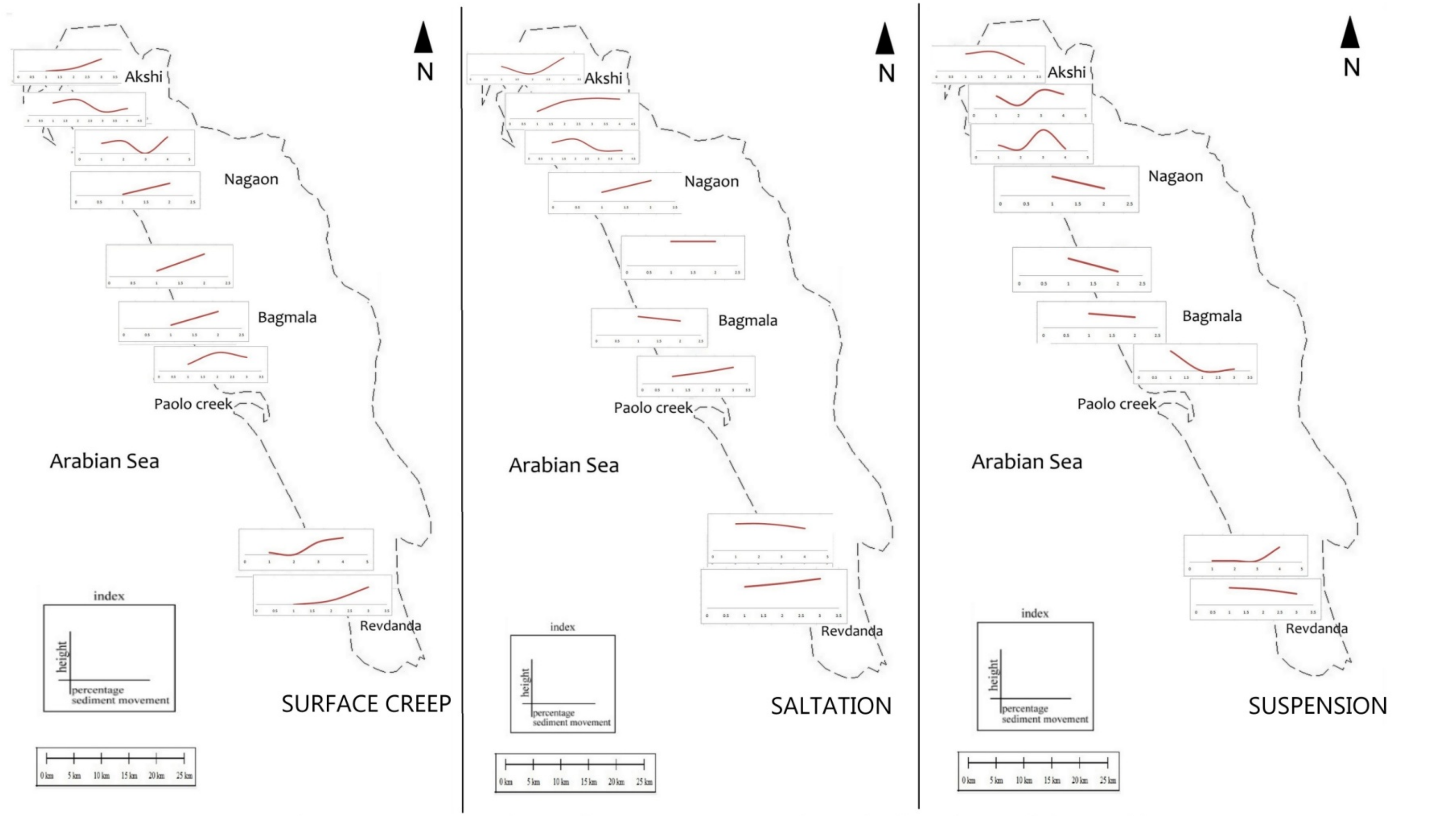


Fig: 4.13 Process wise sediment movement along the locations of the profiles

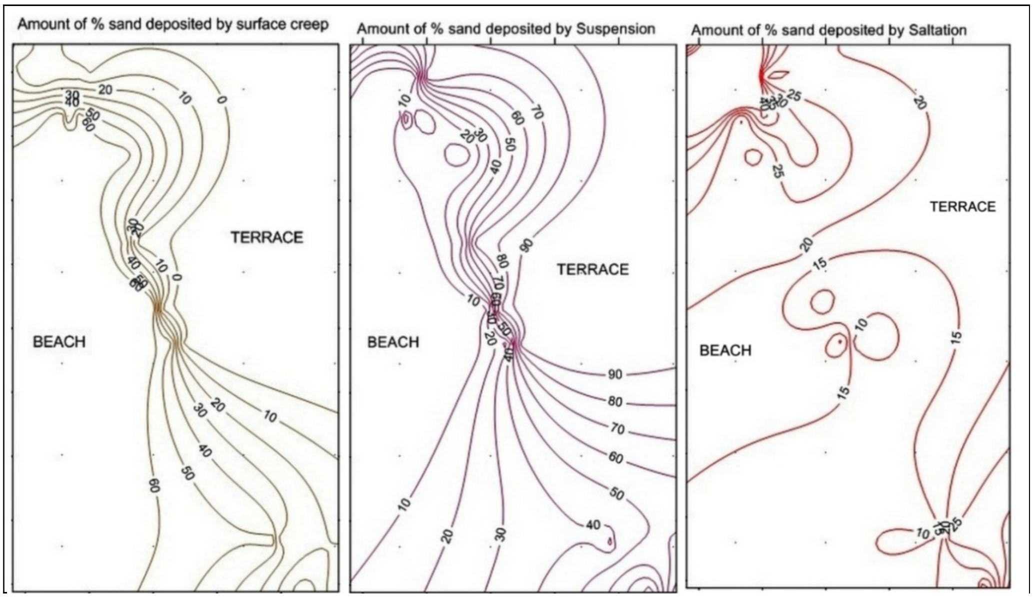


Fig: 4.1 Contours showing process wise sediment movement

C. DUNE STRATIGRAPHY

The dune stratigraphy is the internal expression and preservation of sediments and processes that formed the sediment layers. The sediments in the layers can provide a chronological history of depositional sequence. The stratigraphy provides information on earlier sediment types and depth and amount of disturbance (Short 2000).

The strata thickness, facies type and lamination beddings are all diagnostic of the processes and that were responsible for the development of dunes.

The structure formed during sediment deposition includes flat bedding, cross bedding, lamination and ripple marking (Selley 1985). Large scale aeolian cross bedding is seen in coastal sand dune stratigraphy along with other bedding and lamination types.

Along the dune sector of the study area, only four locations were found where dune stratigraphy was exposed. Since most of the foredunes are eroded, it was not possible to study the continuum of each facies deposited in the dune.

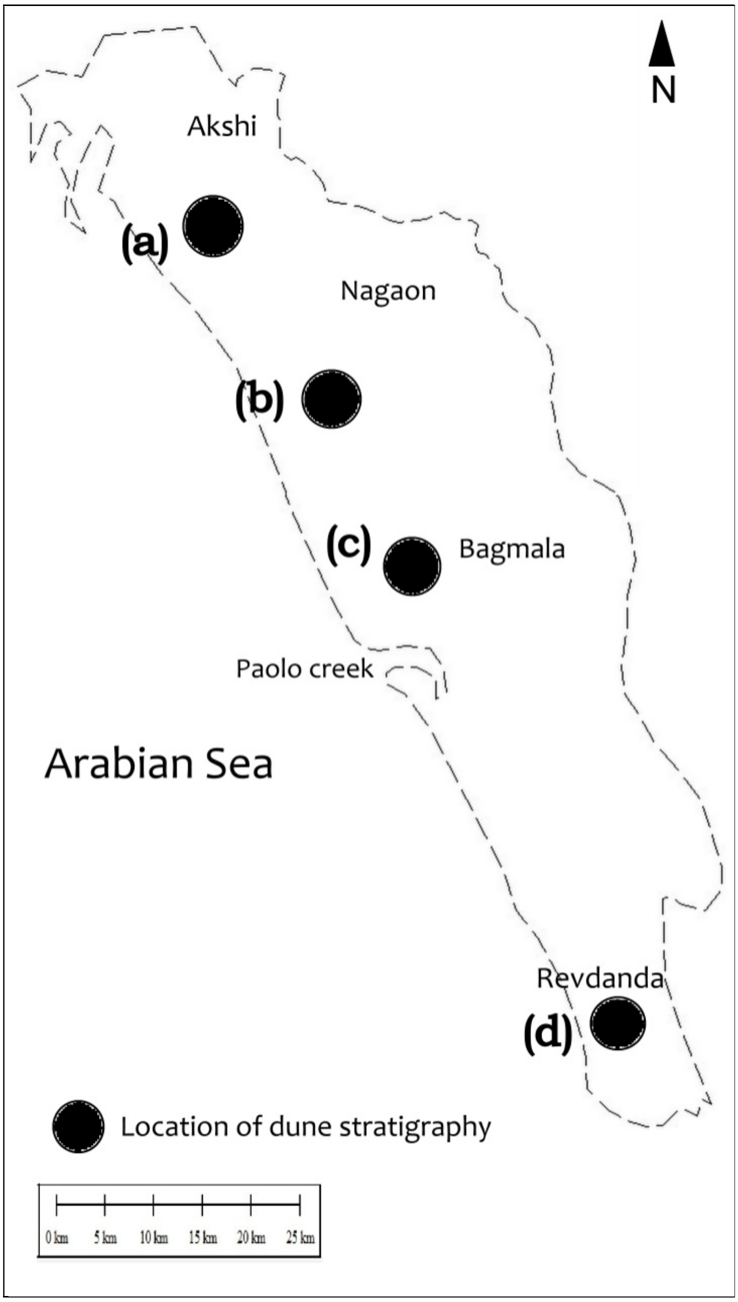


Fig: 4.15 Location of dune observation, sampling and measurement

Exposed facies are easily seen in the northern sector because the dune section is better preserved here. To the south of Paulo creek dunes are very disturbed as the dune section is destroyed by anthropogenic activities. Few places where the low dunes are visible are usually covered with thick cover of Ipomoea creepers.

a. Reconstruction

An attempt was made to reconstruct the stratigraphy of shore parallel foredune from the exposed dune sections. The reconstruction obtained is thus shown in fig: 4.16.

It can be seen that the major depositional facies comprises of horizontal bedding or horizontal lamination. Top portion of the foredunes are the area of blown sand and shingle especially at location 3. Diagonal laminations could be seen in the lower part of the northern dune sector. The lower part of northern dune consists of wet and compact sand. Bioturbation is frequently seen in the northern dune as well as near the southern tip of the lower foredune.

All these facies give a confused and haphazard pattern of dune sand deposition and its erosion or removal.

The overall stabilization is relatively chaotic including diagonal, horizontal, wavy, bioturbation bedding.

The upper section of dunes is sparsely vegetated. The dune stratigraphy exposed also suggests the fact that earlier dunes were also covered by sparred vegetation.

Thick vegetation cover usually increases the cross section bedding (Hesp 1998). Relatively low cross bedding in exposed dune stratigraphy in the study area points to sparse growth of vegetation.

Wave deposited heavy minerals and coarse sediments preserved in few sections also give an idea about erosional environment of earlier days (Short 2000). Aeolian eroded scarps and bioturbation marks could also be identified in the stratigraphy. Rootlets and beach laminations cover a major part of northern dunes.

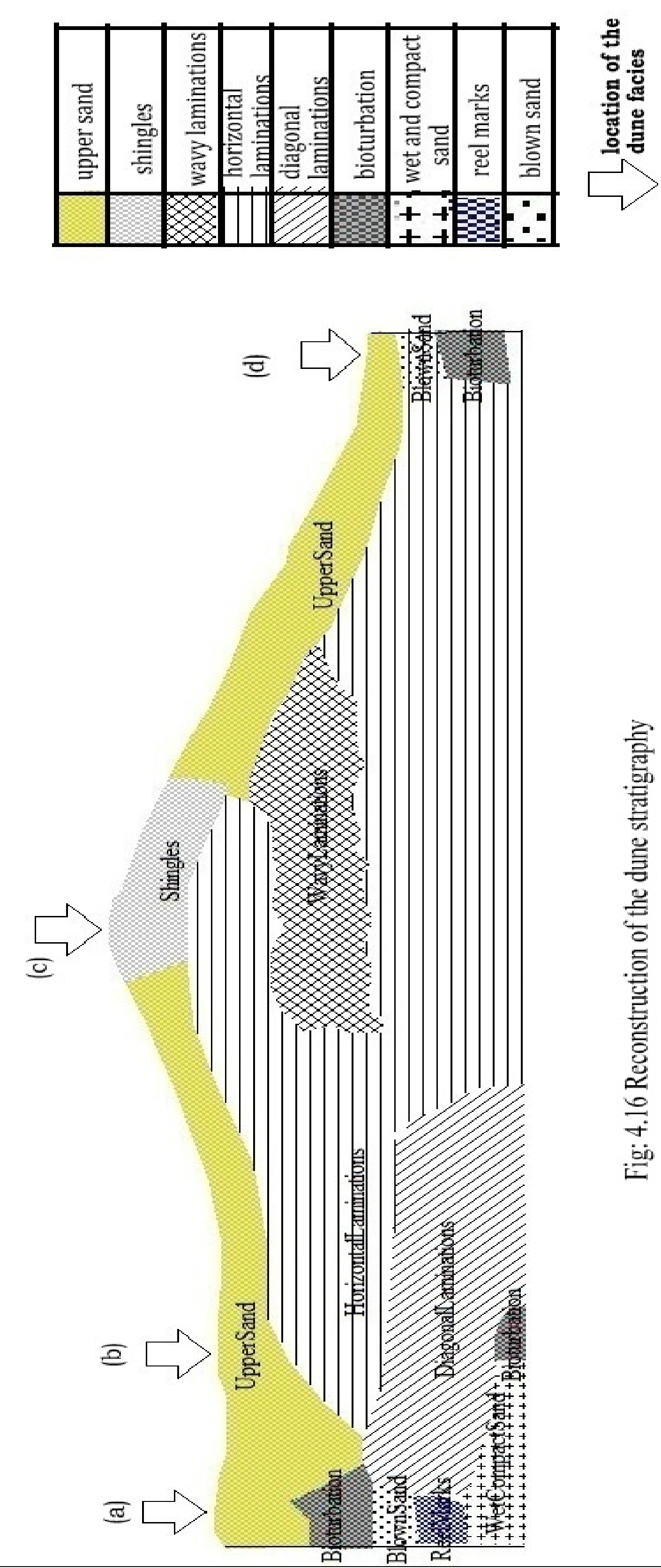
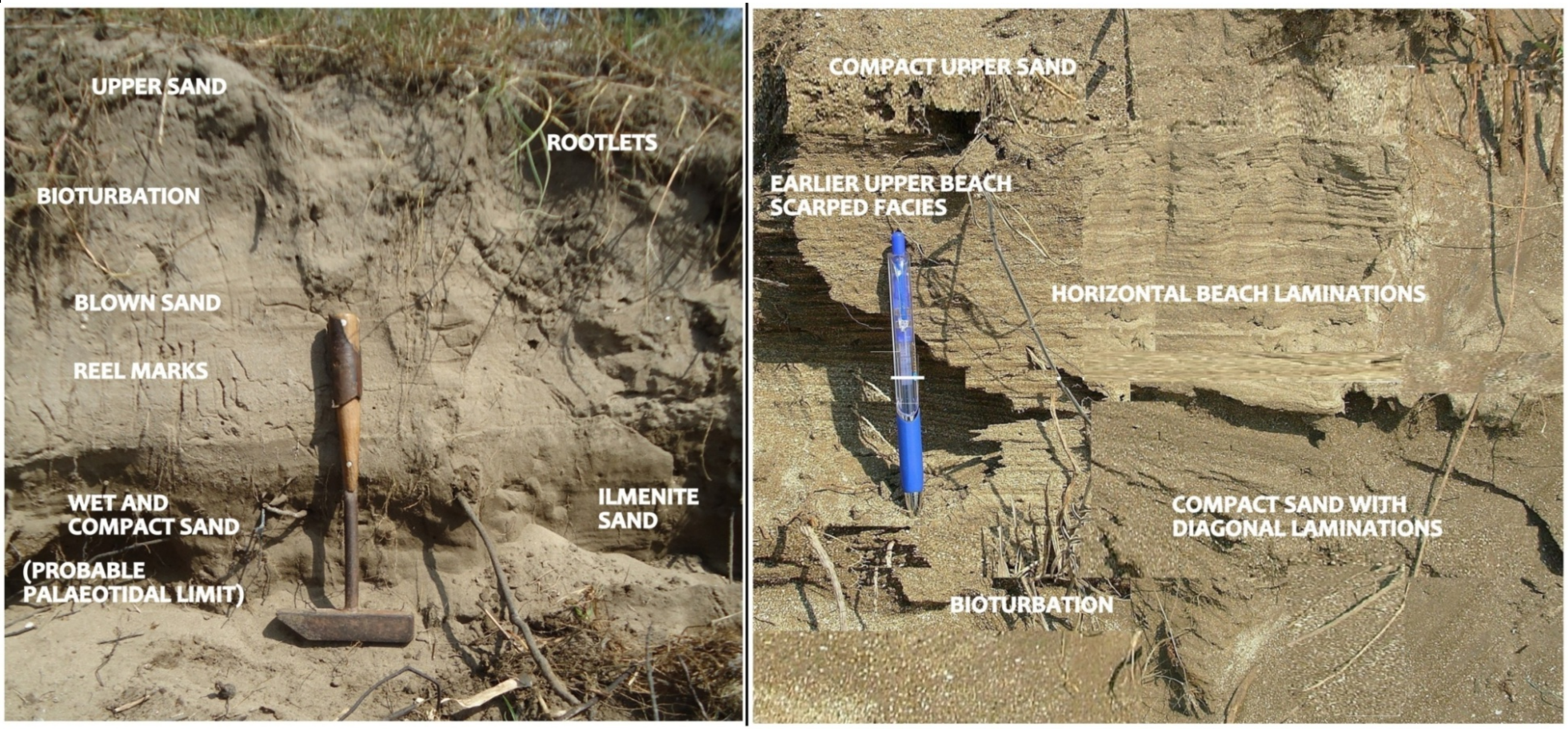
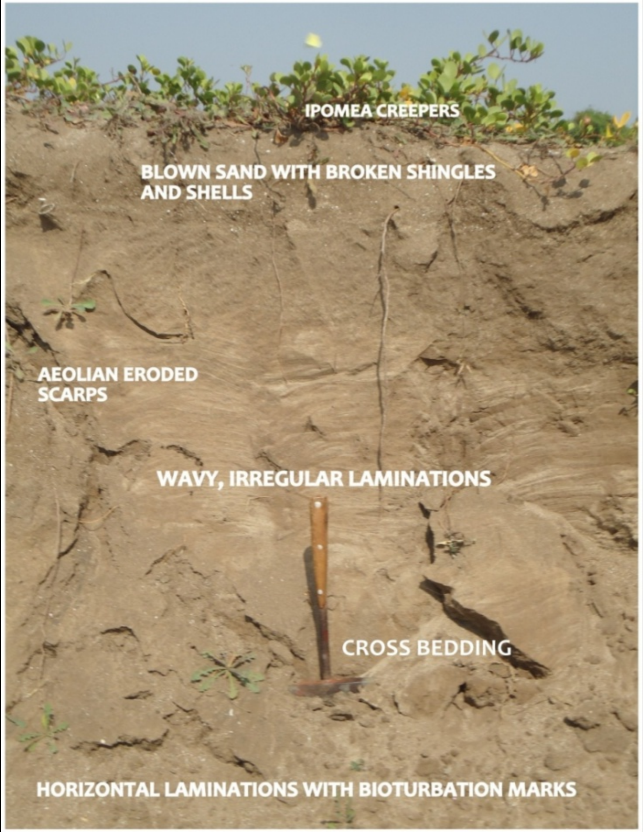


Fig: 4.16 Reconstruction of the dune stratigraphy

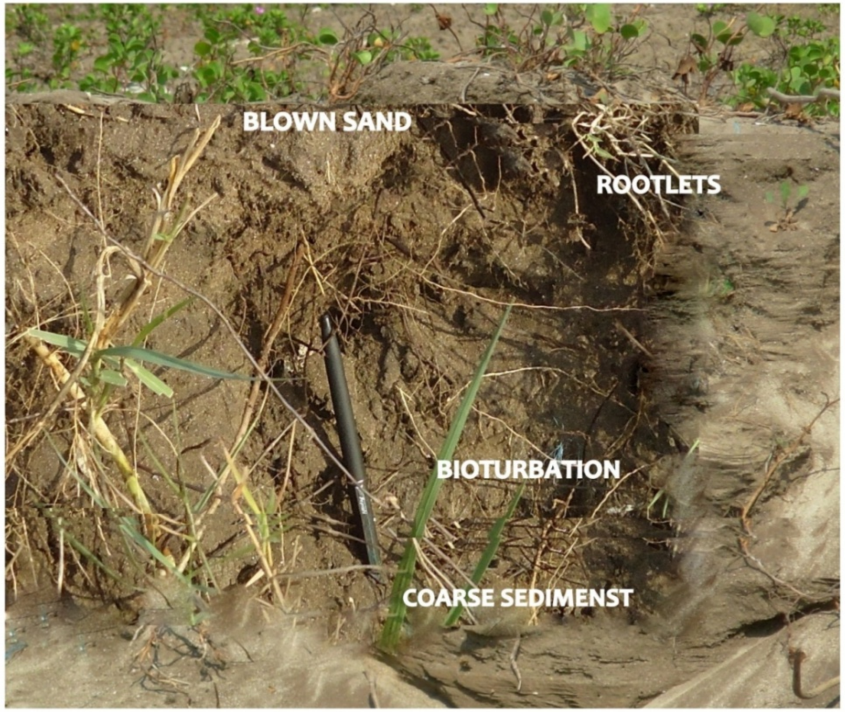


(a) (b)

DUNE STRATIGRAPHY AT LOCATION (a) AND (b)



(c)



(d)

DUNE STRATIGRAPHY AT LOCATION (c) AND (d)

a. The Dune Sediments

Cumulative weight of dune sediments has been plotted on the probability graph to understand the contribution of each type of sediment in dune sector.

Percentage weight of dune sediment

φ-values	SEDIMENT TYPE	s1	s2	s3	s4	s5	s6
0 to 1	coarse sand	14	20	5	8	21	4
1 to 2	midium sand	18	52	20	13	54	26
2 to 3	fine sand	24	13	33	60	15	53
3 to 4	very fine sand	25	6	12	3	2	13
>4	clay silt	11	5	28	1	2	4

Table: 4.8 Sample wise percentage weight of dune sediments

Sample collected from the dune near Nagaon (s1) show 25% of very fine sand and 24% fine sand which indicates that it's the windblown material from the beach.

Percentage of medium sand is higher in the next sample (s2). This is due to the fact that the particular sample was collected from the backdune, where generally the sediments are older and coarser owing to their earlier formation and most of the times they are stabilized.

Nature of the next sample (s3) is a bit odd because they are collected from the area where the tidal channel was coming out from the backshore to the sea forming mud balls near the beach and thus comprises of 28% of silt.

Next sample (s4) is again consists of a very fine sand. It is collected from the top of a foredune and exhibits all the characteristics of the same.

In the next sample (s5), major portion of medium sand is evident. This again is due to the fact that the sample was collected from the back of the dune or the leeward side where it is coarser in nature. This is a highly disturbed area with no prominent foredunes.

The last sample (s6) was collected from the dune that is located near the southern tip of the study area which shows that it mainly contains aeolian fine sand since the aeolian activity is very high in this region due to the presence of the Kundalika creek.(Fig:4.17)

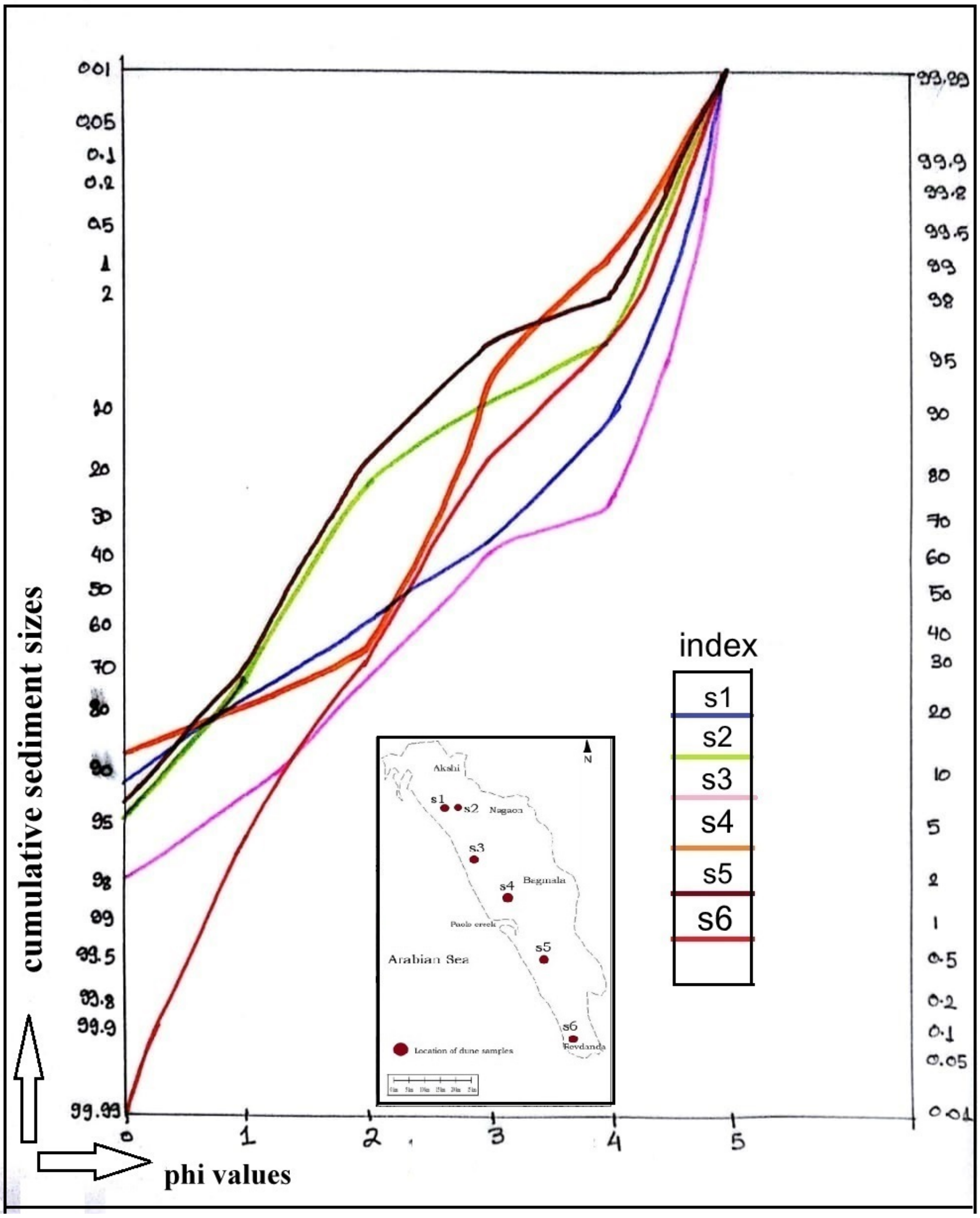


Fig: 4.17 Location and analysis of dune sediment

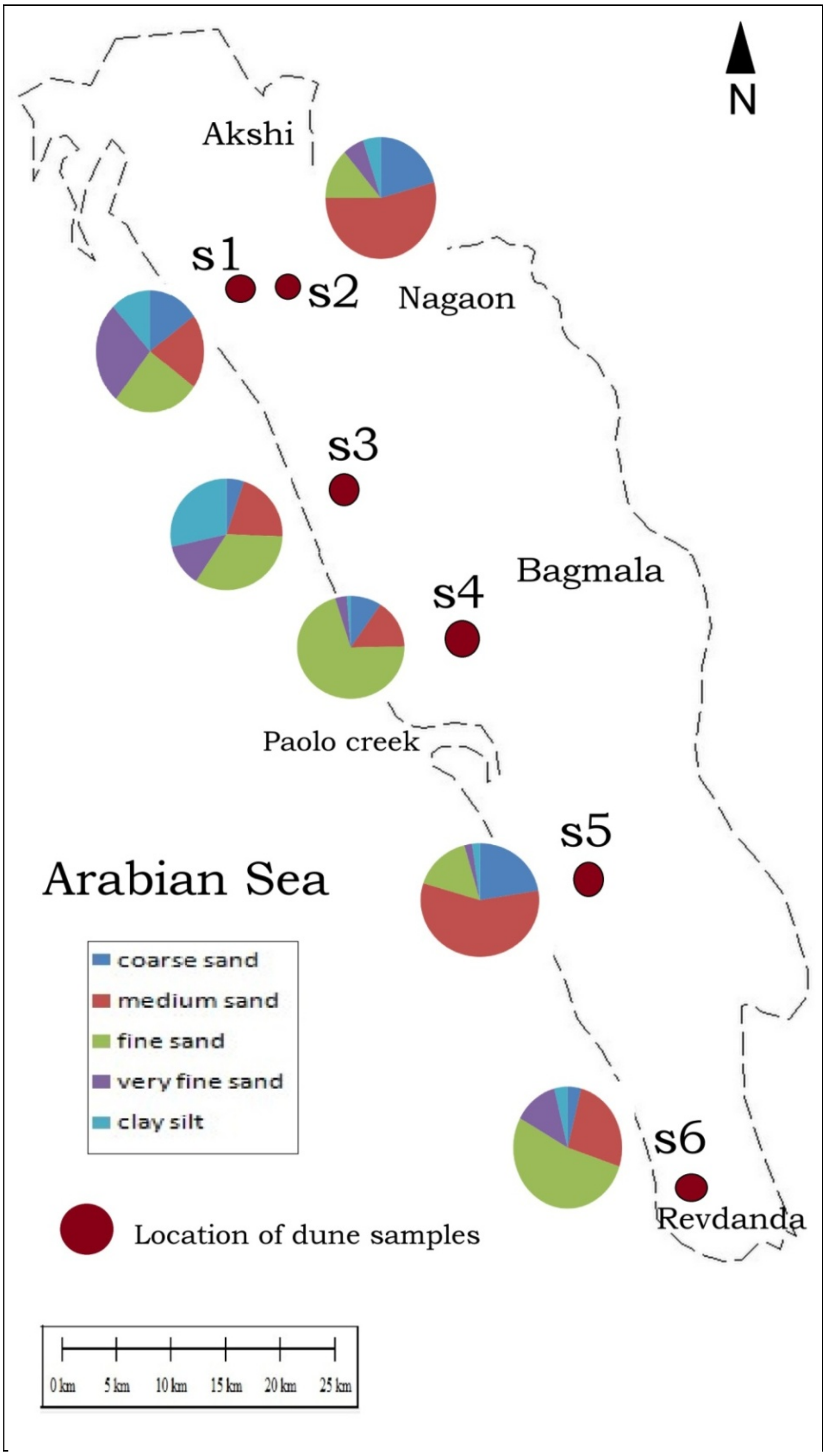


Fig: 4.17.1 Pie chart showing percentage of sediment

CHAPTER FIVE

SUMMARY AND CONCLUSION

The backshore topographic profiles in the study area are intimately connected to the lower shoreface. The extent of backshore in study area is controlled by beach type, beach width, the beach status (eroding in monsoon and accreting in fair weather) and the supply of sand which is low to moderate. In essence the backshore is wide and flat fronted by slightly concave dissipative beach with insignificant berm. The small grain size of sand deposited on beach (1 phi to 5 phis), wave height variation in monsoon and fair weather (3.5m to 1to2 m respectively) and tidal range of 70 to 90 m/sec have resulted in flatter and drier backshore.

The most dominant process in the beach dune sub aerial environment is aeolian sand transport which is reflected in large quantum of sand moved by process of surface creep (around 50%) in the dune zone followed by saltation (10%) and suspension (around 40%).

Probability plots could be very effectively used in the identification of various sediment movement processes on the beach and back beach areas along the said coastline.

The grain-size analysis of the sediment samples usually provides the size frequency spectrum in terms of weight or volume present in a specific size interval. Plotting of the results of single sample analysis on a probability paper no doubt enables us to know about the sediment distribution properties such as mean, median, standard deviation, skewness and kurtosis but it also helps in the identification of processes by which the sediment is deposited (GuhaThakurta and Karlekar, 2017). However, there are processes that cannot be interpreted directly from ordinary statistical techniques. Thus, probability plots hold an advantage over normal techniques, especially in the matter of beach and dune sediment samples. In order to identify different processes, segments on probability curve, are studied separately.

According to Moss (1962-63), three common segments were identified on probability plot. The middle portion is the curve and the two respective ends of the graph are the tails. The segments are designated as “coarse tail”, “central segment”, and “fine tail” by Tanner(2009).

Important hydrodynamic and process changes could be identified no matter from where the samples are collected from the beach or back-beach.

The cumulative sand grain weight against size, on the probability plot, of the fine tail, corresponds to the sediment load carried in suspension. The coarser tail corresponds to the movement of surface creep, while the central segment is denoted by the movement of saltation.

These processes lead to the formation of berm, dune and backdune areas in the northern part of back beach sector of study area.

It was observed that mid tide and low tide significant beach width (80m.) about 80% is available for aeolian transfer of sediment to backshore. Oblique, orthogonal and longshore aeolian sediment transport is important on beach and can be inferred from the 3D models showing dune elevations where prominent development in east-west direction (x-axis) and in north-south direction (y-axis) respectively. There are hidden patterns along and across the study area which was brought forth by the 3D wireframe model of the dune elevation and directional derivative techniques (Fig: 4.11.2).

The backshore from all its characteristics such as erosion of dunes and over wash process in storm season appears to be a transgressive barrier, receding landwards. This is due to slightly rising sea level, sediment deficiency, occurrence of low dunes and monsoon storms. Occurrence of fine sediments on various locations landward such as backdune, terraces, and marshes and estuaries on the landward side of barrier clearly indicate the influence of wave washing over backbeach and berm sectors of the said beach. This is called over wash which is usually more common and dominant on coast with low to moderate tidal range and periodic storm episodes.

Slow and limited growth of vegetation (Ipomoea and sphinifex) on foredunes is a striking feature of dunes in backshore zone. Colonization by new species was found to be meager

Swash constructional landforms on backshore are restricted only to berms which too are not very significant. The beach ridges and storm ridges found on the backshore of many other dissipative beaches are strikingly absent on their coast. The beach cusp is also an infrequent feature on this backshore.

Berm is usually defined as a shore parallel ridge or rise consisting of a steep slope facing sea and topped by a shore parallel crest (Short,2000). It is backed by a flat or landward dipping berm terrace which terminates in a linear runnel, where swash collects water at high tide. The berm produced on this beach is not linear feature and is not found as a discontinuous feature of low height. It is seen mainly in the northern part and is infrequent in the southern section of the beach. The runnel is distinct only at spring high tide.

The 'frontal' or fore dunes in the area attain a maximum height of not more than 1.5m. They are shore parallel asymmetrical ridges formed by aeolian sand. They are topped by scanty cover of dune vegetation. Incipient foredune or newly developing foredunes are found to develop within discrete or relatively discrete clumps of vegetation. The dominance of more spreading, low, rhizomatous plants such as Sphinifex and Ipomoea has resulted in the formation of lower, less hummocky foredune forms in the area (Hesp,1998).

There are hardly any shadow dunes, hummocky dunes and embryo dunes. The area gives an impression that the overall dune development is truncated in later part of Holocene.

In the northern part around Akshi, established foredunes can be traced with some difficulty. They have been modified by anthropogenic activities and have lost their original character. The amount and extent of human interference in such foredunes and backdunes is very severe in the study area.

Monsoon winds appear to induce slight to moderate changes in the morphology of foredunes. Dune scarps, sand slumping and removal of vegetation are signs of this change, seen in four monsoon months. The building of these dunes in fair weather is not very significant due to scarcity of sand and weak winds in fair weather.

Widespread acceleration and deflation in monsoon initiates development of blowouts in the dunal areas. The other reason for their development in study area is negative sediment supply. Such blowouts cannot be traced easily as they are buried due to human activities.

The area has developed and is still developing speedily as a tourist destination. Due to this the backshore especially the backdune area has been modified to a large extent and does not exhibit its natural geomorphic character.

Beyond dunes, at the edge of backshore are found terraces, which are extended up to estuary or tidal channel. These terraces are formed as a response, primarily to wave induced beaches and secondarily as an evolution stage in the formation of barrier system in early Holocene.

The terraces are presently used for various purposes such as agricultural, plantation and settlement. The land units' map of the area amply demonstrates these aspects of backshore zone in the study area.

The extent of land units of the study area reveal that it belongs to an older time, the maximum area of 5.9sq km is covered by the terraces denoting that it belongs to an earlier coastal system. Back dune is the second most extensive feature covering around 3.1sq km situated near the southern mudflat of Revdanda. The presence of a long estuary along the backdune signifies that the area belong to a barrier island system (Fig. 5.1).

The beach and backshore in the study area appears to have a broad temporal scale. It is developed as a barrier system in Holocene. The barrier evolution intimately related to beach-backshore and backshore morphology dynamics.

There are many indications that this area evolved as a barrier system. The beach sediments, tidal inlet sediments and the dune stratigraphy exposed in the area all suggests their evolution with reference to earlier higher sea level in early Holocene.

Sea level movement is the prime control on the development of this barrier system relative to mainland geomorphology like many others in the world (Short 2000).

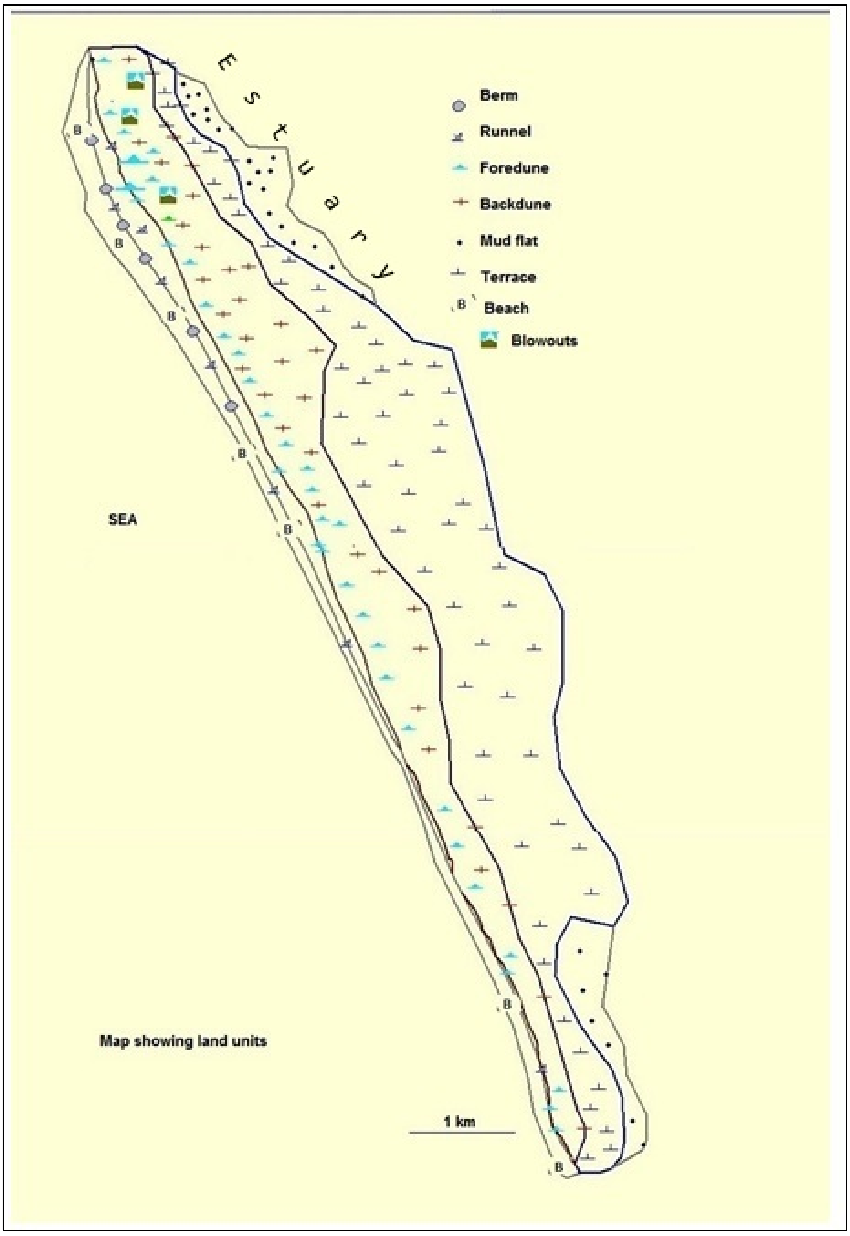


Fig: 5.1 Map showing land units of the study area

The barrier system comprises of definite sequence o coastal landforms which differ in age, and lithology from hinterland landforms. It is basically a barrier between sea and older mainland landforms separated now by partially, filled tidal channels stretching from Akshi in North to Revdanda in South.

The field evidence gathered from sediment deposition sequence exposed in Paulo creek and other small inlets and foredune stratigraphy clearly suggest that the system is formed as a result of landward processes, both of which include aeolian transport and upward accretion of sand.

According to Short (2000), the stratigraphy provides information on earlier sediment types and depth and amount of disturbance. Thickness of strata, facies type and lamination of the beddings are all indicators of the processes that were responsible for dune development.

Sellay in 1985, observed that the structure formed during sediment deposition includes flat bedding, cross bedding, lamination and ripple marking. In a coastal dune stratigraphy, a large scale aeolian cross bedding along with other forms of beddings and laminations are clearly evident.

All the marked facies of the study area give a haphazard pattern of dune deposition and erosion. The overall stabilization of the bedding is relatively chaotic including diagonal, horizontal, wavy, bioturbation. According to Hesp (1998), thick vegetation cover usually increases the cross section bedding. Relatively low cross bedding in exposed dune stratigraphy in the study area points to sparse growth of vegetation. As Short suggested (2000), the heavy minerals and coarse sediments deposited by the waves and preserved in few sections, also give an idea about erosional environment of earlier days.

It appears that the barrier is established during mid to late Holocene and prograde due to falling sea level. The behavior of the barrier is influenced by modern coastal climate prevailing in the area.

Such barriers range in size, position relative to mainland, and stability. This barrier system is attached to mainland and adjusted to falling sea level in late Holocene. The beach is developed on low gradient substrate with an average slope of about 1.8 degrees. The beach has a thin sand deposit (thickness less than 30cm) indicating low sediment supply as well as erosion in monsoon season.

Higher wave energy in monsoon influences the shoreline configuration in that season. The tidal range being slightly more than 2m, tidal prism produced is not very significant. Greater tidal prism is usually reflected in the occurrences of large number of tidal inlets (Hayes 1994). There is only one tidal inlet on this barrier system suggesting limited tidal influence.

Wind is an essential component for dune development on barrier systems. Erosional and low dune form suggests negative sediment supply. Absence of well defined parabolic dunes, blowouts and transgressing dune fields in the area indicate a low to negative sediment supply (Hayes 1984).

The modern beach is a part of a barrier system having limited extent. Beach dune system of study area is backed by a tidal inlet and comprises of beach derived 1.5m high aeolian dune system.

From all field and sedimentary evidences the beach-dune-terrace and tidal inlet barrier system appears to be a “regressive barrier” formed earlier under “regressive sea” condition.

The sea level in early Holocene along Konkan coast was 2m to 6m m higher according to Karlekar 2107. Extensive coastal dune deposits, well above the present sea level formed during mid-Holocene period when sea was well below the present level.

Large quantities of sand were transported onshore during this period together with strong onshore winds. In late Holocene during transgression the barrier system retreated resulting in narrowing of dunes.

As the sea level rises and falls, shoreline transgression regress the coastal sector. The result is deposition of several conformable facies with gradational vertical transitions. Such facies sequence is observed on the seaward margin of barriers.

The sedimentation found in a 3meter thick section in Paolo creek, that gives a clear idea about the sequence of sedimentation in the study area.

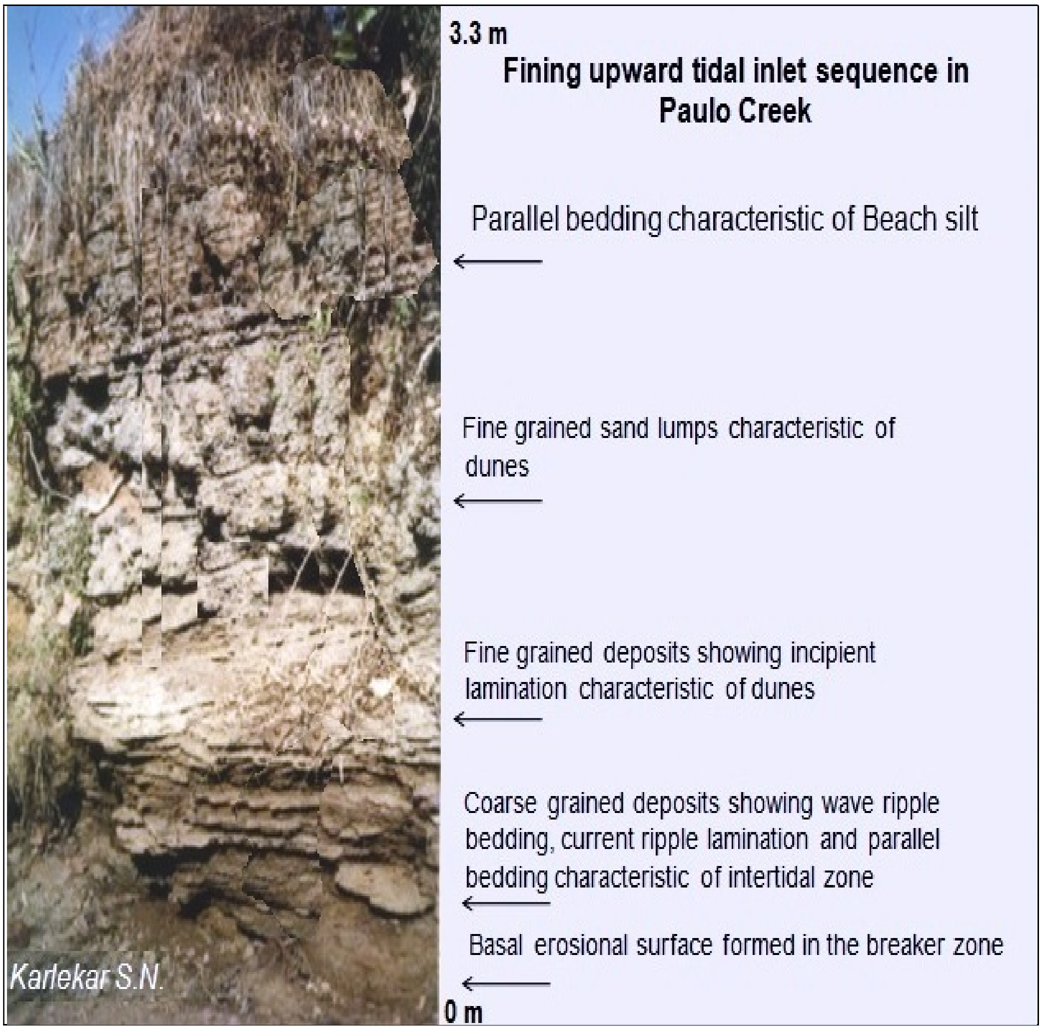


Fig: 5.1 Sequence of sedimentation (Paulo creek)

The topmost layer of the section indicates beach silt that is now lithified. It is 0.75cm thick. Fine grained sand lumps and laminations which are generally found on dunes are witnessed in this lithified profile making it clear that it is a palaeodune. This layer is 1m thick.

A 0.5cm thick sector of fine grained deposits of dunes lies at a depth of 1.75m. The earlier inter tidal zone of sediments show wave ripple bedding, and ripple lamination. They are also seen at the lower end of the sediment column. Earlier beach erosional surfaces, formed in the breaker zone can also be seen at the bottom but with some difficulty. This sedimentary sequence turned in Paulo creek gives a clear idea about the sedimentation that must have taken place in mid Holocene period in the area.

The said barrier system can be classified as retrograding attached system as per the scheme suggested by Short (2000).

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