Study of Coastal Geomorphological Features of Northern Beaches of North Goa

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DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation report entitled, "Study of Coastal Geomorphological Features of Northern Beaches of North Goa" is based on the results of investigations carried out by me in the discipline of Marine Sciences at the School of Earth, Ocean, and Atmospheric Sciences, Goa University under the Supervision of Ms. Manjusha Madkaikar and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities will not be responsible for the correctness of observations / experimental or other findings given in the dissertation. I hereby authorize the University authorities to upload this dissertation on the dissertation repository or anywhere else as the UGC regulations demand and make it available to any one as needed.

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COMPLETION CERTIFICATE

This is to certify that the dissertation report "**Study of Coastal Geomorphological Features of Northern Beaches of North Goa**" is a bonafide work carried out by **Chetan Rahul Puntambekar** under my supervision in partial fulfilment of the requirements for the award of the degree of **Master of Sciences** in the Discipline of Marine Sciences at the School of Earth, Ocean, and Atmospheric Sciences, Goa University.

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PREFACE

The coastal geomorphological systems are highly dynamic and the focus on this topic is increasing due to the rising concern of sea level rise and climate change. Due to this dynamic nature the causalities are produced extremely quickly. In addition, the coastal regions house approximately 1/5th of the world's population. Therefore, are of great importance.

Due to the fact that there are lesser number of studies on the topic with reference to Goa and its link with the tourism of Goa combined with my areas of interest, it motivated me to undertake the study on geomorphology of the coast.

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Chetan R Puntambekar

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ABBREVIATIONS USED

Entity	Abbreviation
Arambol	Ar
Ashvem	A
Cusp deposits	Cd
Berm	B
Dunes	D
Embayments of beach cusps	E
Estuarine end of longshore bar	Est
Horns of beach cusps	H
Longshore bar	Lb
Lower dunes (foredunes)	LD
Low tide zone	Lt
Mandrem	Ma
Morjim	Mo
Marine end of longshore bar	Mrn
No feature	Nf
Querim	Q
Sandbar	Sb
Spit	Sp
Tiracol	T
Upper Dunes (established foredunes or relict foredunes)	UD

ABSTRACT

The study was undertaken to understand the dynamic coastal geomorphological system of the northern part of North Goa coast. Photographs of different geomorphological features were taken and the locations of the same were plotted to create a geomorphological map. Sedimentological data was produced from the grain size analysis of surface sediments which was used to understand the dynamics of the region. The results showed that the coast was aggrading at Tiracol but prograding from Querim to Morjim. Wave notches present at Tiracol and Ashvem indicate a drop in sea level. The sediment transport is occurring from foreshore to backshore and the aeolian transport is peaking at Mandrem. Signatures of a longshore current in the southern direction were found in the textural characteristics of the sediments collected.

Keywords: Coastal Geomorphology; Goa; Sedimentology; GIS; Erosion; Deposition

INTRODUCTION

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The term Coastal Geomorphology is composed of two words:

1. Coast meaning the patch of land that is next to the sea that extends upto a few kilometres wide tract of interacting terrestrial and marine processes between the shoreline and limit of the first major change in terrain (Sharma, 2010)
2. Geomorphology originating from Geo (Latin) meaning Earth, Morph meaning shape and Logos meaning thesis.

Thus, Coastal Geomorphology means the thesis of shapes/features of the Earth on the land next to the sea. The study of geomorphology has been done from ancient Greek and Roman times when philosophers wondered how mountains and other landforms formed. Aristotle, Herodotus, Seneca, Strabo, Xenophanes, and many others discoursed on topics such as the origin of river valleys and deltas, and the presence of seashells in mountains (Huggett,2011)

The geomorphology of any given coastal area is controlled by:

1. The Tectonic Setting – The tectonic setting affects the geomorphology of the coasts on a regional scale, for example, by comparing the western and eastern coasts of India, one comes to understand how the west coast fault has caused the development of western coast of India to be highly linear as compared to the uneven eastern coast.

2. The Lithological Setting – Out of the three types of rocks that occur, igneous and metamorphic rocks have a higher density and are relatively more resistant to weathering and erosion as compared to sedimentary rocks which are less resistant to weathering and erosion.

3. Wave action – A sea wave may be defined as "A moving ridge or swell of water occurring close to the surface of the sea, characterized by oscillating and rising and falling movements, often as a result of the frictional drag of the wind." (accessed from (accessed from: https://www.eionet.europa.eu/gemet/en/concept/9262) Waves in the ocean have an orbital movement which becomes elliptical and eventually linear as the wave approaches the shore. The waves as they reach to the shore refract as there is a difference in velocities of crest of the wave due to the shallow depth of the water. The wave eventually breaks to form a surf and the oscillation of the wave transitions into energy that causes waves to move up and down the beach face forming a swash zone, which deposits sediments as the wave comes in and erodes as the backwash or wave moves out. These waves may create nearshore currents that include longshore currents, rip currents and offshore currents. A longshore current is a current that flows parallel to the shore within the zone of breaking waves, the energy of the current is directly proportional to the angle of approach of the waves, i.e., the steeper the angle the approach higher is the energy releases a higher "burst of energy" leading to a stronger longshore current. These currents lead to sediment transport also known as Longshore Drift (accessed from https://geo.libretexts.org/Bookshelves/Oceanography/Oceanography_101_(

Miracosta)/12%3A_Coasts/12.10%3A_Longshore_Currents_and_Longshore_Drift)

and

(https://oceanservice.noaa.gov/education/tutorial_currents/03coastal2.html.)

Rip currents are formed when the energy that is stored up as edge waves and standing waves through a return flow of water offshore in an evenly spaced cell circulation system of rip currents, which escapes as an undertow at antinodes spaced equal to the edge wavelength (Sharma, 2010). The energy of the wave/currents dictates the amount of sediment that is being transported as well as the type of sediment being transported, the Hjulstrom's diagram indicates that the wave velocity required (directly proportional to the energy in the system) to transport pebbles or cobbles is exponentially greater than the energy required to transport sand or silt.

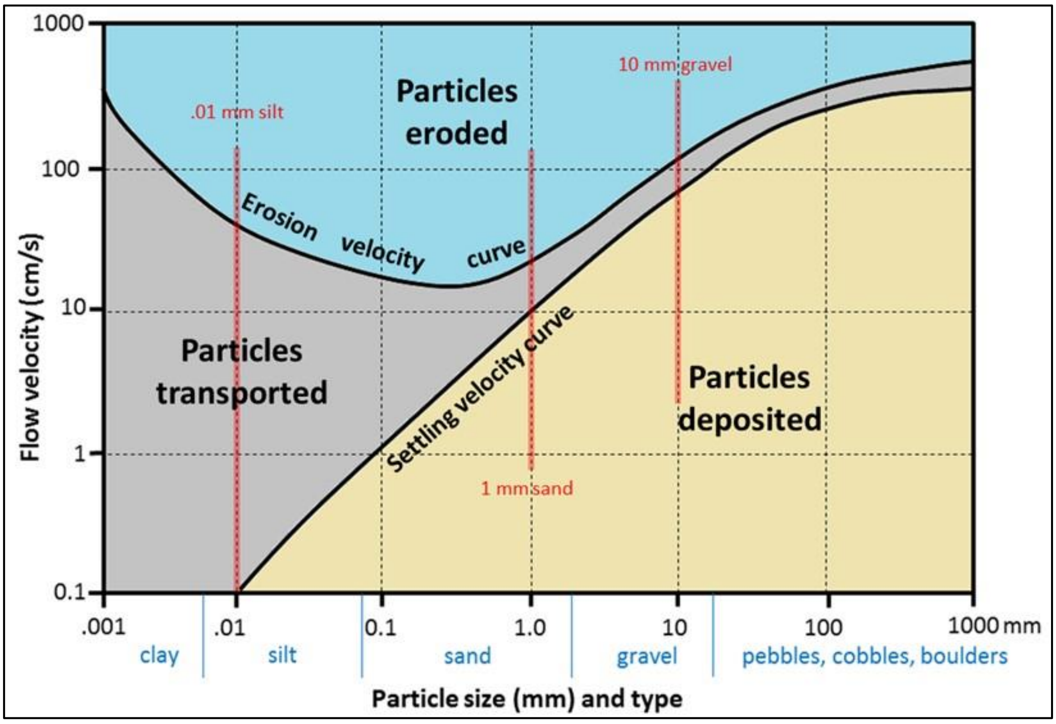


Figure. 1.1 . Hjulstrom Diagram indicating the relation between particle size and wave velocity. (Accessed from https://opentextbc.ca/physicalgeologyearle/wp-content/uploads/sites/145/2016/06/hulstrom-2.png)

4. Tidal action – Tides are a natural phenomenon that occurs every 12.5 hours (approximately) and are caused by the gravitational influence of the moon and to a lesser extent the sun. The alignment of these bodies causes the two main types of tides to form, i.e., flood tide and ebb tide which cause the rise and fall of the shoreline on the foreshore or beach face respectively. When there is a flood tide, deposition of sediment occurs and similarly during an ebb tide there is erosion of sediments.

5. Wind action- Wind is the movement of air parcel from an area of high pressure to an area of low pressure. The velocity of the wind is directly dependant on the pressure difference present between the two areas in question, as this wind moves over the beach, transportation of sediment takes place resulting in different geomorphological features are formed like dunes. Winds are responsible for the movement of lighter sediments along the beach.

6. Sediment deposition: Deposition of sediments mainly occurs through wave action and the wind action, the grain size and type of sediment changes depending on the presence or absence of a river mouth or estuary being present in the vicinity.

7. Storm deposits – Deposition and erosion due to storms and tsunamis. Storms may be defined as a violent disturbance in the atmosphere that may be accompanied with intense winds, rain, lightning and thunder, due to the strong winds, storms also produce strong waves, often referred to as storm surge.

Similarly, tsunamis are a series of waves generally caused due to displacement of large volumes of water. Due such large amounts of water coasts may experience a sudden and large load of deposition / erosion

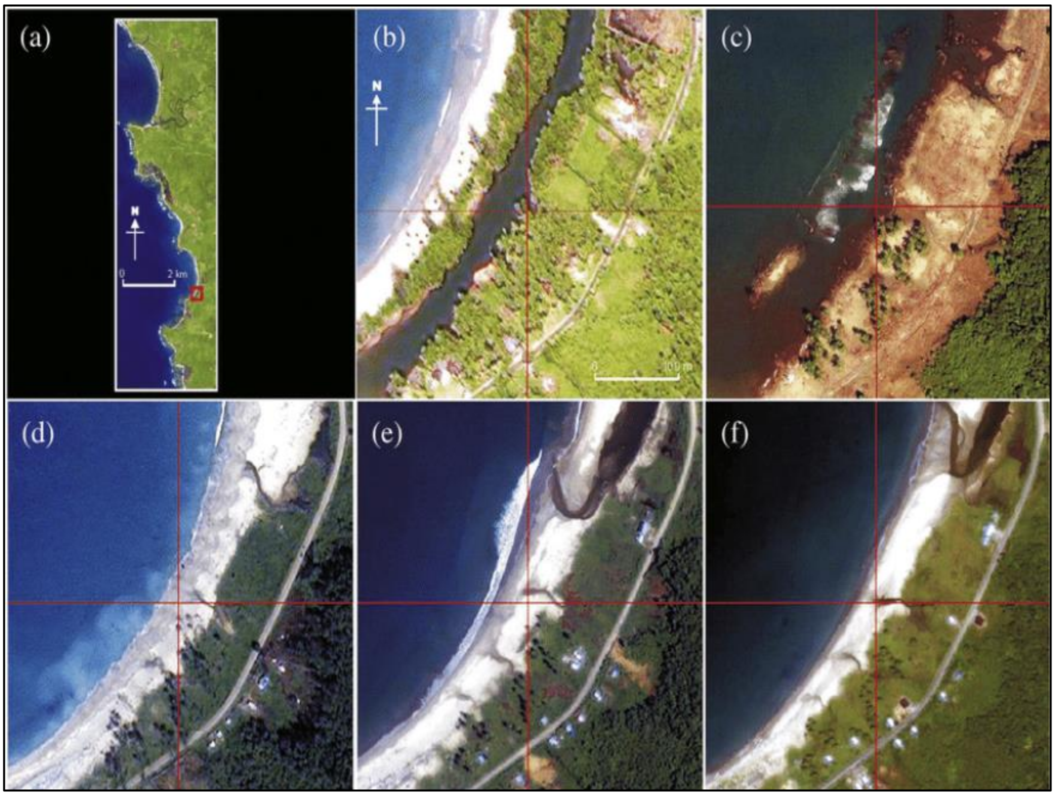
8. 

Figure. 1.2. Tsunami erosion and recovery, northern Aceh coast. (a) Location of the image used for the Aceh coast (b) January 2003, (c) December 2004 (tsunami). (d) February 2006, (e) January 2007, (f) April 2008. Note removal of the beaches, destruction of the wetland, and erosion along swales by the tsunami. Within 13 months after the tsunami, beaches have returned, although the wetland in the centre is under water. Vegetation has returned to the swales, and in general, the effect of the tsunami is not perceptible in the 2006 image. The next two images show the continuation of the rebuilding process. IKONOS images (Liew et al., 2010).

9. Climate - Coastal landform evolution is often considered to be event-driven, with storminess being a major factor driving both erosional and depositional responses. Numerous studies of historical shoreline change implicate storms in the perturbation of long-term behaviour. Subaerial processes are also important, and Moses and Robinson (2011) provide an excellent synthesis of these in relation to chalk cliffs, pointing to the importance of rainfall variability and the frequency of frost action as controls on slope stability and cliff-facing weathering and retreat [8][9].(Liew et al., 2010 and French & Burningham, 2013) Hot and humid climates accelerate the process of chemical weathering by promoting reactions such as hydrolysis, oxidation and dissolution.

10. Anthropogenic - A strong correlation is found between rates of shoreline change and amount of human development over long time periods and large spatial scales. Even moderate amounts of development are associated with reduced erosion indicating that activities associated with protecting and preserving human infrastructure have a substantial and long-lasting impact (Moses & Robinson, 2011)

11. Biological Factors - Coastal vegetation such as mangroves, salt marshes, and dune grasses stabilize sediments, reduce erosion, and contribute to the formation of coastal landforms. Coral reefs, shellfish, and marine organisms can influence coastal geomorphology through processes like bioerosion, bioturbation, sediment production, and reef-building.

Thus, by understanding the geomorphology of an area, measurements and predictions about the aforementioned processes can be done.

1.2 SCOPE

Geomorphology is a product of multiple processes like wave action, anthropogenic activity, tectonic activity, weathering, erosion, biological activity, climate, thus, by studying geomorphology, these processes can be identified and to an extent quantified and qualified. Furthermore, the geomorphological system also an event-based system, thus, geomorphological features hold records of the past events. Alongside the afore-mentioned points geomorphological features are also act as places of tourism as well, thus, controlling the amount of foot traffic to help preserve the features which in turn acts as a way to preserve the biodiversity of the area. Furthermore, coastal geomorphological features help in concentrating placer deposits.

1.3 AIM OF THE STUDY

To study the coastal geomorphological features that are present on the beaches along the Northern coast of North Goa (district).

1.4 OBJECTIVES OF THE STUDY

1. To observe various coastal geomorphological features along the coastal belt in the northern beaches of North Goa and to interpret the same.
2. To interpret factors natural or human aided, responsible for change in coastal features.
3. To study variation in grain size of depositional features.

1.4 STUDY AREA

Goa is a state in India that lies on the western coast of India and is situated between the latitudes of 15.728990°N and 14.911388°N and longitudes of 73.764880°E and 74.334300°E. Goa covers an area of 3702 square kilometers and has a coastline of approximately 105 Km and comprises two Revenue district viz. North Goa and South Goa. Boundaries of Goa State are defined in the North Terekhol river which separates it from Maharashtra, in the East and South by Karnataka State and West by Arabian Sea (Hapke et al. 2013) The climate of Goa is of the hot and humid type. Most of Goa's annual rainfall is received through the monsoons which last till late September (accessed from https://www.goa.gov.in/) Goa state receives mean annual rainfall of about 330 cms. Studies have revealed that SW monsoon contributes 90% of the annual rainfall of the state accessed from (https://dip.goa.gov.in/climate/#:~:text=Goa%2C%20being%20in%20the%20tropical,needed%20respite%20from%20the%20heat.) The state of Goa is divided into four main physiographic divisions, the coastal plains to the west, the tablelands in the central region, isolated hills to the west of the tablelands followed by the western ghats to the east. The elevation rises from 10m to less than 700m above mean sea level as one goes from the west to the east of the state. There are paleoplains associated with three of the four divisions, they are, the Anmode paleoplain associated with the western ghats, the Mopa-Verna paleoplain associated with the isolated hills, the Mollem paleoplain associated with the tablelands in the central region (Metri & Singh, 2010)

Goa is drained by seven rivers which mainly originate in the western ghats and drain into the Arabian sea, with the rivers Mandovi and Zuari being the largest. The geology of Goa consists of Deccan Traps, Basic Intrusive igneous rocks, Acidic Intrusive igneous rocks, metasedimentary rocks like metagreywacke and basement. The major lineament directions in the state are ENE-WSW and NNW-SSE. The coast of Goa is of the rectilinear nature due to its dismemberment from Madagascar approximately 80 million years ago and during the early Tertiary the west coast of India underwent a major faulting event expressed as the West Coast Fault along the Precambrian basement trends followed by the separation of India from Seychelles around 65 million years ago. Around Miocene sedimentation restarted followed by extensive lateritisation. The coast started to emerge around Pliocene followed by the oscillation of the sea level which is evident from the sea caves, ancient beach ridges and drowned river valleys as encountered along the coast of Goa. The number of features that are aggradational are more than the number of features that are degradational in nature, thus, the coast of Goa could be referred as a ‘prograding coast’ with a ria type of coast line characterized with by broad estuaries and a largely emergent coast (Dessai, 2018)

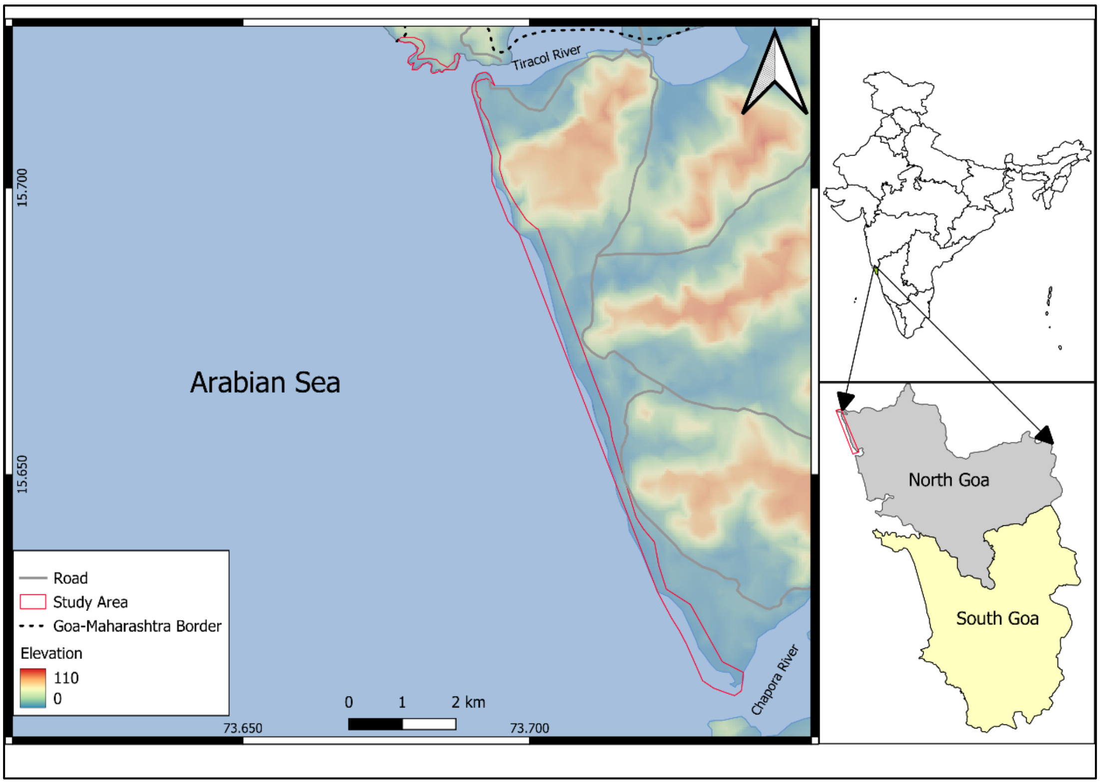


Figure. 1.3. Study Area.

The study area extends from Tiracol at the Goa-Maharashtra border to the Morjim at Chapora River and covers an approximate length of 13 kilometres. The study area consists of low and bold coasts with a few pocket beaches.

LITERATURE REVIEW

CHAPTER 2: LITERATURE REVIEW

Wagle (1982) studied aerial photographs of Goa coast (1:25000 and 1:15000 scale) and classified the geomorphological features into fluvial, aeolian and marine features. The main marine features are cliffs, wave cut platforms, sea stacks, beaches and old beach ridges and for aeolian features dunes were observed. The study concludes that the coast had undergone submergence during the quaternary followed by partial emergence after which it has remained at an intermediate level and furthermore, the coast is prograding along the beaches and retrograding at the headlands and cliffs.

Crooks (2004) concludes that under natural conditions the morphology of a coastline, be it estuarine, deltaic or open shore, reflects a responsive and dynamic equilibrium between the material form of the coast and the hydrodynamic forcing factors of waves and tidal currents and that coastal landforms act to attenuate wave and tidal energy and respond to changing energy conditions at a range of spatial and temporal scales. Further, the morphologies will shift towards the environment which reflects their natural energies and the time taken for shifting will be dependent upon the scale of the morphological features.

Bhatt & Bhonde (2006) studied notch formation and their use in calculating sea level change by the means of notch morphology and radiocarbon dating of biological encrustations found on sea notches to calculate the Biological Mean Sea

Level (BMSL) along the Saurashtra coast, Gujrat. Of the notches, two major paleo sea strands have been identified: The older sea strand lies at an elevation ranging from 12 to 15m above the present BMSL and has been attributed to the last interglacial (MIS-5). Following this, a major tectonic upthrow of about 6 to 9m was experienced by the southern cliffy coast. The Holocene Sea level was recorded at 4 to 5m which is about 2m higher than the general MIS-1 sea level.

Biolchi et al. (2016) classified different landforms as karst, fluvial, anthropogenic, gravity induced etc., which have been backed up by aerial survey beyond the field works and a final geomorphological map that provides the location of different coastal geomorphological features as well as the dominant feature, indicating the dominating processes occurring in the given area.

Dessai (2018) gives the modern stratigraphy of Goa, which consists of Archean gneisses, Ponda group and Barcem group consisting of metamorphic rocks and some younger igneous intrusive rocks. Furthermore, the evolution of the Goa coast is mentioned alongside the different landforms present like sea cliffs, wave cut platforms, sea stacks etc.

Karikalan et al. (2020) grain size data of the surface sediments collected was found and softwares like GRADISTAT were used to calculate the sediment statistics and ERDAS, ArcGis were used to prepare maps upon which the spatial distribution of different parameters are shown. They concluded that estuary and beach area sediments are medium size to fine size grains, the sediments were distributed in size variations indicate different energy conditions. Also, beach sediments show a unimodal distribution due to waves and currents. Furthermore, sediments that are moderately well sorted indicate the influence of stronger energy conditions.

Kunte & Wagle (1994) used satellite imagery to study the coast of Goa. The results show different geomorphological features like dunes, channel bars, turbidity in the near shore waters, lineaments, inselbergs etc. The authors further concluded that old dunes, ancient beach ridges, abandoned cliffs and strand lines observed along the coast indicate that the coast has been progressing seaward and is fairly stable. Rock fractures that run parallel to the coast tend to accelerate the weathering process. Information like this that can be easily found out by the use of satellite images can be of vital importance to the coastal zone planners in managing the area as it of extreme importance, especially for a state like Goa.

Sathish et al. (2018) concludes that the coarse sand is deposited in regions of high wave energy, the foreshore region had grain size ranging from medium to fine sand that was well sorted to moderately well sorted in nature. The study showed that the study area of Vengurla was dominated by medium grain sand. They also demonstrated that the adversely skewed sediments indicate erosion all along the study region.

Friedman (1961) concludes that dune sands generally are positively skewed, irrespective of whether the dunes are barrier island, coastal, lake, riverine or desert dunes. Wind and river transportation results from unidirectional flow and may be responsible for the generally positive skewness of dune and river sands. The grain-size distribution of dune sands is for the most part positively skewed, whereas that of beach sands is for the most part negatively skewed, if the phi scale is used in computation and it is independent of the mineralogy. Dune sand show a lower value of mean(mm) as compared to beach sands.

Hapke et al. (2012) show that given the low percentage of beaches that occur within rocky coastline environments in the New England and Mid-Atlantic region, and the slow rates of shoreline change associated with these environments, the overall erosion hazard for this type of landform is relatively low. On the opposite end of the spectrum, beaches on barrier island exhibit high negative average rates of shoreline change. More heavily developed beaches showing structures such as seawalls and groins are extensive. These structures inhibit the natural response of a beach to storms and exacerbate erosion through scouring, passive erosion and disruption of littoral sediment transport. The lack of accommodation space for response to storms and sea-level rise likely results in increased rates of erosion.

Kamble (2019) after periodically monitor the coastal areas have concluded that human activity has a substantial impact on the rates of erosion of rocky coasts, this can be observed from the comparison of other sites with Velas, which has remained untouched 1995 to 2018, showing very little erosion as compared to other sites that have eroded under anthropogenic influence. Thus, possible effects of this unprecedented tourist interference can deface and deform these geomorphic features.

Balouin et al. (2014) conclude that the beach orientation drastically affects shoreline evolution, with higher erosion where wave incidence is the lowest. However, there are exceptions.

Veerayya and Varadachari (1975) found that different grain size parameters can be used to identify the area of beach from which the sediment has been collected or originated.

Kunte (1994) conclude that sediments deposited along the prograding sector have originated from the retreating sectors that have been transported a short distance. Sediment transport is bi-directional but the net direction of transport is towards south along the coast of Goa.

GAP IN LITERATURE – The literature present regarding to the study of coastal geomorphology of Goa presents two main gaps in literature:

1. The majority of the work published on the coastal geomorphology of Goa is done by analysing satellite imagery as their main data and field work or field sampling as a supporting parameter.
2. There is a lack of work done on the coastal geomorphology of Goa in recent years.

METHODOLOGY

CHAPTER 3: METHODOLOGY

3.1 FIELD WORK

Pre-Field Work Preparations: The extent of the study area was decided via literature review, studying satellite images from Google Earth Pro and toposheet number D43B10 (48E/10). The study area, base maps and study area maps were prepared using the Google Earth Pro images in QGIS 3.32. For preparation of base maps each beach was marked using a black border to indicate the study area which was later superimposed with a Digital Elevation Model (DEM). Similarly for the study area map preparation Google Earth Pro image was used to demarcate the study area after georeferencing of the image and digitisation of the map.

The exploratory followed by detailed field work was carried out in the month of August 2023 to January 2024, with more than 20 days being spent in the field and various coastal geomorphological features like marine terraces, dunes were observed. Measurements of different geomorphological features were done using a measuring tape and their exact coordinates were noted down using Garmin GPSMAP 66s handheld device. The sediment sampling was preferably done during the spring tides as it provided the greatest amount of exposure of the different geomorphological features.

Foreshore and backshore samples were collected at an interval of 500m. Furthermore, samples of different depositional coastal geomorphic features like dunes, berms, spit and beach cusps were collected. The sediment samples were collected using a plastic scoop and were transferred into a zip lock bag for transportation and were labelled according to the nomenclature, where,

- The first letter or the first two letters signify the area, for example – Morjim is abbreviated as Mo.
- It is followed by a number indicative of the sampling location number, 1,2,3,4 etc.
- Finally, the feature name abbreviation is written according to:

D- Dunes (embryo dunes), UD – Upper dunes (established foredune or relict foredunes), LD – Lower Dunes (foredunes), B – Berm, Sb – Sandbar, Nf – No feature, Lt – Low tide zone, Sp – Spit, mrn – marine end of spit, cent – center of spit, est – estuarine end of spit, Cd- cusps deposit, H- horns of the cusps and E- embayment of the cusp deposit.

For example, Berm sample collected at the 4th sampling location at Morjim will be written as Mo4B.

3.2 LABORATORY ANALYSIS

3.2.1 Washing of samples

Macroscopic debris like roots, shells, plastic was removed using forceps. The samples were made salinity free by soaking sample in distilled water. Later the supernatant was decanted once the sample was completely settled using pipe. This process was repeated till salinity was completely removed. The samples were dried in an oven at 60°C till complete dryness.

3.2.2 Pre-treatment

Samples were treated with HCl to remove calcium carbonate 25g of dried sample was taken in a weighed Teflon beaker to which 25 ml of 50% HCl was added and kept for 10 min. h it was heated on a hot plate at 120°C. After 10 min. the HCl was decanted, and the samples were washed with distilled water 3-4 times and kept for drying in the oven at 60°C till complete dryness. After the samples were dried the weights were measured and the amount of carbonate was calculated.

3.2.3 Sieve analysis

20g of dried and decarbonated samples was taken and sieved at 0.1 amplitude for 15 minutes through sieves of mesh size 500 µm, 250 µm, 125 µm, 63µm and the weight of the sample retained was noted down. The sieving was done on a vibrator sieve shaker (Frish analysette 3).

3.3 PREPARATION OF MAP

The locations for different geomorphological features were plotted on Google Earth which were then exported to QGIS 3.32 alongside the data for the creation of Digital Elevation Model (DEM) to create a geomorphological map.

3.4 DATA ANALYSIS

The data generated from sieving was then entered into GRADISTAT software to calculate different sedimentological parameters. The parameters were calculated after Folk and Ward 1957.

They are:

a. Mean: It is a measure of calculating the average grain size of a sample via graphical analysis, it is given by the formula: $\frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$

The resulting phi values are indicative of:

Values from 00 to -1 phi indicate very coarse sand,

values from 1 to 0 phi indicate coarse sand,

values from 2 to 1 phi indicate medium sand,

values from 3 to 2 phi indicate fine sand,

values from 4 to 3 phi indicate very fine sand.

b. Sorting: It is a measure of uniformity of the sediments. Here we consider the sorting found by the Inclusive Graphic Standard Deviation, given by the formula:

$$\frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_{5}}{6.6}$$

The sorting values are indicative of:

Values <0.35 show very well sorted sediments, values from 0.35 to 0.5 indicate well sorted sediments,

values from 0.5 to 0.71 show moderately well sorted sediments,

values from 0.71 to 1.0 show moderately sorted sediments,

values from 1.0 to 2.0 show poorly sorted sediments,

values from 2.0 to 4.0 very poorly sorted sediments,

values >4.0 show extremely poorly sorted sediments.

c. Skewness: It is a measure of the symmetry of the curve. Here we consider the skewness calculated by Inclusive Graphic Skewness, given by:

$$\frac{\phi_{16} + \phi_{18} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_{5} + {}_{90} - 2\phi_{50}}{2(\phi_{95} - \phi_{5})}$$

The skewness values are indicative of:

Values from 1.00 to +.30 indicate strongly fine-skewed sediments,

values from +.30 to +.10 are indicative of fine-skewed sediments,

values from +.10 to -.10 near symmetrical sediments,

values from -.10 to -.30 show coarse-skewed sediments,

values from -.30 to -1 .00 indicate strongly coarse-skewed sediments.

d. Kurtosis: It is a measure of peakedness of the curve by measuring the ratio of the sorting at the extremities to the central region. Here we consider the Graphic Kurtosis, given by the formula:

$$\frac{\phi_{95} - \phi_{5}}{2.44(\phi_{75} - \phi_{25})}$$

The kurtosis values are indicative of:

Values <0.67 show very platykurtic sediments,

values from 0.67 to 0.90 indicate platykurtic sediments,

values from 0.90 to 1.11 indicate mesokurtic sediments,

values from 1.11 to 1.50 are indicative of leptokurtic sediments,

values from 1 .50 to 3.00 indicate very leptokurtic sediments,

values > 3.00 are indicative of extremely leptokurtic sediments.

ANALYSIS

AND

CONCLUSIONS

The study area for the dissertation was selected from Tiracol fort area at Goa-Maharashtra border to Morjim beach.

4.1 TIRACOL COAST

Terekhol coast is a rocky coast and is dominated by laterite rock. Several erosional features as well as depositional features are observed in this area. Figure 4.1 shows the geomorphological map for Tiracol.

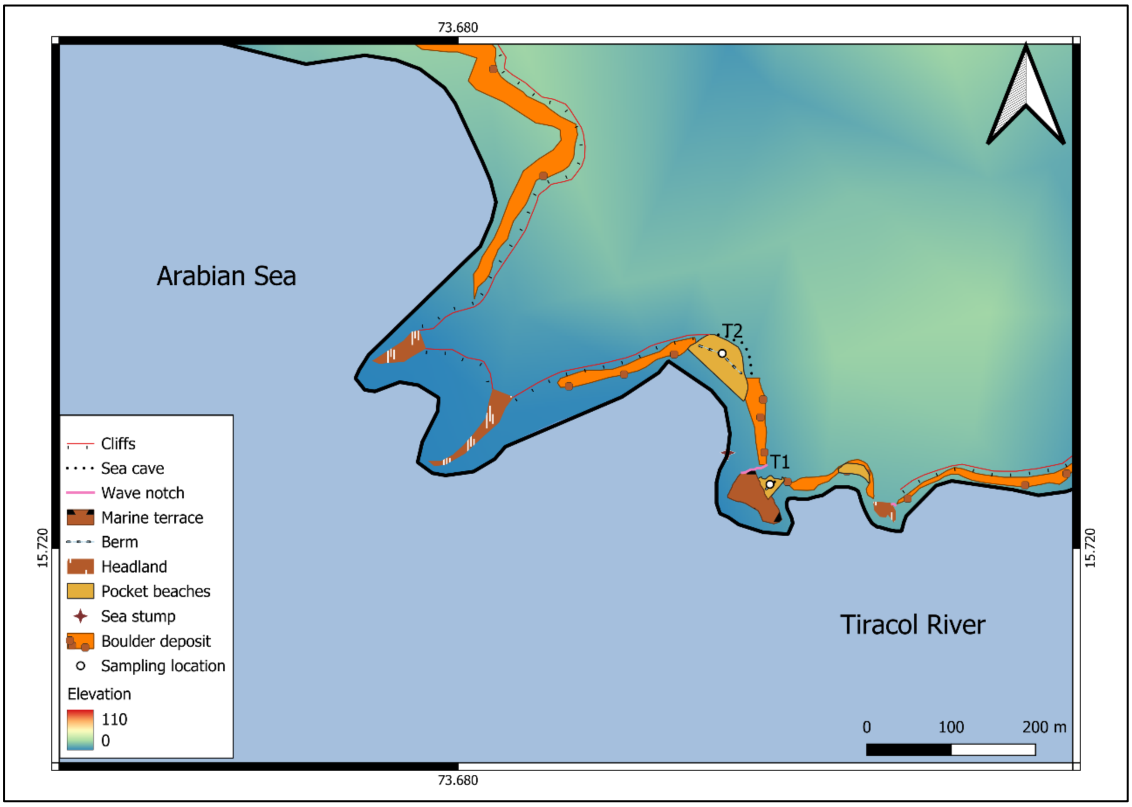


Figure. 4.1. Geomorphological map of Tiracol.

4.1.1 Field Work

4.1.1 a. Erosional features:

Irregular rocky headlands with a very steep slope are observed. Due to wave erosion of these headlands, sea cliffs are formed (Figure 4.2). At the base of these sea cliffs, a sea caves, cavities eroded by wave action along zones of weakness in the cliff rock (Figure 4.3) and several notches are observed. Notches are in the shape of grooves formed due to wave action on cliffs. These grooves vary in size from a centimetre deep to a few meters (Figure 4.4, and 4.5). These are followed by marine terraces, which is developed as the cliff retreats under the combined effects of quarrying and abrasion. They are often referred to as wavecut platforms (Figure. 4.6). They are most common where wave energy is high and are best developed where easily eroded strata are exposed. These strata do not erode evenly because of the changing sea level giving rise to features like mushroom rock (Figure. 4.7). As the coast retreats inland due to wave erosion, erosional remnants of headlands are left behind, which are called sea stacks. Later erosion of these feature result in sea stumps (Figure 4.8). Another result of wave action is the formation of potholes in rocks (Figure. 4.9) which gives clues about the gyroscopic action of water as an agent of erosion. Furthermore, widening of weak planes in rocks (Figure. 4.10) can occur, which results in tilting of the rocks.

Features like wave notches, elevated marine terrace and mushroom rock present at the Tiracol coast serve as indicators of the sea-level drop as the features do not experience the surf action required for further erosion.

Figure 4.2. Irregular rocky headland with steep slope and cliffs formed due to wave erosion.

Figure 4.3. Sea Cave.

Figure. 4.4 Wave notch, with dashed line indicating the shape of the notch. ('V' shape wave notch and mushroom rock)

Figure 4.5 Wave notch, with dashed line indicating the shape of the notch. ('U' shaped wave notch).

Figure 4.6 Marine Terrace

Figure. 4.7 Rocky coast, showing narrowing a headland at the seaward side and a possible proto sea stack (dashed line indicates the possible dimensions pre-erosion).

Figure.4.8 Sea Stump located in the bay area between two headlands (dashed line indicating possible dimensions pre-erosion)

Figure. 4.9. Pothole

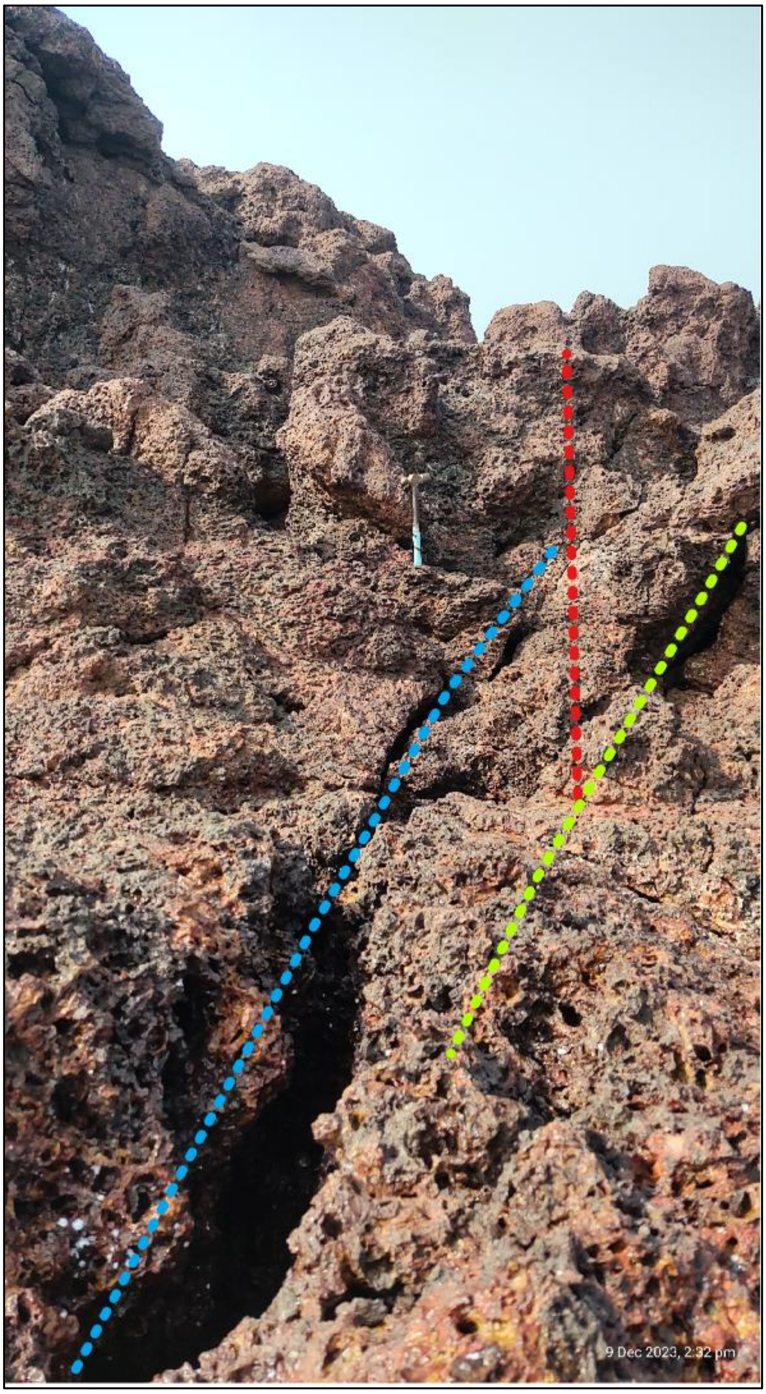


Fig.4.10 Tilting due to jointing (blue line indicating joints, red line is the reference vertical line and green line indicates the tilt.)

4.1.1 b. Depositional features:

Cliffs retreat by wave action leading to the formation of boulder deposits (Figure. 4.11), by erosion of the weaker material from the cliffs, boulders will be deposited at the base of the cliff or steep slope, they may also be formed due to anthropogenic influence, which might be the case for the southern end of the Tiracol coastal area as it lies directly below the Tiracol fort.

As the cliffs retreat suitable conditions for the deposition of sediments occurs due to lower wave velocities, leading to the formation of pocket beaches (Figure. 4.12 and Figure. 4.13) between two headlands, upon further deposition of sediments features like berm (Figure. 4.14) are formed by the rushing of waves up the swash zone, where the suspended sediments get deposited at the top.

The pocket beach at T1 and T2 are formed by the deposition of sediment by longshore currents and wave refraction. Pocket beach at T2 is formed in front of a sea cave, furthermore, the presence of a well-established berm indicates that there might not be erosion of the sea cave by wave action but the weathering and erosion of the sea cave will occur due to the vegetation growth around it.

Figure. 4.11 Boulder deposits at the base of the cliff.

Figure. 4.12 Pocket beach

Figure. 4.13 Pocket beach

Figure. 4.14. Berm

4.1.2 Laboratory Analysis:

Sieve Analysis:

For Tiracol, it is observed that, the mean ranges from 1 phi to 2 phi, the sorting calculated ranges from 0.3 to 0.6. Furthermore, the skewness ranged from 0.29 to 0.4, while the kurtosis ranged from 0.5 to 1.8. (Table 4.1), the above data implying the sediment grains to be medium grained, moderately well sorted and mesokurtic sediments in general.

Figure. 4.15 shows. Cumulative mass retained (%) vs Particle diameter (phi) indicating that the highest grain size proportion to be within the 1 phi to 2 phi size and the samples are unimodal in nature except for T1Lt which is bimodal in nature.

From Figure. 4.16 and 4.19 it is observed that the berm regions have a higher mean and kurtosis value than the low tide region. While Figure 4.18 shows that the value for skewness is higher for the low tide regions than the berms. Since the skewness across the area is positive, there is deposition of sand in the area (Duane, 1964; Brahma et al., 2017) and the Figure 4.17 shows sorting values are the lowest for the T1 berm but the highest for the T2 berm and the low tide of T1 shows an intermediate of the two implying a lower energy of the depositional environment of berm samples than the low tide samples.

From the kurtosis values of T1 sampling location, the berm sediments have been sorted in a relatively higher energy environment than the low tide sample.

Table 4.1. Sedimentological data generated for Tiracol (phi).

SAMPLE NAME	T1B	T1Lt	T2B
FEATURE	Berm	Low Tide	Berm
MEAN	1.788	1.156	2.058
SORTING	0.304	0.509	0.620
SKEWNESS	0.292	0.406	0.291
KURTOSIS	1.773	0.576	0.913
MEAN:	Medium Sand	Medium Sand	Fine Sand
SORTING:	Very Well Sorted	Moderately Well Sorted	Moderately Well Sorted
SKEWNESS:	Fine Skewed	Very Fine Skewed	Fine Skewed
KURTOSIS:	Very Leptokurtic	Very Platykurtic	Mesokurtic
% COARSE SAND:	2.0%	51.7%	7.3%
% MEDIUM SAND:	82.7%	48.0%	61.3%
% FINE SAND:	14.9%	0.3%	28.4%
% V FINE SAND:	0.3%	0.0%	3.0%

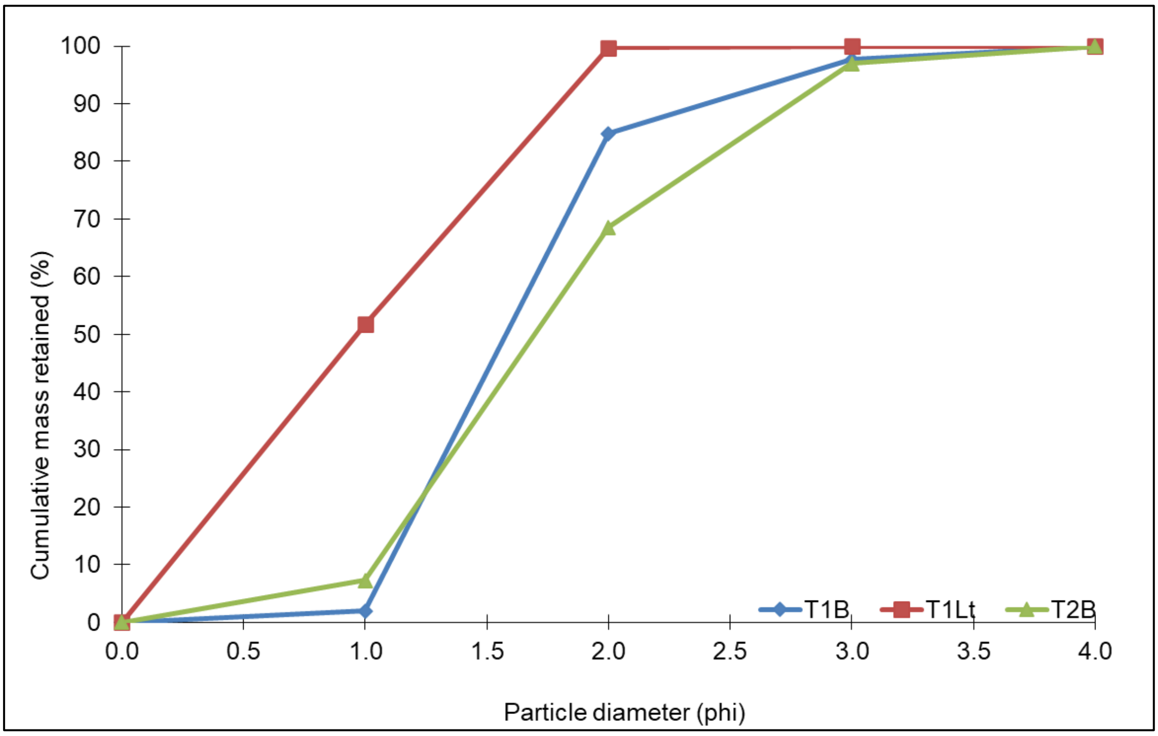


Figure. 4.15. Cumulative mass retained (%) vs Particle diameter (phi)

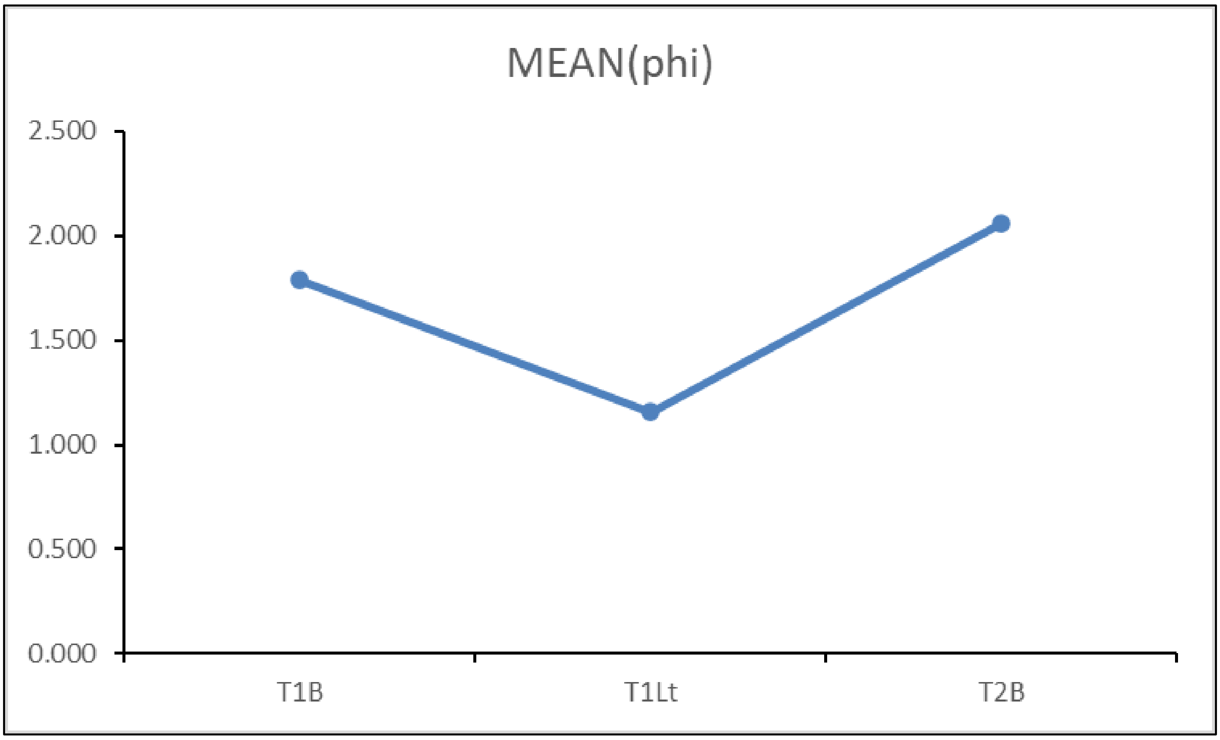


Figure. 4.16 Variation of Mean (phi) across different features.

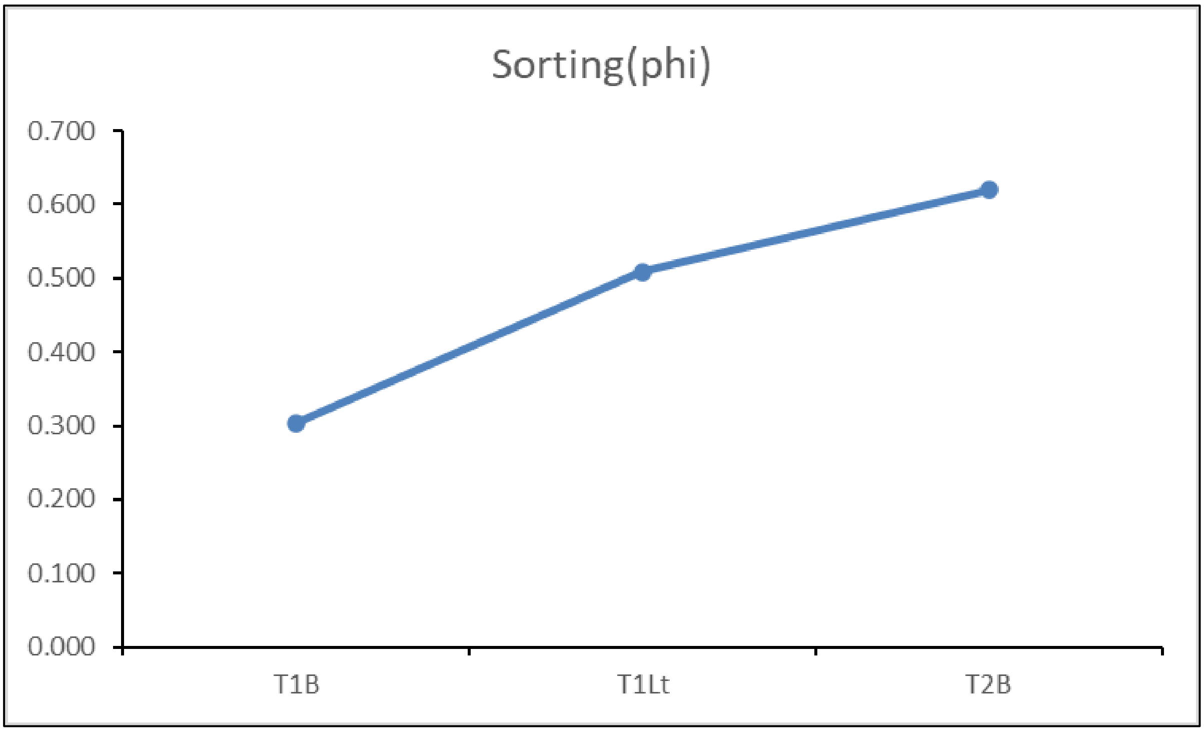


Figure. 4.17 Variation of Sorting (phi) across different features.

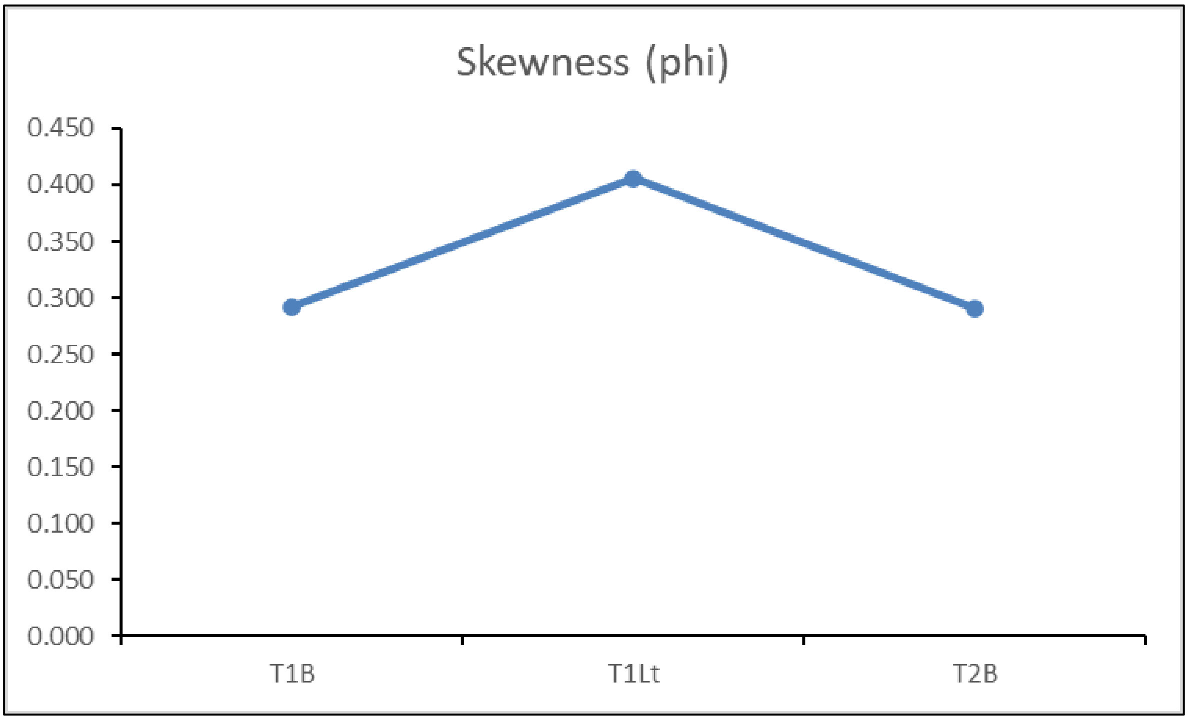


Figure. 4.18 Variation of Skewness (phi) across various geomorphological features.

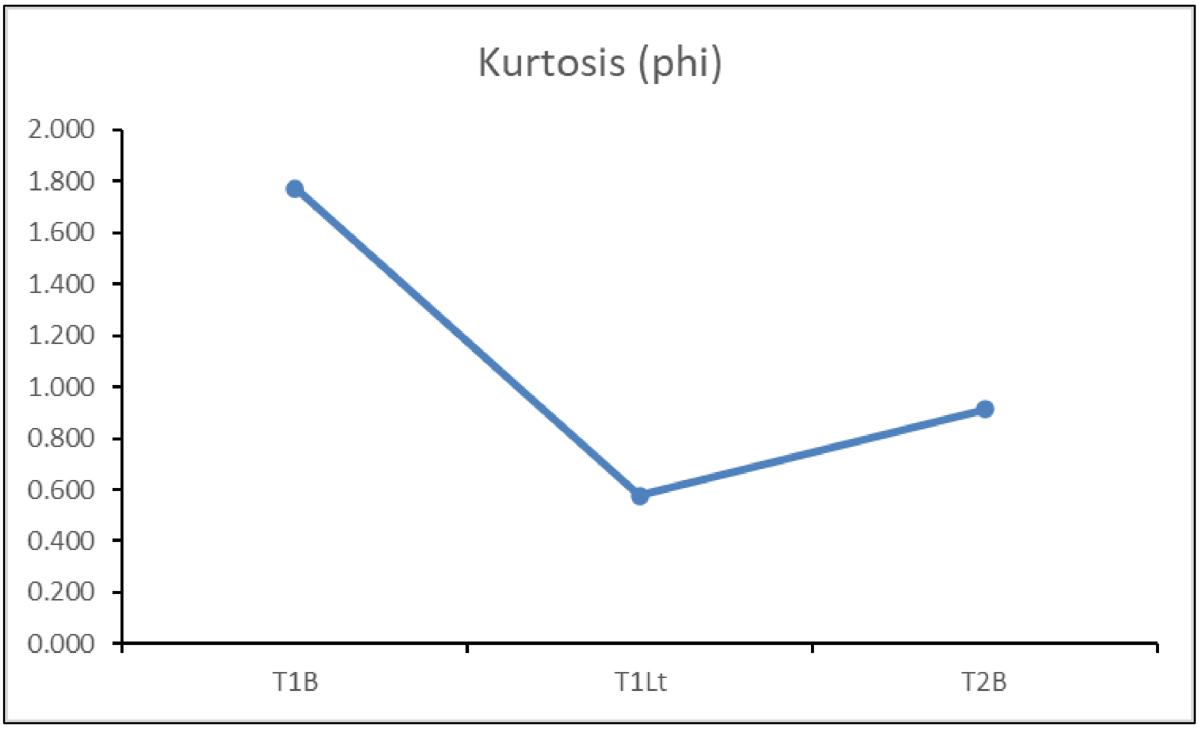


Figure. 4.19. Variation in Kurtosis (phi) across different geomorphological features.

4.2 QUERIM BEACH

Querim coastal area is dominated by depositional geomorphic features like beach, spit, berm. However, at the southern end rocks are exposed showing erosional features. The southern end shows a lithology of laterite and meta-argillite. Figureure 4.20 and Figure. 4.21 provide the geomorphological map of the Querim coastal area.

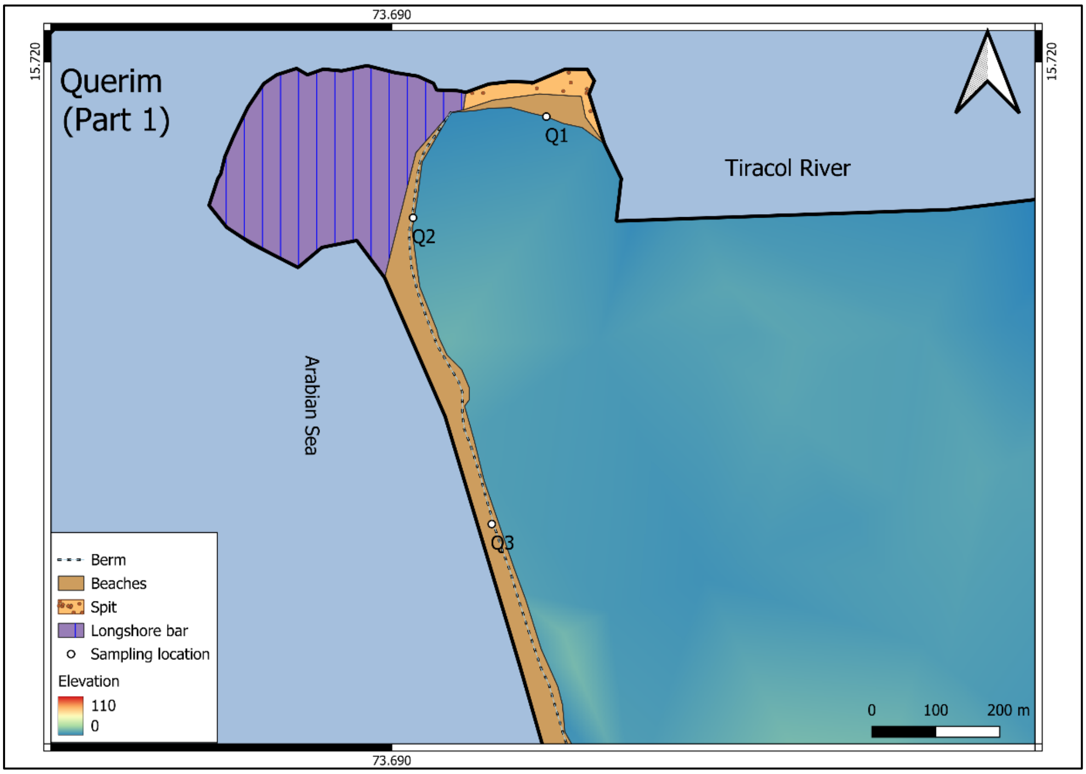


Figure. 4.20 Geomorphological Map of Querim Part 1.

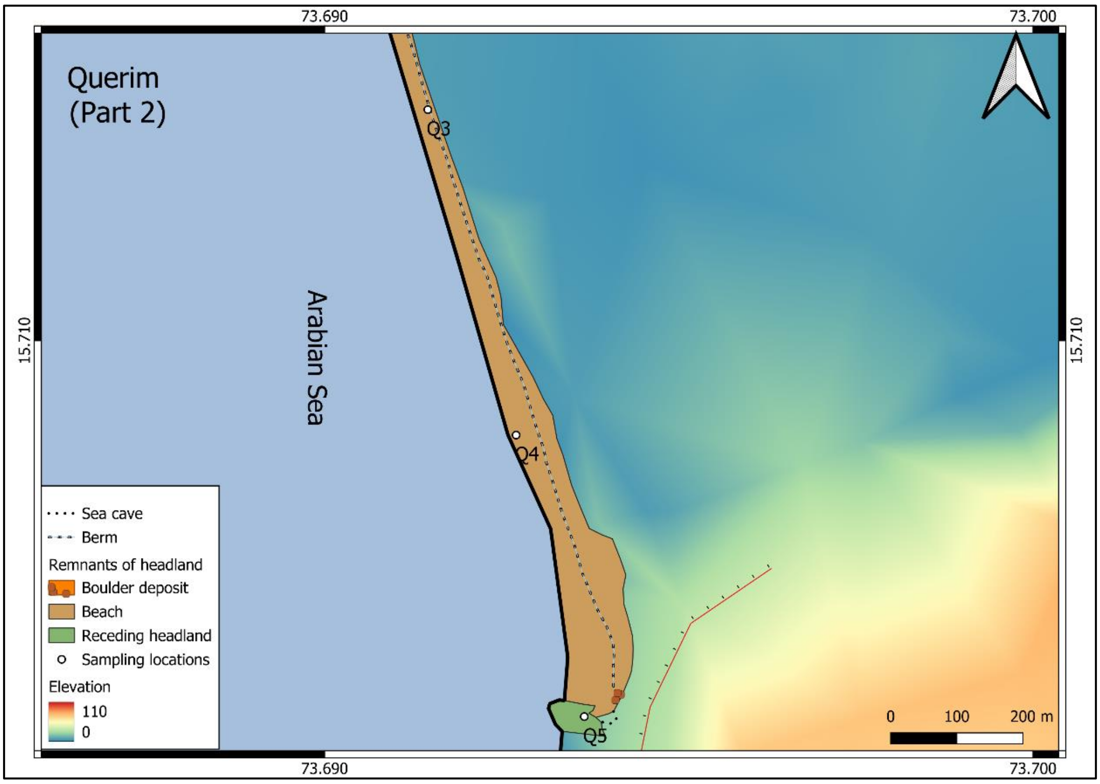


Figure. 4.21 Geomorphological map of Querim Part 2.

4.2.1 Field work:

4.2.1 a. Erosional features:

Receding headlands (Figure.4.22) are observed at the southern end of the Querim beach where the cliffs are eroded and headlands are formed due to wave action, these headlands get further eroded such that the areas of higher resistivity towards weathering and erosion remain as boulders that trace the original shape of the headland. Further erosion of the coast leads to the formation of sea stacks (Figure. 4.23). Coastal straightening is occurring at Querim coastal area, as the cliffs have retreated completely for the majority of the area.

Figure. 4.22. Receding headland

Figure. 4.23. Sea stack

4.2.1 b. Depositional Features:

As the cliffs retreat by wave action loose boulders get deposited at the base of the cliffs in the form of boulder deposits (Figure. 4.24).

Accumulation of loose sediments transported by rivers and erosion of nearby rocky coast leads to the formation of beaches, furthermore due to longshore currents and rip currents different features like berm, scarp and beach face are formed. Berm forms on a beach after further deposition of sediments by the waves occurs at the top as the waves moves up the swash zone, forming a berm (Figure. 4.25), the berm at Querim beach extends for the entire length except the southern part and has a dimension of approximately 15 cm.

If instead of land, the incoming waves interact with a river or an estuary, the sediments get deposited in a feature called as a spit (Figure. 4.26) with one end that is present in the estuary and the other end projects out into the sea, where it may turn due to longshore currents.

Figure. 4.27 shows a longshore bar that forms after erosion of the berm during winter. It may also form due to deposition of sediments by longshore currents and is usually exposed during extreme low tides.

Figure. 24. Boulder deposit

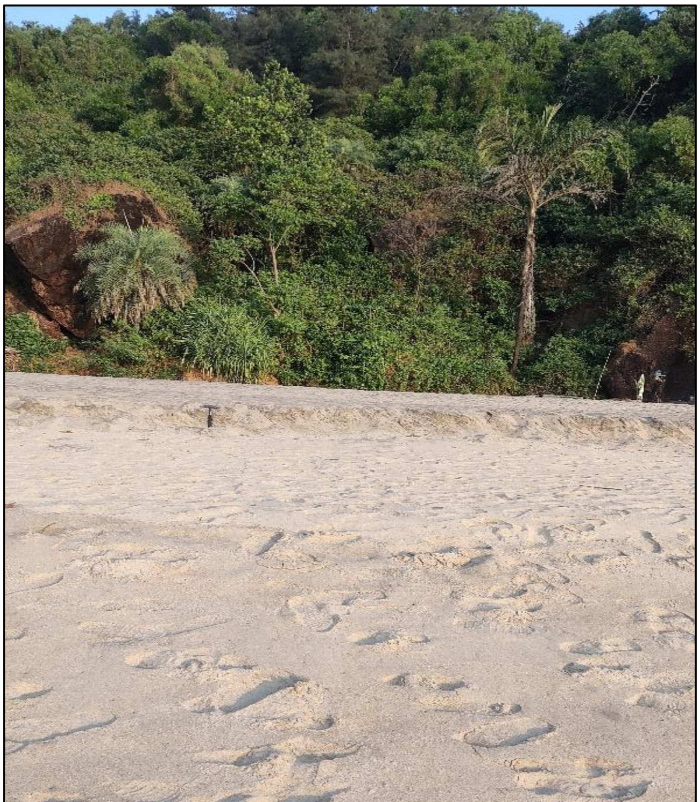


Figure. 14.25 Berm and beach face

Figure. 4.26 Spit.

Figure 4.27 Longshore bar exposed during extreme low tides (yellow line indicating the curve of the spit, green line is a reference line).

4.2.2 Laboratory Analysis:

Sieve Analysis

Table 4.2. Sedimentology data generated for Querim (phi).

Sample Name	Q1Sp	Q2Lbmrn	Q2Lbest	Q2Lt	Q2B	Q3Lt	Q3B	Q4Lt	Q4B	Q5Lt	Q5Nf
Feature	Spit	Longshore bar marine end	Longshore bar estuarine end	Low Tide	Berm	Low Tide	Berm	Low Tide	Berm	Low Tide	No feature
MEAN	1.371	1.410	1.529	1.539	2.358	2.127	2.359	2.397	2.085	2.137	2.361
SORTING	0.507	0.503	0.605	0.595	0.522	0.650	0.516	0.640	0.509	0.758	0.512
SKEWNESS	-0.466	-0.511	-0.266	-0.265	-0.387	0.580	-0.413	-0.189	0.506	0.338	-0.417
KURTOSIS	0.583	0.603	2.337	2.404	0.586	0.865	0.587	0.859	0.612	1.083	0.586
MEAN:	Medium Sand	Medium Sand	Medium Sand	Medium Sand	Fine Sand	Fine Sand	Fine Sand	Fine Sand	Fine Sand	Fine Sand	Fine Sand
SORTING:	Moderately Well Sorted	Moderately Well Sorted	Moderately Well Sorted	Moderately Well Sorted	Moderately Well Sorted	Moderately Well Sorted	Moderately Well Sorted	Moderately Well Sorted	Moderately Well Sorted	Moderately Sorted	Moderately Well Sorted
SKEWNESS:	Very Coarse Skewed	Very Coarse Skewed	Coarse Skewed	Coarse Skewed	Very Coarse Skewed	Very Fine Skewed	Very Coarse Skewed	Coarse Skewed	Very Fine Skewed	Very Fine Skewed	Very Coarse Skewed
KURTOSIS:	Very Platykurtic	Very Platykurtic	Very Leptokurtic	Very Leptokurtic	Very Platykurtic	Platykurtic	Very Platykurtic	Platykurtic	Very Platykurtic	Mesokurtic	Very Platykurtic
% COARSE SAND:	41.9%	34.8%	20.6%	19.1%	0.7%	3.9%	0.8%	1.1%	2.7%	7.5%	0.1%
% MEDIUM SAND:	57.8%	63.4%	65.9%	68.1%	44.2%	56.9%	42.9%	39.3%	62.0%	48.3%	43.3%
% FINE SAND:	0.2%	1.9%	13.5%	12.4%	50.8%	30.4%	53.6%	50.2%	34.0%	35.9%	54.4%
% V FINE SAND:	0.0%	0.0%	0.0%	0.4%	4.3%	8.8%	2.6%	9.4%	1.3%	8.4%	2.2%

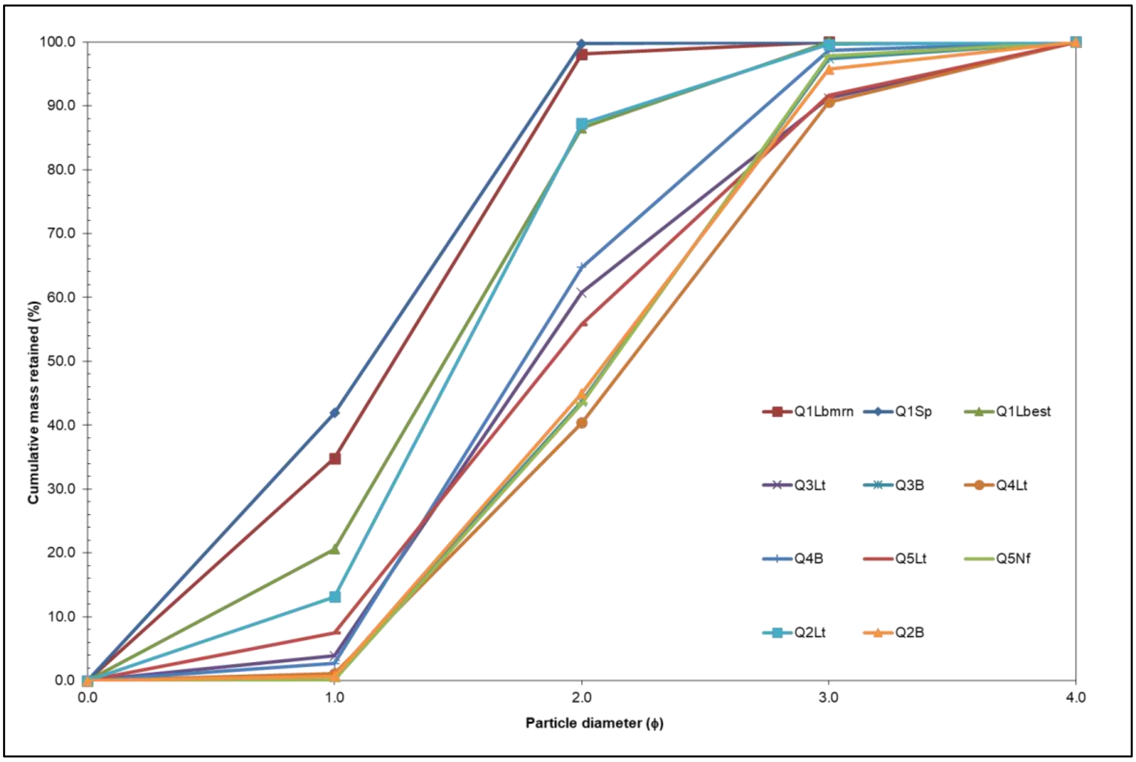


Figure. 4.28. Cumulative mass retained (%) vs particle diameter (phi)

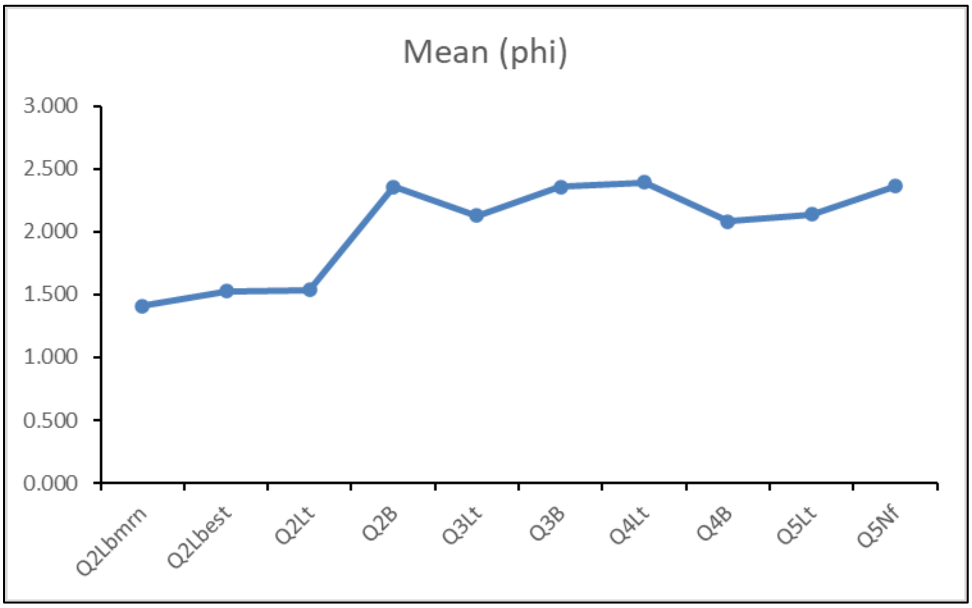


Figure. 4.29. Variation of Mean (phi) across different geomorphological features.

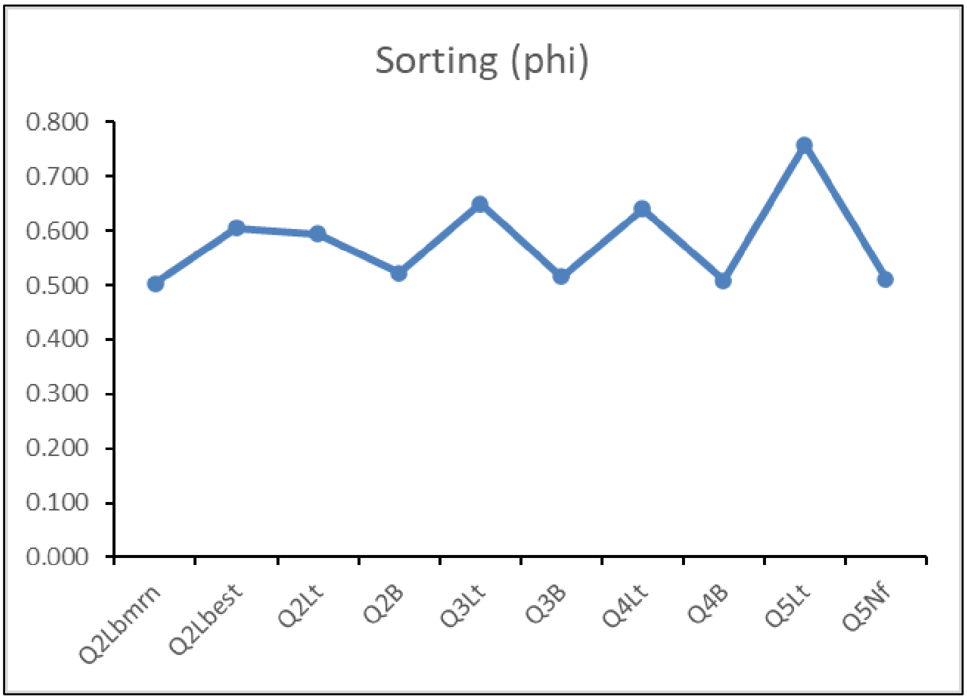


Figure. 4.30. Variation of Sorting (phi) across different geomorphological features.

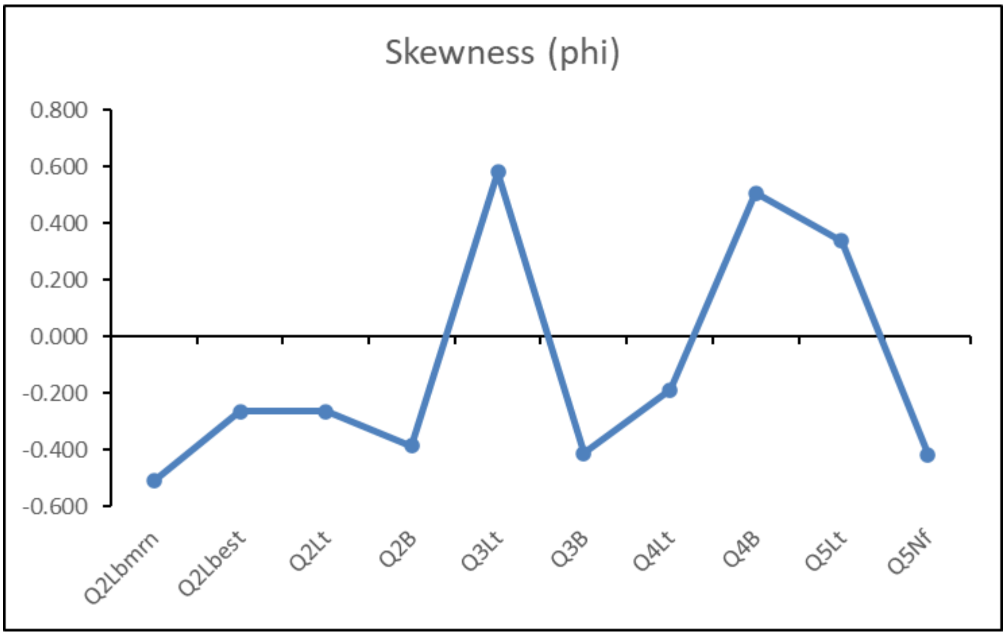


Figure. 4.31. Variation of Skewness (phi) across different geomorphological features

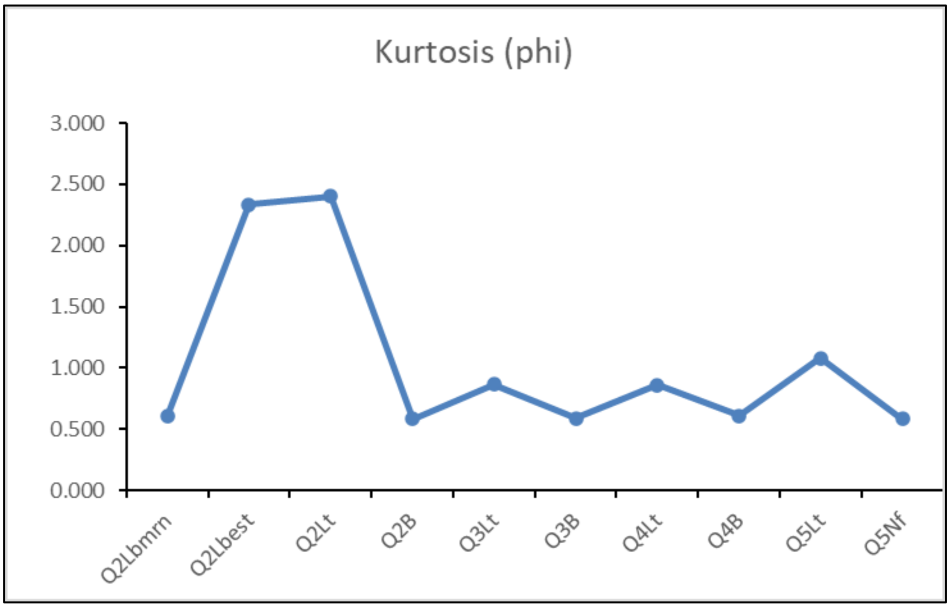


Figure. 4.32. Variation of Kurtosis (phi) across different geomorphological features.

For Querim, it is observed that, the mean ranges from 1 phi to 2.5 phi, the sorting calculated ranges from 0.5 to 0.8. Furthermore, the skewness ranged from -0.5 to 0.6, while the kurtosis ranged from 0.5 to 2.4 (Table 4.2), implies that the sediments vary from medium grained to fine grained in mean size, moderately well sorted to moderately sorted, strongly fine skewed to strongly coarse skewed and very platykurtic to very leptokurtic sediments.

Figure. 4.28 shows. Cumulative mass retained (%) vs Particle diameter (phi) indicates that other than the spit samples rest of the samples show a polymodal distribution.

From Figure. 4.29 it is seen that the spit has a lower mean phi value than the other features and the sediment grain size increases from foreshore to backshore (phi).

From Figure. 4.30 it is observed that the sample collected from the central part of the spit and the low tide zones shows higher values for sorting as compared to other sampling locations. Which may be explained from the fact that the wave energy decreases from the foreshore to the backshore.

From Figure. 4.31. It is observed that the samples from low tide region at Q3 and Q5 and the berm region of Q4 showed positive skewness indicating net deposition of sand arising from a low energy environment, whereas rest of the samples showed negative skewness indicative of net erosion due to high energy environment (Duane, 1964; Brahma et al., 2017).

From Figure. 4.32, the samples taken from Q2Lbest and Q2Lt are very leptokurtic in nature, implying their sediments were sorted in high energy environments while rest of the samples show mesokurtic to very platykurtic nature implying a lower energy environment.

4.3 ARAMBOL BEACH

Arambol Beach is a coastal area dominated by depositional features like sandbar, berm, dunes. Figure. 4.33 and Figure. 4.34 show geomorphological map of Arambol.

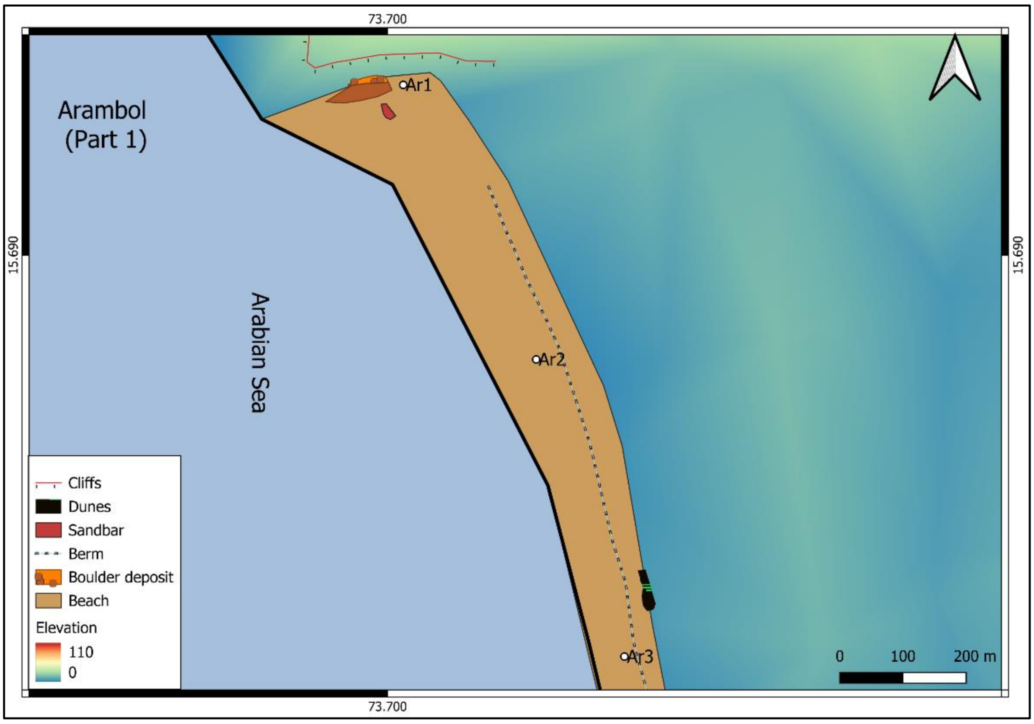


Figure. 4.33. Geomorphological map of Arambol Part 1

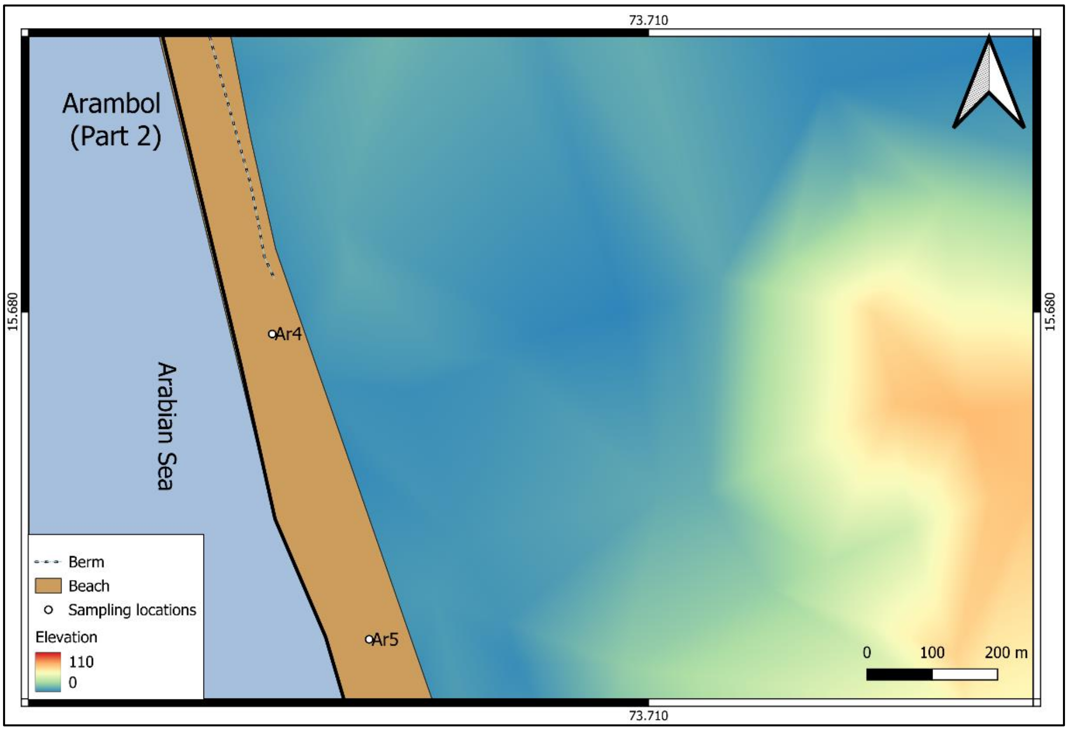


Figure. 4.34. Geomorphological map of Arambol Part 2

Different erosional and depositional geomorphological features were observed at Arambol beach, they are:

4.3.1 Field work

4.3.1. a. Erosional features:

Cliffs present at the northern end of the Arambol beach, retreated due to wave action, leading to a combined effect of quarrying and abrasion forming a platform like feature known as a wave cut platform (Figure. 4.34).

Figure. 4.35. Wave cut platform.

4.3.1 b. Depositional Features:

As the cliffs retreated loose boulders got deposited at the base, these are known as boulder deposits (Figure. 4.35), the boulder deposits at Arambol may be formed due to the construction of eateries and shops on the cliff face.

Furthermore, the retreat of the cliffs leads to the deposition of unconsolidated sediments forming a beach, further deposition of sediments at the top of the swash zone led to the formation of a feature known as berm (Figure. 4.36). However, this feature does not extend to the entirety of the Arambol beach but is absent at the northern and the southern ends.

On the backshore of the beach, aeolian processes dominate the transport of the sediments, causing mound like structures of unconsolidated sediment to form know as embryo dunes (Figure. 4.37), Embryo dunes can also form where pre-existing foredunes are eroded by waves, causing sediment to accumulate at their base (Masselink et al., 2014). The embryo dunes at Arambol were upto 25m in length and ranged from 7 to 10m in length and were approximately 0.5m in height.

At the northern end, there is a small stream that meets the sea, which reduces in velocity causing sediments to be deposited in the form of a bar, forming a sandbar (Figure. 4.38).

Figure 4.36. Boulder deposit

Figure. 4.37. Berm (dashed indicating the berm line)

Figure. 4.38. Embryo dune

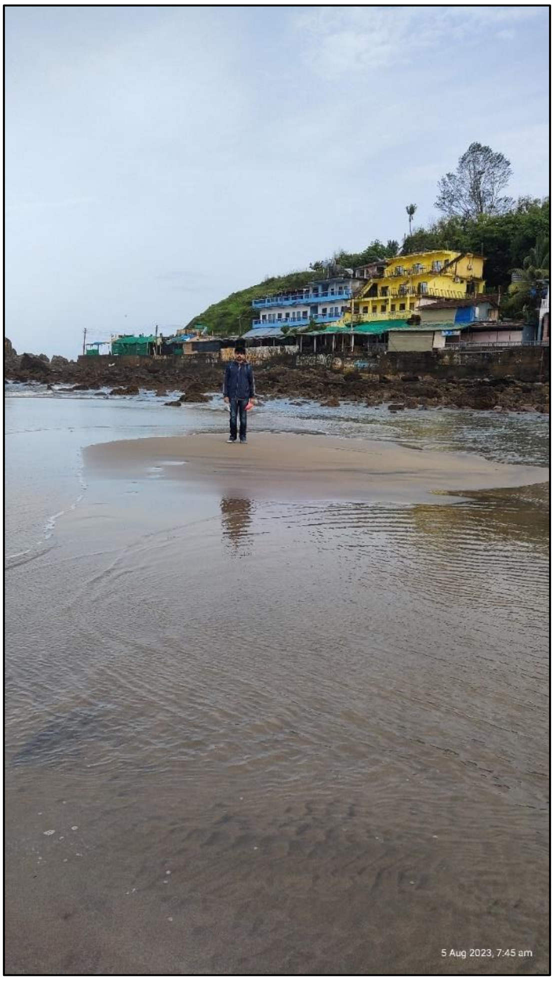


Figure. 4.39. Sandbar

4.3.2 Laboratory analysis:

Sieve analysis:

Table.4. 3. Sedimentological data generated for Arambol (phi)

Sample Name	Ar1Lt	Ar1Sb	Ar1Nf
Feature	Low Tide	Sand Bar	No feature
MEAN	2.157	2.083	2.760
SORTING	0.616	0.661	0.380
SKEWNESS	0.193	0.172	0.068
KURTOSIS	0.789	0.874	2.307
MEAN:	Fine Sand	Fine Sand	Fine Sand
SORTING:	Moderately Well Sorted	Moderately Well Sorted	Well Sorted
SKEWNESS:	Fine Skewed	Fine Skewed	Symmetrical
KURTOSIS:	Platykurtic	Platykurtic	Very Leptokurtic
% COARSE SAND:	5.2%	12.5%	0.0%
% MEDIUM SAND:	45.4%	46.1%	5.1%
% FINE SAND:	45.2%	39.9%	82.6%
% V FINE SAND:	4.2%	1.5%	12.3%

Ar2B	Ar2Lt	Ar3B	Ar3Lt
Berm	Low Tide	Berm	Low Tide
2.539	2.492	2.734	2.528
0.562	0.565	0.421	0.583
-0.272	-0.308	-0.003	-0.267
2.369	2.210	2.469	2.338
Fine Sand	Fine Sand	Fine Sand	Fine Sand
Moderately Well Sorted	Moderately Well Sorted	Well Sorted	Moderately Well Sorted
Coarse Skewed	Very Coarse Skewed	Symmetrical	Coarse Skewed
Very Leptokurtic	Very Leptokurtic	Very Leptokurtic	Very Leptokurtic
0.1%	0.0%	0.0%	0.6%
17.3%	21.8%	11.3%	18.3%
73.4%	71.8%	78.2%	70.4%
9.2%	6.4%	10.4%	10.7%

Ar4Lt	Ar4Nf	Ar5Lt	Ar5Nf
Low Tide	No feature	Low Tide	No feature
2.121	2.947	2.736	3.003
0.518	0.436	0.433	0.468
0.458	0.546	0.001	0.553
0.592	1.696	2.448	1.644
Fine Sand	Fine Sand	Fine Sand	Very Fine Sand
Moderately Well Sorted	Well Sorted	Well Sorted	Well Sorted
Very Fine Skewed	Very Fine Skewed	Symmetrical	Very Fine Skewed
Very Platykurtic	Very Leptokurtic	Very Leptokurtic	Very Leptokurtic
2.3%	0.0%	0.1%	0.1%
55.6%	2.2%	12.2%	0.6%
40.1%	81.1%	75.7%	77.0%
2.0%	16.7%	12.1%	22.3%

Ar3D1	Ar3D2	Ar3D3
Dune	Dune	Dune
3.050	2.990	2.960
0.506	0.586	0.455
0.500	0.290	0.542
0.623	2.209	1.648
Very Fine Sand	Fine Sand	Fine Sand
Moderately Well Sorted	Moderately Well Sorted	Well Sorted
Very Fine Skewed	Fine Skewed	Very Fine Skewed
Very Platykurtic	Very Leptokurtic	Very Leptokurtic
0.0%	0.0%	0.0%
4.3%	7.7%	4.4%
64.0%	69.0%	77.1%
31.7%	23.3%	18.4%

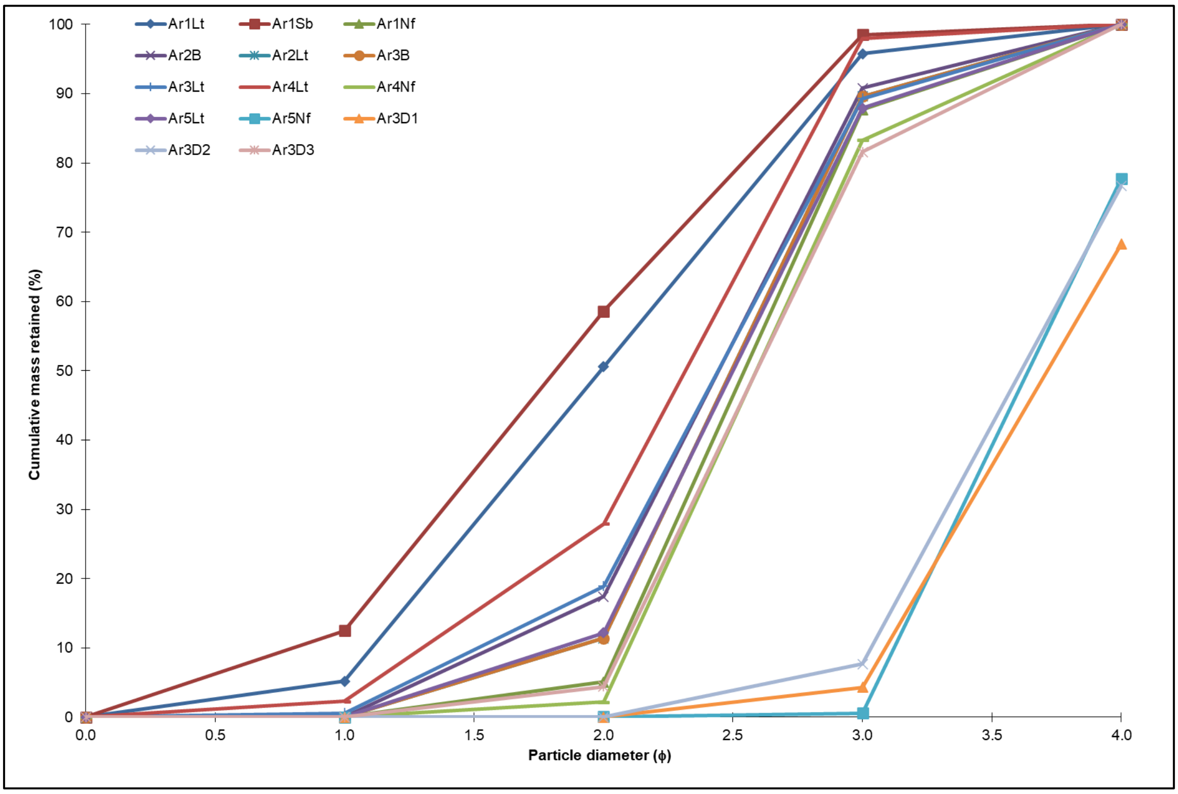


Figure. 4.40. Cumulative mass retained (%) vs Particle diameter (phi)

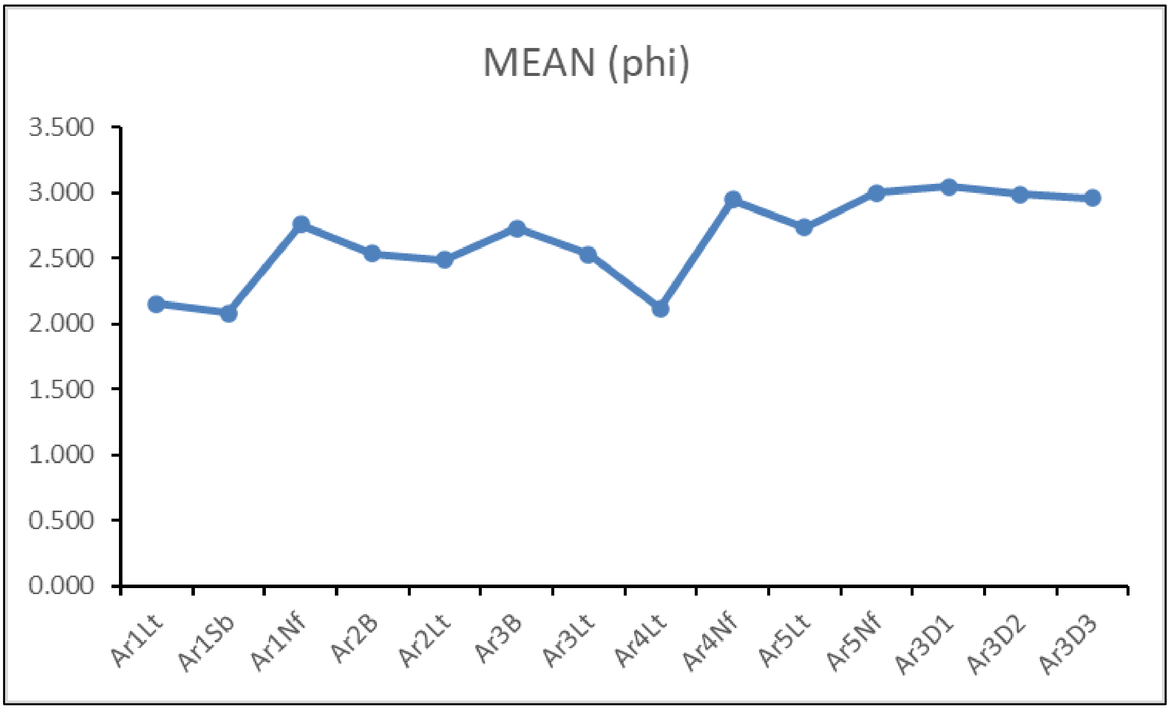


Figure. 4.41. Distribution of Mean (phi) across different geomorphological features.

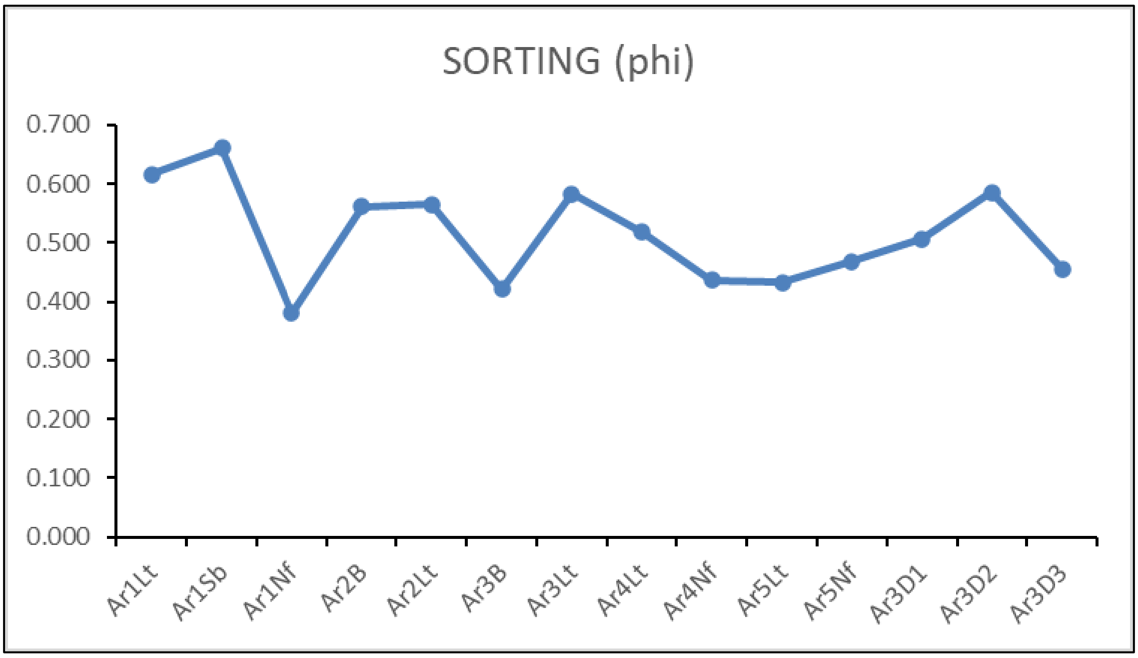


Figure. 4.42. Distribution of Sorting (phi) across different geomorphological features.

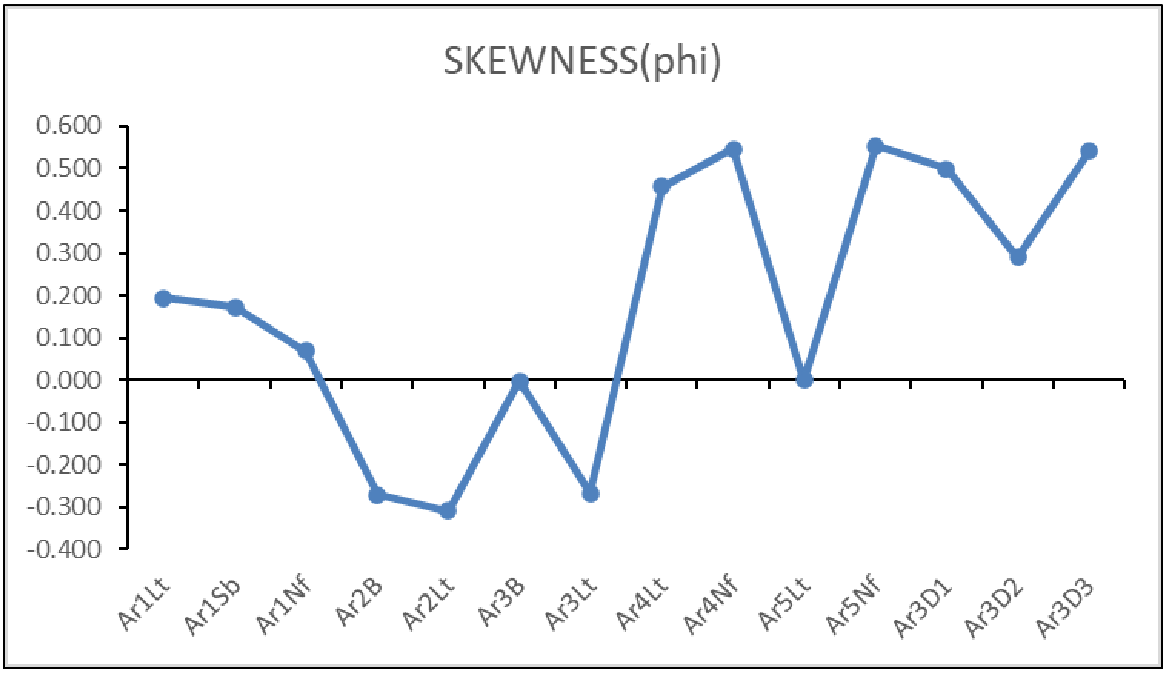


Figure. 4.43. Distribution of Skewness (phi) across different geomorphological features

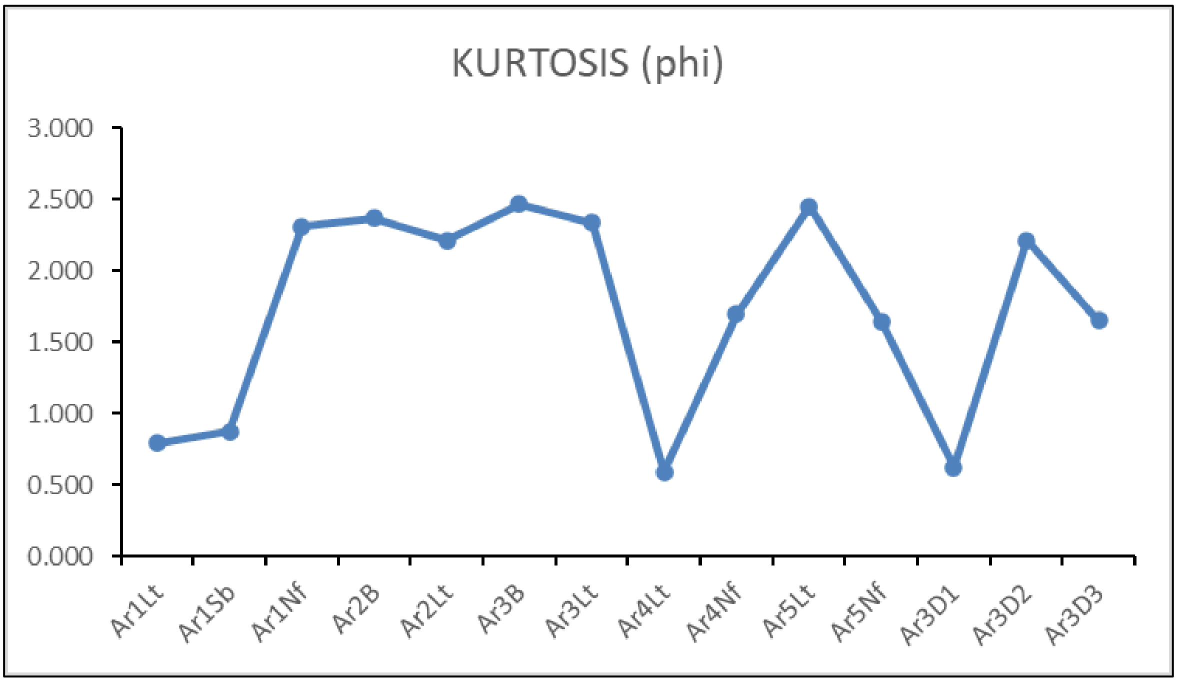


Figure. 4.44. Distribution of Kurtosis (phi) across different geomorphological features.

For Arambol, it is observed that, the mean ranges from 2 phi to 3 phi, the sorting calculated ranges from 0.3 to 0.6. Furthermore, the skewness ranged from -0.3 to 0.5, while the kurtosis ranged from 0.7 to 2.5 (Table 4.3), implying fine grain size with very well to well sorted sediments, that are near symmetrically to strongly fine skewed and show platykurtic to very leptokurtic kurtosis.

Figure. 4.39 shows. Cumulative mass retained (%) vs Particle diameter (phi)., where the samples Ar5Nf, Ar3D2 and Ar3D1 are unimodal in nature, Ar1Sb and Ar1Lt show a bimodal distribution which may be due to their close vicinity and the rest of the samples show a polymodal distribution.

From Figure. 4.40 it can be observed that mean (phi) grain size value is increasing from backshore to foreshore and north to south.

While in Figure. 4.41 it is observed that the samples Ar1Lt, Ar1Sb and Ar3Lt show a higher sorting value which implies a higher wave energy at those locations.

For the parameter of skewness, it can be observed that the sediments collected from Ar2B, Ar2Lt and Ar3Lt are negatively skewed implying an erosional setting whereas, rest of the samples are positively skewed leading to depositional setting. (Figure. 4.42)

Meanwhile, from the Figure. 4.43 it is seen that the sample of Ar1Sb, Ar1Lt, Ar4Lt, Ar3D1 are having a kurtosis value of less than one while the rest of the samples are showing a value of greater than one implying an extremely low energy (Dora et al., 2011; Brahma et al., 2017).

4.4 MANDREM BEACH

Mandrem Beach coastal area is an area dominated by depositional geomorphological features with a few erosional features being present at the southern end. Figureures 4.44 and 4.45 give the geomorphological map of Mandrem.

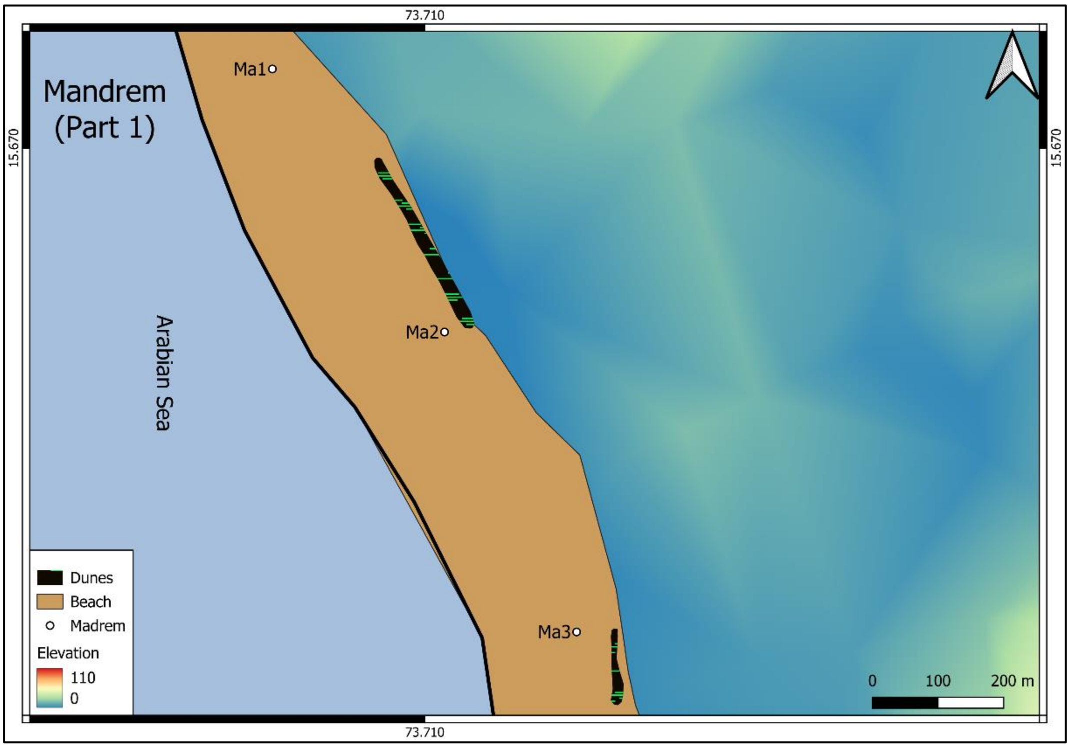


Figure. 4.45 Geomorphological map of Mandrem Part 1

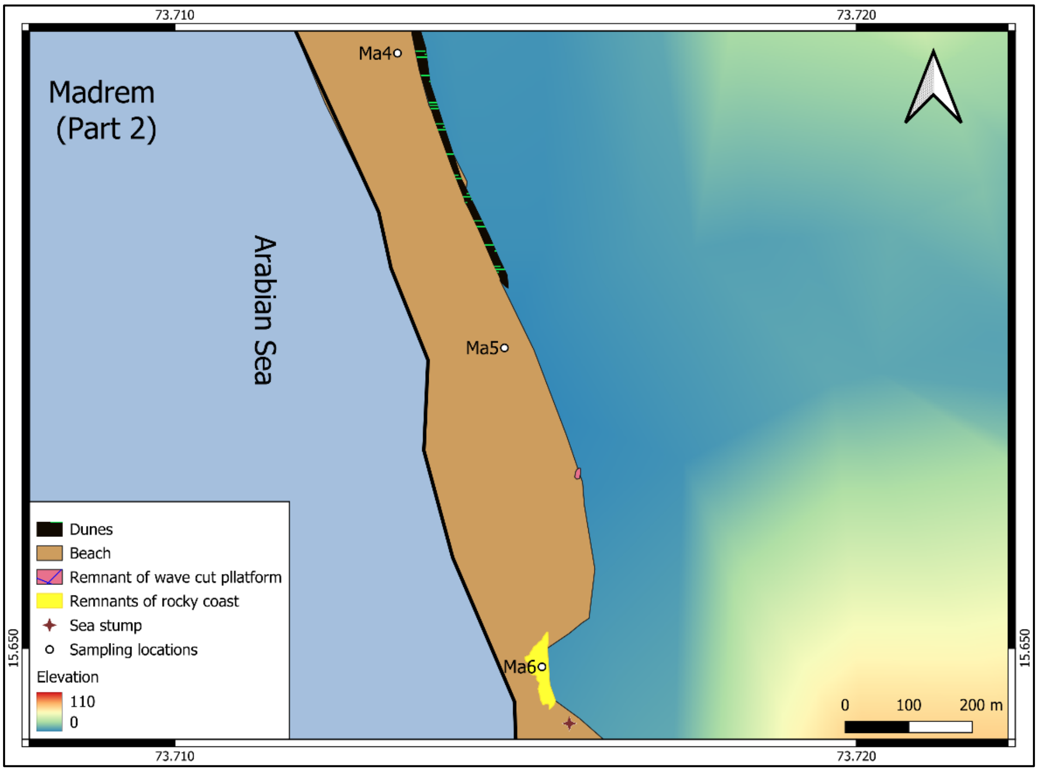


Figure. 4.46 Geomorphology map of Mandrem Part 2

4.4.1 Field Work:

4.4.1 a. Erosional features:

After retreat of cliffs a marine terrace (Figure. 4.46 and Figure. 4.47) is formed, the terrace at Mandrem gets inundated by waves, depositing sediments. The weathering and erosion of wave cut platform has left the remnant of wave cut platform (Figure. 4.48).

Figure.4.47 Remnant of rocky coast. (Top view showing deposition of unconsolidated sediments due to wave inundation)

Figure.4.48 Remnant of rocky coast (side view)

Figure. 4.49. Beach showing remnant of wave cut platform (eroded)

4.4.2 b. Depositional features:

As the cliffs retreated deposition of unconsolidated sediments occurred, leading to the formation of a beach, upon further deposition of the sediments on the top of the swash zone berm formation occurred (Figure. 4.49)

On the backshore due to aeolian transport and deposition embryo dunes (Figure. 4.50) form, the embryo dunes at Mandrem were found in between location 3 and 4 where there was higher vegetation density as compared to the rest of beach. The dunes found at Mandrem ranged from 4 to 10m in length, 5 to 9m in width and approximately 0.5m in height. These embryo dunes further coalesce and form a dune that runs parallel to the shoreline called as a foredune or a foredune ridge (Figure. 4.51 and Figure. 4.52), foredunes between locations 1 and 2 of Mandrem beach (Figure. 4.51) which is approximately 0.5 m in height and 230m in length, while the foredune ridge shown in (Figure 4.52) located between location 3 and 4 of Mandrem beach has a height of approximately 2m and stretched for approximately 250m. If the foredunes lose their foremost position to a new foredune that forms, then it is known as a relict foredune (Figure. 4.53).

Figure. 4.50. Berm

Figure. 4.51. Embryo dunes

Figure. 4.52 Foredune (dashed line indicating the curve of the foredune)

Figure. 4.53 Foredune (blackline indicating the top of the foredune and the footpaths created)

Figure. 4.54 Relict foredune

4.4.2 Laboratory analysis

Sieve analysis

Table. 4. 4. Sedimentological data generated for Mandrem (phi)

Sample Name	Ma1Lt	Ma2Lt	Ma3Lt
Feature	Low Tide	Low Tide	Low Tide
MEAN	2.761	3.327	2.678
SORTING	0.769	0.523	0.773
SKEWNESS	0.004	-0.442	-0.019
KURTOSIS	2.075	0.589	0.992
MEAN:	Fine Sand	Very Fine Sand	Fine Sand
SORTING:	Moderately Sorted	Moderately Well Sorted	Moderately Sorted
SKEWNESS:	Symmetrical	Very Coarse Skewed	Symmetrical
KURTOSIS:	Very Leptokurtic	Very Platykurtic	Mesokurtic
% COARSE SAND:	1.0%	0.0%	1.2%
% MEDIUM SAND:	18.1%	3.9%	24.1%
% FINE SAND:	58.8%	41.6%	57.0%
% V FINE SAND:	22.2%	54.5%	17.7%

Ma4Lt	Ma5Lt	Ma6Lt	Ma1Nf
Low Tide	Low Tide	Low Tide	No feature
2.772	2.762	2.767	2.737
0.870	0.739	0.817	0.433
-0.060	0.011	-0.011	0.001
0.574	2.194	0.914	2.448
Fine Sand	Fine Sand	Fine Sand	Fine Sand
Moderately Sorted	Moderately Sorted	Moderately Sorted	Well Sorted
Symmetrical	Symmetrical	Symmetrical	Symmetrical
Very Platykurtic	Very Leptokurtic	Mesokurtic	Very Leptokurtic
3.9%	0.7%	1.4%	0.1%
24.6%	16.5%	21.7%	12.1%
34.3%	63.1%	48.6%	75.6%
37.2%	19.7%	28.4%	12.2%

Ma2Nf	Ma3Nf	Ma4Nf	Ma5Nf
No feature	No feature	No feature	No feature
2.535	2.958	2.771	2.334
0.574	0.454	0.402	0.516
-0.266	0.542	0.056	-0.373
2.350	1.650	2.317	0.583
Fine Sand	Fine Sand	Fine Sand	Fine Sand
Moderately Well Sorted	Well Sorted	Well Sorted	Moderately Well Sorted
Coarse Skewed	Very Fine Skewed	Symmetrical	Very Coarse Skewed
Very Leptokurtic	Very Leptokurtic	Very Leptokurtic	Very Platykurtic
0.2%	0.0%	0.1%	1.0%
18.0%	4.4%	5.7%	46.9%
71.5%	77.3%	78.3%	50.3%
10.3%	18.3%	15.8%	1.8%

Ma6Mt	Ma1-2UD1	Ma1-2UD2	Ma1-2UD3
Marien Terrace	Relict Foredune	Relict Foredune	Relict Foredune
3.022	2.550	2.719	2.743
0.584	0.541	0.420	0.397
0.305	-0.278	-0.019	0.015
0.904	2.384	2.432	2.450
Very Fine Sand	Fine Sand	Fine Sand	Fine Sand
Moderately Well Sorted	Moderately Well Sorted	Well Sorted	Well Sorted
Very Fine Skewed	Coarse Skewed	Symmetrical	Symmetrical
Mesokurtic	Very Leptokurtic	Very Leptokurtic	Very Leptokurtic
0.3%	0.1%	0.1%	0.1%
5.6%	16.0%	13.9%	7.7%
66.5%	76.1%	77.5%	82.5%
27.6%	7.8%	8.6%	9.7%

Ma1-2LD	Ma3-4D1	Ma3-4D2	Ma3-4D3
Foredune	Embryo Dune	Embryo Dune	Embryo Dune
2.453	2.947	3.078	3.027
0.638	0.536	0.504	0.491
-0.226	0.313	0.490	0.530
0.917	2.296	0.605	0.660
Fine Sand	Fine Sand	Very Fine Sand	Very Fine Sand
Moderately Well Sorted	Moderately Well Sorted	Moderately Well Sorted	Well Sorted
Coarse Skewed	Very Fine Skewed	Very Fine Skewed	Very Fine Skewed
Mesokurtic	Very Leptokurtic	Very Platykurtic	Very Platykurtic
0.2%	0.2%	0.1%	0.1%
31.3%	5.8%	1.2%	2.8%
56.3%	76.4%	63.1%	70.0%
12.2%	17.6%	35.6%	27.0%

Ma3-4D4	Ma3-4D5	Ma3-4D6	Ma3-4D7
Embryo Dune	Embryo Dune	Embryo Dune	Embryo Dune
2.728	3.033	2.741	2.733
0.426	0.485	0.419	0.399
-0.007	0.538	0.005	-0.008
2.456	0.660	2.472	2.455
Fine Sand	Very Fine Sand	Fine Sand	Fine Sand
Well Sorted	Well Sorted	Well Sorted	Well Sorted
Symmetrical	Very Fine Skewed	Symmetrical	Symmetrical
Very Leptokurtic	Very Platykurtic	Very Leptokurtic	Very Leptokurtic
0.1%	0.1%	0.1%	0.0%
12.7%	0.8%	10.0%	9.4%
77.0%	72.2%	78.7%	82.4%
10.2%	27.0%	11.2%	8.2%

Ma3-4D8
Embryo Dune
2.988
0.470
0.544
1.622
Fine Sand
Well Sorted
Very Fine Skewed
Very Leptokurtic
0.1%
3.3%
75.3%
21.4%

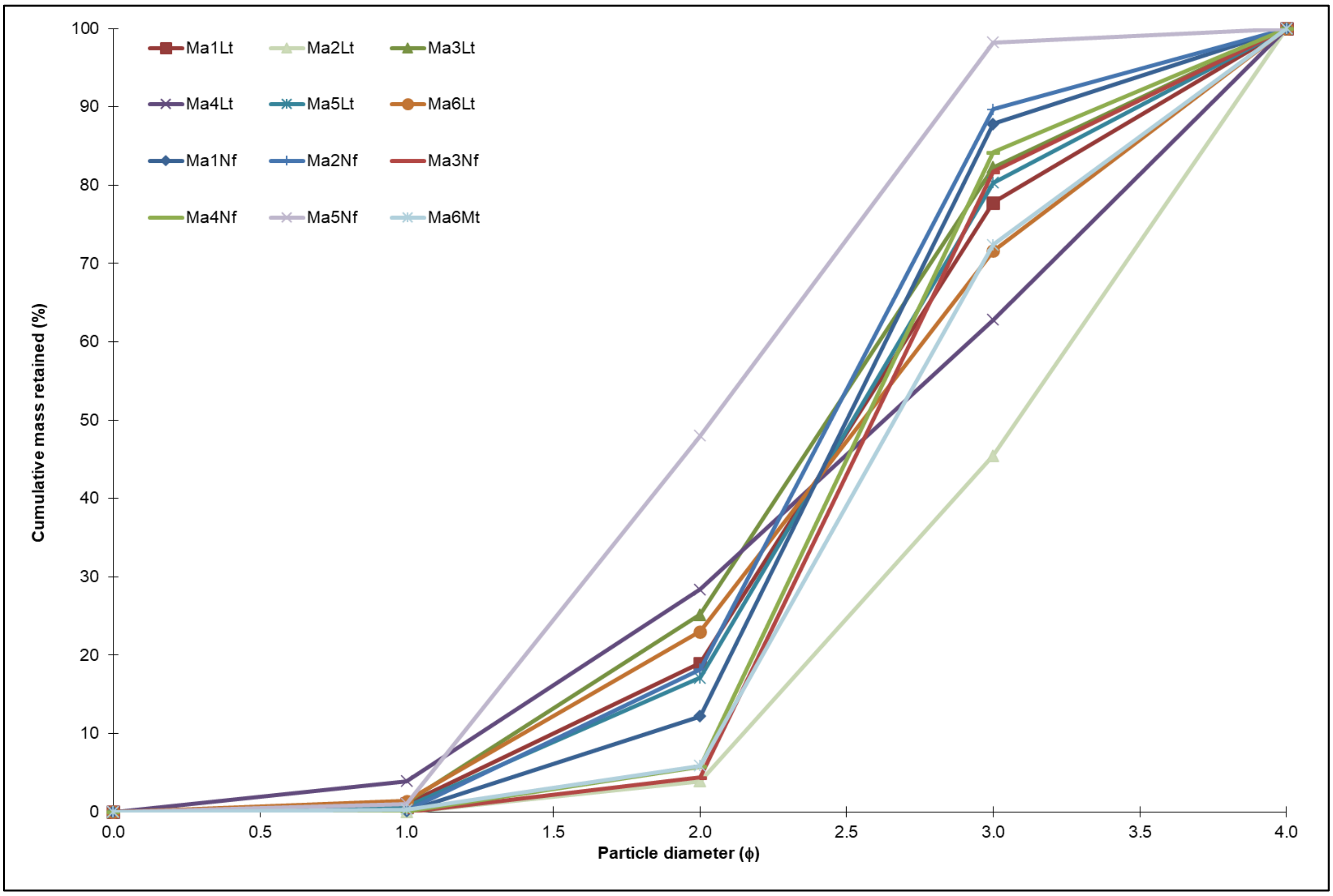


Figure.4.55. Cumulative mass retained (%) vs particle diameter (phi) for Mandrem

(foreshore and backshore).

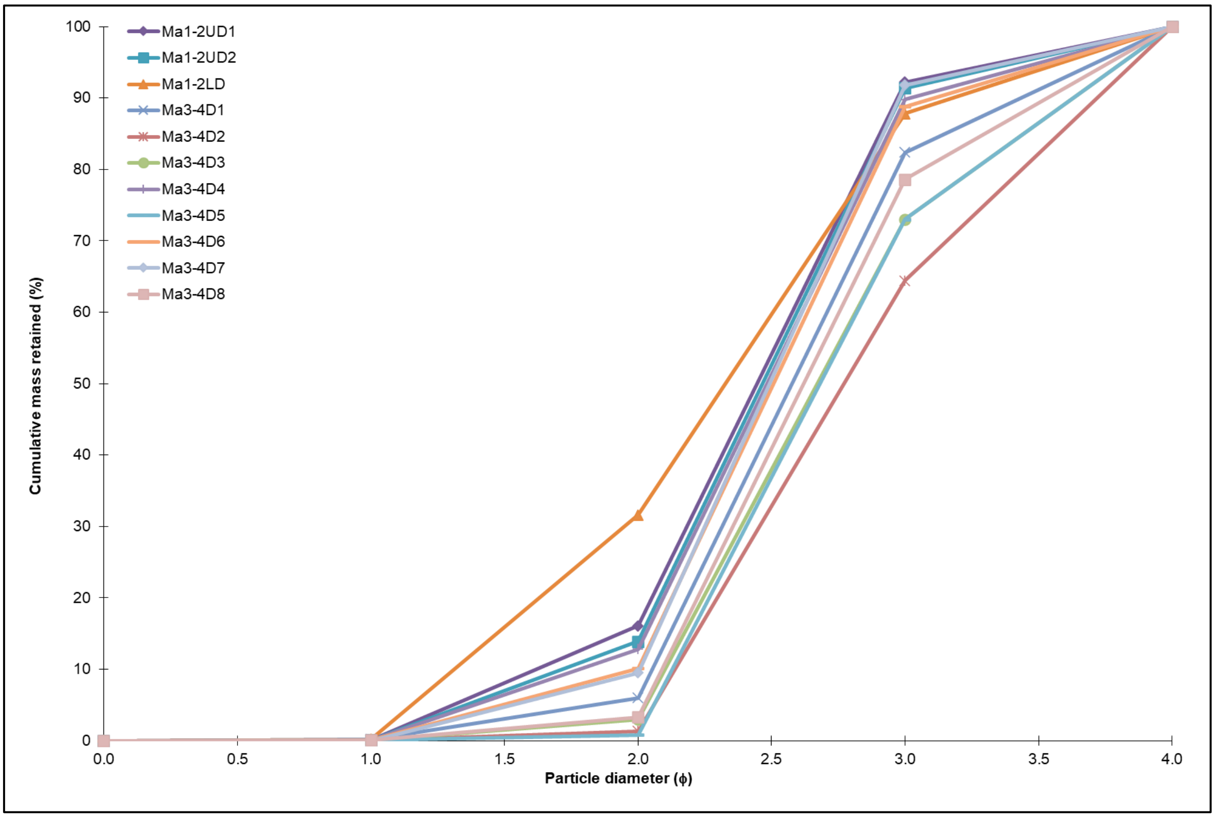


Figure. 4.56. Cumulative mass retained (%) vs particle diameter (phi) for Mandrem (dune samples).

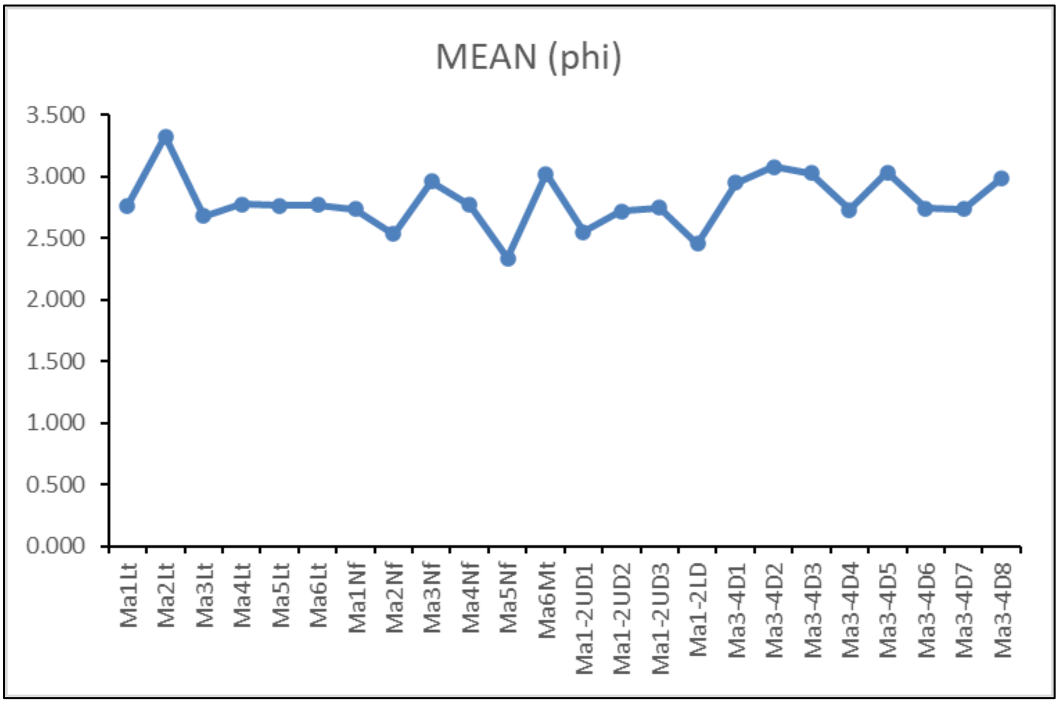


Figure. 4.57. Distribution of mean (phi) for different geomorphological features.

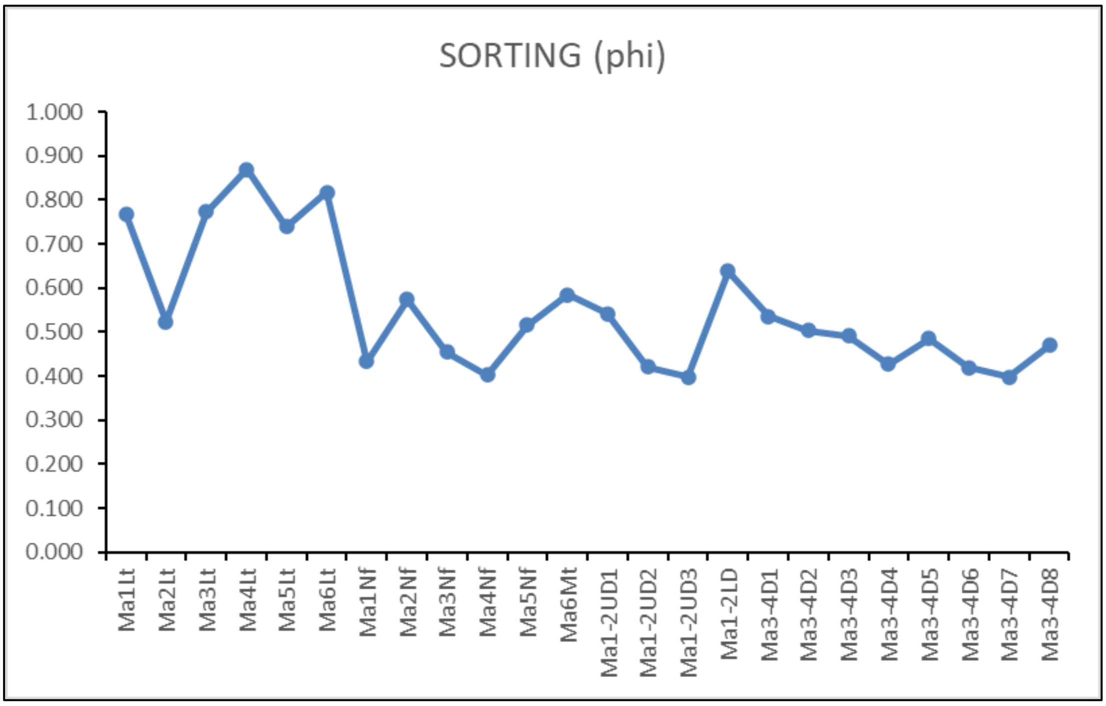


Figure. 4.58. Distribution of sorting (phi) across different geomorphological features.

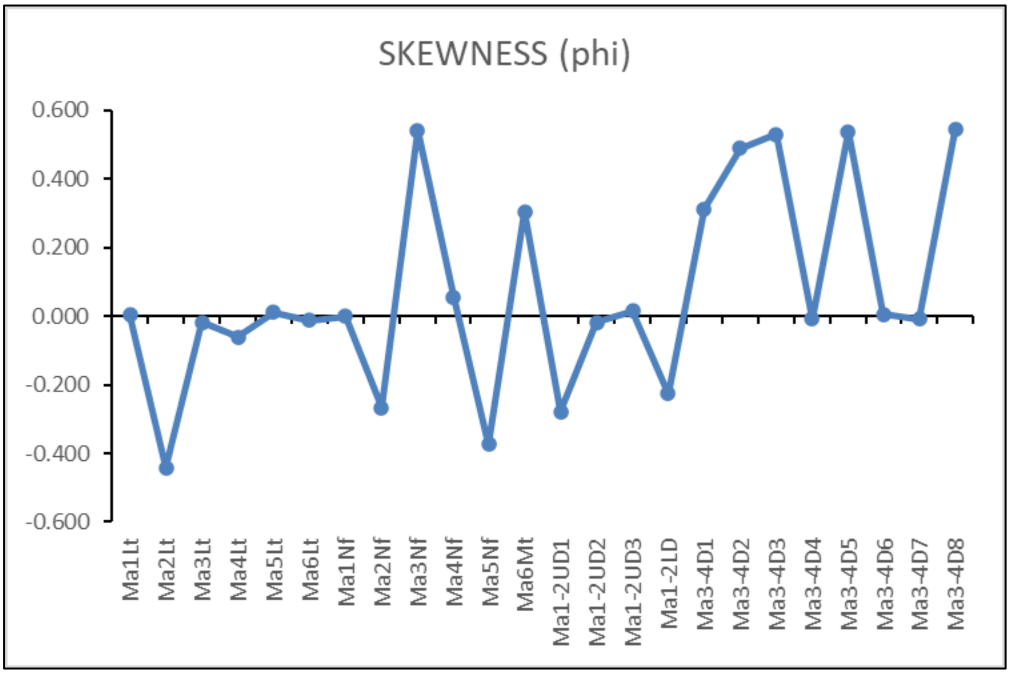


Figure. 4.59. Distribution of Skewness (phi) across different geomorphological features.

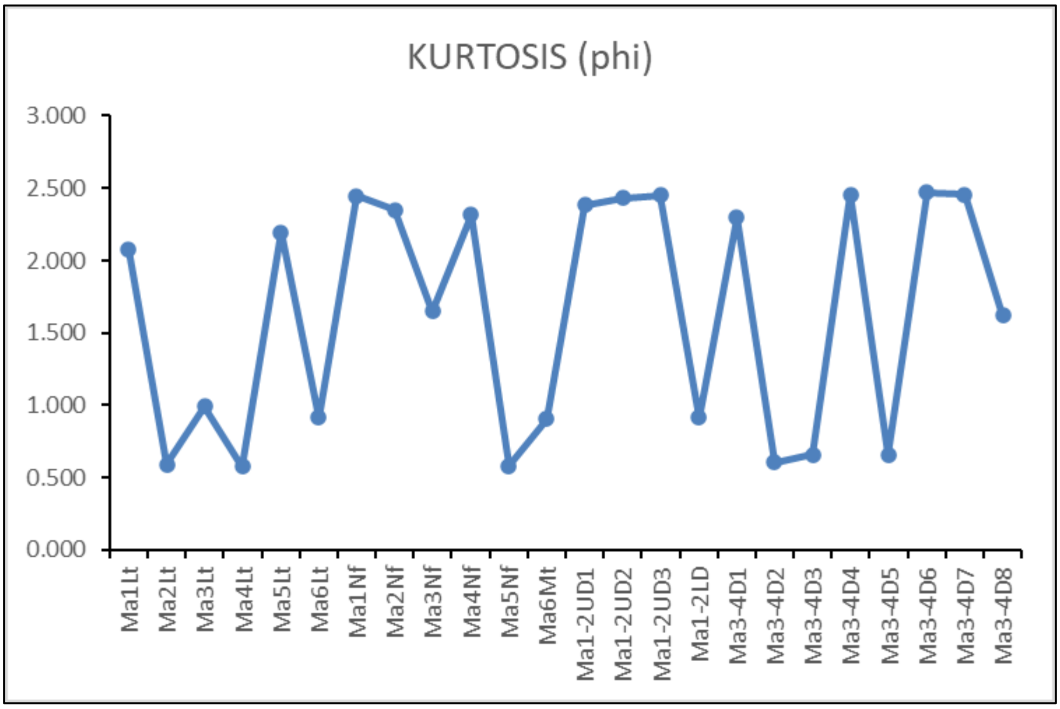


Figure. 4.60. Distribution of Kurtosis (phi) across different geomorphological features.

For Mandrem, it is observed that, the mean ranges from 2 phi to 3 phi, the sorting calculated ranges from 0.4 to 0.8. Furthermore, the skewness ranged from -0.3 to 0.5, while the kurtosis ranged from 0.5 to 2.5 (Table 4.4) implying that the samples are fine grained, well sorted to moderately well sorted sediments, that are coarse skewed to strongly finely skewed and having very platykurtic to very leptokurtic nature.

Figure. 4.54 and Figure. 4.55 shows. Cumulative mass retained (%) vs Particle diameter (phi), where all the samples show a polymodal distribution except for Ma5Nf and Ma2Lt

From Figure. 4.56 it is seen that all the samples show a mean phi value from 2.5 to 3 phi.

The sorting value decreases from foreshore to backshore. (Figure. 4.57)

From Figure. 4.58. it is observed that skewness increases from foreshore to backshore, which possibly hints to the erosional of sediments from the foreshore and their subsequent deposition on the backshore.

The samples of Ma3Lt, Ma4Lt, Ma6Lt, Ma3-4D2, Ma3-4D3, Ma3-4D5 show a kurtosis value in the range of 0.5 to 1 implying a low energy environment while rest of the samples show a kurtosis value in the range of 2 – 2.5 hinting towards a high energy environment except for Ma3Nf and Ma3-4D8 which show kurtosis values in the range of 1.5 to 2. (Figure. 4.59)

4.5 ASHVEM BEACH

Ashvem coastal area is dominated by beach and stumps of laterite rocks are scattered throughout the beach. The lithology of Ashvem beach is that of laterite. The geomorphological map for Ashvem is given in Figure. 4.60.

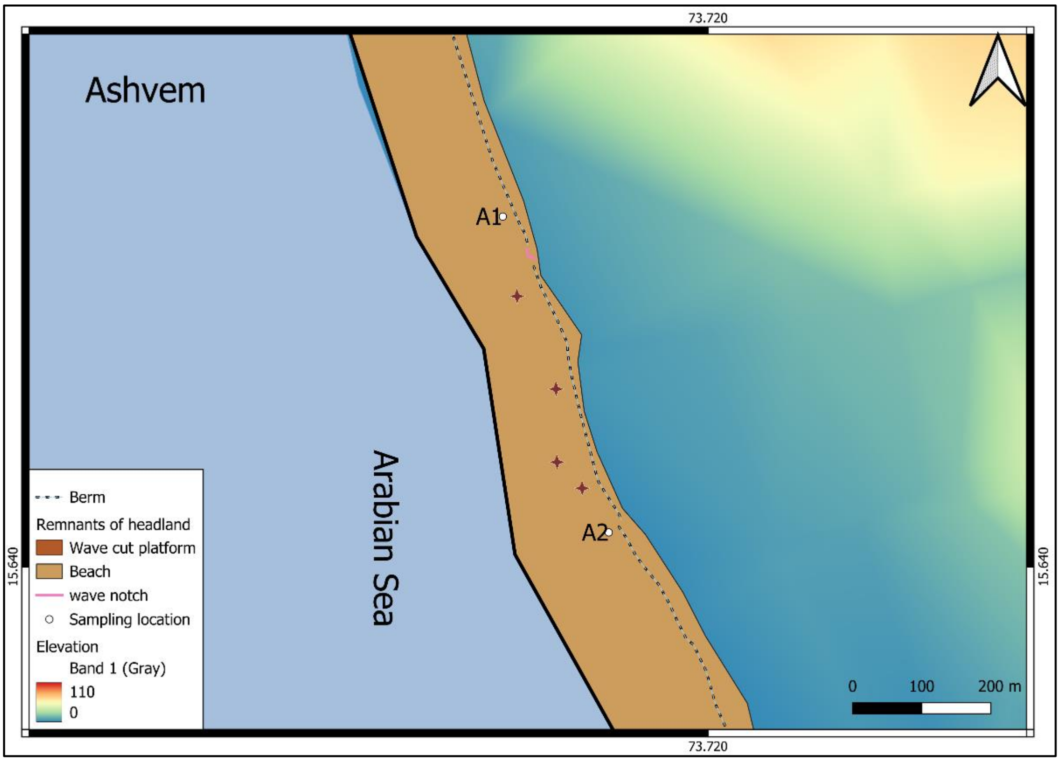


Figure. 4.61 Geomorphological map of Ashvem.

4.5.1 Field work

4.5.1 a. Erosional features:

At the base of cliff cavities are formed by wave action, these cavities are in the shape of grooves or notches and hence are termed as wave notches (Figure. 4.61), the wave notches at Ashvem beach experienced deposition and hence are semi-filled with sediments. Eventually, the cliffs retreat further forming headlands and wave cut platforms which further get eroded to sea stumps (Figure. 4.62), the sea stumps at Ashvem are encrusted by barnacles.

Figure. 4.62 Wave Notch at Ashvem semi-filled by sediment.

Figure. 4.63 Sea Stump encrusted by barnacles. (Black line indicating possible dimensions pre-erosion)

4.5.1 b. Depositional features:

Another result of cliff retreat is the formation of beach by deposition of sediments at the retreated cliff areas forming a beach. As the deposition continues there is piling up of sediments at the top of the swash zone, which is called as a berm (Figure. 4.63), the berm at Ashvem was not very prominent and showed only a subtle change in gradient.

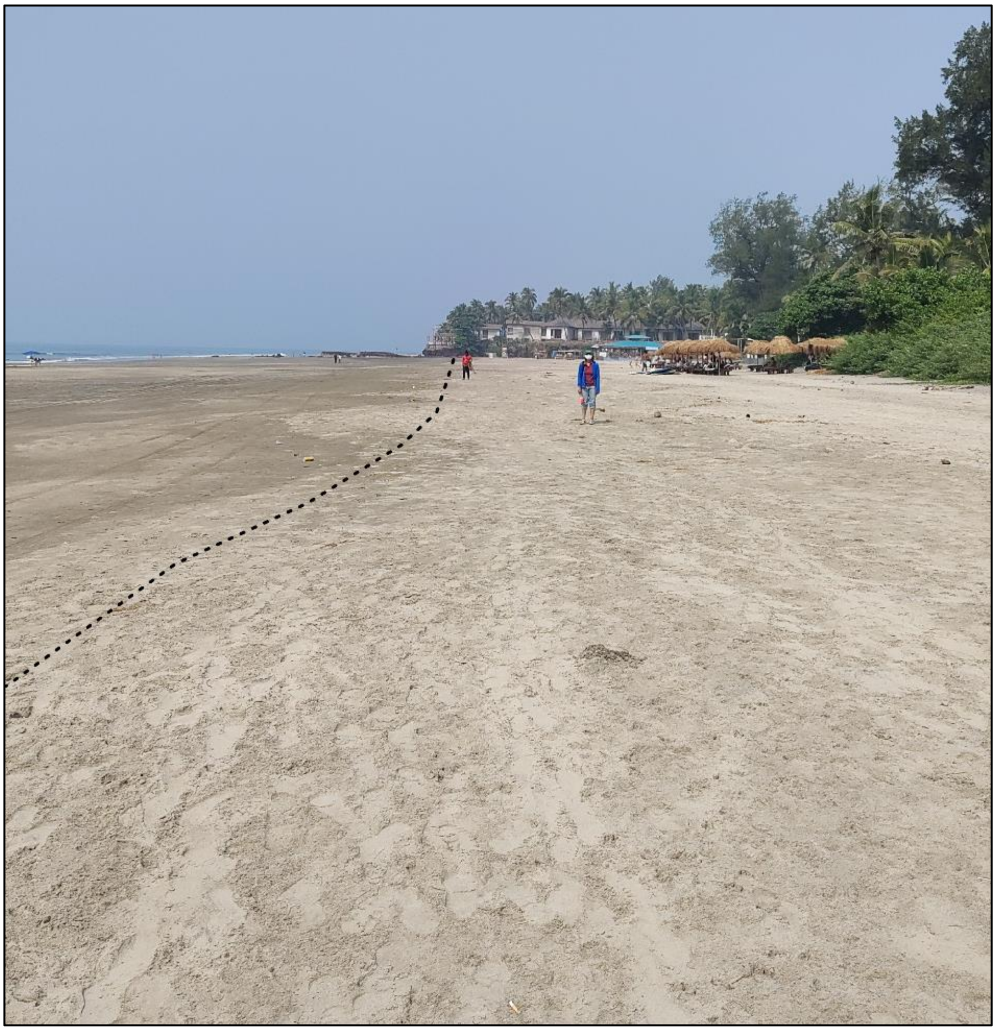


Figure. 4.64 Berm. (Black line indicates the berm line)

4.5.2 Laboratory analysis

Sieve analysis

Table. 4.5 Sedimentological data generated for Ashvem.

SAMPLE NAME	A1Lt	A2Lt	A1B	A2B
FEATURE	Low Tide	Low Tide	Berm	Berm
MEAN	2.718	2.725	2.980	2.988
SORTING	0.807	0.974	0.466	0.471
SKEWNESS	-0.005	-0.162	0.544	0.543
KURTOSIS	0.955	0.825	1.628	1.617
MEAN:	Fine Sand	Fine Sand	Fine Sand	Fine Sand
SORTING:	Moderately Sorted	Moderately Sorted	Well Sorted	Well Sorted
SKEWNESS:	Symmetrical	Coarse Skewed	Very Fine Skewed	Very Fine Skewed
KURTOSIS:	Mesokurtic	Platykurtic	Very Leptokurtic	Very Leptokurtic
% COARSE SAND:	1.4%	9.2%	0.0%	0.1%
% MEDIUM SAND:	24.1%	16.0%	3.8%	3.6%
% FINE SAND:	51.6%	45.6%	75.6%	74.9%
% V FINE SAND:	22.9%	29.2%	20.5%	21.4%

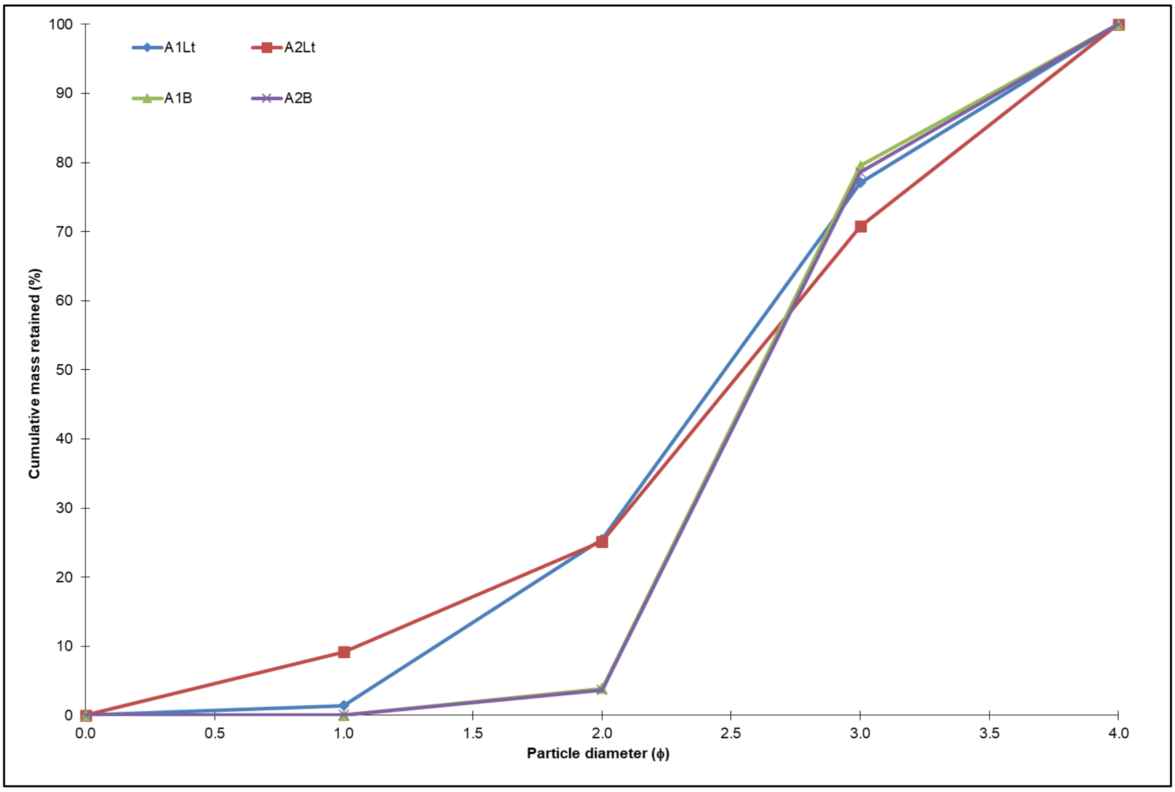


Figure. 4.65. Cumulative mass retained (%) vs Particle Diameter (phi)

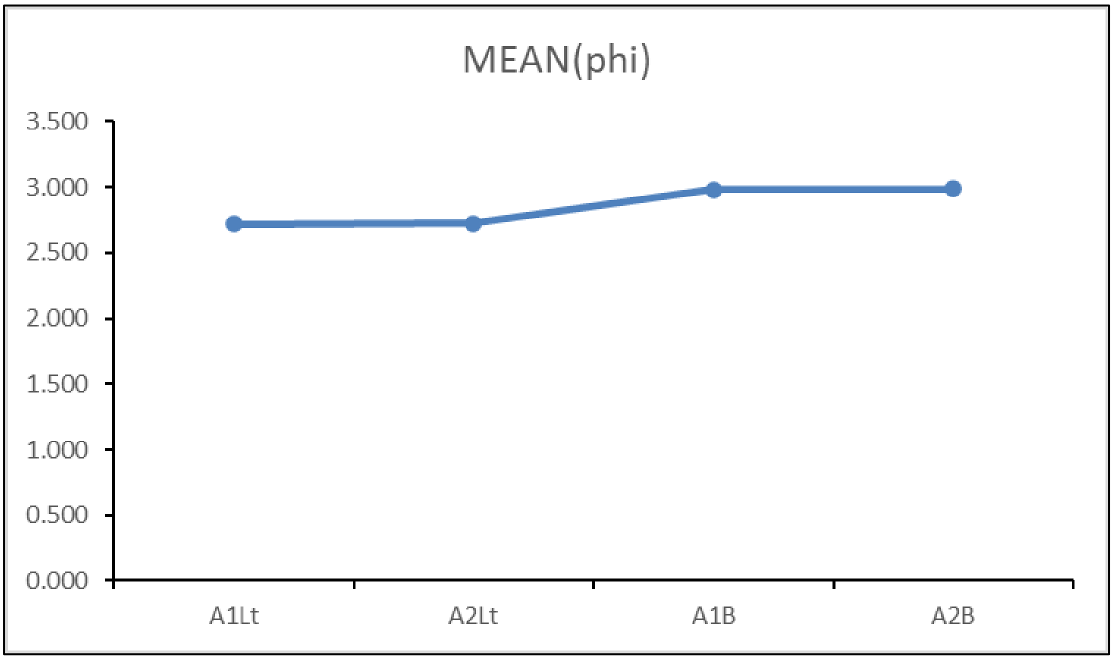


Figure. 4.66. Distribution of Mean (phi) for different geomorphological features.

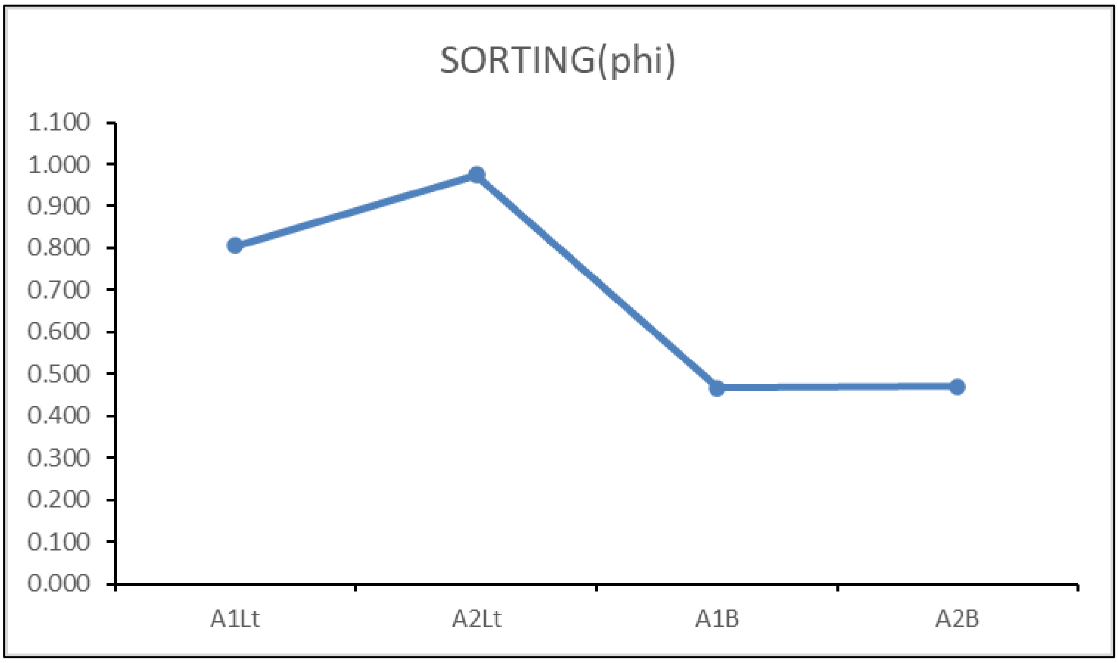


Figure. 4.67. Distribution of Sorting (phi) for different geomorphological features.

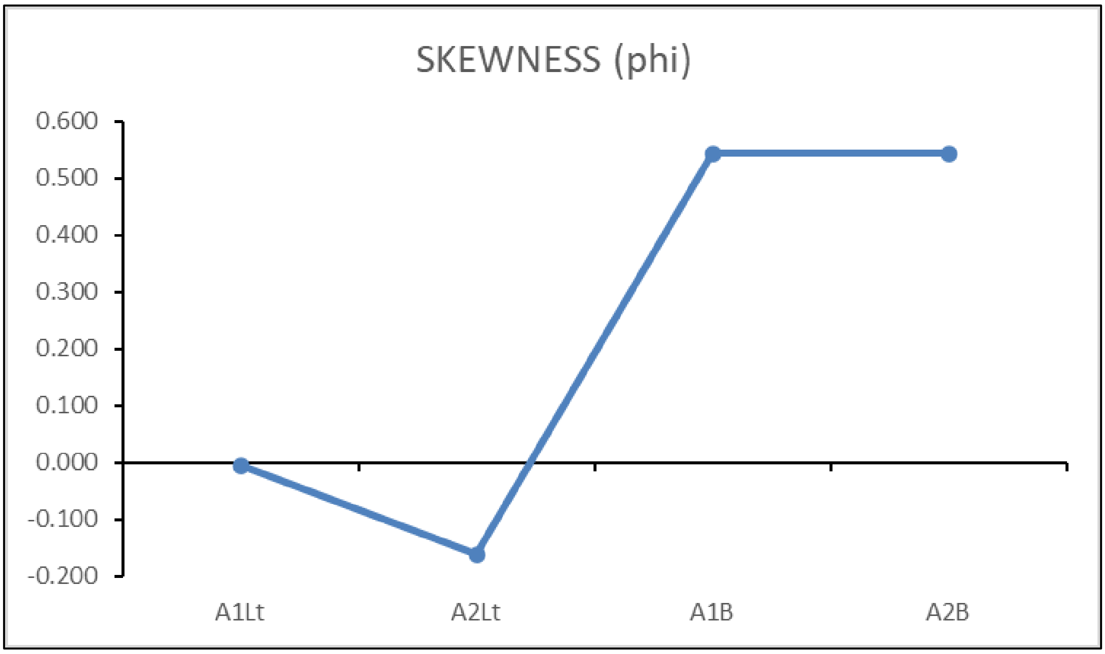


Figure. 4.68. Distribution of Skewness (phi) across different geomorphological features.

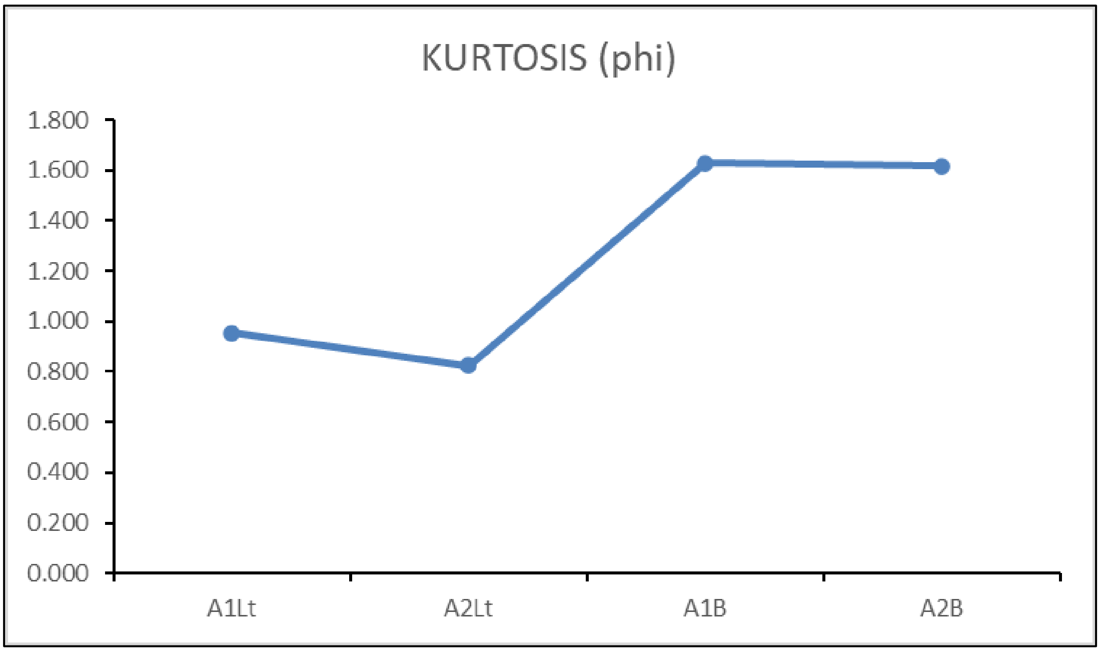


Figure. 4.69. Distribution of Kurtosis (phi) across different geomorphological features

For Ashvem, it is observed that, the mean ranges from 2.5 phi to 3 phi, the sorting calculated ranges from 0.5 to 1. Furthermore, the skewness ranged from -0.3 to 0.5, while the kurtosis ranged from 0.5 to 2.5 (Table 4.5), implying fine grained sediments that are moderately well sorted to moderately sorted and are coarse skewed to strongly fine skewed and are platykurtic to very leptokurtic in nature.

Figure. 4.64 shows. Cumulative mass retained (%) vs Particle diameter (phi) shows that all the samples show a polymodal distribution.

The mean grain size remains constant, i.e. very little to no variation is observed in the backshore and the foreshore sediments. (Figure. 4.65)

The sorting value decreases from foreshore to backshore indicating a drop in energy from foreshore to backshore (Figure. 4.66)

Skewness increases from foreshore to backshore indicating a possible sediment transport from foreshore to backshore (Figure. 4.67)

Kurtosis value increases from foreshore to backshore implying a rise in energy from backshore to foreshore (Figure. 4.68)

4.6 MORJIM BEACH

Morjim coastal area is dominated by depositional features like berm, dune, spit and beach cusps but also has erosional features scattered across the area like wave cut platform, sea stump. The lithology observed at Morjim is predominantly meta-argillite in nature. Figureures 4.69 and 4.70 give the geomorphological maps of Morjim.

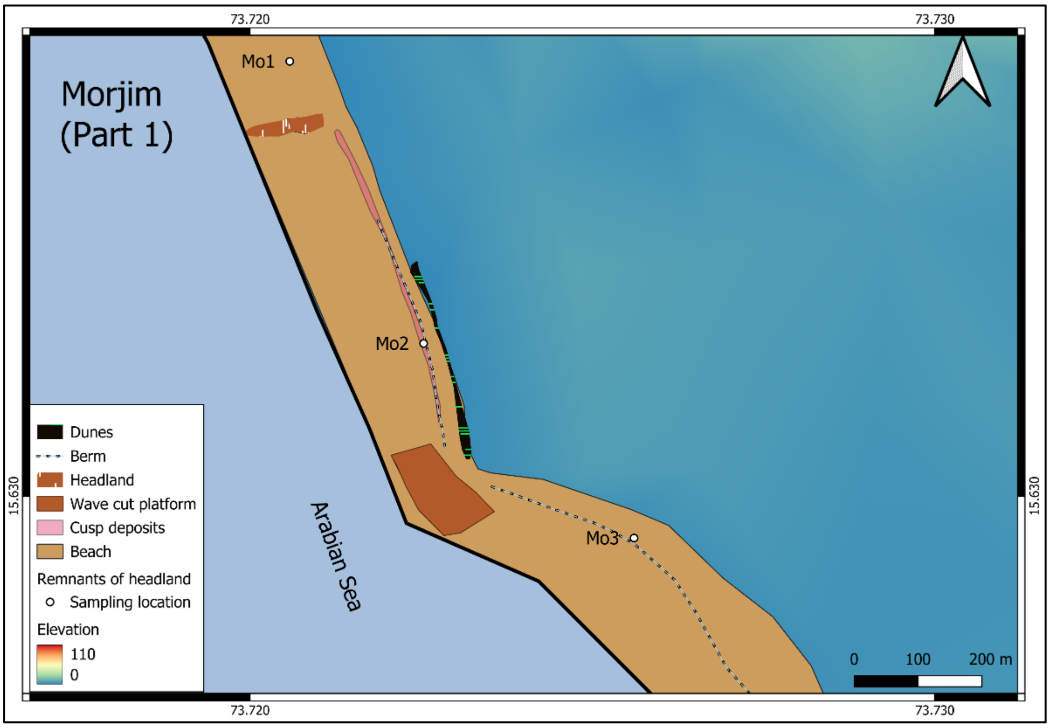


Figure. 4.70. Geomorphology map of Morjim Part 1

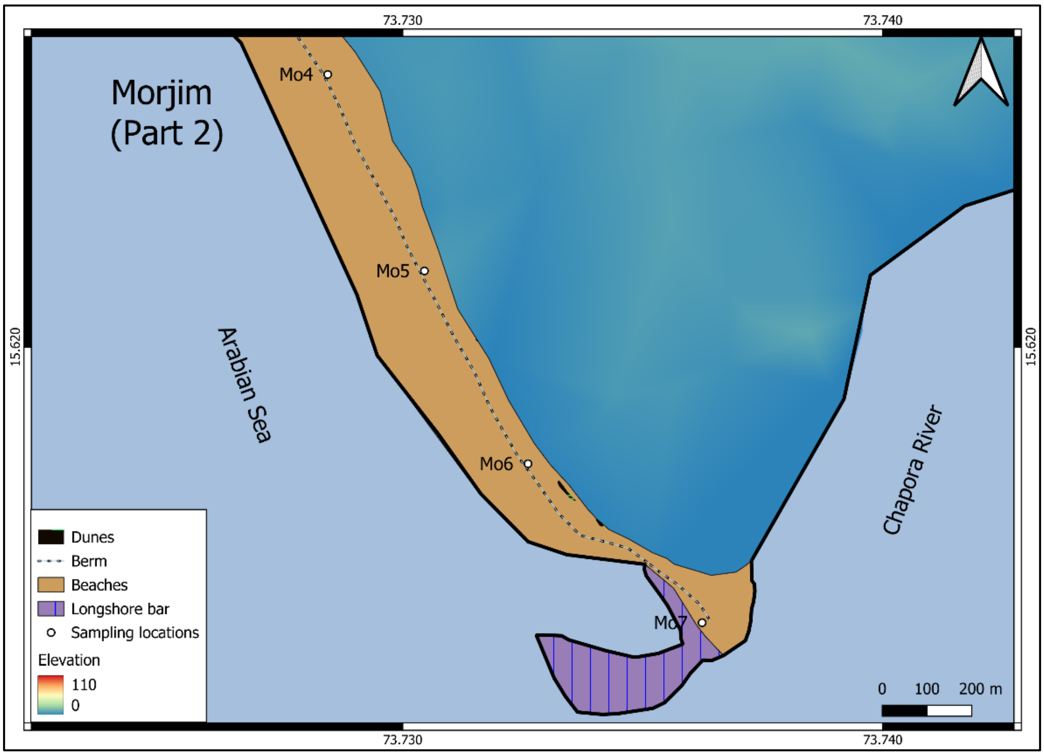


Figure. 4.71. Geomorphology map of Morjim (Part 2)

4.6.1 Field Work

4.6.1 a. Erosional features:

Cliff retreat caused by wave action is followed by the formation of a platform like geomorphological feature called as a wave cut platform (Figure. 31), the wave cut platform present at Morjim shows honeycomb structures in meta-argillite rock.

These platforms along with headlands eroded further to form sea stumps (Figure. 32), the sea stump at Morjim show biological growth around them, by what appears to be a dead coral.

The presence of a possible dead coral around the sea stump is indicative of past sea level as they require complete, permanent submergence underwater, implying the beach was further inland.

Figure. 4.72. Wave Cut Platform.

Figure. 4.73. Sea Stump - Elongated Sea stump showing biological growth around it.

Figure. 4.74 Sea Stump - Sea stump showing biological growth around it.

4.6.1 b. Depositional features:

Sediments deposited by wave action onto the area vacated by retreating cliffs leads to the formation of a beach, as the sediment deposition continues, sediment starts to pile up at the top of the swash zone forming a berm (Figure.4.74), the berm at the southern end of Morjim shows signs erosion on the form of alternating bands of light and dark coloured at Morjim, the berm was present throughout the area except for the northern end,

Figure. 4.75 gives cusp deposits of the cusp spit type which may be formed by deposition by opposing eddy currents or by deposition within wave shadows or longshore drift, building a series of recurved points on a spit with later modification by waves or repeated breaching of the lagoon barrier beach with deposition of sediment washed through the opening or by development by current deflected or modified by sediment masses washed over the barrier beach during storms.(Mii, 1958)

The sediments deposited on the foreshore, once dried may be carried to the backshore by the wind, where they get deposited in small mound like structures called as embryo dunes (Figure. 4.76) shows embryo dunes formed at Morjim and were having a length of approximately 6-7m and were 0.5m high with a width of 3-4m. These embryo dunes coalesce together to form foredunes (Figure. 36), the foredune ridge observed at Morjim was approximately 335m in length and had a height of approximately 3m.

But, if instead of interacting with the coast the waves interacted with a river or an estuary, a spit is formed (Figure. 37) wherein the sediments start getting deposited due a sudden change in the velocity of the transporting medium, the spit is attached to the mainland while the distal end is projected out into the sea, where it may curve due to longshore currents. The spit at Morjim is a hook shaped spit with the distal end curving in the northward direction.

Figure. 4.75. Eroded berm

Figure 4.76. Embryo dunes

(c)

Figure. 4.77. Foredune

Figure. 4.78. Cusp deposit (blackline indicating the shape of the deposit)

Figure. 4.79. Longshore bar.

4.6.2 Laboratory analysis

Sieve analysis.

Table. 6. Sedimentological data generated for Morjim(phi)

SAMPLE NAME	**Mo5-6D1**	**Mo5-6D2**	**Mo5-6D3**
FEATURE	Embryo Dune	Embryo Dune	Embryo Dune
MEAN	3.021	3.037	3.043
SORTING	0.482	0.487	0.487
SKEWNESS	0.541	0.535	0.536
KURTOSIS	0.678	0.654	0.648
MEAN:	Very Fine Sand	Very Fine Sand	Very Fine Sand
SORTING:	Well Sorted	Well Sorted	Well Sorted
SKEWNESS:	Very Fine Skewed	Very Fine Skewed	Very Fine Skewed
KURTOSIS:	Platykurtic	Very Platykurtic	Very Platykurtic
% COARSE SAND:	0.0%	0.0%	0.0%
% MEDIUM SAND:	1.7%	0.9%	0.2%
% FINE SAND:	72.9%	71.5%	71.5%
% V FINE SAND:	25.4%	27.7%	28.3%

Mo6-7D1	**Mo6-7D2**	**Mo1Nf**	**Mo2B**
Embryo Dune	Embryo Dune	No Feature	Berm
2.993	3.012	3.045	2.727
0.463	0.476	0.580	0.442
0.553	0.546	0.312	-0.004
1.655	1.609	0.835	2.406
Fine Sand	Very Fine Sand	Very Fine Sand	Fine Sand
Well Sorted	Well Sorted	Moderately Well Sorted	Well Sorted
Very Fine Skewed	Very Fine Skewed	Very Fine Skewed	Symmetrical
Very Leptokurtic	Very Leptokurtic	Platykurtic	Very Leptokurtic
0.0%	0.1%	0.1%	0.0%
1.1%	1.4%	5.0%	14.8%
77.7%	74.8%	63.6%	73.2%
21.2%	23.8%	31.4%	12.0%

Mo3B	**Mo4B**	**Mo5B**	**Mo6B**
Berm	Berm	Berm	Berm
2.463	2.948	2.506	2.712
0.486	0.442	0.562	0.405
-0.530	0.543	-0.318	-0.044
0.677	1.676	2.305	2.394
Fine Sand	Fine Sand	Fine Sand	Fine Sand
Well Sorted	Well Sorted	Moderately Well Sorted	Well Sorted
Very Coarse Skewed	Very Fine Skewed	Very Coarse Skewed	Symmetrical
Platykurtic	Very Leptokurtic	Very Leptokurtic	Very Leptokurtic
0.0%	0.0%	1.8%	0.6%
25.1%	3.5%	17.9%	13.3%
70.7%	79.5%	73.9%	79.6%
4.2%	17.0%	6.4%	6.5%

Mo2BcE4	Mo2BcE5	Mo2BcH1	Mo2BcH2
Beach Cusps	Beach Cusps	Beach Cusps	Beach Cusps
2.575	2.966	2.449	2.448
0.582	0.579	0.593	0.579
-0.238	0.283	-0.292	-0.316
2.306	2.293	0.907	0.885
Fine Sand	Fine Sand	Fine Sand	Fine Sand
Moderately Well Sorted	Moderately Well Sorted	Moderately Well Sorted	Moderately Well Sorted
Coarse Skewed	Fine Skewed	Coarse Skewed	Very Coarse Skewed
Very Leptokurtic	Very Leptokurtic	Mesokurtic	Platykurtic
0.1%	0.0%	0.6%	0.6%
16.1%	8.6%	27.9%	27.4%
67.9%	70.9%	65.0%	66.5%
15.8%	20.5%	6.5%	5.5%

Mo2BcH3	Mo2BcH4	Mo2BcH5	Mo1Lt
Beach Cusps	Beach Cusps	Beach Cusps	Low Tide
2.414	2.469	2.498	3.301
0.513	0.589	0.473	0.671
-0.498	-0.294	-0.547	-0.571
0.621	0.966	1.659	0.876
Fine Sand	Fine Sand	Fine Sand	Very Fine Sand
Moderately Well Sorted	Moderately Well Sorted	Well Sorted	Moderately Well Sorted
Very Coarse Skewed	Coarse Skewed	Very Coarse Skewed	Very Coarse Skewed
Very Platykurtic	Mesokurtic	Very Leptokurtic	Platykurtic
1.7%	0.5%	1.8%	1.9%
31.3%	24.7%	18.2%	9.8%
62.9%	67.7%	75.2%	33.3%
4.1%	7.1%	4.8%	55.0%

Mo2Lt	Mo3Lt	Mo4Lt	Mo5Lt
Low Tide	Low Tide	Low Tide	Low Tide
3.134	3.389	2.537	2.981
0.621	0.512	0.542	0.603
0.130	-0.538	-0.295	0.266
0.816	0.632	2.348	2.233
Very Fine Sand	Very Fine Sand	Fine Sand	Fine Sand
Moderately Well Sorted	Moderately Well Sorted	Moderately Well Sorted	Moderately Well Sorted
Fine Skewed	Very Coarse Skewed	Coarse Skewed	Fine Skewed
Platykurtic	Very Platykurtic	Very Leptokurtic	Very Leptokurtic
0.2%	0.0%	0.3%	0.5%
6.3%	3.5%	16.7%	9.6%
44.1%	29.5%	76.1%	66.8%
49.3%	67.0%	6.9%	23.1%

Mo7Lbest
Spit
2.402
0.511
-0.504
0.618
Fine Sand
Moderately Well Sorted
Very Coarse Skewed
Very Platykurtic
2.3%
31.6%
63.9%
2.2%

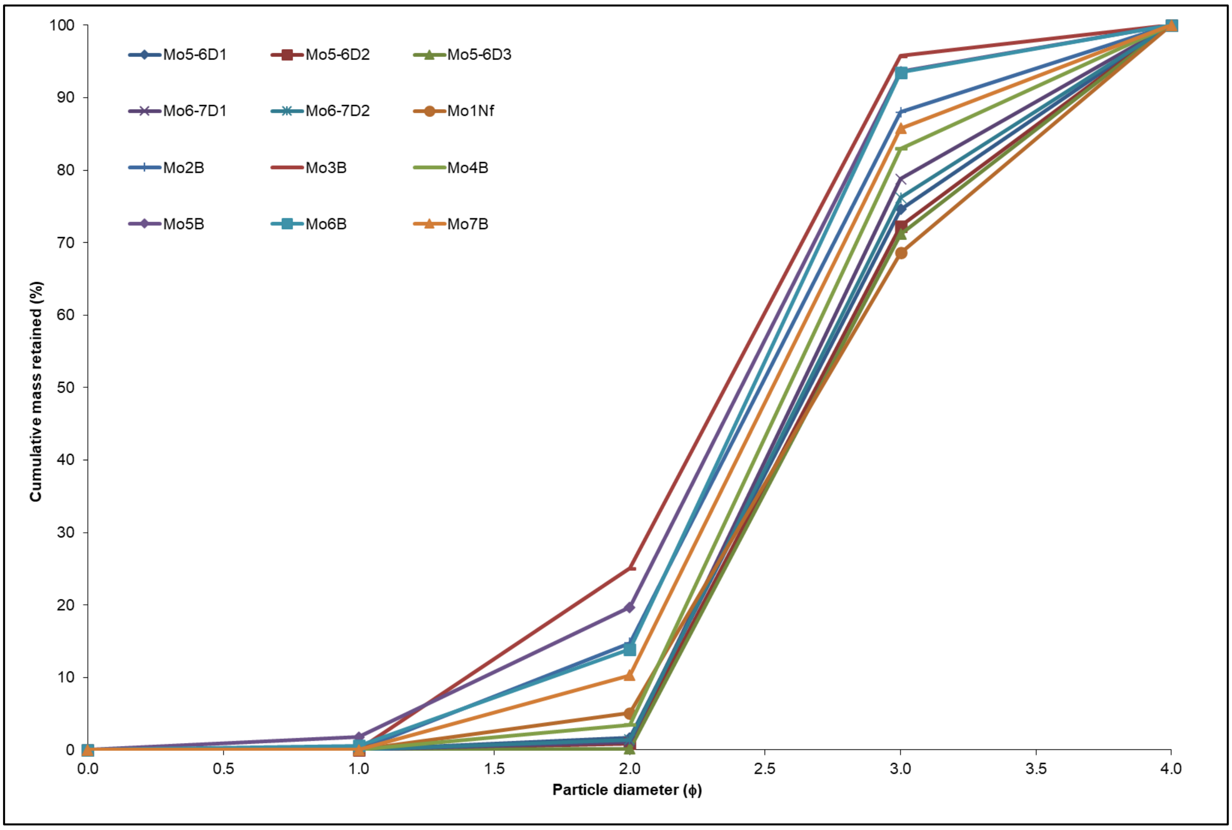


Figure. 4.80. Cumulative Mass Retained (%) vs Particle Diameter (phi), dune and berm samples of Morjim beach.

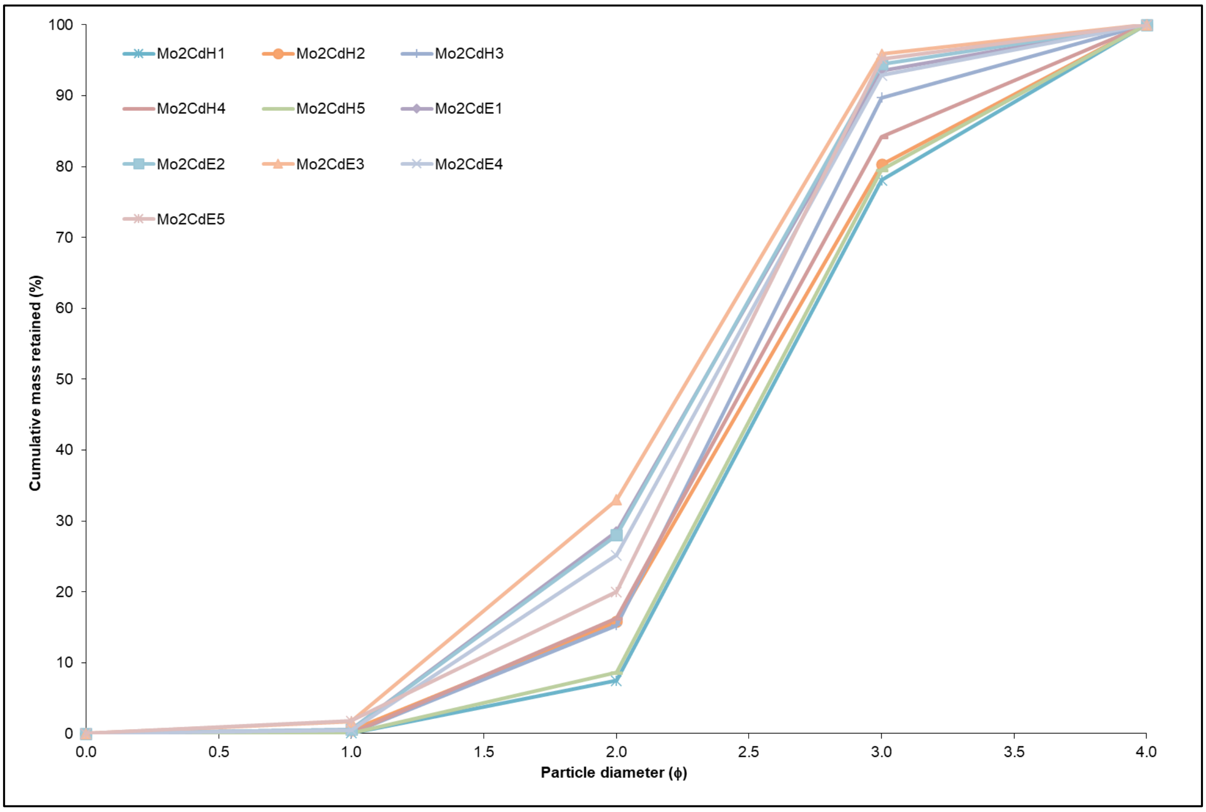


Figure. 4.81. Cumulative Mass Retained (%) vs Particle Diameter (phi), cusp deposit samples of Morjim beach.

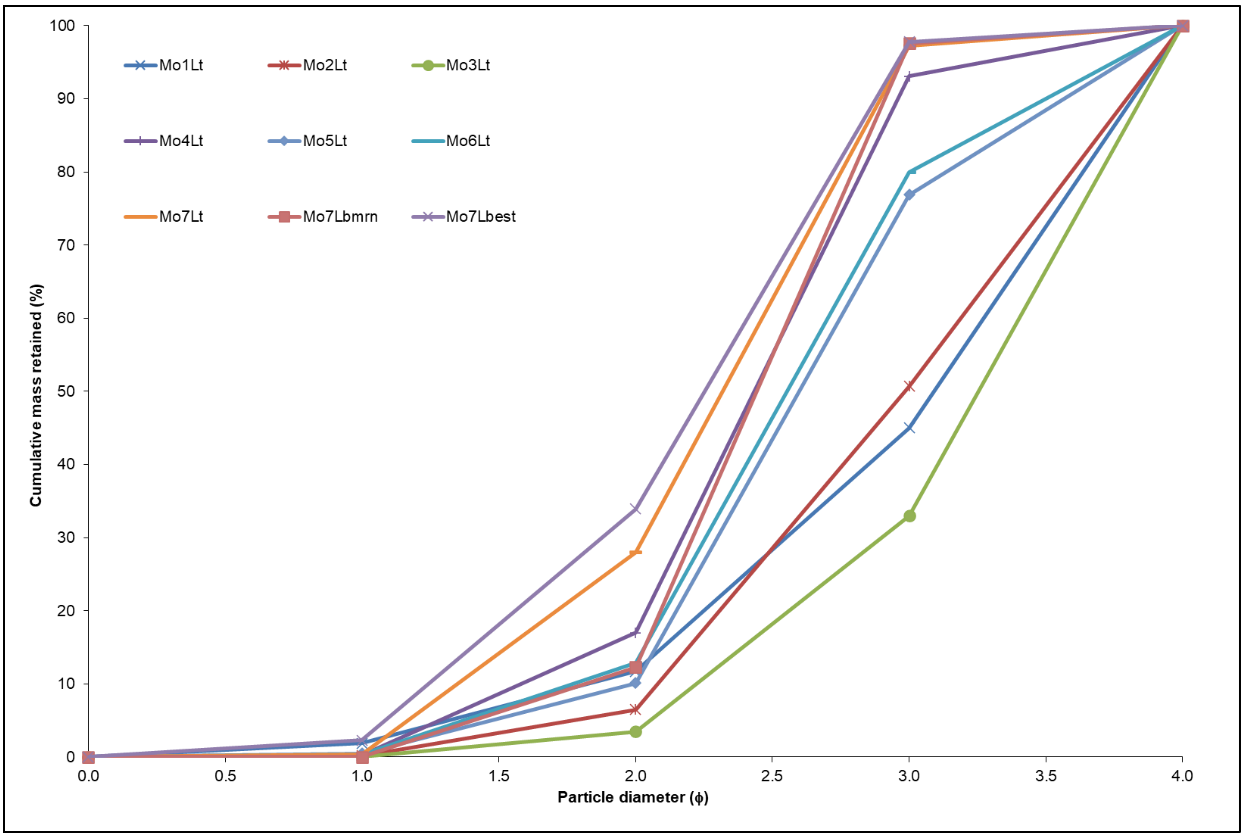


Figure. 4.82. Cumulative Mass Retained (%) vs Particle Diameter (phi), low tide and longshore bar samples of Morjim beach.

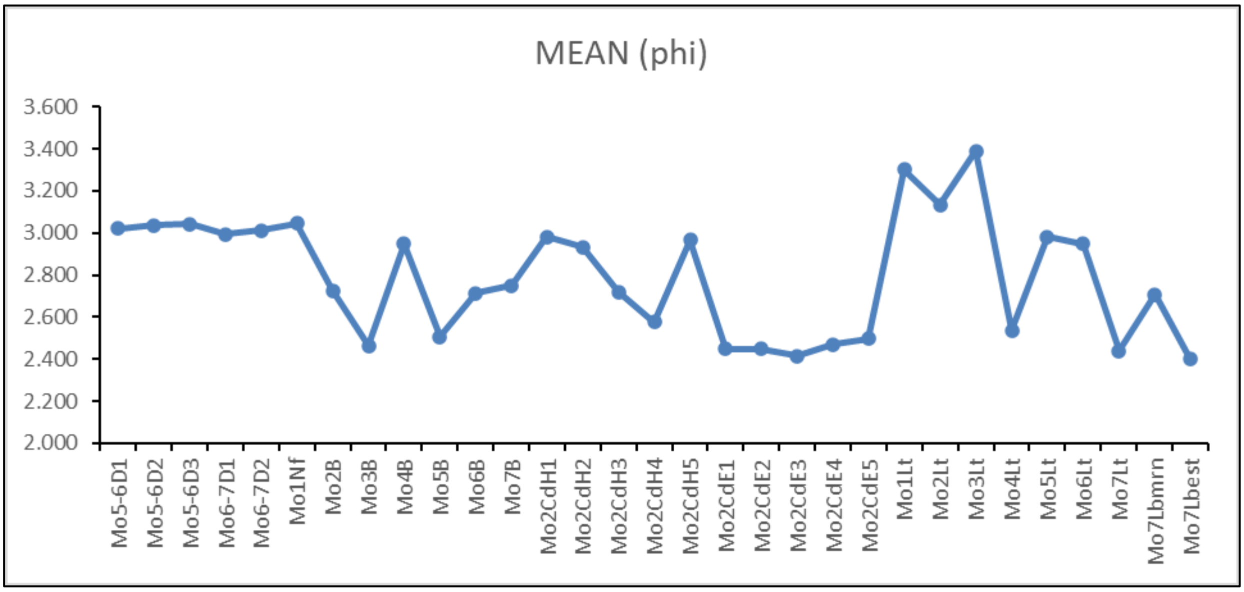


Figure. 4.83. Distribution of Mean (phi) across different geomorphological features.

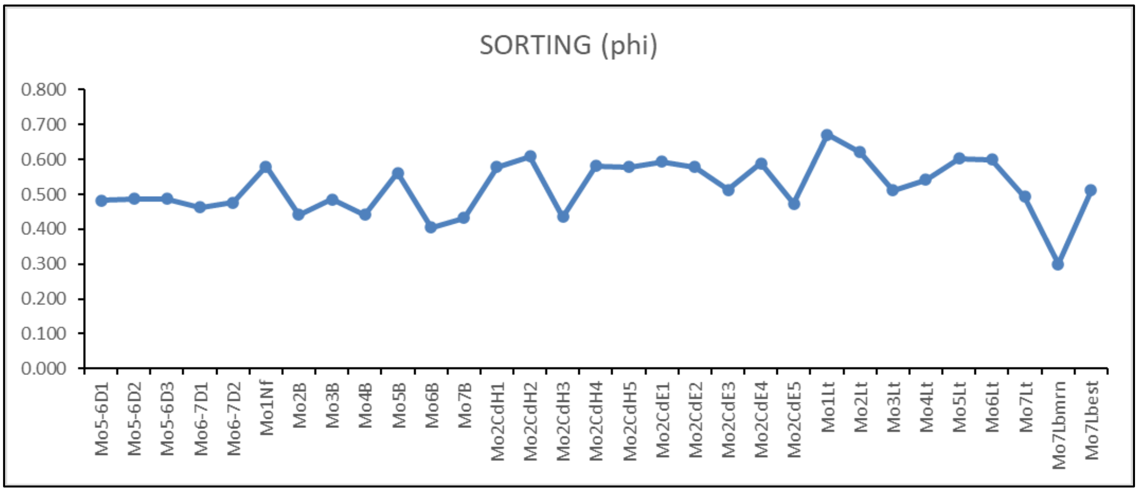


Figure. 4.84. Distribution of Sorting (phi) across different geomorphological features.

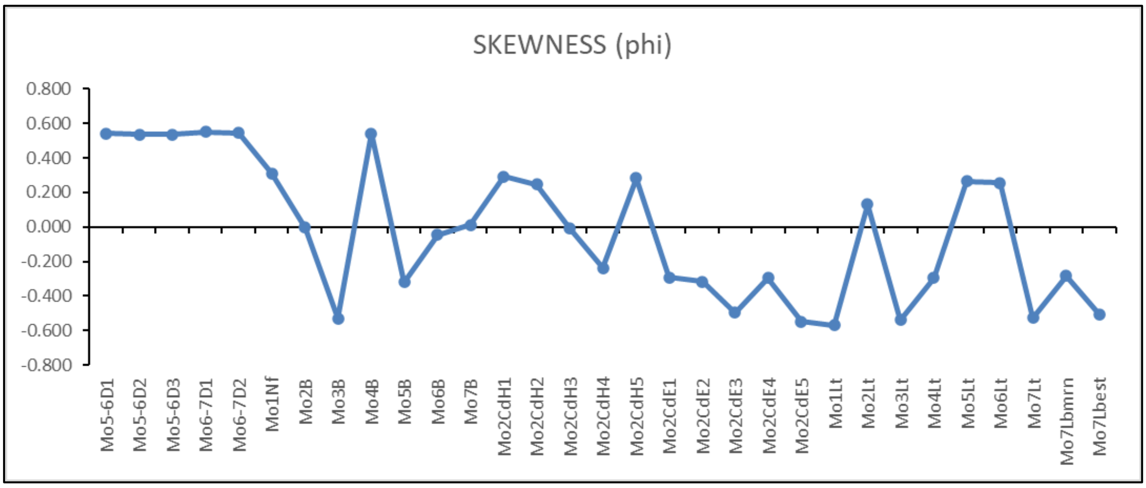


Figure. 4.85. Variation of Skewness (phi) across different geomorphological features.

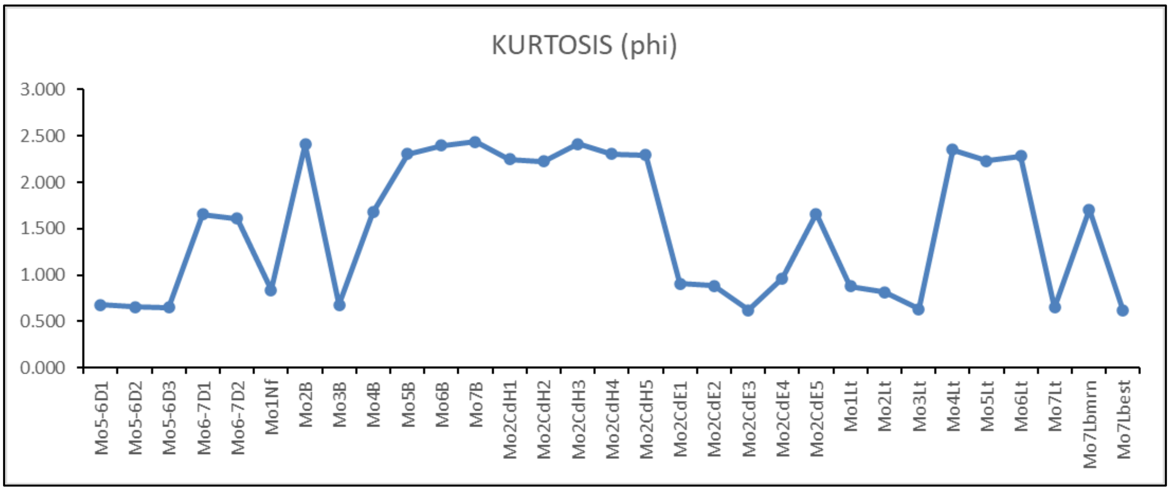


Figure. 4.86 Variation of Kurtosis (phi) across different geomorphological features

For Morjim, it is observed that, the mean ranges from 2.0 phi to 3.5 phi, the sorting calculated ranges from 0.2 to 0.7. Furthermore, the skewness ranged from -0.6 to 0.6, while the kurtosis ranged from 0.5 to 2.5 (Table 6), implying, fine to very fine grain size, very well sorted to moderately well sorted sediments that are strongly fine skewed to strongly coarse skewed and are very platykurtic to very leptokurtic in nature.

Figure. 4.79, 4.80 and 4.81 show Cumulative mass retained (%) vs Particle diameter (phi) for dune and beach samples, beach cusps and low tide (foreshore) and spit samples respectively which show a polymodal distribution.

From Figure. 4.82 it is observed that average mean (phi) grain size increases from foreshore to backshore and reduces from north to south.

Sorting values showed a slight decrease from foreshore to backshore implying a slight increase in the energy from foreshore to backshore (Figure. 4.83.)

The skewness value increases from foreshore to backshore implying the transport of sediments from foreshore to backshore. (Figure. 4.84)

Kurtosis values increase till the berms but then decrease further backshore towards the dunes. (Figure. 4.85)

From Figureures 4.86 to 4.93 the mean (phi) grain size increases from north to south in the backshore as well as the foreshore, while the sorting values remain fairly constant.

Skewness values decrease from north to south in the low tide region indicating an increase in the system from north to south. While in the backshore it is increasing implying a decrease in energy and an increase in the deposition of sediments.

Kurtosis values show an increase in both the backshore as well as the foreshore but the increase in foreshore is substantial less than that of the backshore.

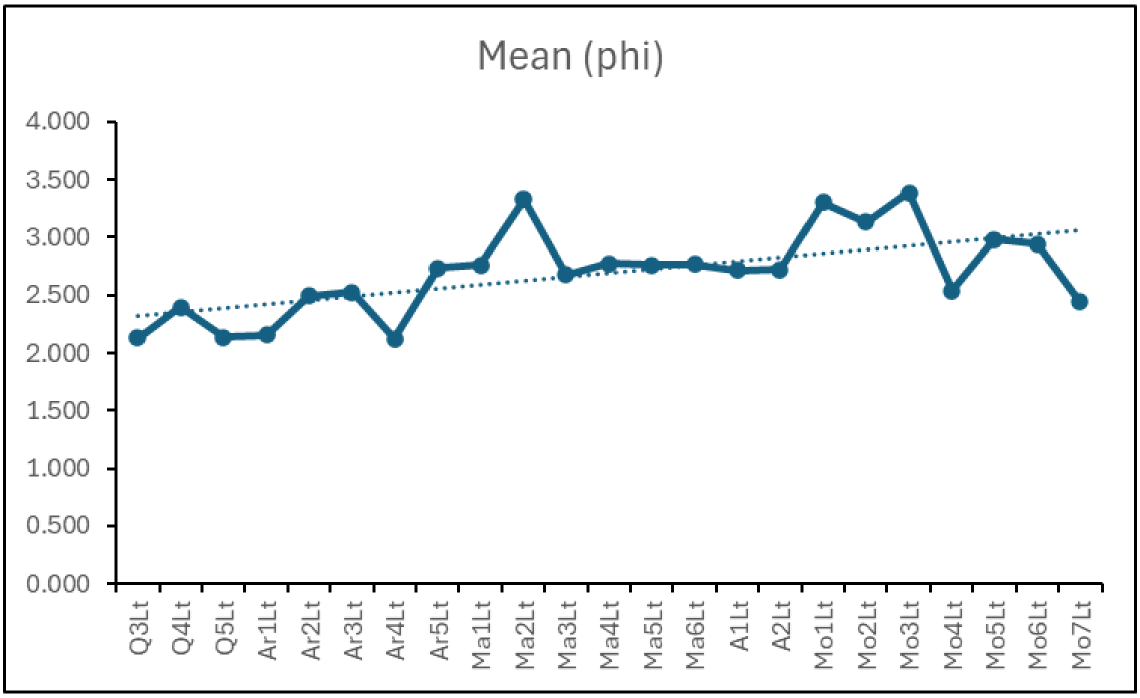


Figure. 4.87. Variation of Mean grain size (phi) from North to South in the foreshore (low tide sediments)

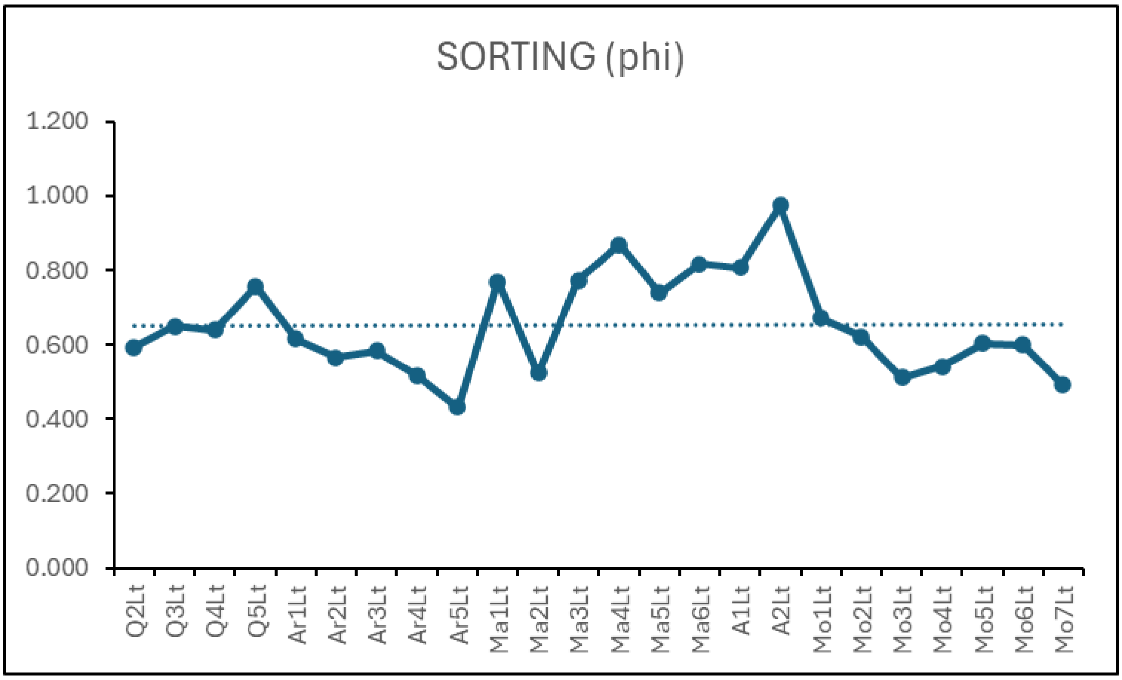


Figure. 4.88. Variation of Sorting (phi) from North to South in the foreshore (low tide sediments)

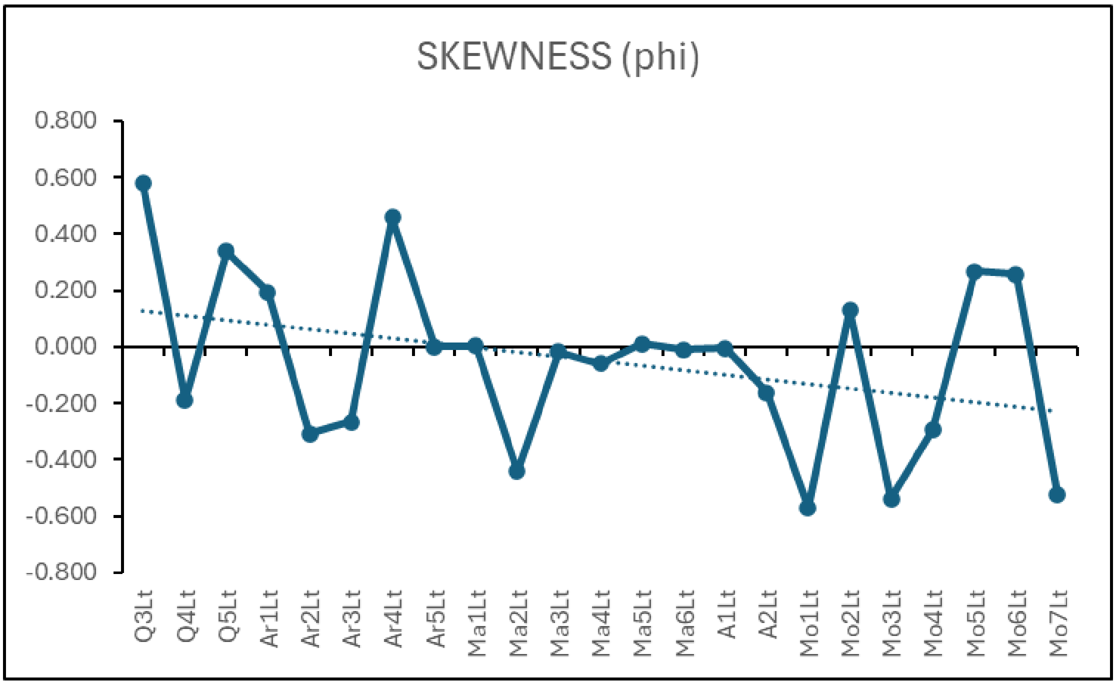


Figure. 4.89. Variation of Skewness (phi) from North to South in the foreshore (low tide sediments)

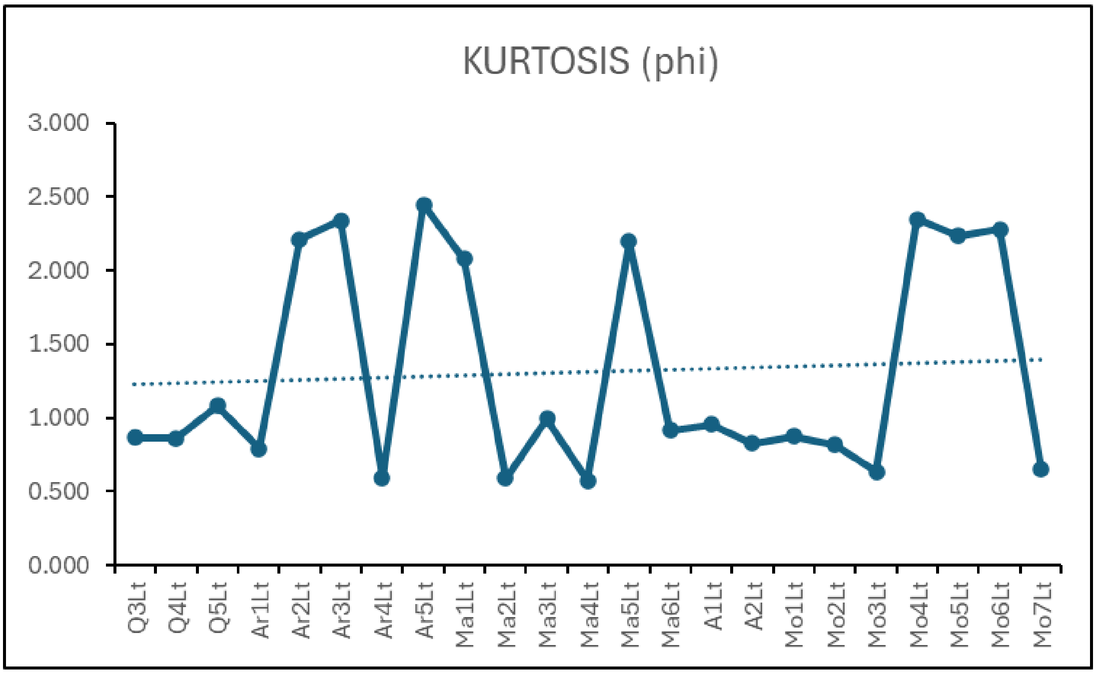


Figure. 4.90. Variation of Kurtosis (phi) from North to South in the foreshore (low tide sediments).

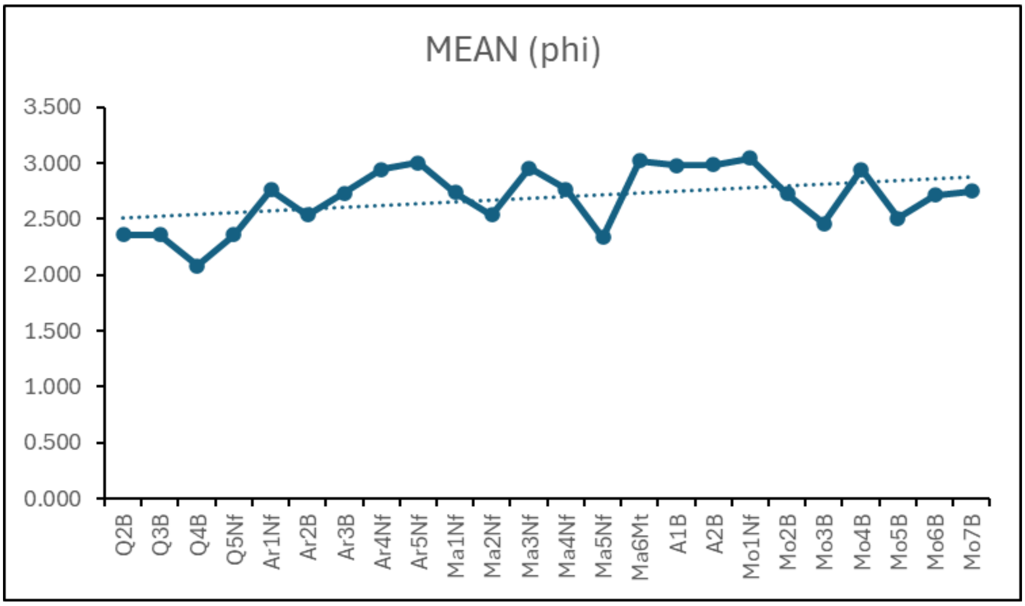


Figure. 4.91. Variation of Mean grain size (phi) from North to South in the backshore sediments.

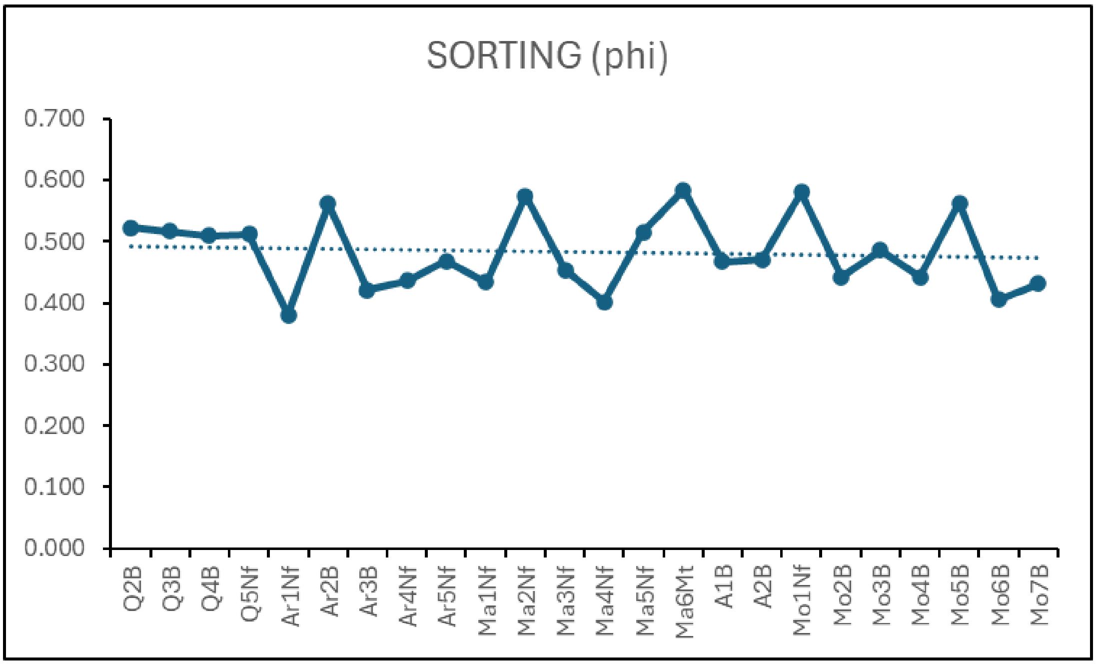


Figure. 4.92. Variation of Sorting (phi) from North to South in the backshore sediments.

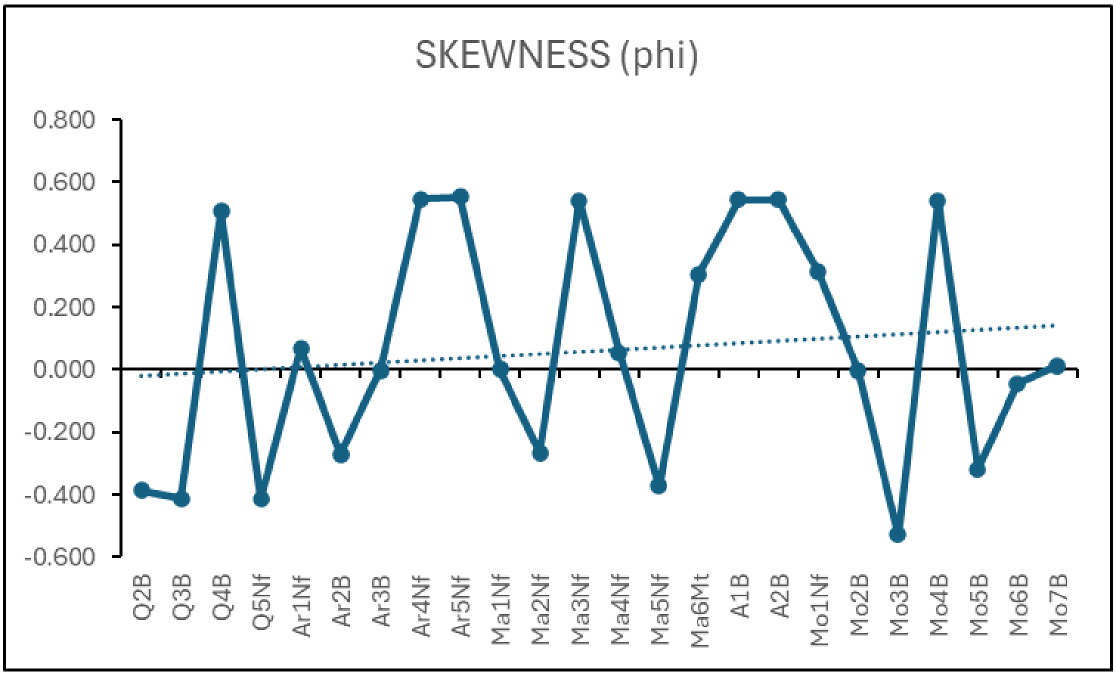


Figure. 4.93. Variation of Skewness (phi) from North to South in the backshore

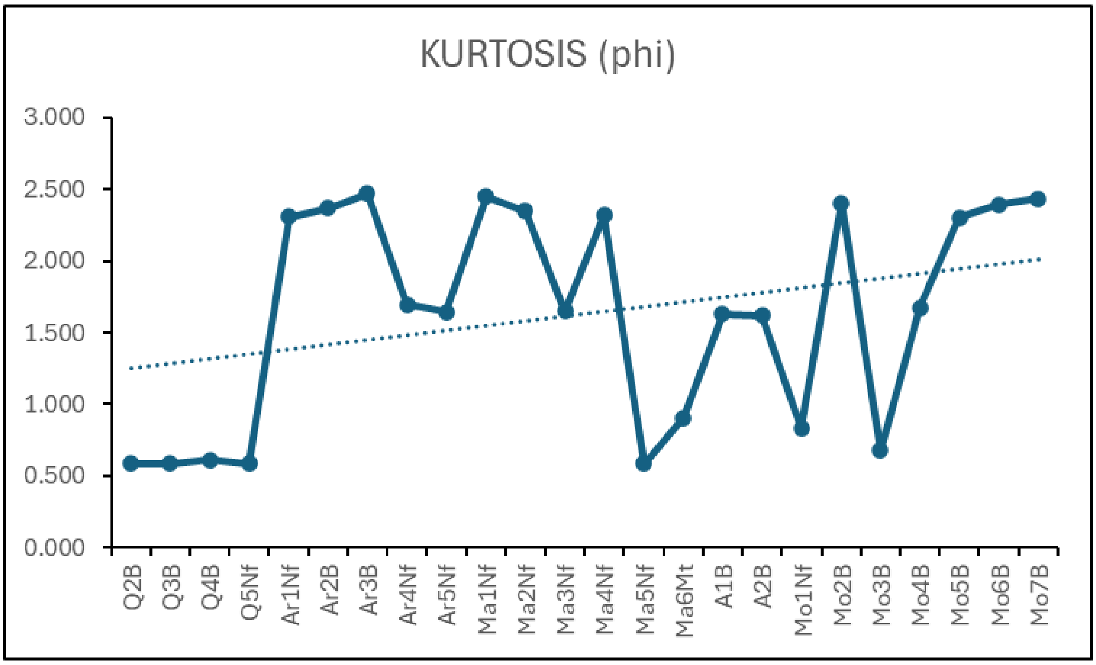


Figure 4.94. Variation of Kurtosis (phi) from North to South in the backshore sediments.

CONCLUSION

- Coastal geomorphology is affected by a variety of factors like wind, wave action, biological activity, lithology, climate and so on which dictate the changes in the system making the coastal geomorphological system one of the most dynamic systems.

- The study area Tiracol – Morjim shows diverse coastal geomorphological features. It is a combination of erosional and depositional coasts, where depositional features like beach, berm, beach face, longshore bar are formed due to erosion of rocky coast, leaving behind erosional features. This signifies dynamic coastal processes during Pleistocene to recent.

- The dominance of erosional features as compared to depositional features along the Tiracol coast indicates that the coast is still largely erosional or aggradational in nature. While the coastal areas from Querim to Morjim is dominated by depositional coast indicating that the coastal areas are depositional or progradational in nature.

- Location 1, Terekhol which is showing irregular rocky coast and very prominent erosional features like wave notches, sea stumps, sea caves, marine terrace, cliffs form due to rock and sea water interaction. They also indicate sea level oscillation.

- Wave action also causes formation of potholes due to grinding action of suspended sediments in the waves (Figure. 4.9), these are also responsible for widening of the joints which may lead to further tilting of the rock strata (Figure. 4.10). Presence of potholes also indicates the substantial wave inundation occurring in the area.

- Depositional features like berm, beach faces, longshore bars form by present day wave action, for example at the southern end of Morjim there is a formation of a longshore bar that is parallel to the longshore current that is formed from the erosion of the berm.

- Berms formed at Querim coastal area and southern part of Morjim coastal area show a higher berm indicative of a larger wave action and/or wave period and occur during low energy swell condition (Masselink et al., 2014). Locations where the berm was not observed i.e. southern end of Querim beach, northern end of Arambol beach and northern end of Morjim beach, had an erosional feature present in the vicinity, which might hinder in the deposition of sediments causing the absence of a berm. This is also the case at Ashvem where the berm is not prominent but the area has erosional features like sea stumps scattered across. The case at the Southern end of the Arambol beach might be different as there was anthropogenic influence in the way of ship maintenance. Furthermore, according to Chandramohan, (1997) the beaches at the southern end of Harmal beach shows concentration of concentration of wave energy during northeast monsoon, which may explain the absence of berm from the southern end of Arambol and northern end of Morjim.

- There is a sea cave present at Tiracol which has experienced deposition and a pocket beach with a berm has formed (Figure. 4.3, Figure. 4.14) indicating that further erosion of the sea cave might not occur due to wave action. Whereas it may occur due to biological activity as there is vegetation growth occurring on the top and the surroundings.

- Cusp deposits found at Morjim indicate possible eddy currents that might be forming due to the interaction of the local rocky geomorphological features and the waves or longshore currents.

- Areas like Ashvem, Mandrem showing remnants of wave cut platform and presence of linear beaches indicates coastal straightening which is formed due to rock and water interaction and sea level oscillation.

- Dunes are formed when there is transport and deposition of sediments by wind action. The number of embryo dunes increases from north to south (Arambol to Morjim), while peaking at the central region of Mandrem, which might be due to the lower interaction with anthropogenic activity.

- Boulder deposits along the Tiracol coast, southern end of the Querim coastal area and northern part of the Arambol coastal area indicate ongoing cliff retreat due to wave action or anthropogenic activity as observed at the southern end of the Tiracol coastal area and the Arambol coastal area. The southern end of the Tiracol coastal area is located directly below the Tiracol fort and there is construction on the cliffs facing the northern end of Arambol coastal area which may indicate that possible origins of the boulder deposits.

- The mean grain size (phi) increases from foreshore to backshore and the sediments become better sorted, implying a drop in the energy of the depositional environment. This will be the case as wave energy decreases as it moves towards the backshore, furthermore, the wind which is responsible for aeolian landforms usually has a lower energy than the waves.

- The skewness value increases from foreshore (where it is mostly negative) to backshore region (where it is mostly positive) indicating that the sediments from foreshore are getting eroded and redeposited at the backshore region.

- According to McLaren and Bowens in the direction of longshore drift, the sediments will become finer and the skewness will become negative, which is the case observed in the foreshore samples from north to south, implying the direction of longshore drift to be due south.

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