



## Seasonal variability of beach characteristics between Candoliam and Colva coast, Goa, India

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### ABSTRACT

The aim of the present study was to investigate the seasonal impact on beach dynamics and the status of heavy mineral distribution along the study area. Beach profile measurements were made in 7 profiling sites between Candoliam and Colva on seasonal basis between pre-monsoon (May 2009) and monsoon (July 2009). Beach profile data was used to calculate the variation in beach width, slope and volumetric changes. The seasonal action of wind and wave currents create near-shore bar and erosion of berms during monsoon. Surface sediment samples were collected from High Tide Line, High Water Line, Water Line and Low Water line to quantify the sediment texture and heavy mineral weight percentage. The results reveal that the deposited sediment has been eroded during the monsoon season and the concentration of heavy mineral percentage increased from pre-monsoon to monsoon. The long-shore current measurement also shows that the current speed varies from pre-monsoon to monsoon. The results suggested that monsoonal action has influenced the seasonal changes in beach morphology and heavy mineral distribution. The beach profile helps to understand the change in the beach morphological characteristic.

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### 1. Introduction

The study of beach dynamic is one of the important areas of research for understanding the morphology at all dimensions. The study is important because the influences of tides, waves and currents energy are working constantly to modify the landforms features in short span of time. The coastal processes which are always impacted by the erosion, accretion and sediment transport are incessantly changing the shoreline configuration.

The Morphological and sedimentological studies have provided valuable information about the nature of beach and its dynamics on depositional environment. Understanding of beach dynamics requires basic knowledge of the coastal landforms and its influences. Studies on beach profiles give a spatio-temporal variation of the backshore/foreshore environment. The coastal regions are generally influenced by land-sea interaction thus forming unique landforms and ecosystems. These include landforms like coastal plains, river deltas, wetlands, beaches and dunes, reefs, mangrove forest, and lagoons.

Regional beach profile study has been carried by various researchers around the world (Saxena et al. 1976; Anil Cherian 2003; Rajamanickam 2006; Antonio and Seelam 2008). The topographical beach profile gives the surface shape, trend, slope and volume of sediments (Guillen et al. 1999). The simplest methods for measuring beach profiles were well explained by Delgado and Lloyd (2004).

History of beach profile measurement and the theory of analysis were well explained by Cooper et al. (2000). Beach profile is very useful for coastal planning authorities who need information when planning new development (Cambers and Ghinna 2005). The beach morphology can be defined as a sensitive indicator for the coastal dynamic processes of a particular coastline (Wright and Short 1983; Hardisty 1994). The spatial and temporal morphological changes of a beach over time, a good estimate of the rate and direction of coastal changes can be obtained (Dean 1983; Brunnsden 2001).

Many studies along the west coast of India have been studied, which is mostly composed of rocky and sandy beaches. Seasonal profile and long-shore sediment transport have been studied. Heavy mineral studies have been carried along the Central West Konkan Coast (Gujar et al. 2007). Joevivek and Chandrasekar (2014) have studied the beach morphology and heavy mineral change with respect to seasonal impact along the central Tamil Nadu coast, India.

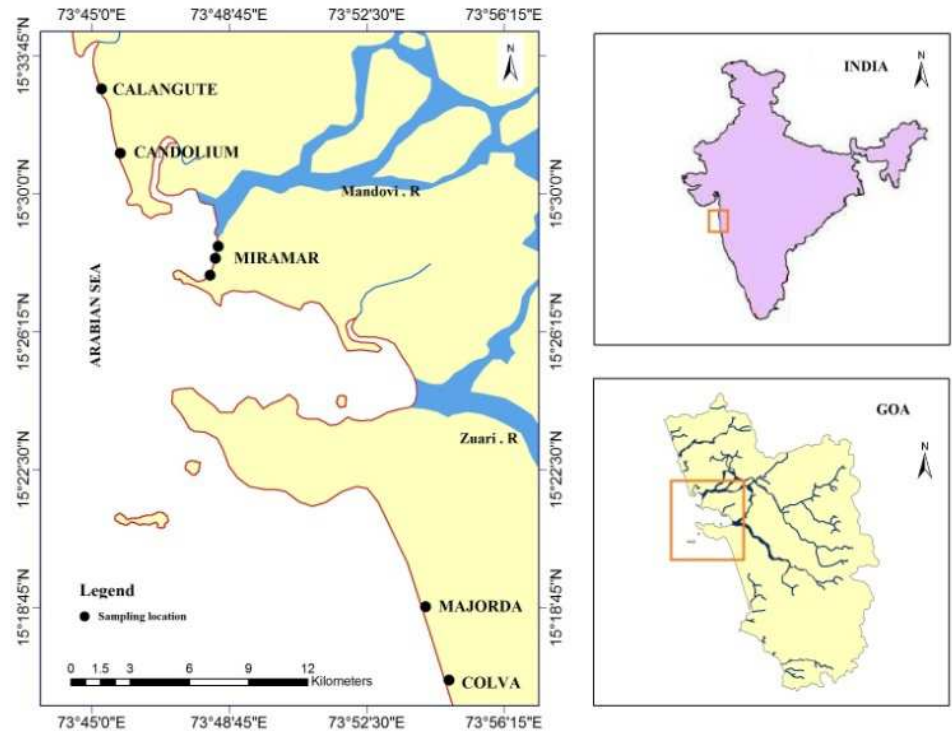
These studies highlight the impact of seasonal change over beach morphology and sediment transport. So far such studies have not been conducted in the Candoliam and Colva coast. This coast has been influenced by high rate of tourism and recreational activities which leads to morphological disturbances. Therefore, the objective of the present study is to quantify the coastal morphological change within seasonal cycle by profiling and sediment analysis.

## 2. Study area

The Goa state is situated along the central west coast of India, covering an area of about 3,702 km<sup>2</sup>. It lies between the latitudes N

govern the drainage system of the area which shows a typical dendritic pattern. The river valley is 'V' shaped in the western high hill ranges, but broadens in central midlands and become 'U' shaped in the low lands and coastal plains CGWB (2010; 2013).

Fig. 1 Location map of the study area



15°48'00"-N 14°53'54" and longitudes E 74°20'13"-E 73°40'33" representing part of the Konkan coast (Fig. 1). It has a coastline of about 105 kms, composed of alternately situated headlines, estuaries, bays and world famous beaches. Along the eastern margin of the state, the highly imposing massive chain of hills of the Western Ghats runs in a general north south direction. Goa experiences a tropical humid climate. It receives rainfall from the southwest monsoon winds from June to September. The annual rainfall ranges from 250 to 300 cm. The temperature in the region varies between 20 and 37° C. For the present study 5 beaches namely Calangute, Candolim, Miramar, Majorda and Colva were selected to understand the spatial and temporal variability. At Miramar, which is a stretch of about 3 Km bounded in the north by river Mandovi and Aguada promontory and in the south by Cabo-da-Gama promontory, 3 locations were chosen to understand the temporal variability of beach morphology.

### 2.1. Physiography

Physiographically, Goa can be broadly divided onto four distinct morphological units from west to east namely, (i) Coastal plain with marine land forms on the west, (ii) Vast stretch plains adjoining the coastal plain, (iii) Low dissected denudational hills & tablelands towards the east, and (iv) Deeply dissected high Western Ghats denudational hills along the eastern most part of the district. Galjibagh is the only perennial River that drains through the district and non-perennial (seasonal) rivers like Sal, Saleri and Talpona, Terekhol, Chapora, Baga, Mandovi and Zuari. The river basin of westerly flowing Galjibagh River originate from the Western Ghats and drain in to the Arabian Sea. Primarily, the underlying rocks

### 2.2. Geology

The geology of Goa is well described by Wagle (1993), it is covered by the pre-cambrian and cuddapah rocks, the rock types representing the Dharwars are quartzites, meta-gray wackes and banded haematite quartzite. These un-fossiliferous meta-sediments of cuddapah age are profusely intruded by basic dykes. The Deccan traps cover the ancient crystalline formation in the northeast. Laterites and lateritic soils of variable thickness are found to occur from the high plateaus of the Sahyadri to the sea level.

### 2.3. Geomorphology

The study of coastal geomorphology helps to understand various processes operating in an area. Therefore, it is important to understand the coastal landforms and related features. The geomorphic features in the study area can be classified into two namely coastal features and near-shore Sea. The coastal features include fluvial and marine which comprise drainage, channel bars, estuary island, river terraces, tidal flats, estuaries, wave cut terraces, beaches, paleo-beach ridges, cliffs, headlands. Aeolian features act on active dunes and stabilized dunes Wagle (1993). The coastal stretch in the study area has gentle to sloping beach and marked with altered crusts and troughs which are formed due to wave action. Vegetation of the study area is comprised of mangroves, dune vegetation, and beach vegetation. Structural features like lineament, inselbergs, laterite mesas are also noticed in the study area. Near-shore morphological features like Shore Island and salt marsh are also seen around the study area.

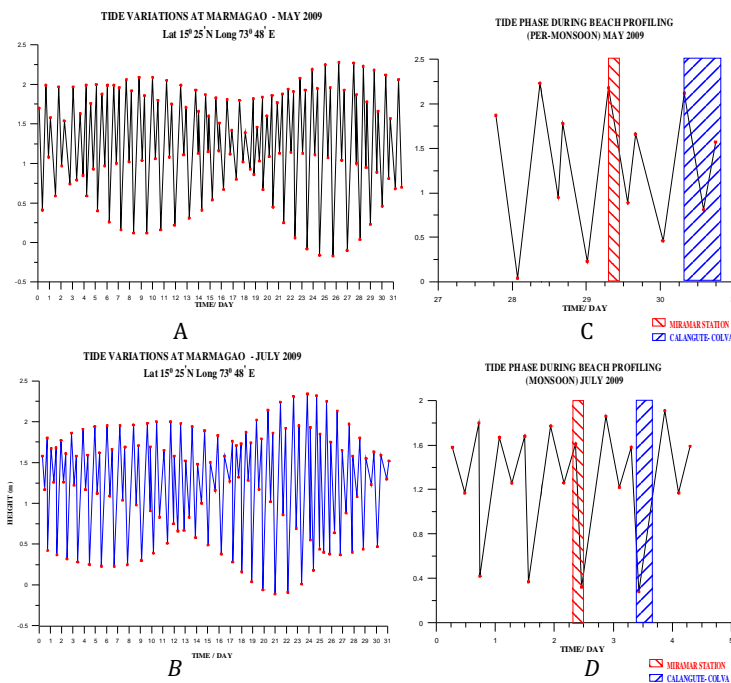
### 3. Methodology

#### 3.1. Field survey

Field survey was carried out in the study area to understand the coastal geomorphology, beach processes, sediment texture, and tidal fluctuations along the study area. After investigating the study area and cross checked with the available literatures and other supplementary data sources to execute the study.

#### 3.2. Tidal Characteristics

Tide is an important parameter that influences the beach morphology. Hence, it is important to understand the tidal characteristics of a region where beach profiling studies are planned. The only tidal station available in Goa is located at Marmagao port. The Indian tide table for the year 2009 was used to obtain the information on the time of occurrence and the height of the high and low tide values. Since the beach profiling studies were planned to understand the temporal variability from pre-monsoon to monsoon season, the months of May and July 2009 were chosen and the tidal information during these months at the Marmagao port were used for analysis. These data were plotted (Fig.2) to understand the tidal variations. It is inferred from the graph that the coast of Goa experiences mixed semi-diurnal tides. In the month of May 2009 the highest high tide is at 12hrs 38mins on 26<sup>th</sup> July and the lowest low tide is on the same day at 05hrs 33secs. And in the month of July 09 the highest high tide is at 12hrs 36mins on 24<sup>th</sup> July and lowest low tide at 03hrs 28mins on 21<sup>st</sup> July. The profiling was carried out during the low tide phase so that the profiling can be taken to a maximum distance.



**Fig. 2** Variation of tidal height at Marmagao port for the month of May and July 2009(A & B), Variation of tidal height during profiling (C & D).

#### 3.3. Positioning and Beach profile measurement

At first a benchmark was selected, which was the starting point for the beach profiling, the benchmark should be a permanent structure. A Ceeducer DGPS was used for obtaining the geographical coordinates of the permanent benchmarks to extreme precision. Before measuring the elevation, all the equipments were calibrated to avoid errors in measurements. After calibration, the benchmark elevation was measured from a fixed distance from the benchmark using dumpy level and measuring staff (Fig. 3).

To understand the beach changes, it is very important to recognize the features of the beach and characterize them. The profile of the beach gives us the information about the general beach morphology. A beach profile is a cross-sectional view of the beach, which has been plotted showing the variation of elevation with distance from a fixed benchmark. The profile of beach at each station was plotted and the HTL (High Tide Line), HWL (High Water Line) WL (Water Line) and LWL (Low Water Line) were marked.

Thereafter, the dune, berm, backshore and foreshore were identified. The accuracy of the measuring staff is 0.01cm. The least count of the leveling staff used is 1cm. A rope was placed in a straight line from the benchmark through the tripod of the dumpy level along which beach elevations were measured at an interval of 5m with the help of dumpy level and measuring staff. To obtain the elevation of the point, this process was repeated until the low water line was reached.



**Fig. 3** Profiling at Miramar beach

The graduated staff reading which denotes the elevation was first reduced with respect to the fixed benchmark. This was necessary as readings were taken with respect to the dumpy level whose position changed from time to time so as to obtain the elevation within the length of the measuring staff. The data values were plotted with distance on the abscissa and reduced elevation on the ordinate for each station.

#### 3.4. Littoral current measurement

The littoral currents were measured using the LEO PLATE. This was done by throwing the plate into the wave breaker zone. The starting point was marked on the shore and when the LEO plate hits back the shore the end point was marked. Simultaneously, the time duration was also noted. The speed of the current was calculated by dividing the distance covered by LEO plate by time.

### 3.4. Sediment sampling and heavy mineral analysis

For profiling, about 7 station have been sites between Candoliam and Colva on seasonal basis between pre-monsoon (May 2009) and monsoon (July 2009). At each of the beach profiling location four sediment samples were collected, one each from the High tide line (HTL), High water line (HWL), Water line (WL) and Low water line (LWL) regions. The collected samples were dried and homogenized by conning and quartering method. 100g of sample was weighed from each location and then treated with dil. HCl to remove carbonates and then treated with hydrogen peroxide to remove the suspended materials. To identify the minerals present, the samples were observed under a microscope and quantified the percentage of heavy and light minerals. The obtained data were visualized using a graph for better understanding.

## 4. Results and discussion

The result of beach profile, including change in slope, width, sediment volume and heavy mineral percentage were analyzed to understand the seasonal beach morphological change and its impact on beach dynamics.

### 4.1. Beach profiling

The profiling data helps to understand the spatio-temporal change in elevation at each point at specific intervals. The profiles inferred that there had been a considerable change in the beach topography (Fig. 4). During the pre-monsoon season the Miramar beach (Station 1) had a well-defined berm and a steep sand dune but, during the monsoon period it was noticed that the berm was completely eroded (Fig. 4a). The region behind the berm was also got remarkably eroded giving rise to the deep “V” shaped cut. However, the dune got eroded to a smaller extent due to the vegetation cover that had protected the dune from getting eroded in a large way. The fore-shore region also got eroded and the elevation of the fore-shore had decreased perhaps, the slope in general remained constant. In terms of width, the backshore earlier had a width of 83m but due to the monsoon waves and runoff it had reduced to 24 m. This reveals that the monsoon wave have affected the beach and has changed its topography.

The dune has not changed much in Miramar (station 2) but it was seen that the berm has completely got eroded (Fig. 4b). Hence, the area behind the berm in the pre-monsoon season became the new berm for the monsoon season. This may be due to the shifting of berm behind a distance of about 40m. The backshore width showed a decrease of 5m from pre-monsoon to monsoon. On looking at the profile, it is apparent that the fore-shore has got eroded. The slope of the foreshore has become flatter and the elevation has also reduced during the monsoon period indicating uniform deposition of sediments and erosion as well. In general, the prominent change that has occurred was the shifting of the berm.

At Miramar (Station 3), the beach underwent erosion all along the profile (Fig. 4c). The most prominent change noticed was the erosion of the berm during monsoon. The slope of the foreshore remained the same. Most dramatic change was noticed in the width of the foreshore. The foreshore width had increased from 34 to 48m while the backshore width had decreased from 80 to 51m.

The total beach width covered in two different seasons was differed to a large extent in Calangute (Fig. 4d). Before the monsoons, it was possible to extend the profiling up to 78m from the benchmark. However, during the monsoon the high waves and

associated water level rise did not permit profiling beyond 40m. It can be seen that for both the seasons, we did not notice any well-marked berm but significantly, there has been erosion and deposition when we compare the two profiles. The most significant change was the erosion in the fore-shore region associated with high monsoon waves. The back-shore width had reduced because major part of the exposed back-shore is under water in the monsoon period.

Candolim beach did not show any significant change in the back-shore from pre-monsoon to monsoon period (Fig. 4e). Erosion was noticed at the berm during monsoon and the entire foreshore also experienced erosion during monsoon. There has also been a slight variation in the slope. The back-shore width has also decreased from 70 to 59m.

The profile variation in Majorda beach is noticed with a decrease in berm crust from pre-monsoon to monsoon (Fig 4f). During the monsoon period, the profile up to 81m away from the benchmark could be taken and we could obtain the offshore bar. In general, Majorda beach was experiencing erosion all along the profile. The most remarkable change was noticed at Colva beach during monsoon with complete erosion of the berm (Fig 4g). A mild deposition was noticed at the location of pre-monsoon backshore. Except for the decrease in elevation, there has been no significant change in the slope of the fore-shore after the pre-monsoon season.

### 4.2. Littoral current measurements and sediment volume analysis

The littoral zone is the most dynamic environment of the coast and one in which constant mobility of sediment is observed. The movement of material in this zone depends mainly on three factors: the nature of material available for transport, orientation and other features of the coast and the angle of wave approach.

The littoral current measurement and sediment volumetric analysis was done, so that it could help us to understand how the beach morphology has been changed from time to time. Current measurements were carried out using the LEO plate for determining the current speed and direction. [Jaya Kumar et al. \(2014\)](#) have studied long-shore sediment transport in Candoliam, Miramar and Keri beach for the post-monsoon. Since the onshore-offshore movement was dominant in Miramar station, along-shore current were not observed. All the other stations, except at Colva beach, along-shore current was observed (Table 1).

Station	Pre-Monsoon 2009	Monsoon 2009
CALANGUTE	0.21 m/sec	0.19 m/sec
CANDOLIM	0.38 m/sec	0.11 m/sec
MAJORDA	0.11 m/sec	0.17 m/sec
COLVA	Onshore/ offshore	0.09 m/sec

**Table. 1** Data showing littoral current values in the study area

The change in slope and beach width has been calculated from the profile data and the values are given in table 2. The reach level of tide during the beach profiling is noted and it is taken as reference from the bench mark, this change is observed from season to season (Table. 3). Sediment volume change is calculated from the difference in profile volume keeping the first profile as reference with respect to the second profile. Expect in Miramar station 1 and 3, all the station shows change in sediment volume at the backshore. There is huge change in volume at the fore-shore region and it is observed in all the station (Table. 3). This data helps to understand how a beach is directly or indirectly influenced by the surrounding environment.

4.3. Heavy mineral

The sediment sample collected during profiling was used for mineral identification and calculating the percentage of heavy mineral along the study area. The heavy minerals in the sediment samples showed significant change from time to time. This is due to transportation of

minerals by current, wave and wind. The weight percentage of heavy and light minerals is calculated and plotted (Fig. 5). The concentration of heavy mineral percentage in Miramar beach was about 2.51% during pre-monsoon and raised to 3.37% during monsoon, rest of the station shows >0.5% in both the seasons. However, the concentration was high in monsoon when compared to

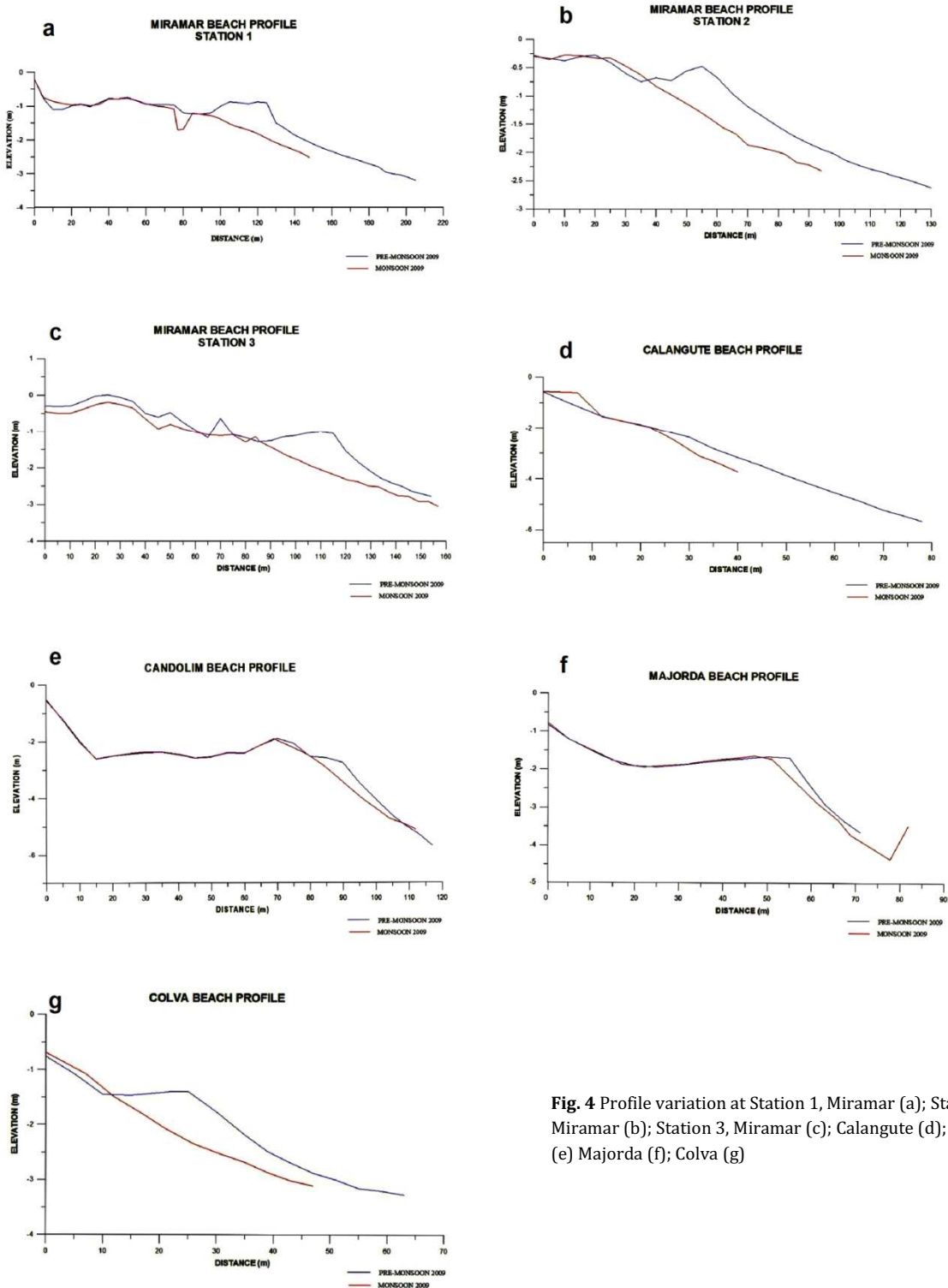


Fig. 4 Profile variation at Station 1, Miramar (a); Station 2, Miramar (b); Station 3, Miramar (c); Calangute (d); Candolim (e) Majorda (f); Colva (g)

Location	Parameter	Pre-Monsoon			Monsoon		
		BS	FS	B	BS	FS	B
Miramar 1	Width	83	45	128	24	49	73
	Slope	-0.011	-0.038	-0.025	0.0134	-0.025	-0.006
Miramar 2	Width	35	60	95	30	44	79
	Slope	0	-0.015	-0.008	-0.035	-0.029	-0.032
Miramar 3	Width	80	34	112	51	48	99
	Slope	0.0024	-0.03	-0.014	-0.003	-0.025	-0.014
Calangute	Width	33	33	66	15	13	28
	Slope	-0.066	-0.065	-0.0655	-0.043	-0.1	-0.071
Candolim	Width	70	32	102	59	38	97
	Slope	-0.02	-0.04	-0.03	0.001	-0.386	-0.193
Majorda	Width	35	16	51	44	15.8	59.8
	Slope	0.015	-0.198	-0.0915	-0.03	0.065	0.018
Colva	Width	20	33	53	14	26	40
	Slope	-0.014	-0.046	-0.03	-0.07	-0.04	-0.054

BS= Backshore, FS= Foreshore, B=Beach, Width (m), Slope (degree)

Table. 2 Slope and beach width change in the study area

Location	Pre-Monsoon				Monsoon				Sediment Volume change m <sup>3</sup>	
	HTL	HWL	WL	LWL	HTL	HWL	WL	LWL	Backshore	Foreshore
Miramar 1	77	160	180	205	77	99	120	148	0.94	-33.265
Miramar 2	35	70	85	130	25	50	66	94	-1.61	-29.085
Miramar 3	75	120	134	154	40	101	121	157	38.5	-10.98
Calangute	20	45	70	78	12	27	32	40	-0.275	-2.69
Candolim	25	85	105	117	15	74	88	112	-0.19	-10.392
Majorda	25	55	63	71	32	66	77.8	81.8	-0.265	-4.416
Colva	10	30	39	63	7	21	31	47	-1.115	-17.61

BS= Backshore, FS= Foreshore, B=Beach, Width (m), Slope (degree)

Table. 3 Tide level variation and sediment volume change (from pre-monsoon to monsoon) in the study area

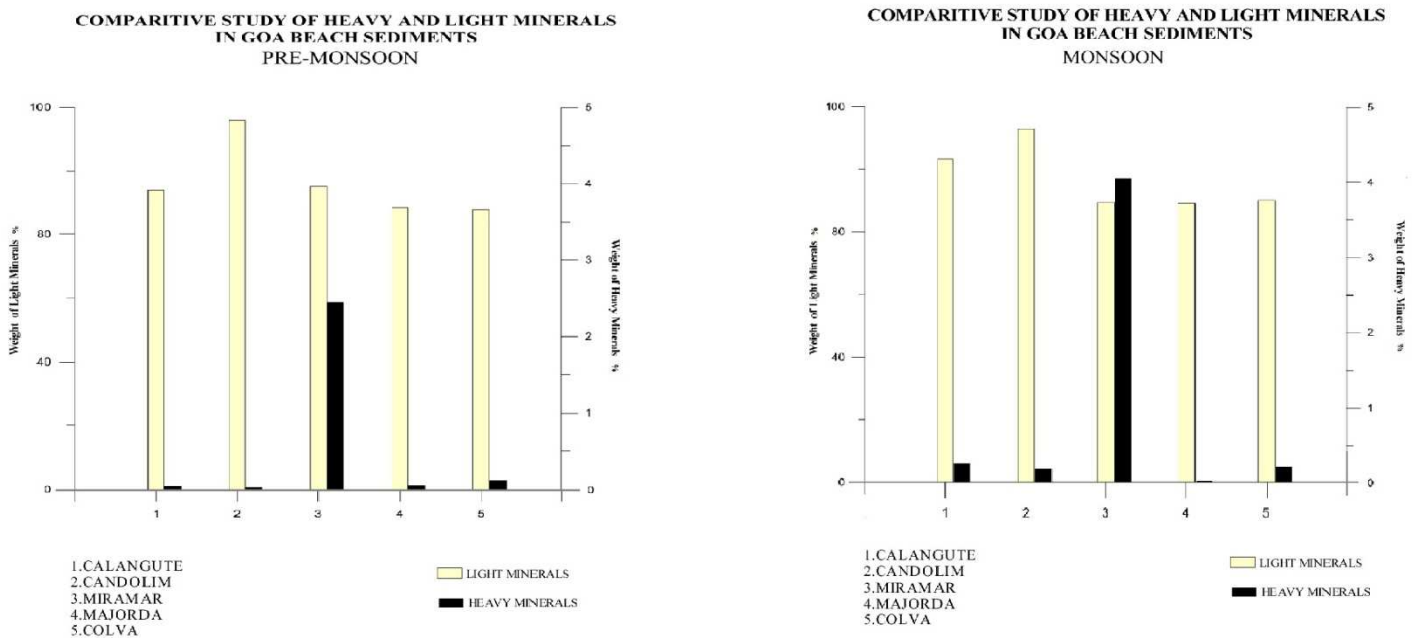


Fig. 5 Heavy/Light mineral percentage changes pre-monsoon & monsoon

pre-monsoon, as the sediment during monsoon (light minerals) are washed away by waves and winds thus leaving back the heavy minerals.

4.4. Shoreline change

The shoreline change is also noticed at different season as it is important to understand the change in beach morphology. Along with beach profiling and sediment analysis, shoreline change analysis is also vital. During the pre-monsoon and monsoon period the shoreline was marked at High Water line with the help of a DGPS. On comparing the shoreline of both the seasons, it was noticed that the shoreline has changed considerably (Fig. 6). During pre-monsoon season the HWL was further away from the benchmark than the HWL of the monsoon season. This can be accounted for the high wave action during the southwest monsoon. A typical monsoon season is characterized by strong winds and heavy rains. Hence, the wave action of the oceans becomes more vigorous and turbulent. As a result, erosion occurs and the HWL also changes. During the monsoon season the shoreline was shifted towards the benchmark and away from the earlier shoreline.

to quite an extent, even though they belonged to the same coastal environment. The fore-shore slope of station 1 was comparatively flatter as compared to the fore-shore slope of station 3. The colour of the beach sand changed from station to station. From a blackish colour, it reduced to a dark-brown colour as we moved from station 1 to station 3. Also, station 1 indicated biological activity in terms of benthos production. On looking at the north and south Goa beaches, Majorda in the south could be considered the steepest beach followed by Candolim beach in the north. As compared to the other beaches, Calangute beach did not have a well-defined berm. There was also a difference in the sediment composition in all the beaches. Candolim had the maximum percentage of laterite. Gun metal was primarily found in Miramar beach and the change in texture was also clearly seen. Candolim beach sands had the coarsest texture while Colva had the finest which contains many shell fragments. On measuring the long-shore current in each beach, it was found that Candolim beach had the highest speed of long-shore current, while Majorda had the lowest. In Colva, mainly onshore and offshore currents were seen. The direction of current is northward in the pre-monsoon and southward in the monsoon season. This change is due to the change in the direction of wave.

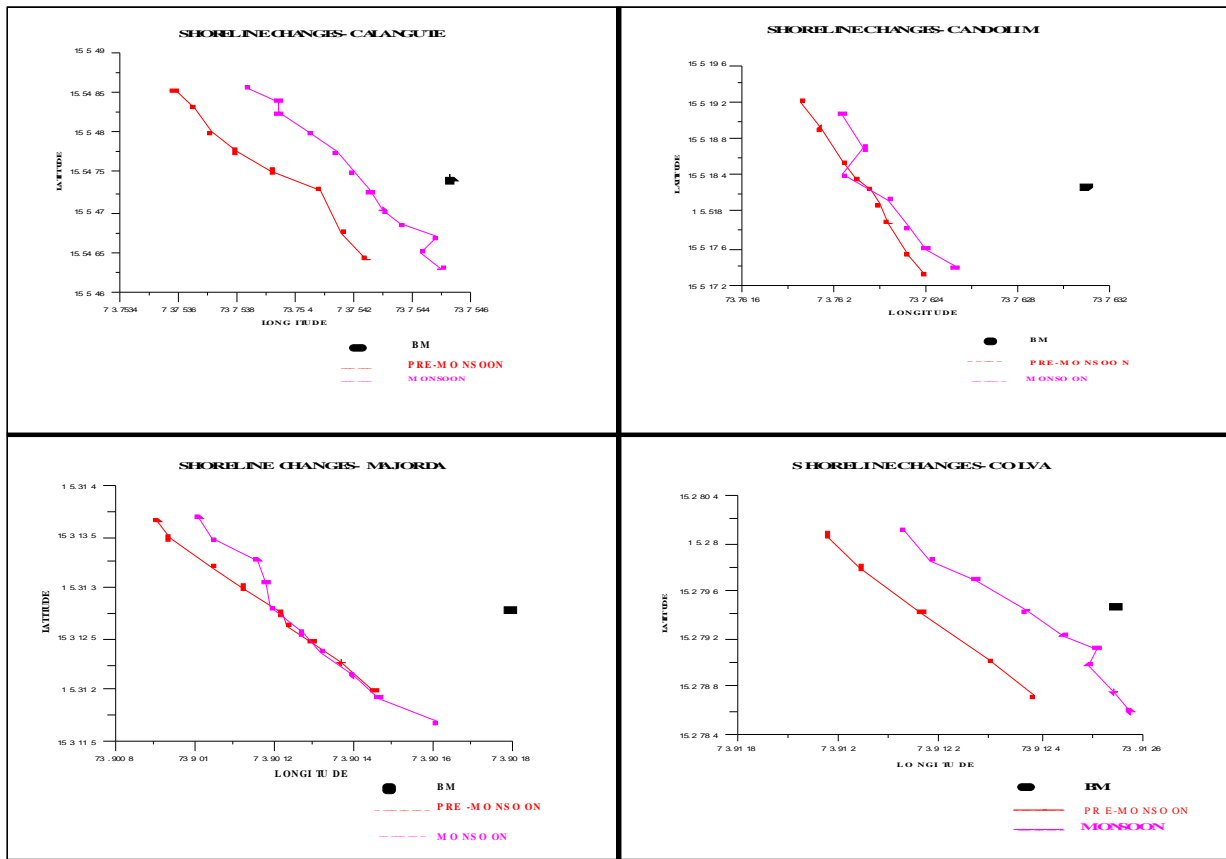


Fig. 6 Shoreline changes from pre-monsoon to monsoon

5. Conclusions

From various studies and analysis from all the beaches, it can be concluded that there is a large variation in the beach topography, sediment type, and the speed of the current. It was noticed that the three stations within Miramar beach were different from each other

In terms of seasonal changes, it can be concluded that there is significant variation in the beach topography, sediment type, water current and shoreline at the HWL. The prominent changes include erosion of the berm, widening and reduction of backshore and foreshore widths and changes in the slope. For all the beaches, the berm is eroded during the monsoon period. In terms of backshore width, it can be said that the width reduces during the monsoon season. The dune slope and the vegetation cover have however not

changed. Majorda and Candolim beaches are the two beaches, which did not undergo any significant change. The maximum variation was noticed in Miramar and Colva. There is also significant increase in the magnetic mineral concentration in the beach sands during the monsoon period except in Majorda beach. The long-shore current in the monsoon season was found to be less than the pre-monsoon season. However, we feel that this may not be the case in reality. It is expected that the long-shore current in the monsoon season should be stronger than the current in the pre-monsoon season. There has been a marked shift in the shoreline. The shoreline has shifted few meters towards the benchmark during the monsoon season. In general, a beach is a dynamic landform and undergoes changes continuously. There is a variation in beach characteristics as we move from the north to the south of Goa. The change in season also brings about changes in the beach. This study reveals the important changes in topography, type of sediment deposition, long-shore current and shoreline.

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