Research Journal of Marine Sciences ISSN 2321-1296
Vol. **11(1),** 1-6, June **(2023)** *Res. J. Marine Sci.*

Case Study

Environmental characteristics of west coast of India – Case study from Kasaragod and Harnai Beaches in India

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Available online at: www.isca.in,www.isca.me
Received 26th June 2021, revised 29th July 2022, accepted 15th April 2023

Abstract

Survey and analyses of the coastal environments and beach materials from the Kasaragod coast of Kerala and Harnai of Maharashtra revealed the various surface structures on the intertidal sand flat that are the characteristics and indicatives of wave influence. Conical dome-like bioturbation structure formed by the Olivancillaria species, a marine macroinvertebrate, on the intertidal zone of Kasaragod has a significant role in reproducing the beach morphology. Typical notches and honeycomb structures, sand bars, and steep sea cliffs characterize the beach processes of Harnai of Konkon coast. Such physical and biological processes, important factors to differentiate the sea beach morphology, are observed and examined from the study areas of Kasaragod coastal zone of Kerala and Harnai of Konkon coastal stretches along the western coast of peninsular India.

Keywords: Coastal zone, Surface sedimentary features, Grain size, Bioturbation structures, Sea cliff, Sand bars, Notches, Honeycomb features.

Introduction

Western coast of India extends from Kerala to Gujarat and its length is about 1400 km encompassing several typical coastal zones. Among them, Kasaragod coastal marine deposits of Kerala and Harnai beach along the coastal stretches of Konkon, Maharashtra, on the Arabian Sea have a stepwise elevation with clear differences of relief features. Kasaragod sea beach of Kerala, the abode of God is located on the Arabian Sea coast and 5 km north of Kasaragod town, the district headquarters in the state of Kerala and 45 km south of Mangalore town, Karnataka, whereas Harnai coastal zone is about 16 km away from Dapoli of Ratnagiri district in the state of Maharashtra. Both Kasaragod and Harnai have a rich socio-cultural heritage coupled with a vibrant tradition of hospitality.

The nature endowed with bountiful flora and fauna and beautiful natural landscape comprising hills, Arabian Sea, the plains, and sometimes crisscrossed with backwaters. Kasaragod sea beach in the state of Kerala is a land of vivid, vibrant colours and breathtaking surprises. On the contrary, Harnai beach of Maharashtra is characterized with the sea cliffs, sand bars, along with the notches and honeycomb coastal features. These beaches invite naturalists to discover the meanings of enchantment. The coast is studded with the lines of lively coconut fringed sandy beaches. Beach sands are collected from the sandy beaches for the analysis of grain size of the beach sediments and micropaleontological study. Grain size analysis of the samples collected from the beach sands revealed a significant environmental sensitivity. Interpretation of grain size of coastal sediments, micropaleontological study along with the identification of surface sedimentary structures like swash-backwash marks, rill marks, current crescents, and bioturbation structures in the beach environment is the objective of the present study.

Materials and Methods

Sediment samples were collected from the intertidal beach zones Kasaragod and Harnai from the west coast of India for the micropaleontological study and grain size analysis. The sediment samples, dried in sunlight, were processed following the standard methods. The coarser fraction of the bulk sediments was considered for the micropaleontological studies, which were retained in the +230 ASTM mesh sieve. To identify the taxonomic position of the foraminifera, mainly picking up and mounting specimens on micropaleontological slides were done. Gravelly sands of seabeach were studied on a petrological microscope. Biostatic components were studied under a binocular microscope after treating the samples with sodium carbonate solution. Different fractions of sediment samples from the beach areas were collected followed by mechanical sieving and those fractions of different grain size retained in the sieve were considered for the micropaleontological studies. Major fauna including foraminifera were found from the +35 fraction to +120 fractions of the mechanically sieved samples.

As the collected and processed sediment samples from the coastal areas along different transects from supratidal to the intertidal zones were mostly above silt sizes, different fractions

of the samples were separated using the sieving method. The fractions of the samples from Kasaragod and Harnai coast are scanned under binocular microscope on the biogenic point of view especially of foraminifera which were properly identified by the micropaleontological experts of the Marine Wing Division of Geological Survey of India. Molluscan specimens comprising both gastropods and bivalves were collected from the selected beaches of west coasts of peninsular India, and they were properly identified by the experts of Mollusca section of the Zoological Survey of India.

Results and Discussion

Coastal Features of Kasaragod: The study area of Kasaragod beach along the coastal stretches of Kerala on the Arabian Sea bounded by Latitude $12^0$30'N and Longitude 75^0E on an elevation of 10.7 m above mean sea level. Kasaragod coast is endowed with abundant water resources having average annual rainfall exceeding 3500 mm, ample sunshine, vast diversity in terms of topo-sequences characterized by a series of small hills and valleys, steep to gentle slopes. The northwest-southeast trending linear beach runs for a stretch of 9.9 km and has a width of about 80 m from the sea face. The beach zone is dominantly composed of coarse sand, silt, and clay. Supratidal beach zone is characterized by aeolian ripple marks without any true dune structures. The sea beach is heavily disturbed by littoral crabs and gastropod species. Compositionally the beach sands contain a variety of macro and micro shells.

Geology, Physiography and Topography: The exposure of crystalline rocks of the Archean group are seen near the seashore indicating the geological formations of Kasaragod coastal areas with the range from Archean to Recent[1]. The crystalline metamorphic rocks are exposed at some places of marine beach deposits of recent formations. Series of backwaters and green lagoons constitute the coastline, a narrow belt. The coastal area with alluvium is found flat for some distances and then the plains succeed the low coastal land in gentle ascents and valleys which get broken at various places by isolated hills[1]. Kasaragod coast can be divided topographically into three longitudinal regions – i. the hilly tract, ii. the midland region, and iii. low land region. The marine beach deposit lies in the lowland close to the Arabian Sea. The narrow coastline with evidence of erosion is flanked by the thick coconut groves. Rainwater is the only source for groundwater recharge in the Kasaragod coastal areas. But rainwater escapes as it runs off towards Arabian Sea. Only about 10% of the annual rainfall can be considered contributing to the groundwater table of the coastal district of north Kerala[2].

Climate: Temperature and rainfall data for a period of about two decades are systematically presented in Table-1. Rainfall data shows a mean value of 3536.01 mm. Total rainy days vary from 60 to 65 days in between June and September and the total rainfall is 3500 mm and above. Kasaragod including some other coastal region of Kerala presents a typical example of low per capita rainwater availability despite more than 3500 mm rainfall, which is even less than that of the dry parts of Rajasthan because of heavy surface run off loss for the steeply sloping topography, excessive deforestation of coastal vegetation, and road construction. The excess run off results in eroding the top fertile soil of the region and leads to poor ground water recharge due to lesser ponding time. Average of 25 years of evaporation data is estimated to be 46.93 mm and this implies an excess of annual precipitation in the area over annual evaporation.

The weather of Kasaragod coastal region is generally pleasant with wind speed ranging from 2.2 to 3.8 km hr^{-1} over the year. The maximum sunshine duration a day is 9.8 hours, and the minimum is 1.6 hour a day in the month of July during the monsoon time[2]. Relative humidity ranging from 76-95% at forenoon and 51-89% in the afternoon in the Kasaragod coastal areas[2]. The year for minimum temperature and the coldest year recorded, is 1991 during a span of two decades (Table-1).

Soil: The coastal soils show tremendous variability. The soils of Kasaragod of north Kerala consist mainly of laterites, clayey loam, gravelly clay, sandy loam, and coastal sands. The salt affected soils occupy extensive areas spread over western coastal regions and include saline, sodic, acid sulphate, marshy and waterlogged subgroups in the low lying areas. High intensity rains result in heavy leaching causing nutrient losses and formation of acid laterite and lateritic soils in the highly permeable areas[1]. The soil of the experimental field is classified as littoral sand with a mechanical composition of 95.8% coarse sand, 3.3% fine sand, 0.2% silt, and 0.7% clay. The field capacity of the soil is 4.2% and wilting point was 0.44 with a bulk density of 1.66 kg m^{-3}.

Texture of sediments: The Kasaragod beach of north Kerala shows greater accumulation of gravelly coarse sand in the supratidal portion of beach with a high concentration of molluscan shells. The sandy sample of the supratidal region is medium sorted (σ_1=1.38phi) with median (Md) value of -0.85 phi and slightly positively skewed (SK_1=0.47phi). The sediment sample of lower intertidal beach of Kasaragod is well sorted (σ_1=0.39phi) fine grained sandy in nature. The sample is slightly positively skewed (SK_1=0.15phi) and is leptokurtic (K_G>1.00) in nature with the median (Md) value of 2.80 phi[3].

Micropaleontology of sediment samples: The sandy samples of the intertidal region shows that the +35 fraction of mechanically sieved samples are with very few quartz grains with one small lamellibranches shell. The +45 fraction with 30% shell fragments of macroinvertebrates, one specimen of foraminifera like *Ammonia beccarii* is identified.; +60 fraction with fine shell fragment of micro invertebrate foraminifera is rare; +80 fraction revealed with biogenic 10%, shell fragment and others 8%, foraminifera 2%, along with the presence of *Ammonia* sp.; +120 fraction with biogenic 10%, fine shell fragments, foraminifera is rare[3].

Table-1: Weather and climate data of Kasaragod, Kerala.

Parameters	Pre-monsoon				Monsoon				Post-monsoon			
	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan
Max Mean monthly Rainfall(mm)	1.2 2001	26.6 1993	135.2 2001	676.8 1990	1421.8 1994	1452.4 1994	844.0 1992	508.6 1998	699.5 2002	495.8 1992	60.6 1997	52.6 2000
Mini Mean monthly Rainfall(mm)	0.6 1996	6.8 1994	0.4 1992	21.8 1996	622.6 1992	416.4 2002	396.9 1999	78.6 1993	85.4 1991	8.4 1991	12.1 1993	0.4 1996
Average Max Annual Rainfall(mm)	0.14	3.22	36.12	267.48	968.62	1057.16	625.87	188.03	285.55	87.2	12.56	4.14
Average Mini Annual Rainfall(mm)	0.00	0.09	1.02	7.56	27.39	29.9	17.7	5.32	8.08	2.46	0.36	0.12
Evaporation (mm)	4.53	5.18	5.78	4.45	3.08	2.43	2.6	3.6	3.3	3.55	4.23	4.2
Max Temp. (^{0}C)	33.3 1999	33.5 2002	34.1 1998	33.9 1991	30.7 1997	29.9 2002	29.0 1998	30.6 1991	31.4 1997	33.1 1994	33.6 2001	33.1 1992
Min Temp. (^{0}C)	16.4 1991	18.8 1991	20.9 1991	20.4 1991	19.3 1991	18.1 1991	17.4 1991	17.8 1991	17.9 1991	16.3 1991	14.2 1991	16.4 1991
Max Wind (km h^{-1})	2.9 1999	3.3 2000	3.8 2002	3.5 2001	3.8 2000	3.3 1999	2.7 1999	2.9 2000	3.1 1999	2.5 2000	2.7 2000	2.8 2002
Average sunshine (hours)	9.05	8.88	8.27	4.28	3.57	2.98	3.83	6.32	5.8	8.22	8.93	8.95
Max Mean Relative humidity(%) : Forenoon	92 2001	90 2000	88 2001	93 2002	93 1999	95 2002	95 1999	95 1999	94 1999	93 1999	90 1999	90 2000
Max Mean Relative humidity(%) : Afternoon	64 2001	63 1994	65 2000	75 1999	86 2000	86 1999	89 2002	78 2000	76 2002	67 2001	60 2000	63 2000

Beach morphology: Sedimentary structures in the field were mapped with Brunton compasses. Measurements of different bedforms were taken in the field. Field photography and sketches were taken for documentation. The granulometric properties of sediments were analyzed by the sieving method and their statistical evaluations were done using the graphic method of Folk and Ward[4,5].

The three subdivisions of the sea beach are easily discernible. All these subdivisions are identified as supratidal zone, transition zone, and intertidal zone revealed clear differences of relief with stepwise elevation from one subdivision to the other towards landward direction. The supratidal zone is highly bio-concentrated with scattered shells. The width of this zone is about 19 m with gentle sloping of 2^0 to 4^0 along with the cliff at landward exposure due to wave induced erosion. The erosional portions are well protected by constructing seawalls using boulders. At the distal end of the sea beach where it merges into the coastline; the mainland is underlain by coarse sands that support enormous coconut plantations. The transitional zone is demarcated only by beach sloping of less than 1^0 from supratidal zone. Only rhomboid marks are seen in the border area in between this zone and the intertidal zone. The width of this zone is about 14 m with equal grain size of sand like the supratidal zone. The width of the intertidal zone is near about 47 m with a few surface structures like swash marks, rill marks, current crescents, and bioturbation structures with birds' footprints. The grain size character of this zone is with fine sands enriched with abundant shells of pelecypods.

Sedimentary structures: Surface structures of Kasaragod beach are indicative of wave influence. Sedimentary structures like swash marks, backwash marks, rhomboid marks and current crescents which are the natural phenomena of the coastal areas of north Kerala. Both physical and biogenic processes are important to differentiate the sea beach morphology. Surface sedimentary structures like swash marks, rhomboid marks, rill marks and current crescents are identified. Current crescents are

abundant in the foreshore of the present study area (Figure-1). Several types of rill marks like partially conical rill marks, bifurcating rill marks, and branching rill marks have been found in the dynamic beach environment of the Kasaragod coastal zone.

Figure-1: Current crescent formation in the intertidal zone of Kasaragod coast in north Kerala; the pen is 15 cm in length.

Bioturbation structures: The sea beach deposit is characterized by the profuse burrowing activity by a tiny bivalve at the site of the swash-backwash zone. When waves come and inundate the beach the tiny bivalves are exposed due to wave action, but they dig into the sands making complete disappearance just after recession of waters. Shells of these macro pelecypods along with others of this class are strewn all over the intertidal zone of the beach. Some macro shells of gastropods and bivalves with their long axes parallel to wave swash and backwash lie embedded on the sand flat surface (Table-2). Conical dome-like structures are found in the beach constructed by a typical gastropod *Olivancillaria gibbosa* which are irregular in shape (Figure-2). The gastropod *Olivancillaria gibbosa* with abundant occurrence in the Kasaragod coast are found in intertidal to subtidal regions where they burrow through sandy substrates leaving a characteristic trail. They are predator/scavengers and fed mostly on small bivalves and crustaceans. *Olivancillaria gibbosa* has small to medium cylindrical shells with a larger body whorl, channeled suture and posterior siphonal notch, columella often calloused, sometimes plicate. The shell of *Olivancillaria gibbosa* is glossy and with a short spire, long narrow aperture, and no operculum[3].

Figure-2: Bioturbation structure formed by *Olivancillaria gibbosa* in the intertidal sand flat; the pen is 15 cm in length.

Table-2: List of identified gastropods and bivalves collected from the intertidal zone of Kasaragod beach.

Phylum	Class	Species name
Mollusca	Gastropoda	*Turritella duplicate* (Linnaeus), *Olivancillaria gibbosa, Turricula javana* (Linnaeus)
	Bivalvia	Anadara *(Tegillarca) rhombea* (Born), *Pernaviridis* (Linnaeus), *Mactra (Mactra) cuneata* Gmelin, *Mactra (Mactrinula) reevasi* Gray, *Apolymetis* sp., *Donax (Donax) nulchella* Hanley, *Donax (Hecuba) scrotum* (Linnaeus), *Sunetta (Sunetta) scripta* (Linnaeus), *Sunetta solanderii* (Gray), *Meretrix* sp.

Coastal Features of Harnai Beach along the Konkan Coast of Maharashtra: Coastal background of about 720 km length and 50 to 60 km width along the hilly terrain of Konkan region of Maharashtra is one of the gifted divisions, which comprise the district Ratnagiri, Thane, Raigad, and Sindhudurg. Being almost flat in nature, topographically, this coastal tract has its elevation less than 10 m above mean sea level. Average number of rivers in this region, influenced by tide, originate from the hilly top of the Sahyadri ranges and flow towards the Arabian Sea. The present study has been carried out at the Harnai beach near Dapoli of Ratnagiri district along the Konkan coast, which is characterized by extensive seacoast measuring about 530 km in length[6]. The geographical location of Harnai beach is between Latitude $17^0$21'N and Longitude $73^0$14'E.

Topography: Sea cliffs, hilly topography interspersed between sand bars, beaches, creeks, marshy lands and *kharland* are the salient geomorphic features of the coastal tract of Konkon. There are several creeks and rocky promontories in the Ratnagiri district which, overall, contribute to the formation of marine depositional lowlands as well as their separation from each other.

In the coastal areas, on shore sand bars and dunes are formed due to the stormy southwest monsoon currents. Sand bars thus formed are locally called *danda*. Depressions at the landward side are generally filled up by the accretion of these *danda*. Thus, these sand bars cause emergence of coastal lowlands. As a result, minor and mini pockets are noticed at recent times as common geomorphic features along this tract. These structures extend into the interior areas due to some complex marine processes. Tidal ingress is noticed on the flood plain of rivers up to the landward distance of 30 to 40 km from the sea. Such *kharlands*, typical of the coastal tract of Konkan, are relatively flat towards the coast and merge with marine coastal plain[6]. Moreover, Konkan coast is characterized with productive and extensive backwaters, mudflats, and mangrove areas. Structures like honeycomb and notches formed due to run off water are

seen in the cliff, which is having a height of 4 m. Sometimes the top/upper surface of the cliff is covered with grass and occasional notches show a steep cliff face with slope of 84^0 (Figure-3).

Climate: The climate of Konkon coast is characterized by frequent long breaks of rainfall of erratic nature although the rainfall is extremely high. The rainfall caused by the southwest monsoon is restricted from the month of June to October reaching its highest peak during the months of July and August. The annual rainfall varies from 2500 to 3500mm. The rate of infiltration for surface soil is 7.84 cm/day, which is found to be low due to the heavy texture of soil of the coastal stretches[7]. The relative humidity ranges from 75 to 80%. Month of May is the hottest, having a mean temperature of 35.5^0C. The temperature is less than 7^0C for the month of December and increases slightly from 8^0C to 10^0C from January to March during the winter[8].

Tide: Semidiurnal tide, characterized with high tides and low tides in the coastal areas of peninsular Indian coastlines, occurs twice a day within the interval of 24 hours 50 minutes. The interval between two consecutive low tides and two consecutive high tides is about 15 days. During high tides sea water rises above its normal level up to 3.5 to 4.5 m and recedes to the same extent during the low tides. The effect of tidal changes is a result of the fluctuations of water level in the estuarine channels and creeks.

Soils: The coastal saline soils, locally known as *kharlands*, create problems in the Konkon coastal areas. These soils are almost unsuitable for agriculture due to repeated ingress of saline waters from the sea as well as upward rise of salts due to shallow groundwater table during the summertime. The average conductivity of the soils lowered down to 25 ds/M during monsoon period. The dominated ions are Na^+, Cl^-, and SO_4^{2-} on the exchange complex. The hydraulic conductivity is reduced due to heavy texture of soils and infiltration rate, which impedes the drainage. However, the productivity of these nutrient rich soils is affected by high content of salts. Distribution of rain helps in reducing the salinity of soil. The surface soils are washed off, diluted, or leached with the onset of monsoon, however, variations in soil salinity do occur during monsoon if dry spells prevail. The salinity increased from the month of November again[9].

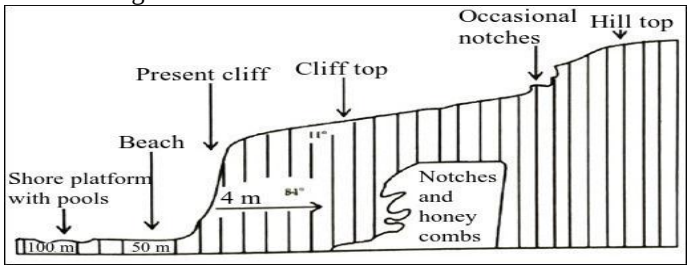

Figure-3: Topographical features of Harnai coastal zone along the Konkon coast of Maharashtra[6].

Beach environment: The width of the entire seashore platform is about 150 m, whereas the beach width ranges from 40 to 50 m. the beach is characterized by the wave cut platform with pools, filled with sands at many places. Exposed laterites and underlying basalts may be the evidence of erosional features on the sea beach of stepped profile. The major reasons considered for erosion are weathering and wave attack. Water comes up to the toe of the cliff face at the contact zone of laterite and basalts during the spring. The high water line is marked by the leaves and debris during each tidal cycle.Local temperature anomaliesare observed in the west coast of India at different depth levels for the changing surface sea temperatures in the coastal areas along the Arabian Sea during the southwest monsoon[10].

Breakers: The coastal stretch of Harnai of Konkan coast is characterized with the spilling types of breakers that follow a smooth curve when ramping on this smoothly sloping beach. The wave energy of these breakers does not exceed 5 J/m^2 in monsoon season and it comes downward to 0.45J/m^2 during the post-monsoon season. Even when the wave is found to be powerful during monsoon time, the height of these breakers never exceeds 4.5m normally except in the events of cyclonic storms. The maximum wave height during the month of September is 2.2m and the minimum is 0.4m with a wave period ranging between 12 and 6 seconds at Harnai beach of Ratnagiri district along the coastal stretches of Konkan region. The slope of these spilling breakers ranges from 20^0 to 30^0. The breakers that occurred in the flat beach of Harnai coast are identified as spilling breakers based on such recorded wave height and wave period. Harnai sea beach, with beach slopes ranging from 1.88^0 to 2.19^0, is recognized as a typical flat beach in nature[11].

Embankments: Construction of strong embankments are helpful for resistance to leaching of saline water intrusion. Side slope of 2:1 with stone pitching on the embankments at seaside and 1:1 on the land side covered with grass is to be optimum. Embankments control marine biota like mudskippers, eels, crabs, ghost shrimps etc. by preventing making burrows and not allowing saline waters into the farming lands. In addition to that, constructions of cut off drains inside the area, parallel to embankments, are found effective in checking the water seepage from the seaside. Sometimes sea dikes and sluice gates help in preventing ingress of sea waters.

Planning and implementation of stone pitching on the seaside and grass cover on the embankment at landside may check the rates of soil erosion that makes the embankment more stabilized. Further, plantation of mangroves helps minimizing the vigour of wave actions and soil erosion thereon. For remedial measures, cut off trenches with a depth of at least 1.5 to 2m and 100 m distance from the embankment at landside, or dug out ponds, drainage wells etc. will be helpful for checking salinity of soils in the landside portions.

Beach sedimentation: Sediments transported by breakers, longshore currents, swash, and backwash helps in beach configuration. Wave characteristics, tidal currents, beach slopes, grain size, breaker type etc. play important roles in beach sedimentation. Wave and tides, the major agents for the sedimentation in the coastal areas, monitor the process of accretion on the intertidal zone of the Harnai beach areas. Rate of deposition is higher during ebb time rather than at flood tide as the current velocity during ebb tide decreases when water recedes. Beach dynamics is a regular phenomenon as the tidal currents and nearshore waves dissipate the energy on the beach flat, which is composed of loose sands and therefore helps in shaping the beach morphology. In general, scooping is the main activity in the post-monsoon season, whereas filling is a major activity during the monsoon time[12].

Sediment Texture: Sediments of Harnai beach are composed of fine to coarse sand particles. Beach materials show gradual coarsening of sediments towards sea. Textural analysis of collected sediment samples from the intertidal beach deposits of Harnai beach are generally well sorted to poorly sorted (σ_1 = 0.43 to 1.57ϕ) with graphic mean size belonging mostly medium to coarse sand fraction (M_Z = -0.04 to 2.38ϕ). Sediment samples are slightly positively to slightly negatively skewed (SK_1 = -1.70 to 1.21 ϕ) and mostly leptokurtic in nature (KG > 1.00).

Conclusion

Beach features along the coastal tracts of Kasaragod are identical with the parallel to shoreline alignment of the bedforms like swash marks, backwash marks, rhomboid marks and current crescents which are the natural phenomena of the coastal areas of north Kerala. Both physical and biogenic processes are important to differentiate the sea beach morphology. Beach morphology is the product of interaction of both physical and biogenic processes. Animal-sediment relationships and their interactions play important roles in controlling the beach morphology.

Swash backwash, wave action, spilling breakers with moderate wave heights are the dominant physical features for shaping the beach zone and controlling the sedimentation pattern of Harnai coast. Harnai beach faces the problems round the year due to several factors like fluctuating tidal amplitudes, huge rainfall, high salinity etc. The groundwater table goes rapidly up to the depth of 2 m during the dry season. The saline soils need to be prevented from recurring effects of salinity by providing a proper environment operating sluice gates and flooding the cultivated land with rainwater. Beach materials are moderately sorted, slightly negatively skewed and leptokurtic in nature. Strongly built embankments are essential which should be managed and monitored scientifically at least to a height more than that of a maximum tide to stop intrusion of saline water from sea[7]. Implantation of mangrove plantation may certainly reduce erosion caused by the tidal regime and wave action and thus help in stabilization of the inland parts of the Harnai coastal areas of Maharashtra and coastal zone of Kasaragod of north Kerala. Mangrove fringe may even change the ecological niches of the coastal ecosystem of the present study areas.

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