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Beach classifications in response to south-west monsoon waves: A case study

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In scientific literature, classification models of beaches according to numerical and theoretical parameters are abundant. This study shows a case study concerning how a sandy beach responds morphologically to monsoonal waves and how the beach is classified as per energy conditions. The dynamics of sediments besides the related morphological variations are expressed as functions of incident wave's climate, traits of sediments, and various environmental determiners. This study substantiates quantitative correlations between incident wave's energy flux, sand grain size, fall speed parameters, and wave's steepness and as sorts beach as per conditions of energy via multiple empirical functions. Additionally, a criterion corresponding with the direction of motion of sediment according to shifting waves' climate is also suggested and verified under field environment.

[**Keywords**: Directional criterion, Fall velocity, Surf scaling factor, Surf similarity index]

Introduction

At a microscopic level, hydrodynamics and transport of sediment, inherently related to it, in nearshore zones is nothing short of utter complexity, remarkably increasing in the said complexity in high-energy beaches. The foreshore, considered be the active part of the beach in terms of morphology, is defined by the perpetual effect of hydrodynamic forces. According to the conditions of said waves, their sediment traits, and profiled shape, the rate of transport of the cross-shore sand will generally denote either a profile exhibiting offshore or onshore properties domineering the whole beach profile. The motion occurring offshore erodes the beach profile's landward end whilst creating a bar near the break point. On the other hand, motion taking place onshore accrete the foreshores and incites the build-up of berms build-up, besides causing the gradual disappearance of the bar. The two profiles differently form beach shapes in reaction and are often observed whether in laboratory or field studies; they are dubbed the bar and berm profiles. Beach profiles depend on the vector of sediment-transport cross-shore direction, which is similar to the definitive criterion for delineating berm and bar and berm profiles. The berm profile indicates that sediments are in motion through the onshore while the bar profile denotes transport across the offshore. Bar and berm profile scan also be considered erosional and accretional, storm and normal, winter and summer, and dissipative and reflective profiles. Incident waves transform when approaching the shore and how they dissipate waves' corresponds to beach gradient; the latter being proportional to wave's steepness. Generally, sand will generally be offshore or onshore over the entire beach profile; this effects erosion or accretion. Continuum of beaches according to energy level is possibly denoted in empirical indices such as surf-scaling factor, dimensionless fall speed parameter, and surf similarity index. The study's purpose is to classify beaches and assess morphological reactions to monsoon waves via various available empirical functions in the literature. Kerala coast is exposed to high erosion during the southwest monsoon where cross-shore sediment transport exceeds that of long shore transport[1-8]. A case study was conducted at Valiathura beach, Trivandrum during the southwest monsoon.

The Valiathura beach (Fig. 1) almost aligns with northwest–southeast orientation. The shelf's isobaths are almost parallel and straight and parallel with an average width of 45 km. The innermost shelf (30/20 m contour) utterly sheer slope is almost 0.002[ref. 8]. Similar other parts of the western coast of India, this coast are affected by the southwest monsoon (June–September). Sea walls are constructed long side the majority of Valiathura coast stretches. From the data requirements for analysis and study, the hydrodynamic data was the first, acquired via field instruments. The wave and current meter values in the near shore site were gauged by deploying an Acoustic Doppler Current Profiler (ADCP) and a wave gauge. The dimensions of the beach profile were surveyed by dumpy level and staff and sampling of surficial sediment. The process occurred twice: the first time was at early-stage deployment while the second in later-stage equipment retrieval. Using the analysis, the sediments size characteristics were deduced. Secondary data were also used for the study.

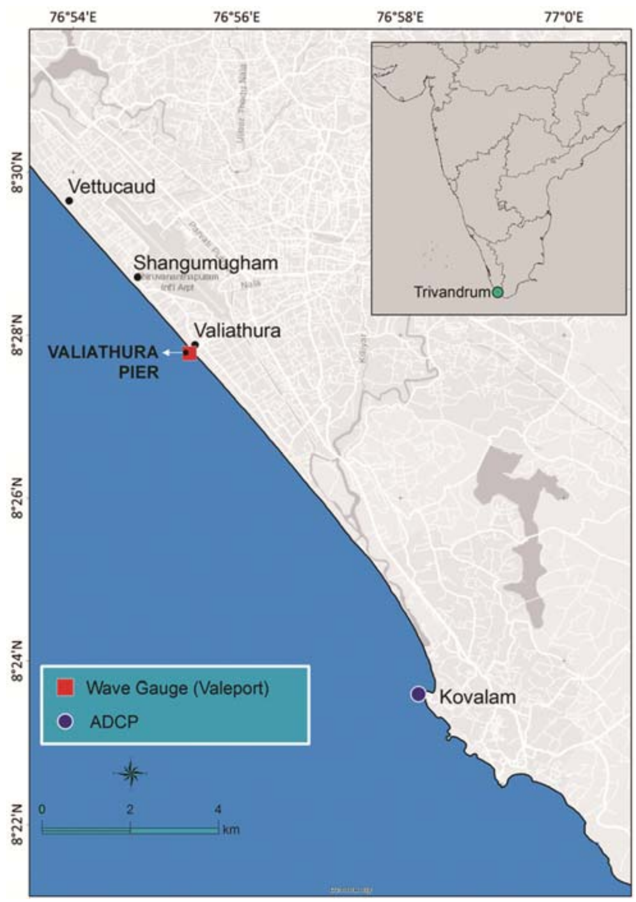

Fig. 1 — Study area, Valiathura coast near Trivandrum

Materials and Methods

Data

As stated previously, the main source for hydrodynamic data was the yield of sophisticated instruments while the secondary data sources were from the National Centre for Earth Science Studies (NCESS) data library. Wave and beach profile measurements besides sampling of surficial sediment sampling took place.

Wave characteristics

Using a Valeport wave gauge an ADCP off Valiathura, the values of waves and currents in the nearshore were gauged at an area of 8m depth (Fig. 1) from 5 to 26 June 2005[ref. 8] NCESS's secondary data were also collated for an in-depth study during the non-monsoon season. The data contributed to a CESS-implemented major wave project at particular locations in the south-western Indian coast. The values of the nearshore sites waves were calculated via a wave gauge (pressure gauge) deployed at a depth of 8 m off Valiathura from May 1980 to May 1985. The waves data recorded from May 1981 to May 1982 were used for analysis and beach energy study. The features of the studied waves show the nature of the typical monsoon waves. The wave's directions show the waves are predominantly from west–southwest and southwest directions. Although waves come from the south and northwest directions, they are relatively less (< 5 %). Waves in the range of 1 – 1.5 m are from the southwest direction. The waves within the measured period's statistics are given in Table 1. June 2005's wave's statistics show that H_s lies between 0.94 and 2.78 m, maintaining a mean and

Table 1 — Nearshore wave statistics off Valiathura

Parameters	Period	Min.	Max.	Mean	Standard Dev.
Wave height (H_s), m	Monsoon	0.94	2.78	1.8	0.44
Wave period, (T_z) s	(06.06.2005 –26.06.2005)	6.8	9.8	8.3	0.75
Wave direction, °N		185	298	234	24.8
Wave height (H_s), m	Monsoon	1.0	3.5	1.7	0.50
Wave period, (T_z) sec	(Mid-May – September, 1981)	6.1	11.8	8.3	1.44
Wave direction, °N		200	270	235	20.46
Wave height (H_s), m	Post-monsoon (October 1981– January 1982)	0.36	2.31	0.82	0.39
Wave period, (T_z) sec		7.27	13.56	10.3	1.28
Wave direction, °N		200	210	205	1.31
Wave height (H_s), m	Pre-monsoon (February – May 1982)	0.42	1.34	0.75	0.18
Wave period, (T_z) sec		7.72	12.8	10.2	1.07
Wave direction, °N		190	210	199.7	2.16

standard deviation of 1.8 m and 0.44, respectively. During June 2005's monsoon time interval, the majority of the waves spanned over a short time T_z ranging from 6.8 to 9.8 sec. The mean wave's direction is 234 °N, which is almost normal to the coast and it fuels the cross-shore transport of the sediments during the season. The H_s observed in 1981 from June to September ranged from 1.0 to 3.5 m, maintaining 1.7 m and 0.50 as mean and standard deviation, respectively. The mean significant wave heights taking place in 1981 and 2005's monsoons almost maintain the same magnitude. The T_z observed in June–September 1981 exhibits a narrow range, from 6.05 to 11.8 sec, maintaining 8.31 sec as the mean T_z. The lowest periods are notice din June's first week. In the course of the monsoon (June–September 1981), the wave direction is persisting in a westerly fashion resulting from the southwest monsoon's action, and high waves can be seen during this season.

In the post-monsoon time (October 1981 – January 1982), the H_s is in the range of 0.36 – 2.3 m (Table 1). H_s's maximum value was observed to be 2.31 m, with 0.82 m and 0.39 for mean and standard deviation values, respectively. The wave period surges and to be within 7.27 – 13.56 sec post-monsoon, with 10.31 sec as the mean value. The wave's direction is influenced by waves from 200 to 210 °N in the post-monsoon season (February – mid May 1982), where the intensity of waves begins to surge dramatically. In this time frame, values of H_s start at 0.42 and end at 1.34 m, with 0.75 m and 0.18 for the mean and standard deviation values, respectively. The utmost wave was recorded in May's second half. Values of H_s ranged from 1.0 to 1.4 m within the third week of May, but they rose to 1.2 – 1.8 m during the last week of May. In the pre-monsoon period, T_z more or less maintains the same characteristics like in the post-monsoon period (see Table 1) and wave directions fall in the range of 190 – 210 °N.

Beach profiles

Measurements of beach profiles took place via dumpy level and staff alongside surficial sediment sampling following the offshore deployment and immediately prior to the equipment retrieval. The elevations were gauged at 5 m intervals following a fixed benchmark. The locations of berms, shoreline, scarps, etc. were accounted for as well; positions of shoreline were determined from the profile survey. The foreshore slope was derived from beaches profiles. To verify erosional characteristics of the beach within the monsoon's initial phases, the beach profiles data were collected at different days during the initial phases of monsoon 2005 and at the final stages of the study period. The profiles exhibit extreme erosion at beach face followed by nearshore bar development during the inception of the monsoon (Fig. 2). The beach's accretion characteristics during the post-monsoon season have been verified from the study conducted by Thomas[9] during September 1981. The profiles show accretion characteristics and berm formation on the beach faces.

Sediment characteristics

Size of sediment is an important criterion in beach morphodynamics study; hence, the textural analysis was conducted on acquired sediment samples during the monsoon. The characteristics of size (Table S1) give away the medium-sized nature of and mean size of 0.25 mm in berm; in the beach face, the sediments are extracted from medium-sized (0.37 mm). The size is also characteristic of the high energy parameters of the beach in the southwest monsoon.

Bar-Berm criteria

Several of bar-berm criteria had been devised to anticipate the common reaction of a beach profile (a bar or berm profile) to incident waves[10-13]. The steepness of deep water waves H_o/L_o (the height of the wave: the length of the wave in deep water, a dimensionless parameter) is a part of all criteria. Bed material suspension relies on wave's energy flux. Incident wave's energy flux effects beach morphology variations, which makes up the under-wave velocity field and the mixture offluid[14]. The energy flux can be denoted in terms of height and steepness of deep water waves (Fig. S1). Different

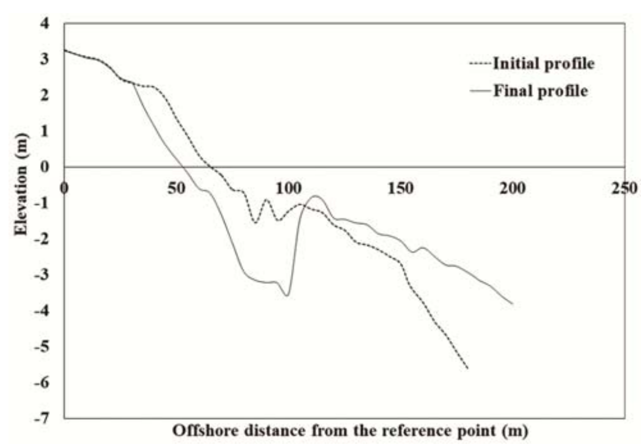

Fig. 2 — Measured beach profiles at Valiathura pier in the monsoon season, June 2005

parameters included average grain size, sediment characteristics, beach slope, and the fall velocity. Dean[10], Hattori & Kawamata[11], Sunarnura & Horikawa[12], and Kraus *et al.*[13] proposed some of the most important criteria. In all criteria, the wave period was included and performed equally. The criteria postulated by Larson & Kraus[15] performed adequately owing to the accounting for height of the wave: immense wave height was used in the criteria as a predicting parameter. Hattori & Kawamata[11] accounted for surf zone width as a criterion that affects the direction of sediment, whereas Sunarnura & Horikawa[12] considered the slope of the beaches a crucial parameter. Kraus *et al.*[13] used the dimensionless fall speed criterion to anticipate sediment's direction of movement, which under predicts erosion events.

An assessment of the berm or bar criteria was suggested by Larson & Kraus[15], the most commonly used one, takes place via the different locations comprehensive field data. It is utilized to delineate the erosion and accretion characteristics of the beach as a reaction to waves. The criteria consisted of the steepness of the deep-water waves H_o/L_o (wave height: wavelength in deepwater) and characteristics of sediment, e.g., the average size of grain size or velocity of sediment fall and slope of the beach. The criteria maintain a distinct physical meaning. H_o/L_o is a gauge of the asymmetry of the wave, affecting the flow field's direction in the water column. H_o/wT stands for the speed of dimensionless fall, an indicator of how long a sediment particle maintains suspension in the water.

As illustrated in Eq. 1, the utilized criteria to fix the direction of transport are as follows:

$$(H_o/L_o) < M\,(H_o/wT)^3, \text{ offshore transport (bar profile)} \quad \ldots (1)$$

$$> M\,(H_o/wT)^3, \text{ onshore transport (berm profile)}$$

Where, M = 0.0007 is a constant value, H_o represents field observations significant wave height in deepwater, w denotes the fall velocity of sediments (m/sec), and T represents the period elapsed of zero-crossing wave (sec). The wave steepness (H_o/L_o) points to the wave asymmetry and fluid motion's direction.

Results and Discussion

Parameters of deep water waves were evaluated from the acquired wave data for June 2005 and September 1981. H_o/wT and steepness of waves were gauged for all data sets. Figure 3 exhibits a plot depicting the steepness of waves in correlation to dimensionless fall speed for Valiathura within the season of monsoon. It is obvious that most of the time wave steepness does not surpass the fall speed criterion. Simply put, the profile is a bar profile distinguished by transporting sediments offshore, which is evident in the field signature such as high erosion, bar formations, etc. Figure 4 illustrates a plot depicting the steepness of waves in correlation to dimensionless fall speed for Valiathura in the post-monsoon season. It is evident that the time wave steepness mostly does not exceed the fall speed criterion and it indicates onshore transport of sediments, which leads to accretion. Namely, the profile is a berm profile, which is evident in the signatures such as formations of the berm, high accretion[9], etc. Therefore, this parameter can be

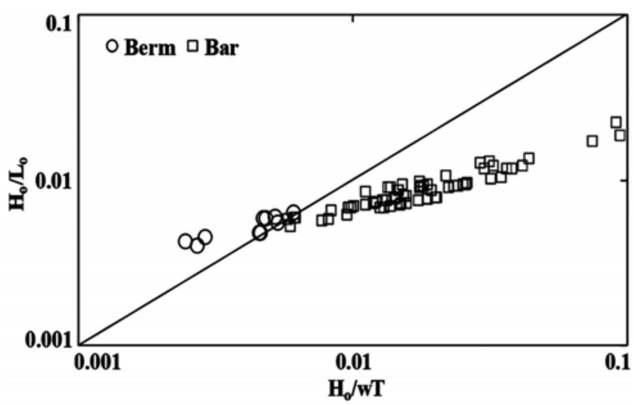

Fig. 3 — Categorization into bar and berm profiles for the study period: monsoon 2005 based on wave steepness and dimensionless fall speed parameter at Valiathura

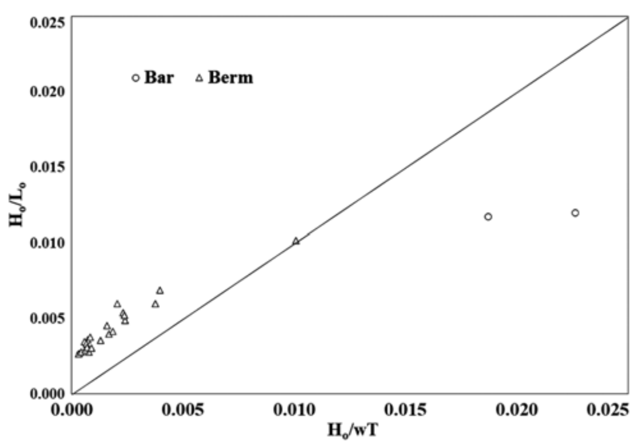

Fig. 4 — Categorization into bar and berm profiles for the study period: post-monsoon 1981-82 based on wave steepness and dimensionless fall velocity at Valiathura

appropriated to this coast and others alike, where similar environmental conditions occur.

Directional criterion

The direction constant is another suggested criterion to substantiate the erosional/ accretional beach's character of the beach in reaction to waves is suggested according to the current study, which is the ratio between the steepness of wave steepness and the parameter of fall speed. If the value of the constant of direction is less than one, the seaward motion of the sediment occurs, causing erosion. While if the value of direction constant is greater than one, the onshore movement of sediments occurs, denoting accretion. Figure 5 illustrates the direction constant exhibiting the count of events compared to each value at the study areas. It is clear that the direction constant's values are less than one in the majority of the cases, leaving few cases exceeding the value of one; this indicates the eroding characteristics of the beach, evident from the field measurements. Therefore, the postulated directional criterion could be effectively utilized to determine the beach profile response to incident waves.

Validation of directional criterion

The direction constant was tested under field conditions during the monsoon period with severe erosion and the same was validated with accretion characteristics of the beach profile in response to the post-monsoon waves. The accretional nature of the beach prevails throughout the study period and it is obvious from the field conditions taking place in the post-monsoon season. The directional criterion validated in the post-monsoon season is presented in Figure 6. From the figure, it is clear that most of the values of the direction's constant surpass one, implying the accretional nature of the beach, which is common during the post-monsoon season along the Valiathura coast (Fig. 7).

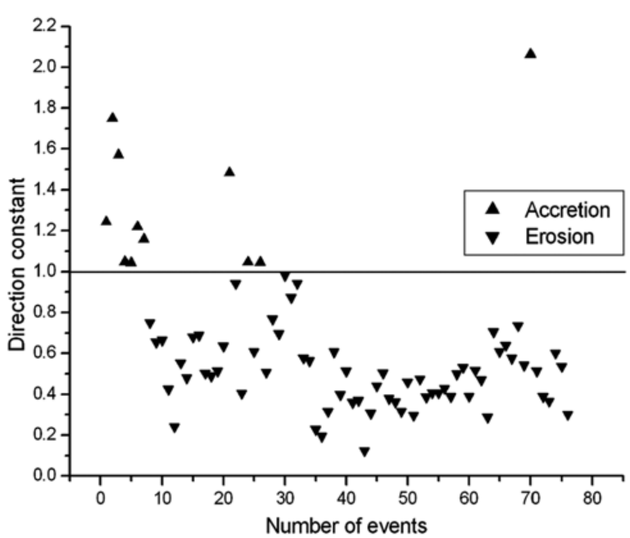

Fig. 5 — Directional criterion for erosion/accretion for the study period at Valiathura during monsoon 2005

Beach volume calculations

The beach volume changes between the initial and final profiles during the monsoon season were deduced from the data of the beach profile and presented in Table 2. Generally the exponential tendency for erosion was witnessed during the monsoon (-155.62 m^3/m) with a maximum horizontal

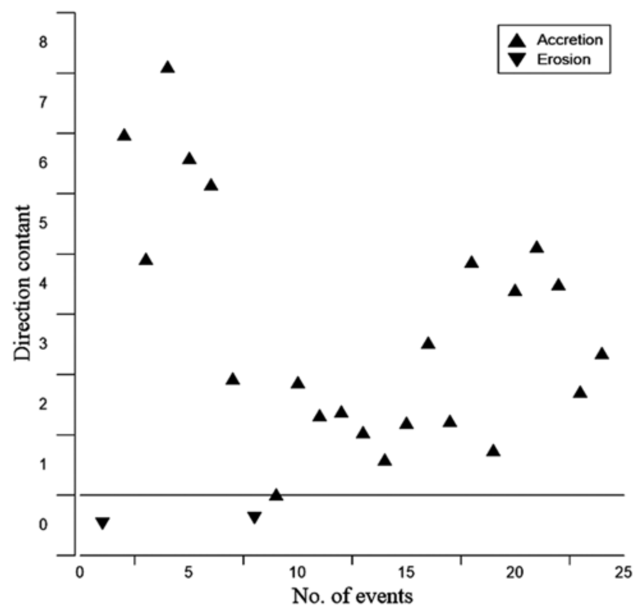

Fig. 6 — Directional criterion for erosion/accretion for the study period at Valiathura during post-monsoon 1981-82

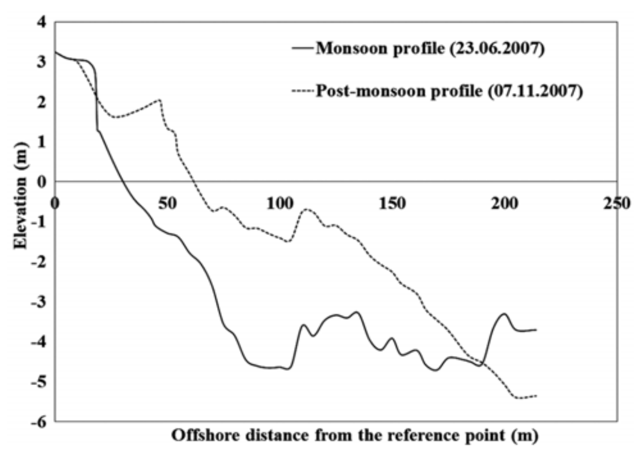

Fig. 7 — Measured beach profiles during the monsoon and post-monsoon season (2007) at the Valiathura pier

retreat of 12 m during the study period. During the post-monsoon season, the beach shows the maximum accretions (213.06 m^3/m), with a maximum horizontal advance of 30 m (Fig. 7); this validates the results of the directional criterion. The beach volume change calculation validates the directional criterion proposed in both the seasons of monsoon and post-monsoon. The beach volume was calculated at another year to validate the criterion proposed.

Beach classification

Several terms classify the wave-dominant such as sand size and wave height and period. Beaches like the one in the current study are active in terms of transporting sediment cross-shore and along shore, which is caused by the significant wave action[16]. Beach morphodynamics various stages are defined by considering incident wave's intensity and duration[17]. The surf zone-beach morphodynamics concept was devised to evaluate the energy status of the coast. Of three variants of coasts, the Valiathura coast was deemed an intermediate-type beach, which is a wave-breaking type most of the time.

The surf-scaling factor (ε)[9] and surf similarity index (ζ)[18] are important parameters used for the classification of a beach based on its energy characteristics. The surf-scaling factor quantifies beach reflectivity and is given by:

$$\varepsilon = 2\pi^2 H^2 / gT^2 \tan^2 \beta \qquad \text{... (2)}$$

Where, T represents the wave period, g is gravity-caused acceleration, and tan β is a beach or inshore slope. The surf-scaling factor can be used to identify reflective and dissipative beaches. The presence of an offshore bar in the study area in the monsoon season causes reflection and dissipation of wave energy. Hence, the beach stability study using the surf-scaling factor (ε) is important in the study area, where the same environmental characteristics prevail. For the beach-based classification according to wave energy, the long shore bar present in the offshore is taken into account for the current study. The values of ε were computed for the study period during the monsoon season and are presented in Figure 8. During the study period, most of the values of ε fall in the range of 2.5 – 20, suggesting that the beach is partially reflective. If the values are less than 2.5, the energy of the incident will be reflected to the sea, and if it is greater than 33, the beach will be highly dissipative. Hence, the study underlines the intermediate characteristics of the Valiathura coast during the monsoon season.

Table 2 — Beach volume changes at Valiathura during monsoon and post-monsoon season of different years

Sl. No.	Stations	Period	Beach volume change (m^3/m)	Remarks
1.	Pier	10/06/05 - 27/06/05	-155.62	Erosion
2.	Pier	23/06/07 - 07/11/07	213.06	Accretion

The slope-dependent surf similarity index (ζ) is used as a good prediction indicator for an intermediate beach and it can be used to identify the different types of wave breaking. ζ can be defined by the Hunt formula[19]:

$$\zeta = \frac{\tan\beta}{\sqrt{Ho / Lo}} \qquad \text{... (3)}$$

Where, tan β is a beach or inshore slope and H_o/L_o is wave steepness.

A study of ζ was carried out during the monsoon period and most of the values of ζ fall in the range of 0.65 – 1.07, suggesting that the beach is partially reflective.

Using ζ, most of the values indicate the intermediate-type nature of the Trivandrum coast (Table S2). Another important parameter related to beach state is dimensionless fall velocity (Ω)[20] which is given by:

$$\Omega = \frac{Hb}{Ws\,T} \qquad \text{... (4)}$$

Where, H_b is the height of a breaker wave (m), W_s represents the velocity of sediment fall (m/sec), and T stands for wave period (sec).

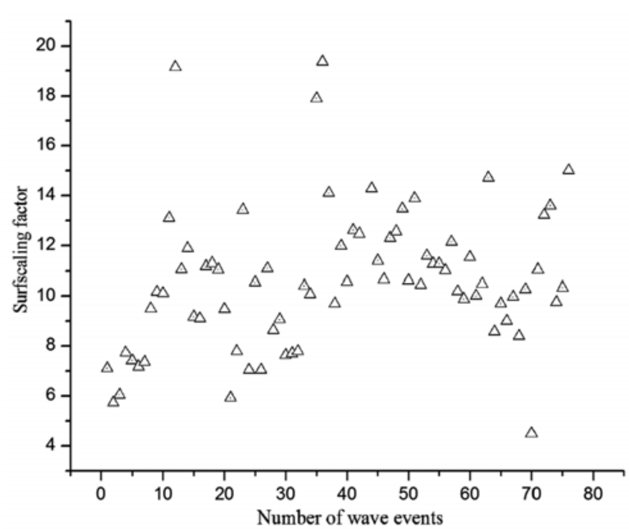

Fig. 8 — Distribution of surf scaling factor over study period

If Ω is between 1and 6, the nature of the beach will be intermediate with bar characteristics. The study using dimensionless fall velocity in the Trivandrum coast shows that most of the values of Ω are within the range of 2.32 – 4.56 (Table S2). Hence, parameters such as the surf-scaling factor (ε), surf similarity index (ζ), and dimensionless fall velocity (Ω) classify the coast of Trivandrum as an intermediate-energy beach.

Conclusion

The beach morphological variations study varied during the initial stages of the southwest monsoon at a micro-tidal beach. Utilizing hydrodynamics and data from the profile of the beach yielded insight into beach morphodynamics corresponding to intensified monsoon waves. Quantitative correlations were attested between the energy flux of incidents, speed of dimensionless, the size of the median grain, and the deep water wave steepness. The criterion of bar/berm was optimally evaluated in the field and it is eligible as a modelling tool. The novel directional criterion can be employed to determine the reaction of a certain beach to a particular wave climate. Although Valiathura, Trivandrum beach is renowned as a high-energy beach, this study, according to empirical functions such as the surf-scaling factor, dimensionless fall velocity and surf similarity index classifies it as an intermediate-energy beach.

Supplementary Data

Supplementary data associated with this article is available in the electronic form at http://nopr.niscair.res.in/jinfo/ijms/IJMS_50(01)14-20_SupplData.pdf

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Conflict of Interest

The author declare that there is no conflict of interest.

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