Post-monsoon equilibrium beach profiles and longshore sediment transport rates at Candolim, Miramar and Keri beaches of Goa, India

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Equilibrium profile is one of the concepts in coastal geomorphology which is a result of the balance of destructive versus constructive forces. Two equilibrium beach profile models, viz. Bruun/Dean's two-thirds power model and modified Bodge exponential model were used to analyse the measured post-monsoon (winter) beach profiles from three beaches in Goa having varying coastal morphology settings. The major factors that affect the equilibrium beach profile, viz. the median grain size (D_{50}) and the profile shape factor m, which are inversely proportional to each other, have been analysed for their application to the study site. Also, the variation of these two parameters with beach slope and grain size is studied. Longshore sediment transport rates (LSTRs) are estimated at these three beaches from the littoral environmental observations. LSTRs show that during winter months, the net transport is of the order of 10.83×10^6 m^3/year (southerly transport) and 9.02×10^6 m^3/year (southerly transport) respectively, at Candolim and Keri beaches, whereas it is about 0.62×10^6 m^3/year (northerly transport) at Miramar. This article discusses the methods used and results of measurements of beach morphology, LSTRs, analysis of equilibrium profiles and influence of various parameters related to equilibrium profiles.

Keywords: Equilibrium beach profile, littoral environment, longshore sediment transport rate, sediment scale parameter, slope parameter.

BEACH is a landform of unconsolidated material extending landward up to a permanent vegetation line or where a change in physiographic form is seen from low waterline, including foreshore and backshore[1]. Beaches are greatly influenced by the action of waves, wind, tide, etc. and thus their morphology is highly dynamic. Beach morphology changes in terms of erosion/accretion pattern of the region can be estimated through studies on the variation of longshore sediment transport and beach profiles over different timescales. Long-term beach profiling is one of the first steps to understanding complex beach processes. This information, combined with ocean current and wave data, enables us to understand why and how fast the beaches erode. Erosion is often caused by a rise in sea level resulting in rapid shoreline geometry changes and increase of drift quantity; removal of beach material by wind drift and sudden outburst of flood waters also causes erosion. Sometimes erosion is enhanced by anthropogenic activities[2]. Saville[3] distinguishes beach profiles into summer and storm profiles, while Shepard[4] divides the Pacific coast profiles into winter or concave-up profiles and summer or concave-down profiles. A large number of factors influence the shape of beach profiles in nature. These are categorized into active and passive factors[5]. The active factors are waves, tides, winds, rainfall, temperature and duration of influence of these active factors. The passive factors are beach material, initial profile shape, geology and/or other constraints.

A beach profile can adequately be represented by an equilibrium profile. For any given sediment size there will be a unique beach profile in equilibrium with the given wave and tidal characteristics of the beach, i.e. the constructive and destructive forces on the sand grains are in balance. If any of the wave and tide conditions are altered a new equilibrium profile will exist, and the previous profile will evolve towards the new equilibrium shape. Study of equilibrium profiles helps to understand the variation of beaches, based on which shore nourishment projects can be carried out. Karunarathna *et al.*[6] compared beach profiles along the Australian coast with Dean's[7] equilibrium profile and Vellinga's[8] erosion profile, and found that Dean's profile satisfactorily represents the profiles of the respective beaches. If an initial profile is much steeper than the equilibrium profile, equilibrium can be achieved by providing the extra material to build up the offshore depths. This could come naturally by longshore or cross-shore sediment transport, thus providing a milder beach profile[9]. Equilibrium profiles have

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several well-known features: (i) they tend to be concave upward, (ii) smaller and larger sand grain sizes are associated with milder and steeper slopes respectively, (iii) the beach face is approximately planar and (iv) steep waves result in milder slopes and a tendency for bar formation[7]. Understanding the equilibrium beach profile is important for interpreting natural beach processes and engineering applications. When applying equilibrium beach profile concepts to problems requiring an estimate of profile retreat or advance, a related concept is the principle of conservation of sand across the profile, i.e. no net gain or loss of sediments[1]. There has been no systematic field verification of the validity of the equilibrium profile equation; nevertheless, it has been accepted as valid and useful by many coastal researchers[10]. A barred beach profile described based on its inner surf zone, landward slope of the bar and nearshore region and two-thirds power law can be used to explain the inner surf zone and nearshore region[11]. Wang and Kraus[12] developed a nearshore bar which is analysed for six SUPERTANK cases, and the power function by Dean[13] described the equilibrium beach profile reasonably well for irregular waves, except at break-point bar.

A power function suggested by Bruun[14], $h = Ax^m$, is widely used for description of equilibrium profiles, but Dean[13] concluded that profile shape factor, m, may be considered constant and equals 2/3 (or 0.66) if the energy dissipation per unit water volume is uniform across the surf zone. Few other models explaining equilibrium beach at various conditions are Larson's model[15], exponential model by Bodge[16], those by Komar and McDougal[17], Edelman[18], and Inman *et al.*[19]. Some of these models attempted to address the profile changes by adapting the Bruun/Dean model to account for the presence of bars and troughs. They segregated the beach into cross-sectional segments between successive features and noted that each of these segments followed the general Bruun/Dean profile form. Bodge[16] employed the exponential beach profile and observed that it provides better fit with measured data than the Bruun/Dean model. Later, Komar and McDougal[17] modified the Bodge model, including beach face slope and arrived at a similar conclusion. The Bruun/Dean model considers infinite slope at the shoreline, but in case of exponential model slope decreases exponentially with offshore distance and the advantage of this model is that slope at the shoreline is non-zero.

Sediment scale parameter, A, is empirically related to grain size of the beach sediment[20] and corresponding settling velocity[21]. Empirical correlation between scale parameter and the sediment size (D_{50}) or fall velocity (w) allows computation of equilibrium beach profile[17]. The shape of each profile has a definite combination of A and m values. Coefficients A and m show a distinct inverse relationship in temperate climate and m value is inversely proportional to D_{50} (ref. 22). Profile shape coefficient (m) of a shore-rise profile depends on (a) the magnitude of wave, (b) volume of shore sediments and (c) the ability of sediments to resist transport[23]. Dubois[23] showed that for the nearshore and shore-rise zones, m varies from profile to profile within shore region and among shore regions, and A is inversely related to m. Using 'blind-folded test' while comparing measured profiles with predicted equilibrium profiles, there may be differences in the shape due to one or more reasons which does not indicate that the profile is in disequilibrium, or limitation of the model. According to local equilibrium theory, the corresponding depths of measured and equilibrium profile need not be at the same offshore distance, but should have the same shape. Thus a profile with m not equal to two-thirds may not reflect a disequilibrium state[24].

Longshore sediment transport rate (LSTR) is generally calculated using parameters like wave height, wave period, wave angle, beach face slope, etc. Chandramohan and Nayak[25] developed an empirical sediment transport model based on longshore energy flux equation using ship-reported wave data and identified that annual net transport along the east coast of India is towards north and along the west coast of India towards south. Kumar *et al.*[26], based on measured wave and current data, estimated that net longshore sediment transport rate along the east coast of India is towards north, whereas it is mostly towards south along the west coast. Using multi-temporal satellite images, Kunte *et al.*[27] also identified that dominant net transport is towards NE along the east coast of India.

This article discusses studies carried out (i) to estimate the erosion/accretion pattern within a winter season (December–February), (ii) to test the global acceptance of the equilibrium profile coefficients A and m (= 0.66) using two different methods available in the literature, (iii) to understand the influence of coefficients A and m in relation to the grain-size variations and (iv) to study the related longshore sediment transport using observations of littoral environmental parameters.

Study area

Three beaches in Goa on the west coast of India are considered here, viz. Candolim, Miramar and Keri, to understand the spatial and temporal variability and to analyse these beaches during winter season from December 2011 to February 2012 (Figure 1). Goa encompasses an area of 3702 km^2 and lies between lat. 14°53′54″–15°40′00″N and long. 73°40′33″–74°20′13″E. Candolim beach (15°30′38″N; 73°45′53″E) is located 14 km north of Panaji, the capital of Goa. An ore-carrier *MV River Princess* ran aground about 500 m off Candolim beach on 6 June 2000 and since then has been affecting the beach[28]. Miramar (15°28′57″N; 73°48′27″E), situated in Panaji, is a dissipative beach stretched within two promontories

Cabo-da-Gama in the south and Fort Aguada in the north, with River Mandovi having its confluence with the Arabian Sea. Earlier beach profile measurements from Miramar beach, Goa during November–December 1999 concluded that the beach is accreting[29]. Keri beach (15°43′05″N; 73°41′25″E) also known as Querim beach, is a reflective beach located on the northern boundary of Goa. During the last 5–6 years heavy beach and dune erosion was seen along this beach. About 1000 casurina trees were planted on the sand dunes for protection, of which about 800 have been washed away due to sea erosion[30].

Methodology

Longshore sediment transport

Longshore sediment transport (LST), a result from the interaction of wind, waves, currents, tides, sediments and other phenomena in the littoral zone, is estimated using the littoral environmental observation (LEO) parameters, viz. breaker height, wave period, wave angle, wind speed, wind direction, longshore current, etc. Wave breaker angle is estimated in LEO program based on the method by Chandramohan *et al.*[31] considering two fixed-point observations of the breaker. LEO plate is used to measure current speed. Longshore sediment transport rate was calculated using Walton's equation[32]

$$Q = \frac{1290 \rho g H_b W v C_f}{0.78(5\pi/2)(v/v_0)_{LH}}, \tag{1}$$

where Q is the annual alongshore sediment transport (m^3/year), ρ the density of water (1024 kg/m^3), g the acceleration due to gravity (9.81 m/s^2), $C_f = 0.01$ the friction coefficient, H_b the breaker height (m), W the surf zone width (m) and $(v/v_0)_{LH}$ is the theoretical dimensionless longshore current velocity[33] given by eq. (2)

$$(v/v_0)_{LH} = 0.2\left(\frac{X}{W}\right) - 0.714\left(\frac{X}{W}\right)\ln\left(\frac{X}{W}\right), \tag{2}$$

where X is the distance of longshore current measurement from the shoreline.

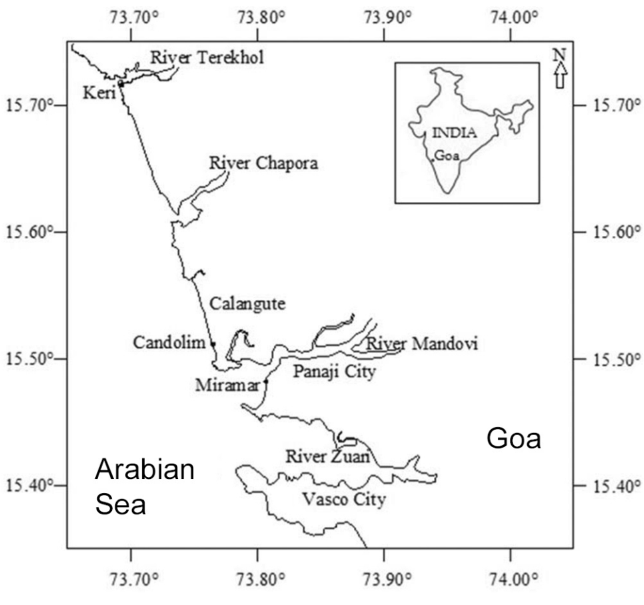

Figure 1. Location of the study area.

Equilibrium profiles

The beach profiles in the study area were measured using Leica Total Position System (TPS), wherein the TPS gives point id, easting, northing, elevation at that point and corresponding time. Beach profiles are drawn using these data. The concept of equilibrium beach/shoreface profile has become the guiding principle behind the development of most shoreline change models[10]. The generic power law suggested by Bruun[14] is

$$h(y) = Ax^m, \tag{3}$$

where $h(y)$ is the variation of depth with offshore direction y, A the sediment scale factor, x the offshore distance and m the profile shape factor. Dean[13] concluded that m can be considered as a constant, which equals 2/3 (= 0.66). The value of A is quantified based on either sediment grain size diameter (taking D_{50} value) or sediment settling velocity (w_s) as given in eqs (4) and (5).

$$A_1 = 0.21 D^{0.48} \text{ (ref. 20)}, \tag{4}$$

$$A_2 = 0.067 W_s^{0.44} \text{ (ref. 21)}, \tag{5}$$

where D is the median sediment size and w_s is given by

$$w_s = \frac{(\rho_s - \rho) g d^2}{18\mu}, \tag{6}$$

where ρ_s is the density of the sediment, ρ the density of sea water, g the acceleration due to gravity, d the sediment size and μ the dynamic viscosity of water.

Another equilibrium beach profile model considered is the exponential model described by Bodge[16] and modified by Komar and McDougal[17]

$$h = h_c(1 - e^{-kx}), \tag{7}$$

$$k = \frac{s_0}{h_c}, \tag{8}$$

where s_0 is the beach face slope, x the seaward distance and k gives the concavity of the profile and hence is called concavity coefficient, which can be determined by a best fit comparison with the total measured profile and can be approximated from a single offshore closure depth (h_c) using eq. (8).

Equilibrium beach profiles are drawn for comparing whether A_1 or A_2 gives better fit and also to clarify whether Bodge's exponential model or Bruun/Dean two-thirds power law is a better model for this region. Three plots are drawn for each of the beach profiles for comparison. In each plot the measured profile and corresponding equilibrium profiles are compared and the quality of fit is determined using eq. (9).

$$\varepsilon = \frac{\sum (a_i - b_i)^2}{\sum a_i^2} \times 100, \qquad (9)$$

where a_i and b_i are any two arrays of variables. If ε is zero, the corresponding values are in good fit, and increasing values of ε show poor fit.

The analysis of the equilibrium beach profiles is carried out in three ways. First, the effect of the sediment scale factor A is studied in Bruun/Dean model. Secondly, a comparison between Bruun/Dean model and exponential model is carried out with the parameters which provide a better fit individually. Thirdly, use of Bruun/Dean model in compound profiles is studied by considering various segments of the foreshore beach that have distinct slope variations. A brief description of these three types of analysis is described below.

Effect of parameter A: Using Bruun/Dean two-thirds power law equilibrium measured beach profiles and equilibrium profiles using three equations (eqs (10)–(12)) are plotted to identify which profile fits better. In this plot (referred to as plot 1), equilibrium profiles derived using A_1 (from eq. (4)) and A_2 (from eq. (5)) are compared with A which is any arbitrary value which provides a better fit with the measured profile.

$$h_1(y) = Ax^{0.66}, \qquad (10)$$

$$h_2(y) = A_1x^{0.66}, \qquad (11)$$

$$h_3(y) = A_2x^{0.66}, \qquad (12)$$

Comparison of Bruun/Dean and Bodge exponential models: The equilibrium profiles drawn using the Bruun/Dean model with A_2 (eq. (12)) and exponential model (eq. (7)) are compared with measured profile to find out which model is better. These plots (referred to as plot 2) are drawn from foreshore towards the sea.

Compound profiles: The compound profile introduced by Inman *et al.*[19] using Bruun/Dean model to account for the presence of bars and troughs is as shown in eq. (13).

$$h(y)_i = A_i x_i^{m_i}, \ldots, h(y)_n = A_n x_n^{m_n}, \qquad (13)$$

where i = 1 to n and A is calculated using eq. (5).

In this study compound profiles (referred to as plot 3) are drawn from foreshore towards the sea using values of D_{50} at high water level (HWL) and low water level (LWL). The profile thus calculated is also compared with the measured profile.

In addition to the above three methods of profile analysis, to find the inter-relationships between A, m, D_{50} and beach face slope, histograms and scatter plots are drawn with these parameters along the x-axis and relative frequency (ratio of number of observations of a given parameter and total number of observations) along the y-axis following the method in Are and Reimnitz[22].

Results

Beach profiles

The results presented are based on winter beach profiles collected from Candolim, Miramar and Keri beaches of Goa during December 2011 to February 2012 (Table 1). Among the profiles collected during the survey, two profiles each are taken from each beach for further analysis.

Candolim: Datasets used for comparing the profiles at Candolim beach and the difference in beach volume between stations 1 and 2 with respect to their previous measured profiles are calculated (Figure 2 *a* and *b*). At

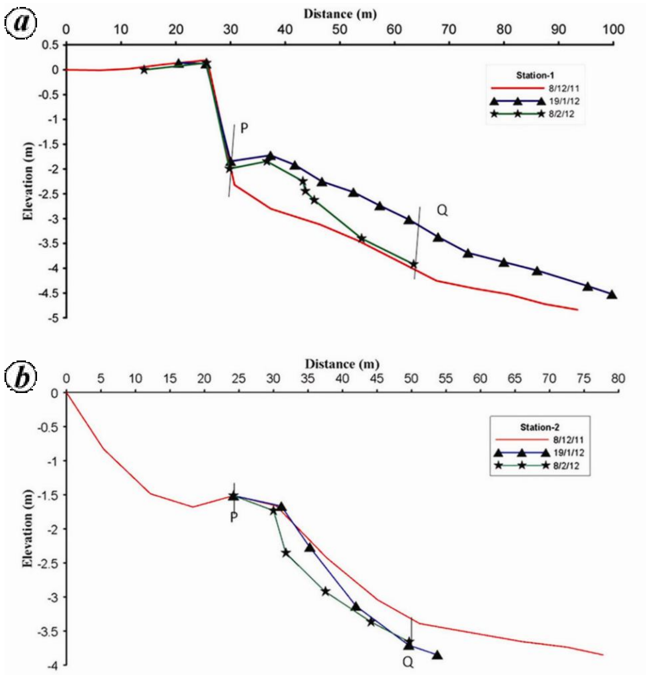

Figure 2. Beach profiles at Candolim (***a***) station-1 and (***b***) station-2.

Table 1. Longshore sediment transport rates (LSTR) (m^3/year) during the study period

Location	Date	*H* (m)	*T* (s)	*W* (m)	*V* (m/s)	LSTR (m^3/year)	Net LSTR (m^3/year)	Gross LSTR (m^3/year)
Candolim	8/12/2011	0.89	16	90	0.11	1,005,762	–10,831,154	12,842,678
	19/1/2012	0.65	10	80	–0.38	–2,456,333		
	8/2/2012	1.40	6	70	–0.70	–9,380,583		
Miramar	9/12/2011	0.74	8.50	20	0.09	404,659	620,884	620,884
	21/2/2012	0.30	7.50	30	0.10	216,224		
Keri	20/2/2012	0.56	25	90	0.10	575,308	–9,020,716	15,225,263
	17/1/2012	0.60	20	150	0.36	2,526,965		
	7/2/2012	1.16	8.57	30	–1.45	–12,122,990		

station-1 in Candolim, rapid variations were observed at the foreshore. From December to January large volume of sand was deposited and a berm of length 7.2 m was formed. But in February the deposited sand eroded and berm length decreased to 6 m, and the foreshore steepened further. During December to February, the backshore width decreased from 27.54 to 13.43 m. Backshore slope gently increased from the crest of the berm in January. The shipwreck acted as an offshore breakwater and a salient was formed. But as the shipwreck was being removed during the profile measurements, erosion was observed at this location. When comparing profiles of December and January it was found that at this station 30.85 m^3 of sediments was deposited, but between January and February 15.58 m^3 of sediments was eroded from this station (Figure 2 *a*).

Measurement of beach profiles at station-2 was carried out on the left (southern) side of the salient. During January and February backshore profile between the hinterland and foreshore was obstructed as this region was inaccessible due to erection of beach shacks. Therefore, the profile measurements for these periods were carried out from foreshore onwards. Comparing these profiles it can be seen that the beach is eroding each month. It was found that the average foreshore slope increased from 0.06 to 0.13. Comparing the profiles between December and February, the foreshore eroded and steepened further. After the berm line gentle foreshore slope was observed, but after that the profile slope decreased gradually. At this station, between points *P* and *Q*, 9.408 m^3 of sand eroded from the beach between December and February (Figure 2 *b*).

Miramar: This is a flat beach with fine sand and mild wave condition. Due to a large surfzone width, this beach is dissipative. Comparison of beach profiles measured at station-1 showed erosion between December and January, with the foreshore slope having a maximum steepness in January. However, during February accumulation of sediments was observed. The volume of sediment transported was calculated between points *P* and *Q* (Figure 3 *a*). About 13 m^3 of sediments was eroded at this station between December and January. In February, 11.53 m^3 of sand accumulated on the beach compared to January. Between December and February, an overall erosion of 1.38 m^3 was observed between points *P* and *Q*. At station-2, profiles were compared between 70 m from the temporary benchmark and the waterline, as no significant changes in that region were observed. A comparison of the foreshore profiles showed erosion at this station. Between points *P* and *Q*, even though small volume of sand deposited from December to January (0.25 m^3) a large volume of sediments (6.18 m^3) was found to be eroded from this station during December to February (Figure 3 *b*).

Keri: Profiles were measured at the northern end of Keri beach at station-1. On this steep beach, wave action was comparatively severe and large amount of sand is transported by the waves from the crest. From December to February the backshore width decreased from 61 to 38 m. About 9.14 m^3 sediment was transported from the crest of the berm during December to February (Figure 4).

Longshore sediment transport

At Candolim beach, plunging breakers with breaker height of about 1.40 m were observed during February, albeit the wind being calm. Longshore current was found to be southerly during January and February with a maximum longshore velocity of 0.7 m/s. The gross LSTR was 12.84×10^6 m^3/year and the net LSTR was -10.83×10^6 m^3/year in the southern direction.

At Keri southerly longshore sediment transport was observed during February, but in December and January it was towards north. Average breaker height of 1.16 m was observed at Keri during the measurement period. Net sediment transport was estimated to be -9.02×10^6 m^3/year towards south. And the annual gross LSTR at Keri was about 15.22×10^6 m^3/year.

The surging breakers at Miramar were about 0.74 m high on 9 December 2011. The maximum longshore velocity of 0.1 m/s was observed on 20 February 2012, with a northerly direction. The gross and net sediment transport rate from station-1 at Miramar was 0.62 × 10^6 m^3/year.

Net sediment transport at Miramar is much lower than Candolim and Keri. Maximum net sediment transport was found at Candolim because the wave approaches at greater angle, and larger breaker height with smaller wave period.

Equilibrium beach profile

Equilibrium beach profiles are drawn using the two-thirds power model of Bruun/Dean and the exponential model[16]. Analysing the three plots of the profiles (Figure 5 *a*–*c*), it is found that sediment scale parameter, profile shape factor and beach face slope, are indeed the major factors establishing the equilibrium shape of the profile. Using the profiles derived from compound profile method[19], $h(y)$, with different A and m values for each sector, fits well with measured profile compared to the those derived from a single value of A either derived from D_{50} or w_s, or a single value of m, either fixed (two-thirds) or arbitrary. Sediment scale parameter A, selected according to the slope of the profile to obtain a better fit profile, is larger than the calculated A_1 or A_2 (Figure 6). However, between profiles obtained with A_2 resulted in much better fit than those derived using A_1. Comparing Bruun/Dean model and exponential model with measured profiles from Candolim, Miramar and Keri beaches of Goa, shows that out of the nine profiles the exponential model fits better in six profiles (Figure 5 *b*). The quality of fit obtained between

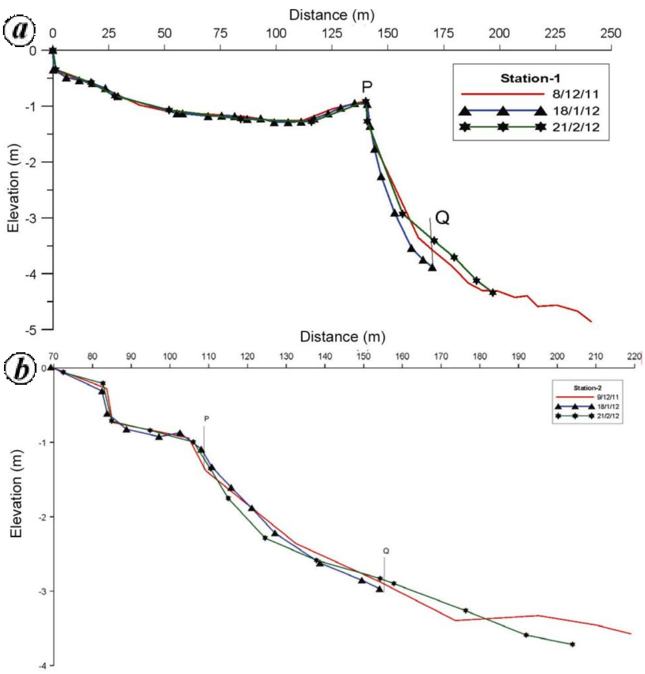

Figure 3. Beach profile at Miramar (*a*) station-1 and (*b*) station-2.

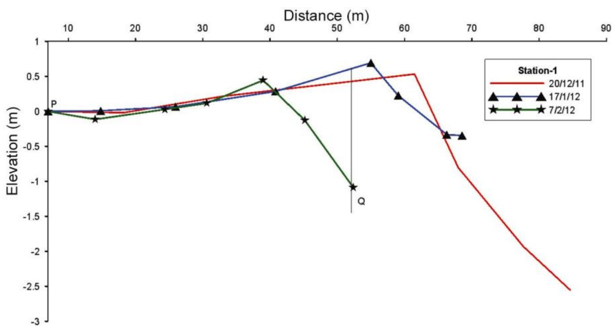

Figure 4. Beach profile at Keri station-1.

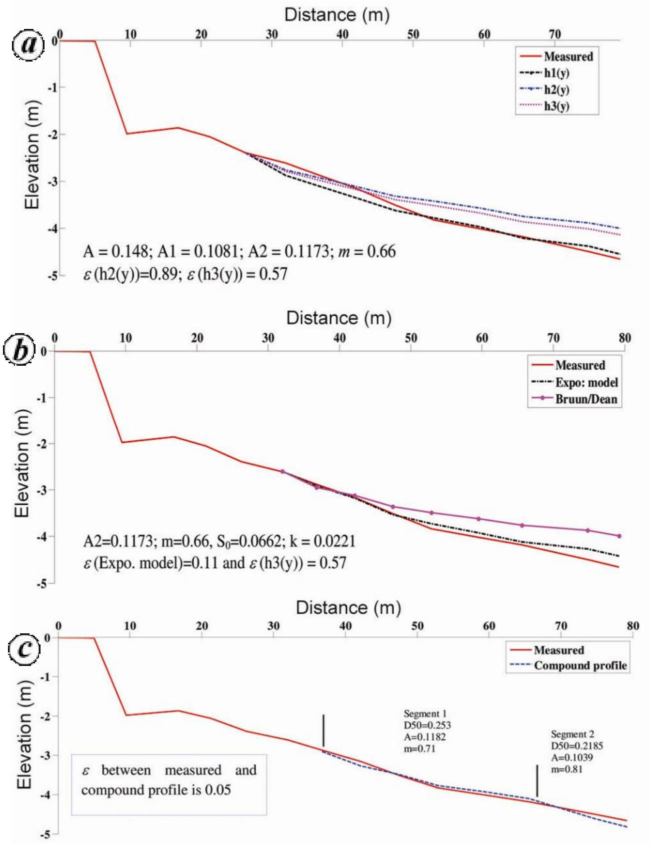

Figure 5. Plot-1 (*a*), plot-2 (*b*) and plot-3 (*c*) of equilibrium beach profiles from Candolim (19 January 2012).

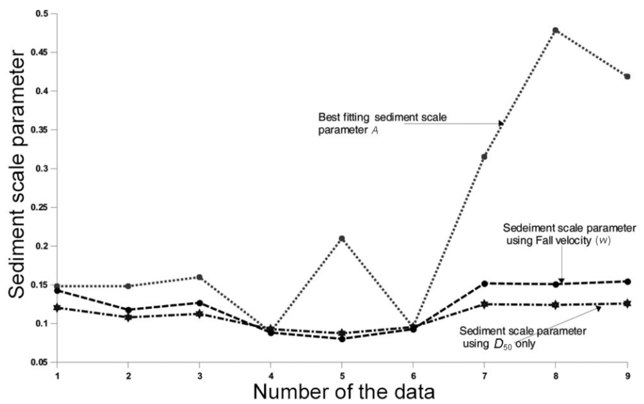

Figure 6. Dependence of sediment scale parameter A on sediment grain size and fall velocity.

Table 2. Comparison of sediment scale parameter (A_2) and profile shape factor (m_2)

Month		Candolim D_{50}	Candolim A_2	Candolim m_2	Candolim Slope	Miramar D_{50}	Miramar A_2	Miramar m_2	Miramar Slope	Keri D_{50}	Keri A_2	Keri m_2	Keri Slope
December	Average	0.3126	0.1424	0.69		0.1803	0.0877	0.66		0.3352	0.1514	0.93	
	HWL	0.406	0.1425	0.7	0.035	0.1775	0.0801	0.68	0.025	0.4062	0.1792	1.05	0.096
	LWL	0.313	0.1792	0.61		0.176	0.0928	0.67		0.2345	0.1105	0.82	
January	Average	0.2508	0.1173	0.71		0.1627	0.0865	1		0.3323	0.1502	1.13	
	HWL	0.2530	0.1039	0.75	0.066	0.1675	0.0822	1.1	0.066	0.3650	0.1641	1.17	0.14
	LWL	0.2185	0.1182	0.74		0.1332	0.0887	1.05		0.3275	0.1483	1.1	
February	Average	0.2726	0.1262	0.74		0.1923	0.0859	0.66		0.3429	0.1544	1.18	
	HWL	0.209	0.0977	0.62	0.077	0.1881	0.0672	0.77	0.028	0.3437	0.1547	1.44	0.26
	LWL	0.203	0.0999	0.86		0.1825	0.091	0.66		0.3125	0.1423	1.17	

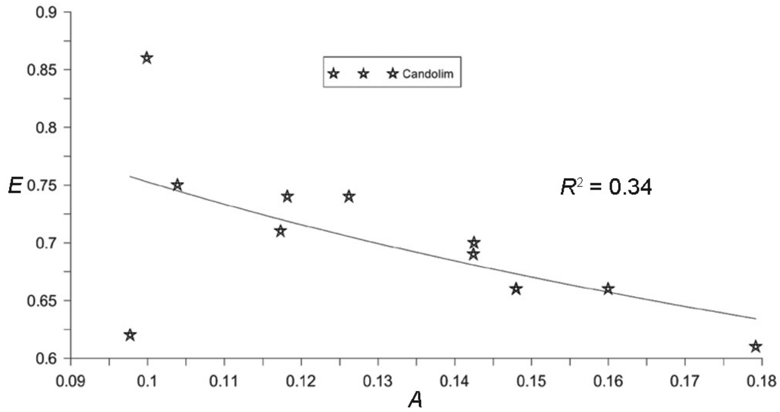

Figure 7. Relationship between sediment scale parameter and profile shape factor for profiles from Candolim.

compound profile and measured profile is more or less equal to zero (Figure 5 *c*). Therefore visually compound profiles can establish the beach morphology of these profiles from Candolim, Miramar and Keri beaches. Comparison between A and m for all the beaches (Table 2) shows an inverse relationship and also gives a better correlation for large values of A (Figure 7).

Average value of A_2 for all these beaches is found to be 0.12 and about 51% of A_2 values is between 0.08 and 0.12 (Figure 8 *a*). Considering each beach separately, the average A_2 is less at Miramar (~0.08) than in Candolim (0.12) and Keri (0.15). Keri showed the largest average A_2 value of 0.15. The relationship between sediment scale parameter and sediment size being linear, confirms that A_2 is proportional to the sediment size. Miramar has finer sand than Keri and Candolim, and hence a smaller A_2 value or vice versa. The average best-fit values of m_2 (profile shape factor corresponding to A_2) for nine profiles from the three beaches of Goa during December to February is 0.87. But from the histogram (Figure 8 *b*), only 14% of the m values prevailed in the range 0.8–1, whereas 51% of values prevailed in the range 0.6–0.8. Comparing each beach separately, m_2 values in the range 0.6–0.8 are more prevalent at Miramar, while at Keri it ranges between 1 and 1.2, but at Candolim m_2 is in the range 0.68–0.76.

From the above results it can be inferred that if the profile slope is large, with m as 0.66 we need A to be greater than A_1 and A_2 to get an equilibrium profile that fits the measured profile. Profiles at Candolim and Keri have steeper slopes than profiles from Miramar; so the A values for Candolim and Keri vary between 0.14 and 0.47, whereas at Miramar they vary between 0.08 and 0.2. Profiles estimated using A_1 and A_2, in most cases, do not fit with the measured profiles when m is 0.66. Hence after changing the m values in accordance with the shape of the profiles manually it is found that m must be higher than 0.66 to obtain an equilibrium profile that fits with measured profiles. This relation between beach face slope A_2 and m_2 is shown in Figure 9. The figure also reveals that in order to obtain better equilibrium profile for a steep beach any one of the sediment scale parameters or profile shape factors should be larger than theoretical and calculated values.

Sediment size variations

Three sediment samples were collected during each beach survey from the backshore, HWL and LWL regions. Relationship between beach face slope and average D_{50} (Table 2) shows that the grain size variation between

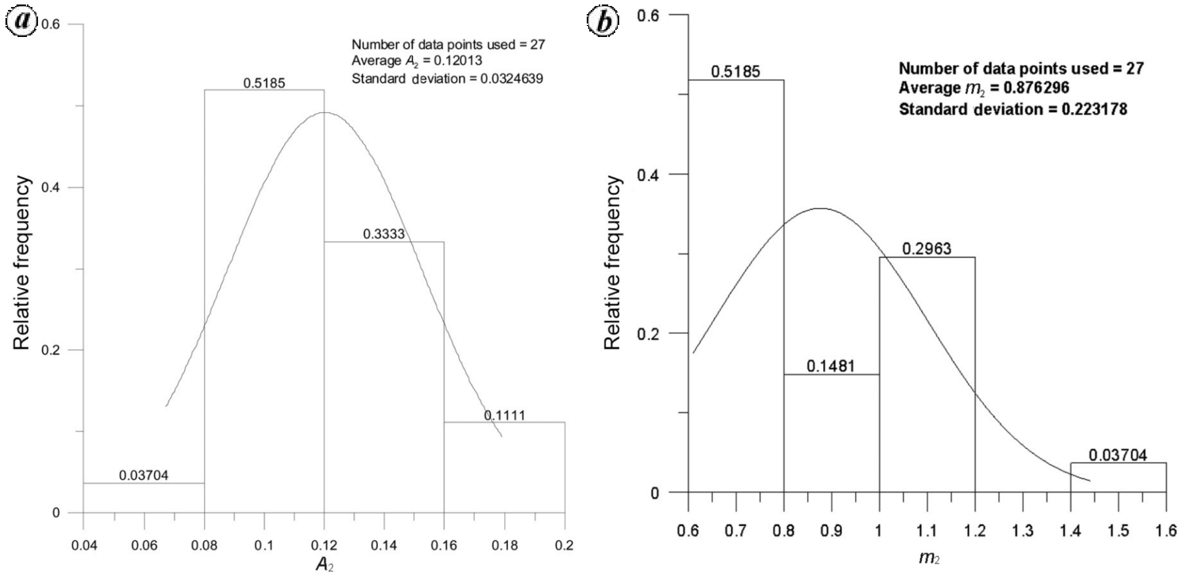

Figure 8. Histogram of best-fit values of (***a***) A_2 and (***b***) m_2 for nine profiles from Candolim, Miramar and Keri beaches.

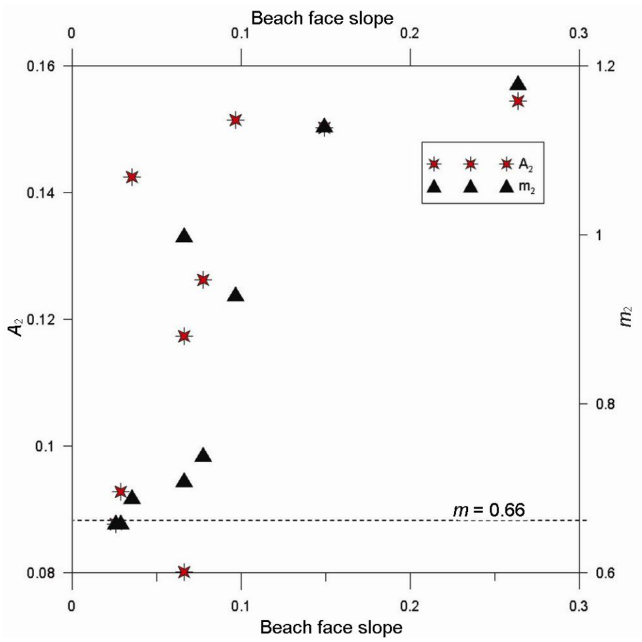

Figure 9. Variation of A_2 and m_2 with respect to beach face slope.

different regions on the profile is evident for similar beach slopes at Miramar and Candolim, whereas for Keri beach, the sediment size variation is minimal but the slope variation is obvious. As the slope increases the sediment size is also observed to increase with maximum values at Keri and minimum in Miramar. At Candolim, sediment size is larger than Miramar and the beach has moderate steepness.

Conclusions

Beach profile and longshore sediment transport studies were carried out at Candolim, Miramar and Keri during winter season (December 2011–February 2012). The estimated longshore sediment transport reveals that at Candolim and Keri net transport is towards south, but at Miramar it is towards north. The yearly gross LSTR obtained from Candolim is about 12.84×10^6 m^3/year, at Miramar it is about 0.62×10^6 m^3/year and at Keri it is about 15.22×10^6 m^3/year.

Equilibrium profiles drawn using arbitrary A fit well with the measured profile than the equilibrium profiles drawn using calculated A_1 or A_2; with A_2 providing a better fit than A_1. In order to obtain better equilibrium profile for a steep beach, A or m should be larger than theoretical or estimated values. Average value of A is greater at Keri, but lesser at Miramar. Considering best fit profile shape factor of all the profiles, m in the range 0.6–0.8 prevails for about 51% of the data considered. But considering each beach separately, profile shape factor varies with respect to the morphology of the beach. Comparing each beach separately, m_2 values in the range 0.68–0.76 are more prevalent at Candolim; at Keri m_2 is between 1 and 1.2, but at Miramar it is within 0.6–0.68. Therefore, a generalized value of $m = 0.66$ is not a good parameter to give a better fit to the equilibrium profile for the foreshore and intertidal regions. Compared to Bruun/Dean model, the Bodge's exponential model provides a better fit; this result is in line with earlier comparison studies of Komar and McDougal[17]. However, for compound profiles, the Bruun/Dean model is found to provide exact match with the measured foreshore profiles.

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