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AN OVERVIEW OF BEACH MORPHODYNAMIC CLASSIFICATION ALONG THE BEACHES BETWEEN OVARI AND KANYAKUMARI, SOUTHERN TAMILNADU COAST, INDIA

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Beach morphology relates the mutual adjustment between topography and fluid dynamics. The morphological makeup of beach systems is not accidental because the arrangement and association of forms occur in an organized contextual space and time. Since the classification derived by Wright and Short (1983) from the analysis of the evolution in a number of Southern Tamilnadu beach sites, beach systems are comprehended in terms of three-dimensional morphodynamic models that include quantitative parameters (wave breaking height, sediment fall velocity, wave period, and beach slope) and boundary conditions for definable form-processes association (e.g., the presence or absence of bars as well as their types). This has led to the classification of beaches into three main categories relating the beach state observations with the physical forcing (Short, 1999) dissipative, intermediate (from the intermediate–dissipative domain to the intermediate-reflective domain), and reflective modes. The morphodynamic classification of beach types was based on the Wright–Short equations (1984) (*dimensionless fall velocity–Dean parameter)*.

Keywords: beach, Wright–Short equations, waves, morphodynamic, India.

1. Introduction

Beach type will occur under certain ranges of waves and grain size parameters under the assumption that the beach will fully respond to governing parameters, which may take days (e.g., associated with storm periods) or to about a year (e.g., modifications of sediment size and type by nourishment projects) (Benedet et al., 2004). In this way, limitations in applying the Wright–Short approach are a recognized particularity for intermediate phase prediction. Wright et al. (1987) found only 36% of agreement between observed and predicted beach states. This classification is quantified by means of a dimensionless fall velocity parameter, which is defined as

$$\Omega = \frac{H_b}{T} W_s ,$$

where H_b is the wave breaking height, T is the wave period, and W_s is the sediment fall velocity.

Here we describe and discuss the morphodynamics of the beaches, based on the results obtained by cross shore beach profile surveys and *in situ* observations of the beaches in the last two years. The main goal of this paper is to elucidate the beach morphodynamic sequence and the classification of beaches in Southern Tamilnadu coast.

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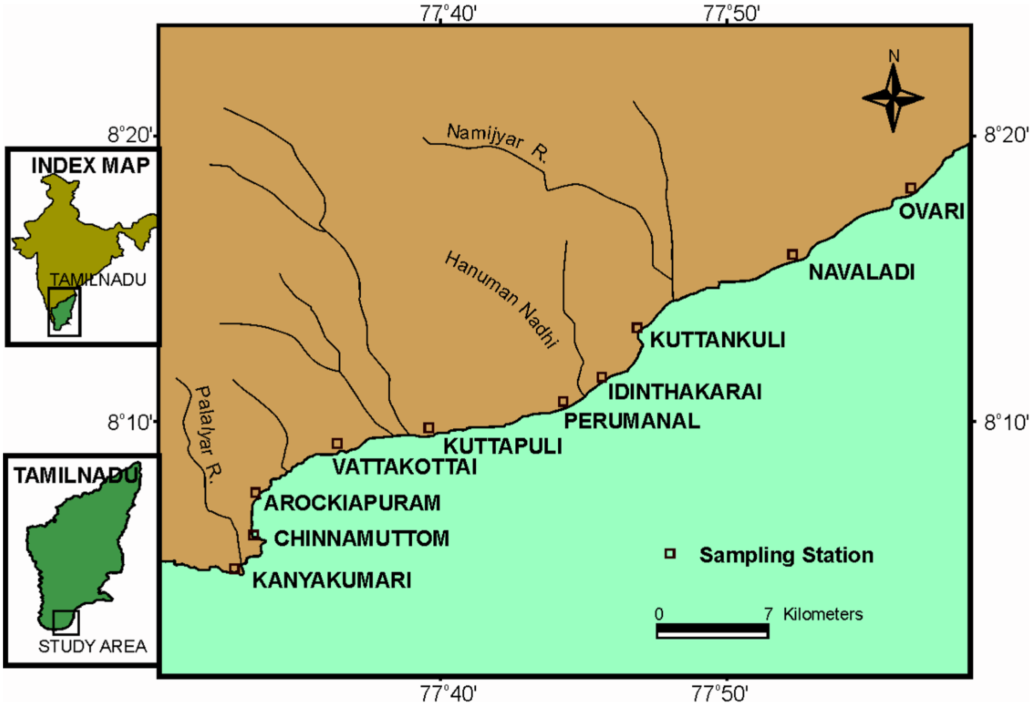

Fig. 1. Location map of the study area.

2. Study Area

The study area extends from Ovari to Kanyakumari (78°02′N, 8°54′E and 78°16′N, 8°79′E) along the southern coastal tract of Tamilnadu State, India, covering about 110 km. It falls under the districts of Tirunelveli and Kanyakumari. It is bounded in the north eastern side by foot-shaped Rameswaram Island, in the East by the Bay of Bengal, in the west by Western Ghat, and in the south by Kanyakumari coast, which is characterized by the confluence of Indian Ocean, Arabian Sea, and the Bay of Bengal (Fig. 1). Morphometric analysis of the drainage network reveals the prevalence of dendritic to subdendritic drainages. Nambiyar River drains some parts of the Tirunelveli district. It originates in the Mayamparambur area located at the foothills of Mahendragiri and receives water from Thamarai Aru and Kombai Aru and joins at Kuttankuli. In the study region, prominent changes are observed in the bathymetry between Kanyakumari and Ovari. The wave length of sand waves is less and in the range around 250 m, and the wave height is greater in the deeper part, which is of the order of 2000 m in wave length. Loveson (1994) identified the existence of different blocks on the basis of different major lineaments and the nature of variation in geomorphic landforms along this study area: (i) Thiruchendur–Navaladi, (ii) Navaladi–Kanyakumari are one of those things. R. Srinivasan and V. Srinivasan (1990) divided the entire stretch of Tamilnadu coast into eight different blocks. Waves and longshore currents also played an important role in shaping the shoreline. The coastline configuration of the study region displays a varying trend in NE–SW and NNE–SSW directions (Fig. 2).

Sheik Mujabar et al. (2007) reported that the tsunami induced a large amount of beach erosion along the study area. Saravanan et al. (2009) reported the post-tsunami assessment in the coastal region between Kanyakumari and Ovari, Tamilnadu. Angusamy (1998) made a panoramic classification of the beaches between Mandapam and Kanyakumari, Tamilnadu, based upon the beach composition, beach gradient, and beach configuration. Chandrasekar et al. (2001) proposed that unsystematic garnet sand mining affected the beach morphology, especially the littoral zone along the coast between Periyathalai and Navaladi, Tamilnadu.

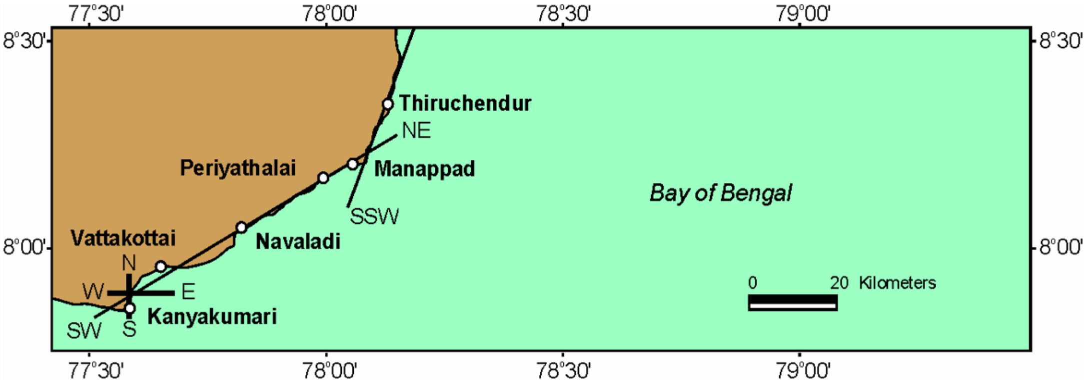

Fig. 2. Coastline configuration along the coast.

3. Data and Methods

3.1. Sediment Characterization. A total of 122 sand samples were collected at 10 sandy beaches. Samples were taken at several cross-shore elevations in transects perpendicular to the shore at locations with different morphological features (e.g., beach face, surf domain, troughs, or bars). Samples were rinsed with fresh water, dried for 24 hours in an oven at 90°C, and divided into subsamples for sieving and settling analysis. Dry sieve analysis was performed using a series of sieves ranging in mesh size from 0.063 mm to 4.76 mm. Grain size distributions were determined using the GRADISTAT package.

For each fraction, a textural analysis was performed. We have found a good agreement with the sediment velocity values predicted by the Gibbs equation, although using D_{50} sieve size and empirical sand density rather than quartz.

3.2. Classification of Beaches. Beaches can be divided into various types on the basis of (i) their composition, (ii) their gradient, and (iii) their configuration. Along the study area, beaches are both sandy and rocky in nature. Some are of mixed type. On the strength of the nature of rocks exposed along the beaches, the rocky beaches can be further grouped into beaches made up of (i) coralline rocks, (ii) crystalline rocks, (iii) hard calcareous sandstone, and (iv) calcrete. A discontinuous exposure of crystalline rocks of khondalitic-charnockitic nature is abutting the Ovari–Kanyakumari beach segment. This crystalline shoreline is protected by sandy permeable beaches of varying width of 30 to 100 m. The monsoonal wave climate sometimes strips off the sandy beaches, exposing the cliff face to wave attack and erosion. As a result, erosive features like kettle holes, sea caves, and wave cut platforms are well developed in this crystalline shoreline. The extension of these rock exposures into offshore is also observed in certain beaches.

4. Morphodynamic State

Morphodynamic states of reflective, dissipative, and intermediate beaches of the study area are assessed on the basis of energy regimes, gradient of the beaches, beach width, backshore width, wave type, coast exposure, and morphological features in the nearshore zone.

4.1. Beach Morphodynamic Condition. The morphodynamic state of the beaches along the Southern Tamilnadu coast is shown in Fig. 3. A highly complex interaction between natural beach conditions such as the forcing waves, currents, and winds and the human effect modify the beach morphology. The improved compre-

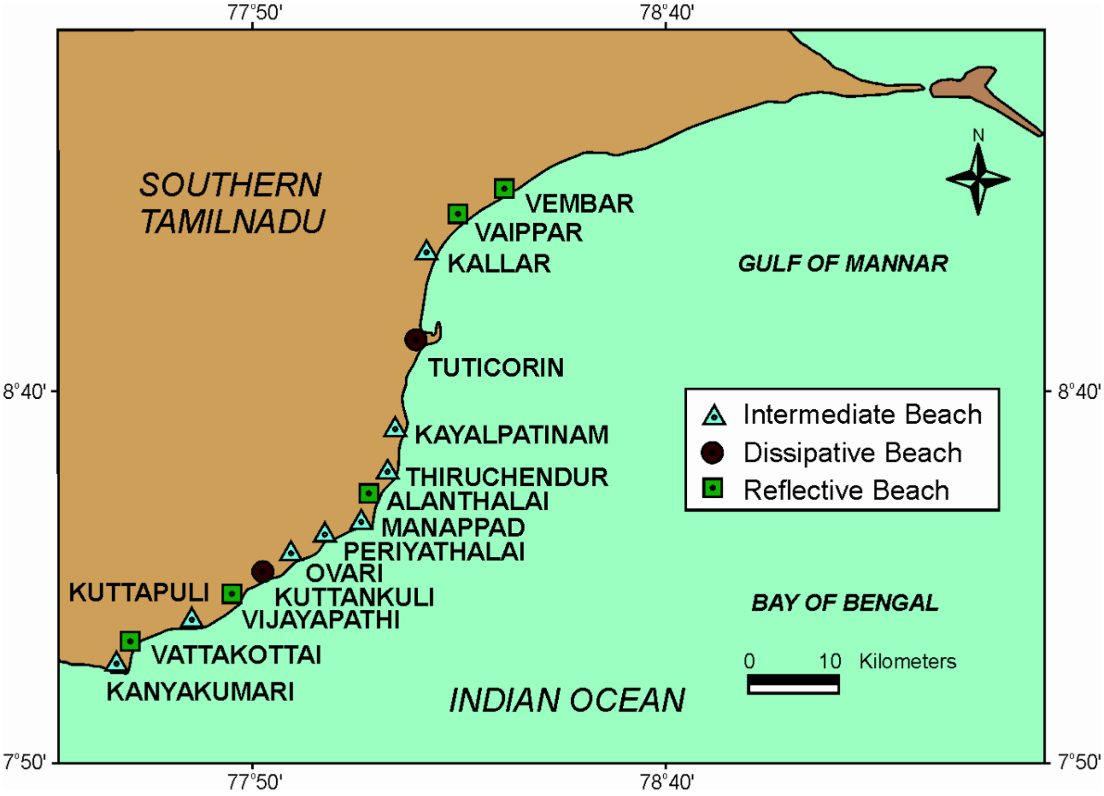

Fig. 3. Morphodynamic state of the beaches along the Southern Tamilnadu coast.

Table 1. Standard Limit Values for Morphodynamic Beach Types and Breaker Type

Breaker type (Battjes, 1974)	Spilling $\xi b < 0.4$	Plunging $0.4 < \xi b < 2.0$	Surging $\xi b > 2$
Beach type (Wright & Short, 1984)	Reflective $\Omega < 1$	Intermediate $1 < \Omega < 6$	Dissipative $\Omega > 6$

hension of the processes producing erosion and accretion has been the goal of many oceanographers and marine geoscientists. However, the relation between cause and effect is often ambiguous. A beach profile analysis assists us to understand and quantify the discrepancy in the sediment level, which is undergoing continuous changes in response to the environment process variables such as wind, waves, tides, etc. Major changes in the sand volume on the beach tend to be systematic and can be related to the character of wave motion, tidal cycles, and currents (Sastry et al., 1979). The beach profile survey also facilitates us to decipher the longshore and cross-shore sediment movement.

4.2. Morphodynamic Classification. The morphodynamic classification of beach types was based on the equations of Wright and Short, 1984 *(dimensionless fall velocity–Dean Parameter)*. For the equation, it was assumed that $W_S = 0.06$ for a medium grain size of 0.45 mm in Table 1.

4.3. Beach Profile. The beach profile survey was carried out using graduated poles and measuring tape as described by Lafond and Prasada Rao (1954) and Emery (1961). Beach profiling was carried out every month

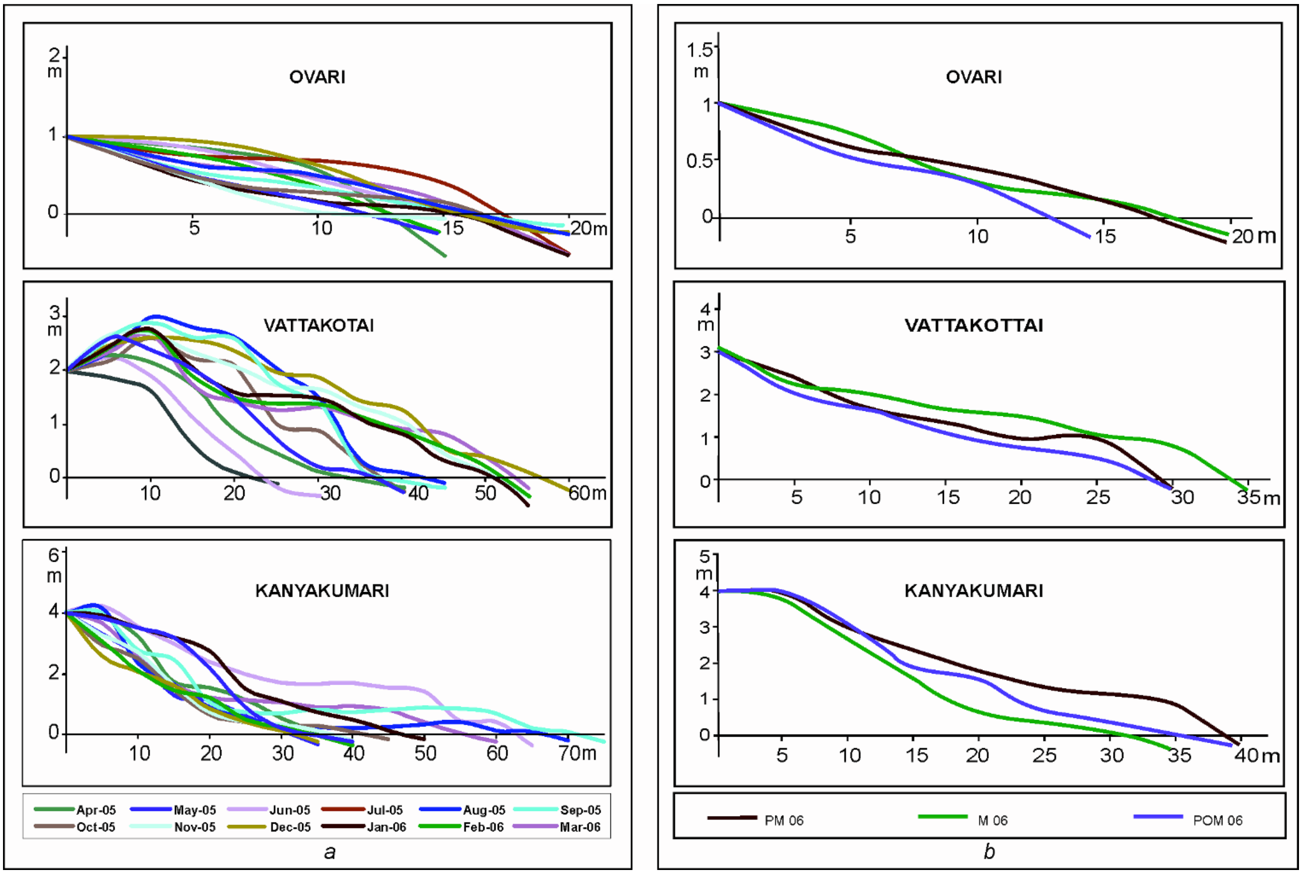

Fig. 4. Monthly (a) and seasonal (b) variations in beach profile (some selected areas; X-axis, distance from the reference point (in m); Y-axis, elevation point (in m); PM, Pre Monsoon; M, Monsoon; POM, Post Monsoon).

before the full moon day at the time of low tide to beyond the low water level as far as wading depth. The beach morphology was monitored monthly for 24 months and seasonally from April 2005 to March 2007 at 10 locations selected in the study area. Altogether 876 surface samples were collected from dune (if present), backshore (berm), high-tide zone (high-water line), mid-tide zone, and low-tide zone (low-water line).

From the data collected during these surveys, the monthly and seasonal beach profile variations are graphically represented to appreciate the variability in the beach profile configuration (Figs. 4a and 4b). From these data, changes in the volume of sediments are calculated using a computer package to scrutinize the temporal variation. The study area is characterized by short-term features such as transverse bars as well as long-term features such as protuberances due to the presence of those offshore islands and submerged sand shoals.

5. Wave Refraction

A study of wave refraction along the beaches between Ovari and Kanyakumari has been made to investigate the changes that occur in the wave characteristics near the coast as deep-water waves of different periods approach the coast from various directions (Figs. 5a–5e). In the present area of investigation, the wave climate is characterized by the southwest monsoon (June–September), northeast monsoon (October–January), and non-monsoon periods (February–May). The predominant wave directions prevailing in the study region are referred in the wave atlas (Chandramohan et al., 1990) as SE during SW monsoon and NW during the NE monsoon. As the study area shows a trend of EW–NS orientation, the waves approach the coast predominantly from 45°SE during SW monsoon, and 20°NW during NE monsoon. Since the orientation of the shoreline along the study area is, in general, the NS–EW direction, the waves approaching the coast between 110°N and 135°N are of greatest significance in conjunction with littoral processes.

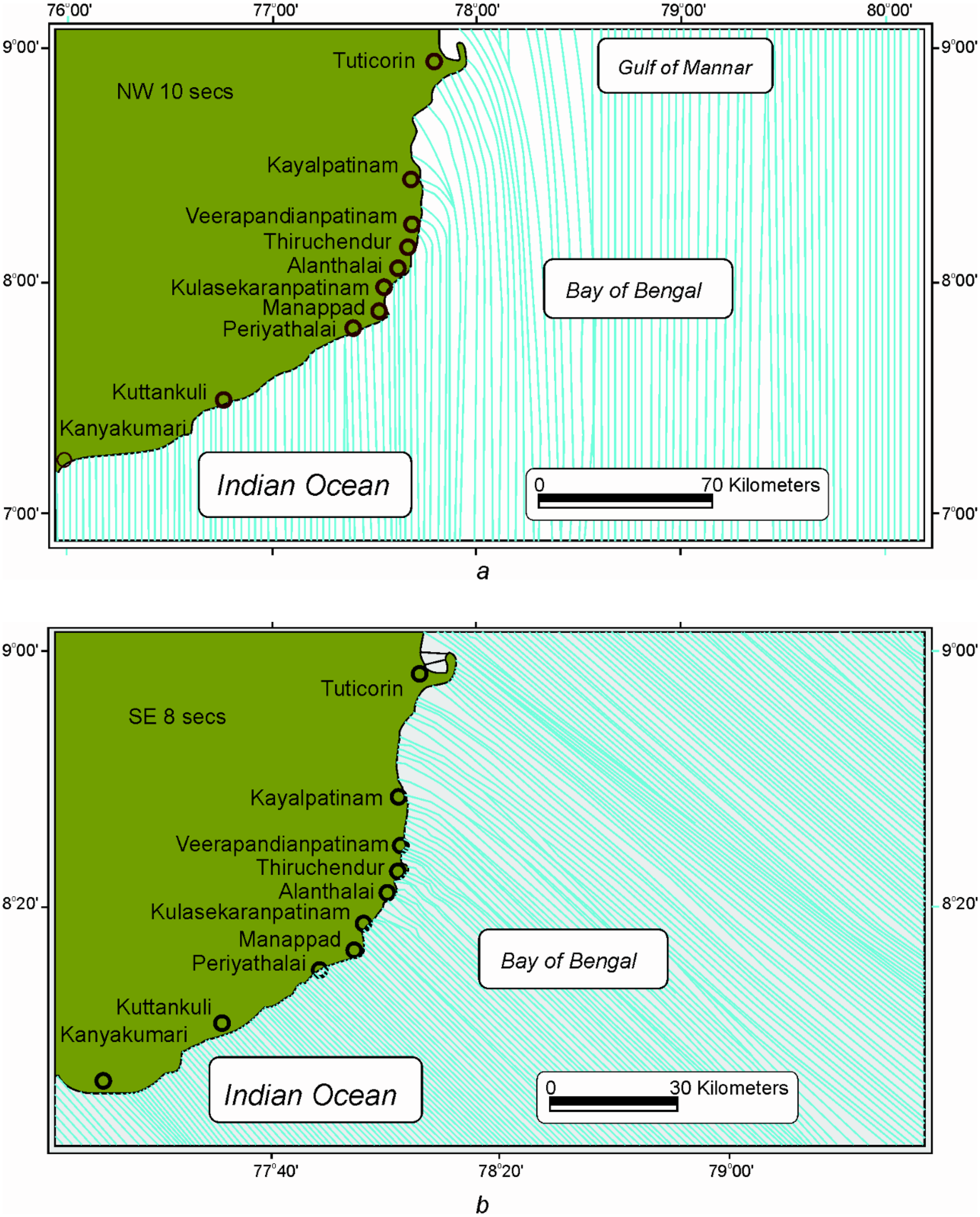

Fig. 5. Wave refraction diagram of the study area.

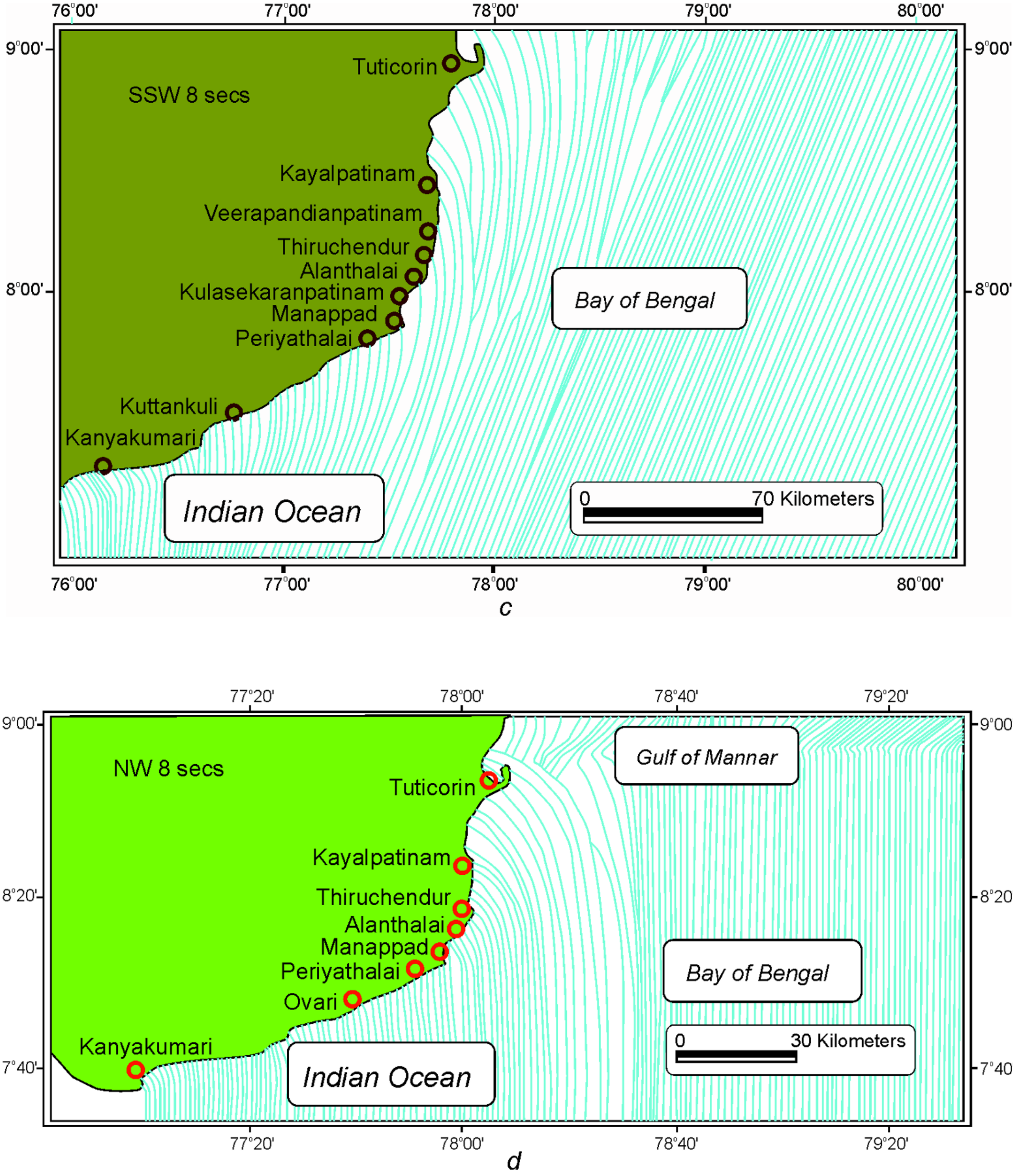

Fig. 5 (*Continued*)

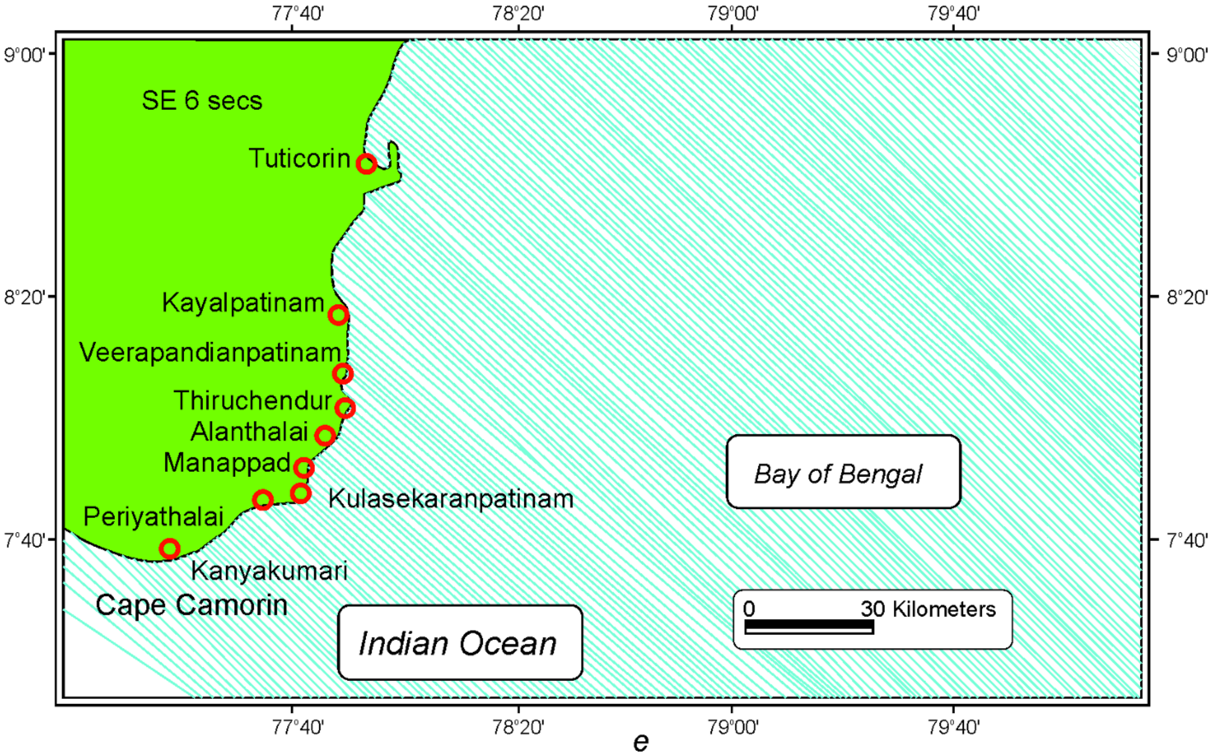

Fig. 5 (***Continued***)

Refraction diagrams have therefore been prepared for waves of periods of 8 and 10 sec approaching from 110°N and 135°N by following the Tarangam Program. This program was developed in the National Institute of Oceanography, Goa, on the basis of finite amplitude wave theory for computing the wave transformation factors (Chandramohan, 1988). The naval hydrographic chart (1973) was used to assess the water depth at a point for drawing bathymetric contours.

The wave refraction pattern for SE for the periods of 6, 8 and 10 sec are shown in Figs. 5a–5e. The wave energy condition prevailing along the study area in different wave directions for different periods is given in Table 2. In the pattern of 10 sec, the wave convergence is observed at Thiruchendur, Manappad, Periyathalai, and Vattakottai. An overview of refraction patterns of three wave periods reveals that wave energy is more pronounced and concentrated in the wave period of 10 sec than in the other two periods. It is also inferred that the wave period of 10 sec plays a predominant role in the shaping of various landforms of depositional and erosional nature and in the redistribution of sediments.

Rajamanickam et al. (1986), Veerayya and Pankajashan et al. (1988), and Gujar (1996) have indicated from their studies along the west coast of India that the predominant directions of waves in the area are from SW, WSW, W, and WNW with periods ranging from 6 to 10 sec. Anbarasu (1994), Chandrasekar (1992), Angusamy et al. (1998), and Chandrasekar et al. (2001) discussed the wave refraction pattern and its role in the redistribution of sediments along the east coast of India.

The overall pattern of wave refraction in the study area of SE direction displays strong convergence in the number of beaches, and the same may be ascribed to the prevalence of high energy conditions unlike the other two directions. This leads to the inference that sediment transportation and their degree of sorting are likely to be more intensive in the southwest monsoon period. The change in wave energy from convergence to divergence in a particular beach in a different period was attributed to the change in the quantum of sediment movement from one period to the other (Hanamgond, 1993).

Table 2. Wave Energy Conditions Prevailing along the Study Area

Station	SE			NW		SSW
	6S	8S	10S	8S	10S	8S
OVR	I	C	C	I	I	I
NAV	I	I	I	I	I	I
KUT	I	C	C	I	I	I
IDI	I	D	D	D	D	D
PERU	I	I	I	I	I	I
KUP	I	I	C	I	I	I
VAT	I	I	I	I	I	I
ARO	D	C	C	I	I	D
CHI	I	C	C	C	D	D
KAN	I	I	I	I	I	I

Comments: I, Inept condition; D, divergence; C, convergence. Here and in Tables 3–5: OVR, Ovari; NAV, Navaladi; KUT, Kuttankuli; IDI, Identhakarai; PERU, Perumanal; KUP, Kuttapuli; VAT, Vattakottai; ARO, Arokiapuram; CHI, Chinnamuttom; KAN, Kanyakumari.

The nature of cliffed coastline from Kuttankuli to Vattakottai with high order of erosion indicates a zone of high energy environment. This inference is also supported by strong convergent zones.

6. Littoral Sediment Transport

The movement of material in this zone depends mainly on three factors: the nature of material available for transport (size and density), orientation and other features of the coast, and the angle of wave approach (Swift, 1976; King, 1972). Littoral transport plays a major role in the development of certain shoreline features like spits and bars and causes considerable coastal erosion and accretion (King, 1974). The monthly longshore sediment transport rates estimated on the basis of monthly observations on breaking wave height, surf zone width, and longshore currents are presented in the Tables 3–5. The monthly volume of longshore sediment transport rates and directions are estimated for the coast at Kuttankuli, Vattakottai, Thiruchendur, Alanthalai, Manappad, Periyathalai, Ovari, and Kanyakumari.

In general, the sediment transport is northerly during March to October and southerly during November to February. The longshore sediment transport is higher in the northerly direction as compared with the southerly direction at all locations except Kanyakumari. This occurs because the rocky outcrops shelter the Kanyakumari beach, and manmade features such as a harbor across the surf zone would act as a barrier and sand would be deposited on the updrift side of this barrier.

7. Results and Discussion

The wave refraction analysis has delineated different wave energy conditions prevailing in the study area. There are areas of erosion and accretion observed along the coastal stretch, which depends primarily on the direction of wave approach, wave period, and wave refraction pattern. In the nearshore zone of the present study area, the movement of sand alongshore is due to the action of waves and currents.

Table 3. Monthly Data of Long Shore Current (V) along the Study Area (m/sec)

Station	A	M	J	J	A	S	O	N	D	J	F	M
OVR	0.48	0.01	–0.16	–0.01	–0.18	–0.06	–0.36	–0.39	–0.43	–0.09	0.14	0.29
NAV	0.44	0.13	–0.20	–0.32	–0.22	–0.22	–0.30	–0.22	–0.32	–0.16	0.11	0.20
KUT	0.40	0.14	–0.21	–0.33	–0.24	–0.24	–0.30	–0.33	–0.33	–0.10	0.12	0.18
IDI	0.31	–0.10	–0.09	–0.07	–0.21	–0.08	–0.07	–0.01	0.03	–0.11	0.04	0.04
PERU	0.42	0.04	–0.20	–0.13	–0.26	–0.10	–0.29	–0.14	–0.34	–0.06	0.12	0.18
KUP	0.38	0.02	–0.23	–0.20	–0.23	–0.31	–0.26	–0.16	–0.32	–0.04	0.16	0.16
VAT	0.50	0.03	–0.05	–0.10	–0.01	–0.21	–0.31	–0.16	–0.30	–0.08	0.10	0.16
ARO	0.30	0.12	–0.10	–0.06	–0.28	–0.09	–0.07	–0.04	0.06	–0.13	0.06	0.08
CHI	0.39	0.02	–0.07	–0.04	–0.1	–0.07	–0.3	–0.4	0.05	–0.07	0.01	0.16
KAN	0.34	0.14	–0.04	–0.20	–0.07	–0.20	–0.30	–0.15	–0.30	–0.17	0.10	0.16

Comment: (–) Northerly direction, (+) Southerly direction.

Table 4. Monthly Data of Breaking Wave Height (HH) along the Study Area (m)

Station	A	M	J	J	A	S	O	N	D	J	F	M
OVR	0.50	0.20	0.20	0.50	0.30	0.45	0.70	0.45	0.60	0.45	0.50	0.50
NAV	0.40	0.45	0.30	0.15	0.40	0.30	0.55	0.40	0.35	0.45	0.445	0.60
KUT	0.50	0.50	0.25	0.20	0.20	0.15	0.50	0.20	0.25	0.40	0.55	0.55
IDI	0.40	0.45	0.40	0.25	0.30	0.70	0.30	0.60	0.80	0.30	0.45	0.30
PERU	0.50	0.35	0.15	0.20	0.30	0.20	0.45	0.20	0.55	0.45	0.35	0.45
KUP	0.30	0.40	0.20	0.15	0.25	0.10	0.60	0.30	0.45	0.25	0.40	0.40
VAT	0.25	0.15	0.05	0.25	0.10	0.25	0.20	0.20	0.20	0.05	0.15	0.20
ARO	0.30	0.40	0.25	0.25	0.35	0.60	0.20	0.45	0.60	0.25	0.35	0.20
CHI	0.40	0.20	0.25	0.20	0.25	0.35	0.85	0.50	0.55	0.35	0.55	0.50
KAN	0.20	0.20	0.25	0.20	0.15	0.30	0.35	0.35	0.15	0.25	0.20	0.20

Table 5. Monthly Data of Surf Zone Width (W) along the Study Area (m)

Station	A	M	J	J	A	S	O	N	D	J	F	M
OVR	18	20	20	22	15	19	18	17	20	18	20	20
NAV	19	20	16	18	17	20	16	16	20	20	20	20
KUT	18	16	15	15	20	18	17	15	17	15	20	20
IDI	13	12	12	11	12	14	13	12	14	12	12	14
PERU	17	20	15	15	20	18	17	15	17	15	20	20
KUP	20	18	15	16	17	20	18	17	16	18	19	20
VAT	16	14	18	14	14	17	15	14	17	18	16	16
ARO	20	22	20	17	19	20	17	16	18	19	22	22
CHI	17	17	16	18	17	19	20	17	20	18	20	20
KAN	16	14	13	16	15	12	14	15	14	17	18	16

Table 6. Beach Morphodynamic Classification along the Beaches between Ovari and Kanyakumari

I. Breaker type (Battjes, 1974)	Spilling $\xi b < 0.4$	Plunging $0.4 < \xi b < 2.0$	Surging $\xi b > 2$
Locations	Kuttapuli, Vijayapathi, Arokiapuram and Vattakottai	Kuttankuli, Chinnamuttom and Kanyakumari	Ovari and Perumanal
II. Beach type (Wright & Short, 1984)	Reflective $\Omega < 1$	Intermediate $1 < \Omega < 6$	Dissipative $\Omega > 6$
Locations	Kuttapuli, Vijayapathi, Arokiapuram and Vattakottai	Kuttankuli, Chinnamuttom and Kanyakumari	Ovari and Perumanal

A complete study of wave dynamics is imperative at this instant, which includes the measurement across the swash and surf zones of local sediment transport, wave height, wave energy conditions, longshore current, etc., to comprehend and describe the swash processes precisely. Also the time scale of each study should be commensurate with that of the duration of the directional wave event that drives the transport. Further, emphasis has to be placed on formulating computer models to conjecture the performance of sediment movement for the development and management of the coastal zone.

The direction of littoral drift is from south to north during the period of March to October when the waves are between S and SE, and from north to south during the period of November to February when the wave directions are between E and ENE. The seasonal changes in the direction of littoral drift with SW and NE monsoons cause cyclic variations of the beach morphology along the coast under investigation. The rocky outcrops scattered across the littoral zone cause the reversal of beach cycles at different stations along the coast. For example, at Kanyakumari (October) during SW monsoon, the southerly movement of sediment is observed. The net littoral drift at all stations is generally from south to north with the exception of the Kanyakumari station, where the net drift is southwards. The net erosive nature of the study area (except Kanyakumari) from March to October is due to the prevalence of high waves from S and SE directions.

The morphodynamic states of reflective, dissipative, and intermediate beaches of the study area (Table 6) are assessed on the basis of energy regimes, gradient of beaches, beach width, backshore width, wave type, coast exposure, and morphological features in the nearshore zone.

Dissipative Beaches. The high wave energy condition with low gradient beach slope has a surf scaling parameter. They have higher rate of dune and backshore recession. Dissipative beaches in the study area are composed of fine to medium sand, and, hence, the mobility of the beaches is more enhanced than the higher energy conditions of the reflective beaches. Due to the repeated oscillations of high wave energy condition in the dissipative beaches, scarping of the beach profiles occur. Beaches falling under this category are Ovari and Perumanal.

Reflective Beaches. Low modal wave heights and steep gradients of the beach have resulted in a low surf scaling parameter. However, if the wave height increases seasonally, the beaches in these environments would be severely affected by erosional processes. The same is attested by the present study during the northeast monsoon, and the erosion-sensitive concave beach profiles dominate over convex profiles. The mobility of the beaches is hindered by the coarseness of the sediments, low energy condition, and steep beach gradients. Beaches like Kuttapuli, Vijayapathi, Arokiapuram, and Vattakottai fall under this category.

Intermediate Beaches. Intermediate domains exhibit the characters of both reflective and dissipative beaches. Moderate gradient and abundant supply of sediments are seen more with dominant alongshore movement than with onshore–offshore movement. Broad backshore width is observed in the intermediate state of beaches in Perumanal and Vijayapathi coast. Flat and moderate beach gradients with strong rip current and well developed cusps that disappear as the reflective shoreline conditions dominate over the intermediate state are perceptible in the zeta form bay between Kuttapuli and Arokiapuram. The gradients of the beaches that are gentle with low energy conditions are seen in Ovari coast. Along with other modes of beach cuttings, rip currents developed in this coast caused the continual erosion. Along the study area, such beaches as Kuttankuli, Chinnamuttom, and Kanyakumari belong to this category.

CONCLUSIONS

The morphodynamic behavior of beaches has been identified in the beaches of the area between Ovari and Kanyakumari. The different morphologies of appearance on the beaches show that the morphodynamic behavior also has a direct influence on the wave refraction, with the mechanical processes of a wave. The morphodynamic behavior of the beaches is presented as a determinant factor that should be incorporated into the coastal recovery in order to estimate the time of recovery of sandy beaches and the efficiency of the clearing methods in the most precise way. However, within the proposed model and from the existing data, it is not possible to determine the time scale of these processes, nor the influence that the possible contributions of waves from the continental shelf would have on this natural process of sediment regeneration.

Clearly, regardless of the wave-climate strength, the nearshore zone of the coast is constantly modified, which requires the use of observation and interpretation tools with high acquisition frequencies. The complementary data provided will enable the precise determination of the energy and temporal scales to which the coastal dynamics are sensitive (for instance, the wave-action duration involving morphological changes in the intertidal domain). Also, they will allow more precise calculations of the sand-transport rate due to littoral drift. Finally, with the aim of simulating coastline morphodynamics, it will be necessary to better define the wave-height threshold beyond which the ridge morphology is modified. To conclude this paper, we must note that cross-shore morphodynamics need to be studied in order to complete the analysis of the morphodynamics of the coast. In addition, the interaction between the systems must be intensively investigated.

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