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Shoreline management plan for a medium energy coast along west coast of India

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Abstract

Studies on coastal hydrodynamics and sediment transport help to unravel the coastal processes and facilitate formulation of shoreline management plans. An integrated approach which includes, extensive field data collection and numerical modelling is lacking along most of the coasts around the world, particularly along Indian coasts. The coastal stretch from Beypore to Puthiyappa, southwest coast of India has been selected for this present investigation. Harbour breakwaters in the northern and southern boundary of the study region have major impacts on shoreline modifications along this sector. In addition, a small harbour and associated breakwaters are located in the middle of the study region. Seawalls, and combination of seawall and smaller groins are constructed at many places as part of coastal protection. Sediment transport along the coast was computed with LITDRIFT model and the results show net northerly drift of $1.5 * 10^5$ m^3/year. The model results are comparable with the quantity of beach sediment mined from Puthiyappa beach (approximately of $0.8 * 10^5$ m^3/year). In addition, illegal mining is carried out in the region. Further, the model computed the shoreline evolution along the sector and major accumulation occurs south of Puthiyappa breakwater. Sand deposition close to groins and breakwaters along the study region support the model results. No further intervention along this sector is required for shore protection except, the maintenance of the existing protective measures such as seawalls and groins.

Keywords Shoreline management plan · Sediment drift · LITDRIFT · Mudbanks

Introduction

Shoreline Management Plans (SMPs) set out the strategy for the protection of the coast, coastal communities and the resources for a specified length of the coast. The strategy takes into account the natural coastal processes, human influences, land use and other environmental aspects. The concept of coastal cells helps to rationalise shoreline management by dividing the coastal area into units based on natural processes. The boundaries adopted for SMPs have to coincide with the boundaries of the sediment cells. The hinterland boundaries follow identifiable topographical features that define potential limits of possible flooding. Offshore boundary for the management plan will include the areas that have an impact upon the shoreline processes. In cases, where the sediment cells are too large for workable SMPs, the cells will be divided into sub cells. Pethick et al. (2013) has proposed a total of 27 Primary Cells covering the whole coastline of India out of which 10 are for the west coast and rest for the east coast. Impact of erosion and the required management options are dependent on the development status of the particular coastal sediment cell, the requirements of coastal communities and sensitivity and importance of coastal ecosystems and morphology.

Integrated Coastal and Marine Area Management Project Directorate (ICMAM PD), Ministry of Earth Sciences, Chennai was the first institute to initiate the preparation of SMPs in India. The SMPs have been prepared by ICMAM PD included those for Chennai, Pulicat Lake to Mahabalipuram coastal stretch, Goa and Netravathi- Gurpur tidal inlet area (www.icmam.gov.in; ICMAM 2006; Subramanian et al. 2007a). Modern tools like GIS, Remote sensing, and

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Numerical Modelling (MIKE-21) were used in the study. Detailed field and model investigations on various dynamical aspects (water level variations, currents and circulation, tides, waves, bathymetric variations, sediment transport, shoreline changes, etc) were conducted. A similar study was undertaken by ICMAM PD and National Centre for Earth Science Studies (NCESS), along the southwest coast of India at a selected site (Panathura in Thiruvananthapuram) (Thomas et al. 2007).

These studies were continued at Kayamkulam - Chettuwa stretch and Varkala to Veli sector (Subramanian et al. 2007b; Thomas et al. 2013; Noujas et al. 2014, 2016). The Beypore – Elathur coastal stretch located along the north coast of Kerala

(Fig. 1) which has distinctly different morphological and environmental characteristics is examined in the present study. The urban nature of the coast with major development activities, densely populated fishermen community, recreational requirement of beach for sustained tourism and the occurrence of mudbanks make it appropriate to develop a shoreline management plan for the coast. Accordingly a shoreline management plan for this partially mudbank controlled coast is proposed with possible intervention for coastal protection for identified erosion hotspots with the help of numerical model studies. The present study also discusses the morpho-dynamic relationship between mudbanks and coastal zone.

Fig. 1 Location map with artificial structures and longterm shoreline change
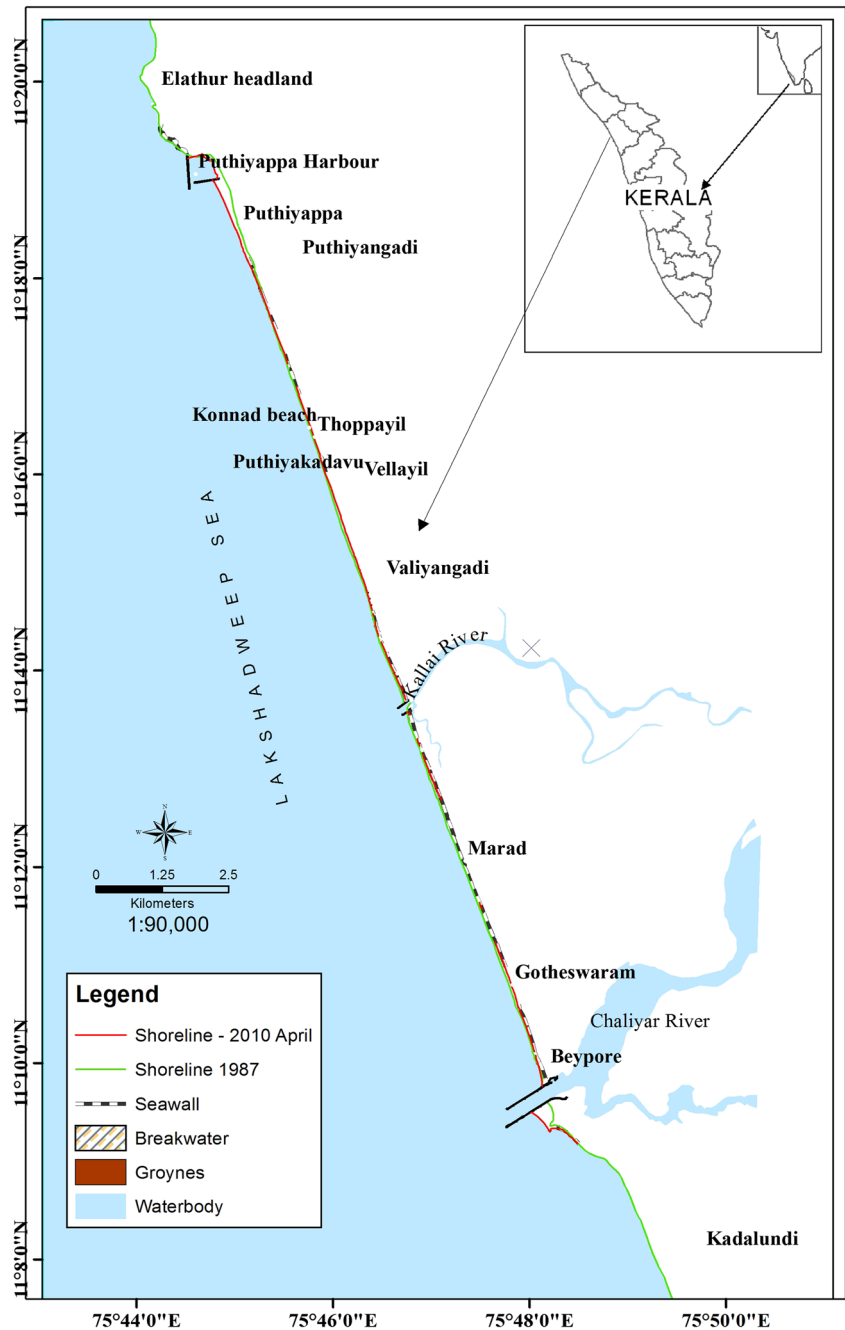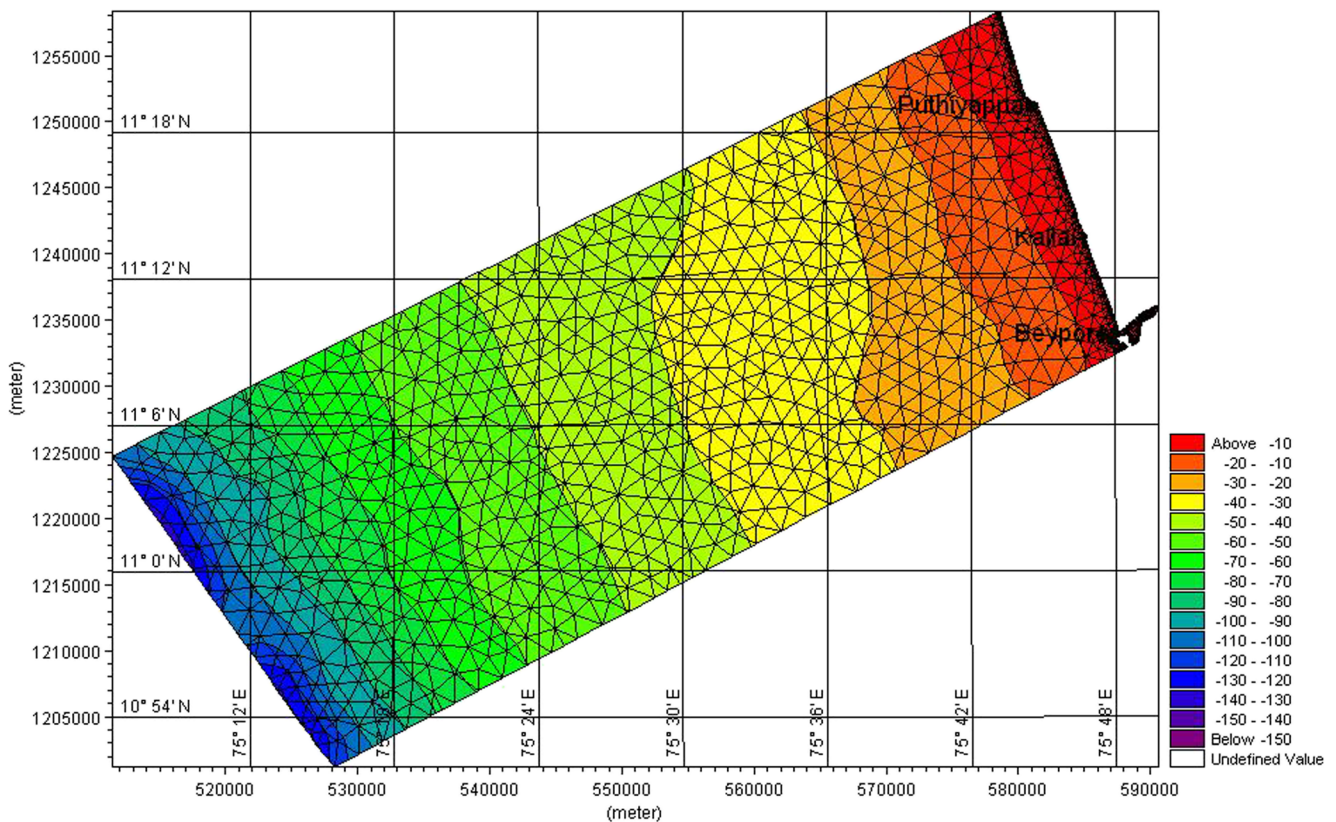
Fig. 2 Bathymetric mesh used for SW modelling

Region settings

The study region of Beypore – Elathur is a coastal plain between the tidal inlet/port at Beypore and the headland at Elathur and it is a medium energy coast. This forms a subcell within the Kollam - Ettikulam Primary Sediment Cell defined by Pethick et al. (2013). The Beypore – Elathur coastal stretch is highly undulated with morphological features like lateritic cliffs, rock outcrops, pocket beaches and tidal inlets. The Chaliyar River debouches to the sea at Beypore inlet. There is another tidal inlet in between where the Kallayi River joins the sea. Seawalls exist along the southern sector extending from Beypore inlet to Valiyangadi for about 9 km (Fig. 1). There are beaches seaward of the seawalls for about 550 m north of the Beypore breakwater. Further north the seawall has a few seaward projections and rocky outcrop. Seasonal frontal beaches are present south of the projections and rock outcrops. There is a gap in the seawalls for about 700 m at Gotheswaram and beaches are present throughout the year. No beach forms seaward of seawalls along the Marad sector. There is a series of short groins for about 1.5 km between Kallai and Valiyangadi, which is a combination of seawalls and groins. Further north seawalls are present in certain locations in small stretches. The 2 piers of Kozhikode Port are now in ruins. The construction of breakwater at Beypore was undertaken during 1982–88. Breakwaters at Puthiyappa were constructed between 1988 and 1996. A new harbour construction work is underway at Vellayil and impacts of these harbour breakwaters are not included here.

Materials and methods

Data collection

Extensive field data were collected during the period 2010–12 to understand the coastal processes responsible for sediment transport and shoreline change along the study region. Nearshore waves, tides, currents, bathymetry, shoreline tracking and sediment characteristics were collected in representative seasons. Wave data was collected at Beypore, Kallai and Puthiyappa during January–February (pre-monsoon season), August (monsoon season) and November (post-monsoon season). Shoreline tracking was carried out for different months using hand held GPS (Global Positioning System) with an accuracy of 5 m. Sediment data was collected from beach and offshore. Grain size was analysed by sieving method. The median grain diameter d_{50} was considered as grain diameter for sediment drift computation and extracted by following geometric graphicalmeasures Folk and Ward (1957) using
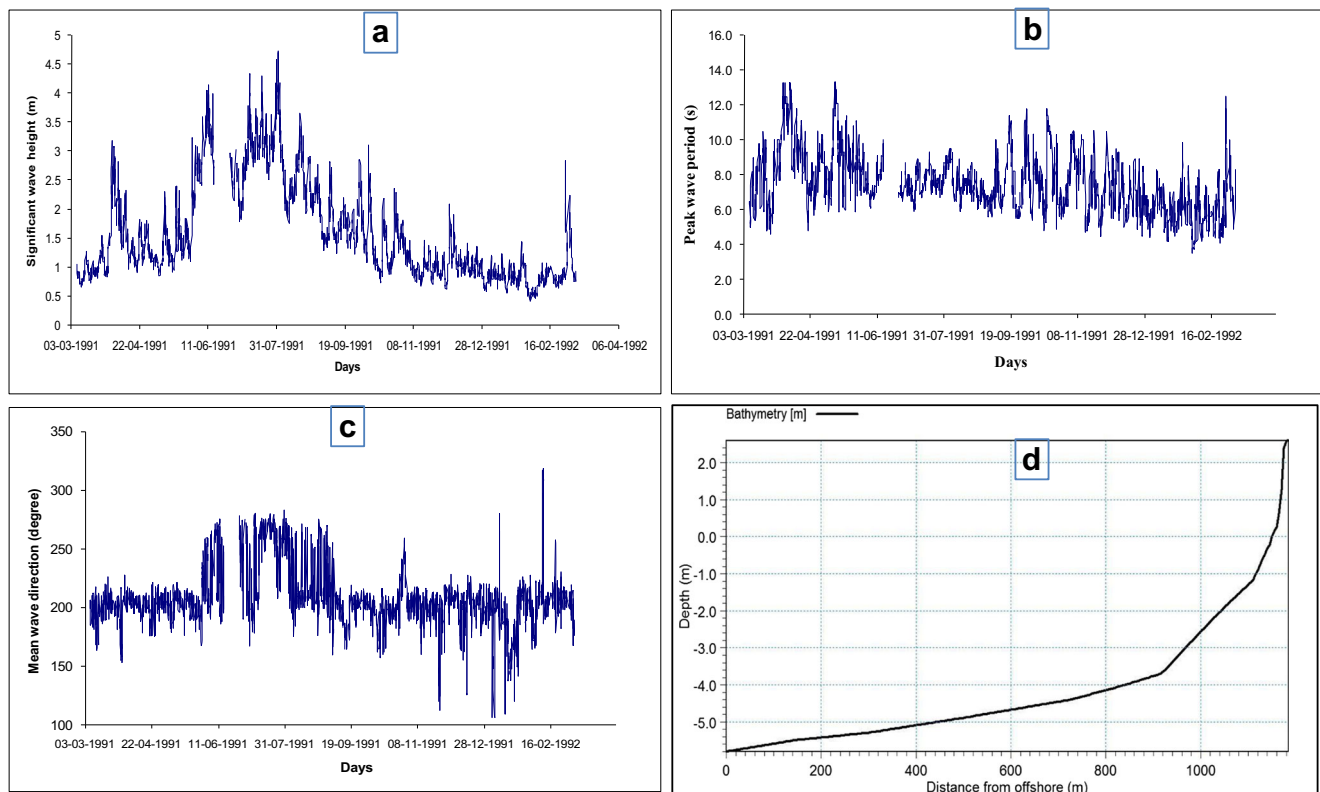
Fig. 3 Inputs for modelling; **a** Significant wave height **b** Peak wave period **c** Mean wave direction **d** Cross-shore profile

GRADISTAT (Blott and Pye 2001). The position of mudbanks and various other morphological signatures like shoreline positions, old seawalls, berm crests have been measured using GPS. These are supplemented by information obtained locally from fisher community and earlier studies (Silas 1984; Thomas et al. 2013).

The accuracy of all numerical simulations primarily depends on how accurately the bathymetry is generated. The bathymetry was generated from the C-MAP in deep waters and bathymetric data for the nearshore were collected using an echo-sounder in a close interval of 250 m (Fig. 2). The echo sounder was integrated with GPS for accurate positions. The data was collected and interpolated using MIKE 21 Mesh Generator for obtaining the continuous bathymetry of the area.

Table 1 Sediment characteristics

Parameter	Value
Mean grain diameter (mm)	0.09 to 0.37
Fall velocity (m/s)	0.0076 to 0.128
Bed roughness (m)	0.0018 to 0.0074
Geometrical spreading	1.5

Coarser mesh is used in the offshore and finer mesh in the nearshore area.

Numerical modelling

MIKE 21 Spectral Wave (SW) model and LITPACK software, both developed by Danish Hydraulic Institute, Denamrk (DHI 2012), were used for numerical model studies. The wave climate at nearshore is required for estimation of longshore transport and shoreline evolution and it is obtained by transforming wave data using MIKE 21 SW model. The SW model simulates the growth, decay and transformation of wind generated sea waves and swells both in the offshore and nearshore. Waves measured using directional wave rider buoy deployed off Kavarathi during March 1991 to February 1992 (Baba et al. 1992; Figs. 3a-c), were given as offshore boundary of the MIKE 21 SW model to get nearshore wave climate. Black et al. (2008) have shown the suitability of waves off Kavaratti for offshore wave data on the southwest coast of India. Sediment transport and shoreline change were estimated using the LITPACK model. It is a numerical model in MIKE software package for simulating non-cohesive sediment transport driven by waves and currents along quasi-uniform beaches.

Sediment transport along the coast under study has been computed with LITDRIFT module of LITPACK. The LITDRIFT simulates the cross-shore distribution of wave height, setup and longshore current for an arbitrary coastal profile. It provides a detailed deterministic description of the cross-shore distribution of the longshore sediment transport and calculates the net/gross littoral transport for a section of coastline over a specific design period.

LITDRFIT consists mainly of two computation steps: longshore current calculation (hydrodynamic model) and sediment transport computation (sediment transport model, STP). The cross-shore distribution of longshore current, wave height and setup for an arbitrary coastal profile, is found by solving the long and cross-shore momentum balance equations. The hydrodynamic model includes a description for regular and irregular waves, influence of tidal
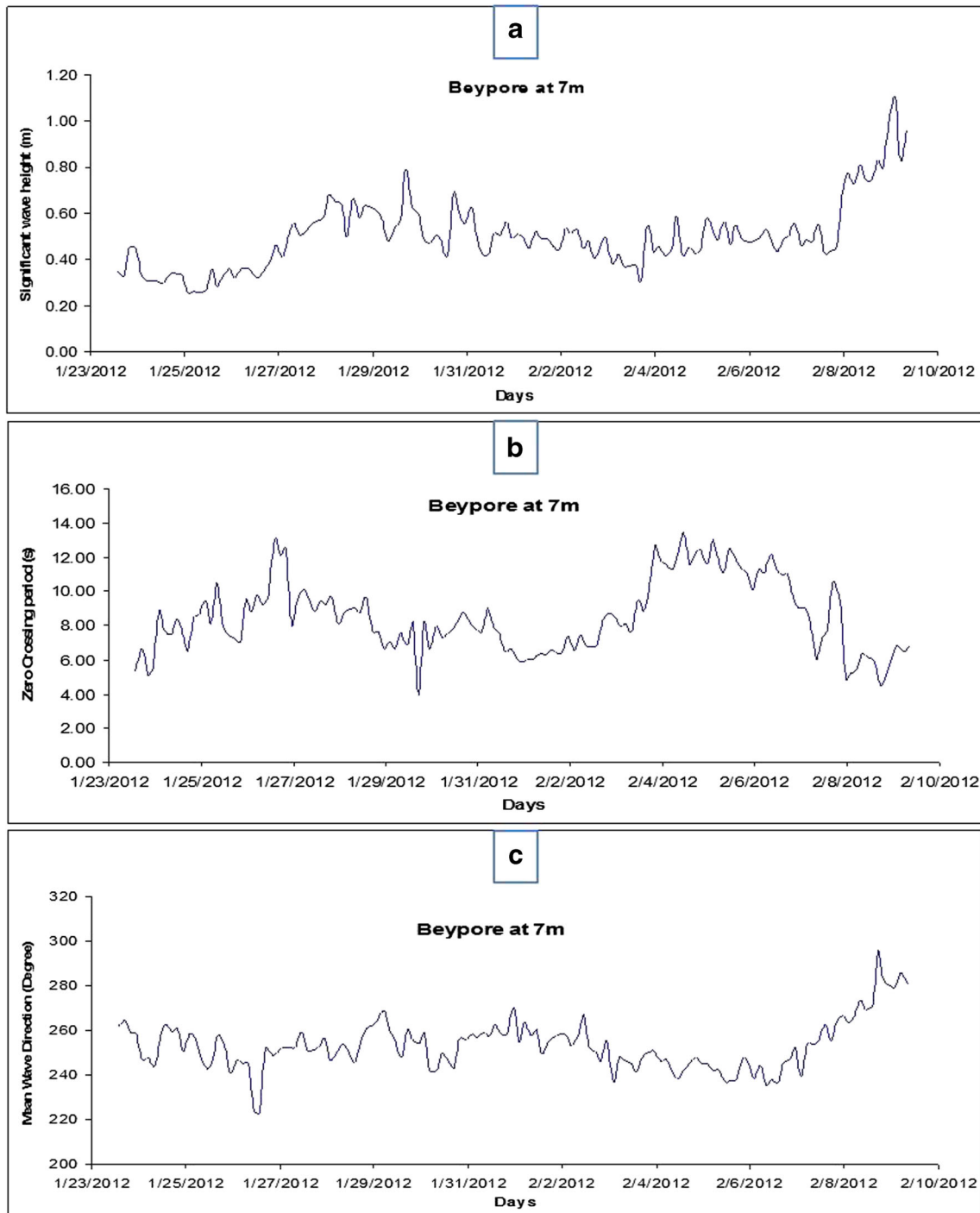

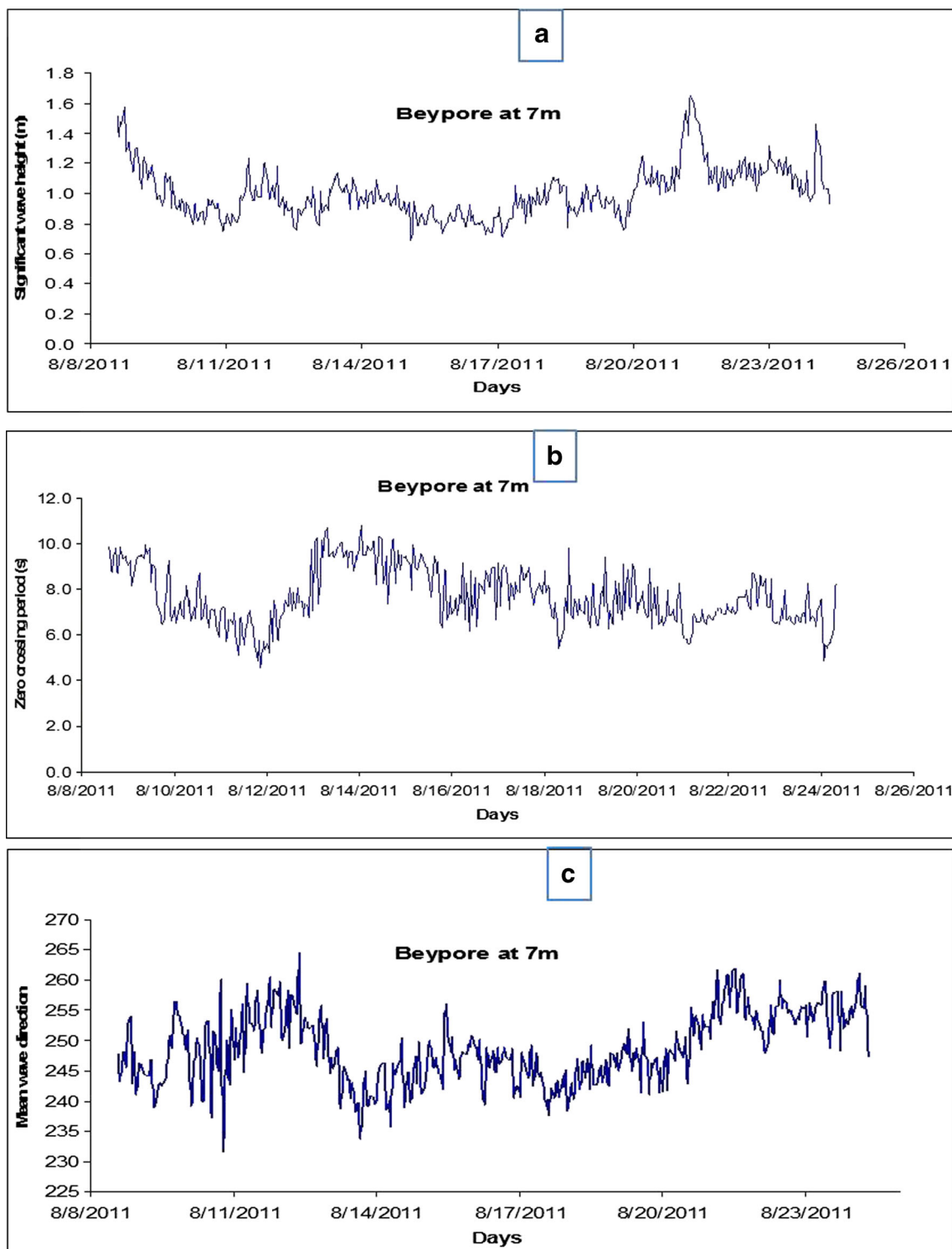Fig. 4 Wave characteristics at Beypore during Jan-Feb 2012

Fig. 5 Wave characteristics at Beypore during August 2011

current, wind stress and non-uniform bottom friction as well as wave refraction, shoaling and breaking.

The sediment transport model, STP forms the basic sediment transport description from combined wave and current action. In combined waves and current the turbulent interaction in the near bed boundary layer is of importance for the bed shear stresses as well as for the eddy viscosity distribution. The basis for the sediment transport description is the model for turbulent wave-current boundary layers of Fredsøe (1984). Total sediment load is split into bed load and suspended load, which are calculated separately. Transport of non-cohesive material
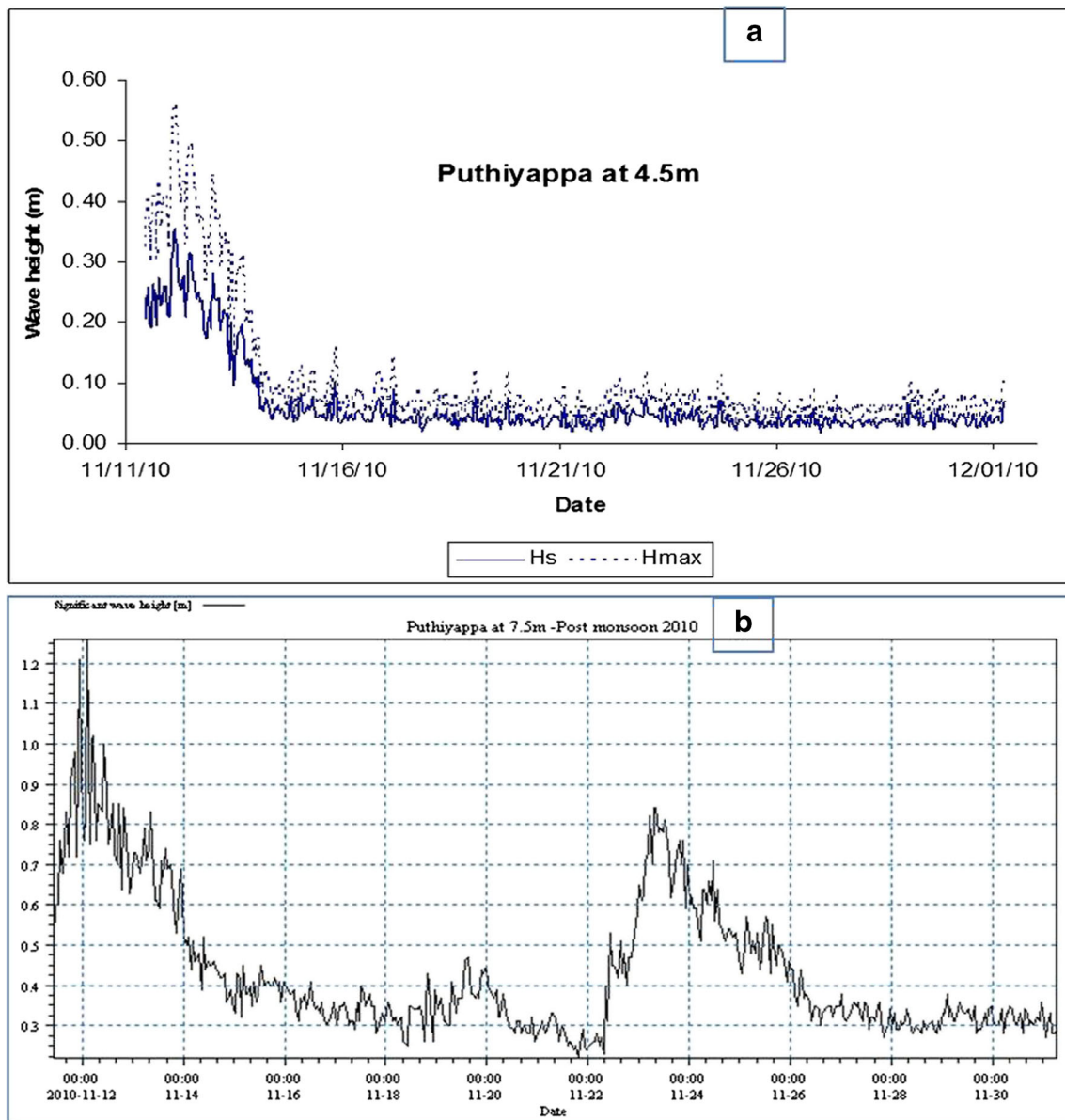
Fig. 6 Wave attenuation in mudbanks location at Puthiyappa

as bed load is calculated according to the model presented by Engelund and Fredsøe (1976). The vertical variation of suspended sediment concentration is calculated from vertical diffusion equation for suspended sediment (Fredsøe et al. 1985). Total sediment transport is dominated by transport contributions from areas where wave breaking occurs. The point selection procedure therefore gives preference to points in this area. This gives the distribution of sediment transport across the cross-shore profile, which is integrated to obtain the total longshore sediment transport rate. The grid spacing of cross-shore profile was taken as 5 m and Sediment transport computed for each grid points across cross-shore profile by STP model.

Based on the results from LITDRIFT, the LITLINE simulates the coastal response to gradients in the longshore sediment transport. The LITLINE calculates the coastline evolution by solving a continuity equation for the sediment in the littoral zone. The influence of structures, sources and sinks is included. With jetties and breakwaters, the influence of diffraction on the wave climate is included. It calculates the coastline position based on input of the wave climate as a time series. The model, with minor modifications, is based on one-line theory, in which the cross-shore profile is assumed to remain unchanged during erosion/accretion. Thus, the coastal morphology is solely described by the coastline position (cross-shore direction) and the coastal profile at a given

Fig. 7 Mudbanks locations along study region
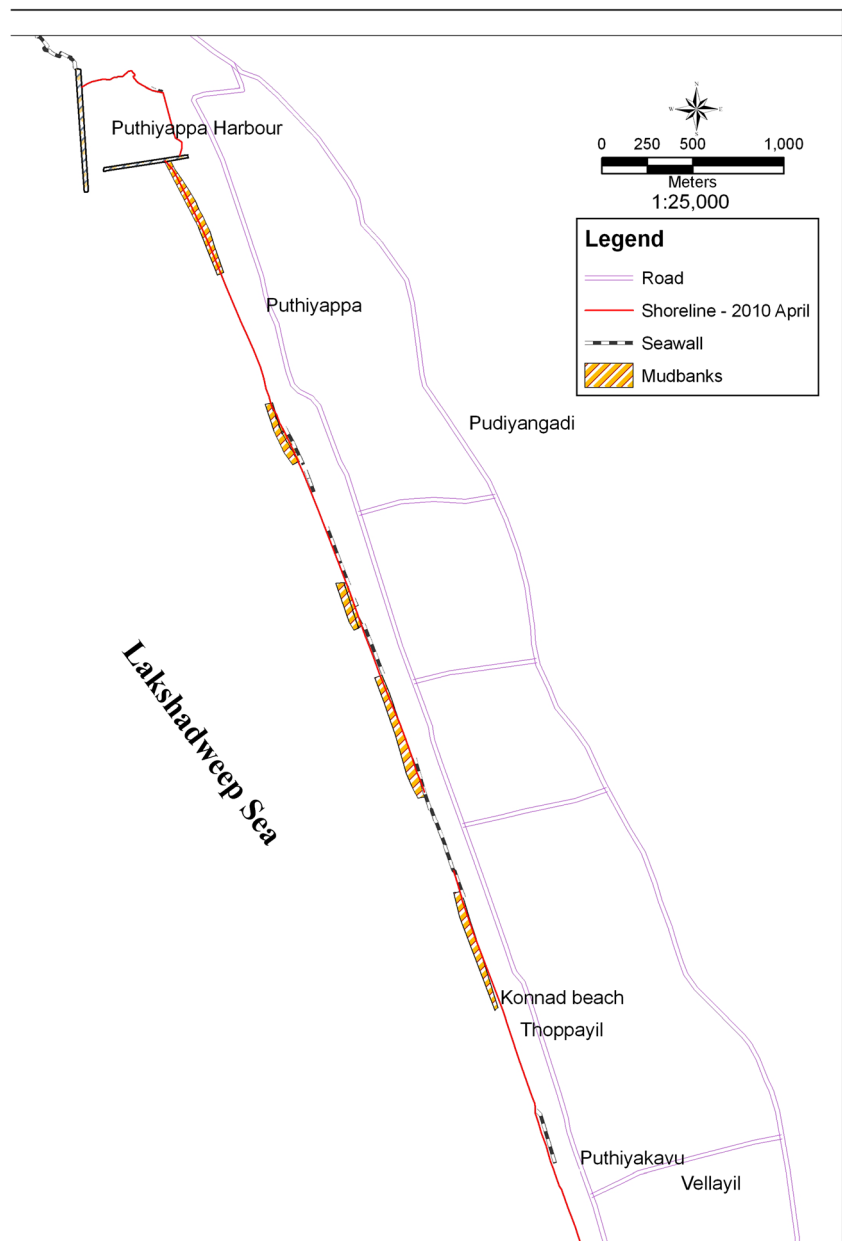
longshore position. Through successive calls to LITDRIFT, the associated program LINTABL calculates and tabulates transport rates as functions of water level, surface slope due to regional currents, and wave period, height and direction with respect to the coastline normal.

The major input for LITDRIFT model is bathymetry, which is given as cross-shore profile (Fig. 3d), and nearshore wave climate. In addition, sediment characteristics are also given as an input for LITDRIFT model (Table 1). The major inputs for LITLINE model are nearshore

Table 2 SW calibration

Location	Parameter	Measured	Simulated
Beypore at 7.5 m depth (11/11/10–01/12/10)	Hs (m)	0.47	0.62
	Wave direction (Degree)	232	223
Puthiyappa at 6.5 m depth (8/8/11–15/8/11)	Hs (m)	1.13	1.41
	Wave direction (Degree)	253	241
Puthiyappa at 5 m depth (23/1/12–09/2/12)	Hs (m)	0.47	0.49
	Wave direction (Degree	246	233

Table 3 One year wave climate in nearshore derived from SW model

Period	H_{rms} (m)	Tz (s)	Mean wave direction (Degree)
01/03/91–31/03/91	0.45	10.3	232
01/04/91–12/04/91	0.95	12.1	237
13/04/91–30/04/91	0.61	11	234
01/05/91–31/05/91	0.65	10.7	235
01/06/91–14/06/91	1.24	10.1	245
15/06/91–08/07/91	0.97	10	243
09/07/91–30/07/91	1.24	9.6	252
31/07/91–06/08/91	1.37	9.9	253
07/08/91–16/08/91	1	10.2	242
17/08/91–21/08/91	1.19	10.2	244
22/8/91–7/9/91	0.88	9.5	240
8/9/91–12/9/91	0.9	12.3	236
13/9/91–27/9/91	0.69	10.7	232
28/9/91–10/10/91	0.77	11.4	234
11/10/91–31/10/91	0.56	8.7	233
01/11/91–30/11/91	0.46	9.6	231
01/12/91–31/12/91	0.5	10.4	233
01/01/92–31/01/92	0.37	9.5	229
01/02/92–28/02/92	0.38	10.5	234

waves, initial coastline, cross shore profile and sediment transport table (LINTABLE). Initial coastline is given as a distance from baseline.

Results and discussions

Coastal processes and associated changes

Coastal processes along Kozhikode coast in detail including waves, tides, currents, shoreline change, and beach volume

Table 4 Computed sediment transport using LITDRIFT

Period	Duration (% per year)	Sediment drift (m³)
01/03/91–31/03/91	8.49	10,950
01/04/91–12/04/91	3.29	12,338
13/04/91–30/04/91	4.93	10,712
01/05/91–31/05/91	8.49	20,251
01/06/91–14/06/91	3.84	7124
15/06/91–08/07/91	6.57	10,468
09/07/91–30/07/91	6.03	−13,355
31/07/91–06/08/91	1.92	−7122
07/08/91–16/08/91	3.65	5461
17/08/91–21/08/91	1.37	2825
22/8/91–7/9/91	4.66	9569
8/9/91–12/9/91	1.37	5199
13/9/91–27/9/91	4.12	12,856
28/9/91–10/10/91	3.56	10,758
11/10/91–31/10/91	5.75	8945
01/11/91–30/11/91	8.22	11,177
01/12/91–31/12/91	8.49	15,149
01/01/92–31/01/92	8.49	8025
01/02/92–28/02/92	7.67	5841

Annual net sediment drift = 147,171 m³/year,
Annual Gross drift = 188,125 m³/year

Table 5 Estimation of beach sand mined from Puthiyappa

- 45 to 65 loads in Mini Lorry per day
- Average taken as 55 loads per day
- Approximate volume of sand contained in one lorry is 5m³
- Quantity of sand mined per day = 55 * 5 m³ = 275 m³
- Number of mining days (all days except Government holidays and Sundays) = 280 days
- Total quantity of sand mined = 280 * 275 m³ = 77,000 m³/year
- In addition to the above amount, illegal mining also takes place

change are studied by Thomas et al. (2013). The major factors responsible for coastal processes along this sector are waves. Tidal range is about 1 m for all seasons during the years 2010–12 and hence do not have much influence on the coastal process. Harbour breakwaters at Beypore and Puthiyappa and other interventions have significant influence on the shoreline processes in the coastal stretch under study. Harbour breakwaters together with Elathur headland (north of Puthiyappaharbour) make this coast a well defined sediment cell within which the sediment transport is confined. In addition to the above breakwaters, the coast has many other interventions such as seawalls, revetments, short groins and breakwaters (small having lengths 220 m north arm and 165 m length for south arm) at Kallai.

With the construction of the breakwaters at Beypore, the coast north of breakwaters along Beypore-Marad-Kozhikode began eroding which was stabilized with construction of seawalls and groins. However, the coast south of Puthiyappa harbor breakwaters accreted and widened after the construction of the breakwaters due to net northerly transport (Fig. 1). The entire coastal stretch except Marad coast has frontal beaches forming seaward of seawalls and revetments during fair season. The groin cells also have beaches during the fair season. The presence of frontal beaches indicates that erosion is limited mostly to monsoon season. Erosion along coastal stretches at Thoppayil- Puthiyakadavu-Puthiyangadi is seasonal and happens only during monsoon. These stretches have frontal beaches and seawalls have been constructed along monsoon berm crest. Thoppayil, Puthiyakadavu and Puthiyangadi sector is also a mudbank area. Based on the local information from fisher community the mudbanks have started reforming since 2010 along the sector after a gap of about 10 years. The mudbanks provide stability to the coast (Thomas et al. 2013). Down drift erosion adjoining to mudbanks may not be that serious due to the presence of wide beaches in the area. Another factor adversely affecting the stability of the above coastal stretch is the beach sand mining at Puthiyappa. The ongoing construction of harbor breakwaters at Vellayil may destabilize the stable coast.
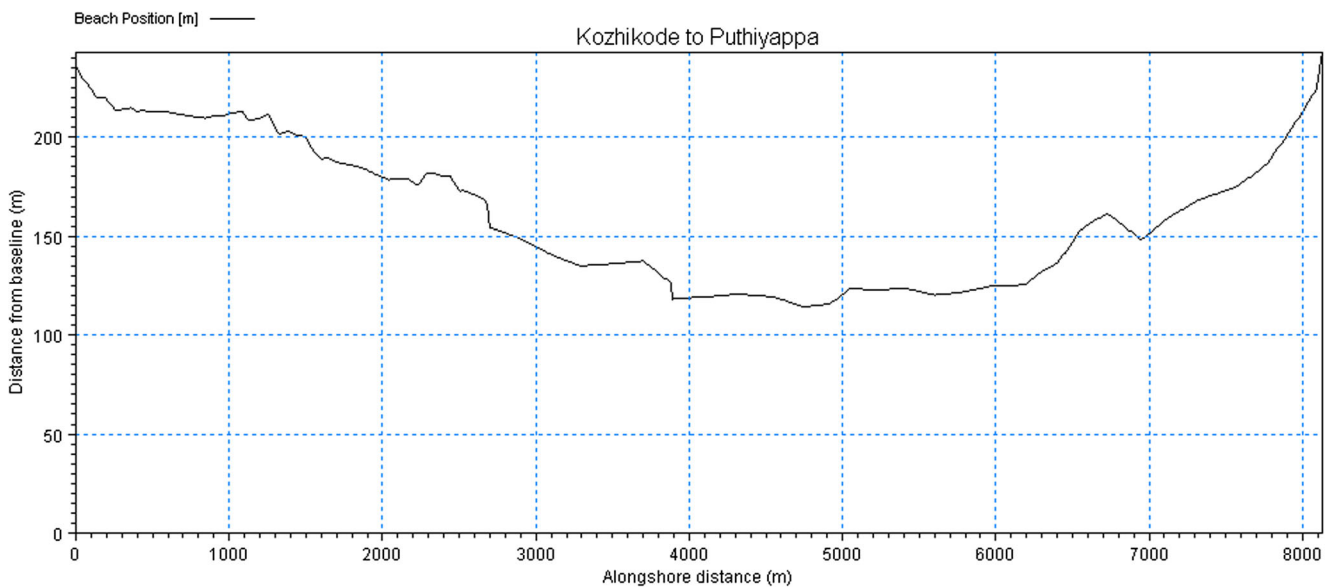
Beach Position [m] ————

Fig. 8 Initial coastline used for shoreline evolution modelling

Pre-monsoon season wave data was collected during 23rd January to 8th February 2012. Significant wave height (H_s) is mostly below 0.60 m and zero crossing period (T_z) is generally between 6 to 9 s (Fig. 4). The dominating mean wave direction is 240–260^0. During the monsoon season (August) wave height is comparatively higher. The H_s ranged between 0.8–1.6 m and highest H_s was obtained on 22nd August (Fig. 5). Dominating mean wave direction was 240–260^0 and T_z

was between 6 and 9 s. Wave characteristics did not show much variation compared to pre-monsoon season, which could be due to data collection period coincided with the break period in the monsoon.

Wave data was collected during post monsoon in the year 2010 for understanding the wave characteristics during the mudbank period. H_s in the nearshore at Puthiyappa are abnormally low because of the presence of mudbanks, which dampens waves. Mudbank effect was noticed after 3 days of
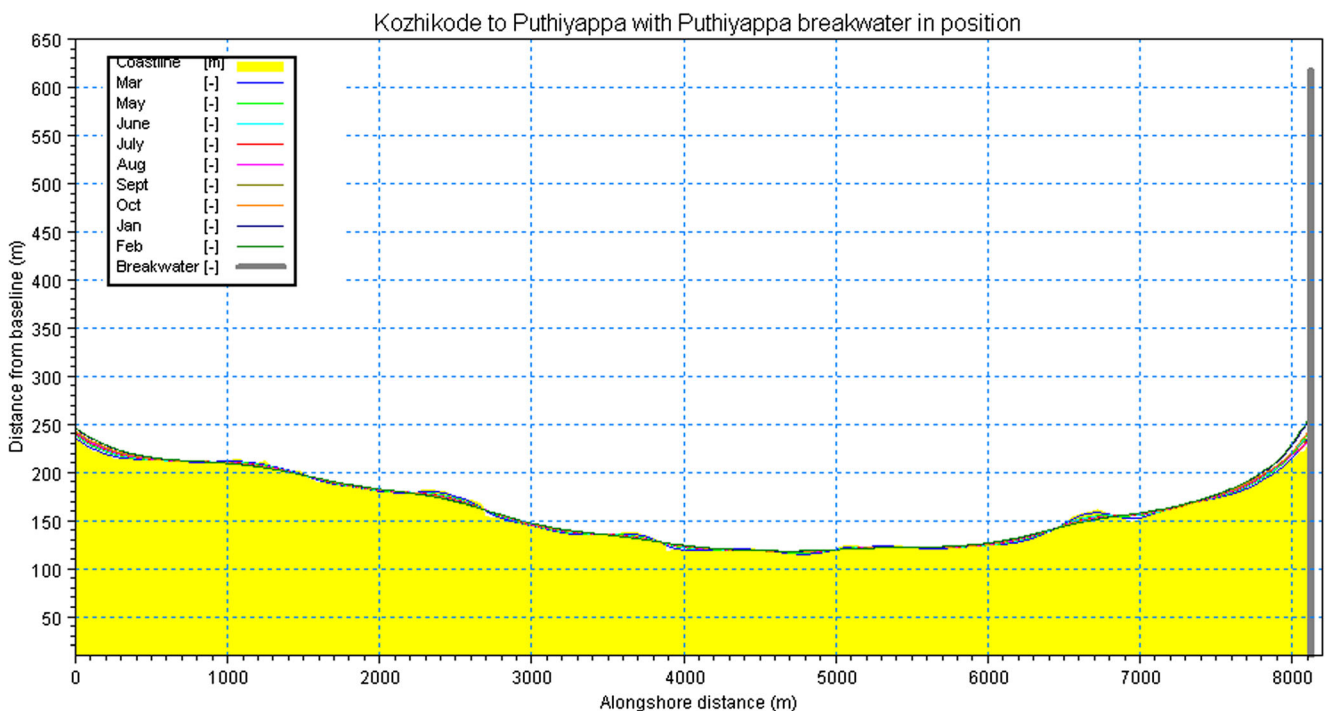

Fig. 9 Shoreline evolution for one year (Kozhikode to Puthiyappa)

instrument deployment (Fig. 6a). Waves were mostly of 0.10 m once the mudbanks formed and Maximum wave height (H_{max}) was also very low during those periods (Fig. 6a). Offshore station at Puthiyappa was beyond the mudbank area. Hence normal wave pattern was observed and the H_s was in the range of 0.2 to 1.3 m (Fig. 6b).

Mudbanks formed along Puthiyappa-Vellayil sector during the year 2010–2011. Puthiyappa is a one of the earliest mudbank locations and it did not occur for about 10 years before reappearing in 2010 (Fig. 7). The mudbanks appeared along this sector during the latter half of monsoon. The presence of mudbanks is another reason for the beach build up towards south of Puthiyappa breakwater (Fig. 1). It is also noticed that part of the mudbank gets segmented and migrates along Puthiyangadi - Vellayil sector triggering erosion at down drift locations of mudbank segments.

Annual longshore sediment transport

H_s and mean wave direction, extracted from the wave data off Kavarathi using a calibrated MIKE 21 SW model (Thomas et al. 2013), are found to be comparable with those of nearshore observations (Table 2). Measured shallow water data are not available for the same period (1991–92) and hence the model result is compared with the shallow water wave data available during 2010–12. One year wave climate derived from calibrated SW model was used to compute sediment drift and shoreline evolution along the study sector for a period of one year (Table. 3). The longshore sediment transport

obtained from model results shows that net northerly drift is about $1.5 * 10^5$ m³/year (Table 4). Northerly transport was dominant throughout the year except 2nd week of July to 1st week of August. Maximum northerly transport was obtained during the month of May and Northerly transport is more prominent during September to December.

Based on the data collected from Harbour Engineering Department, $0.77 * 10^5$ m³ sediment is approximately being dredged from Puthiyappa (Table 5) in a year. Illegal mining also takes place in the region. The values indicate sediment transport model results are comparable with the present quantity of dredging from Puthiyappa. Also, the present model result is comparable in magnitude but differs in direction from earlier studies (Sajeev et al. 1997; Kumar et al. 2006). Morphological indicators such as sand deposition close to groins and breakwaters support the present model results.

Shoreline evolution

Shoreline evolution modelling work was carried out for Kozhikode to Puthiyaapa sector (middle to north) where seasonal erosion occurs during the southwest monsoon. Initial coastline is given as a distance from baseline. The baseline is drawn in such a way that the normal with respect to true north is 250^0. The initial coastline is digitized at 10 m interval (Fig. 8). The grid numbering starts from extreme south at Kozhikode Pier to extreme north at Puthiyappa breakwater. The cross-shore profile used for modelling is shown above (Fig. 3d). Model was run including Puthiyappa breakwater
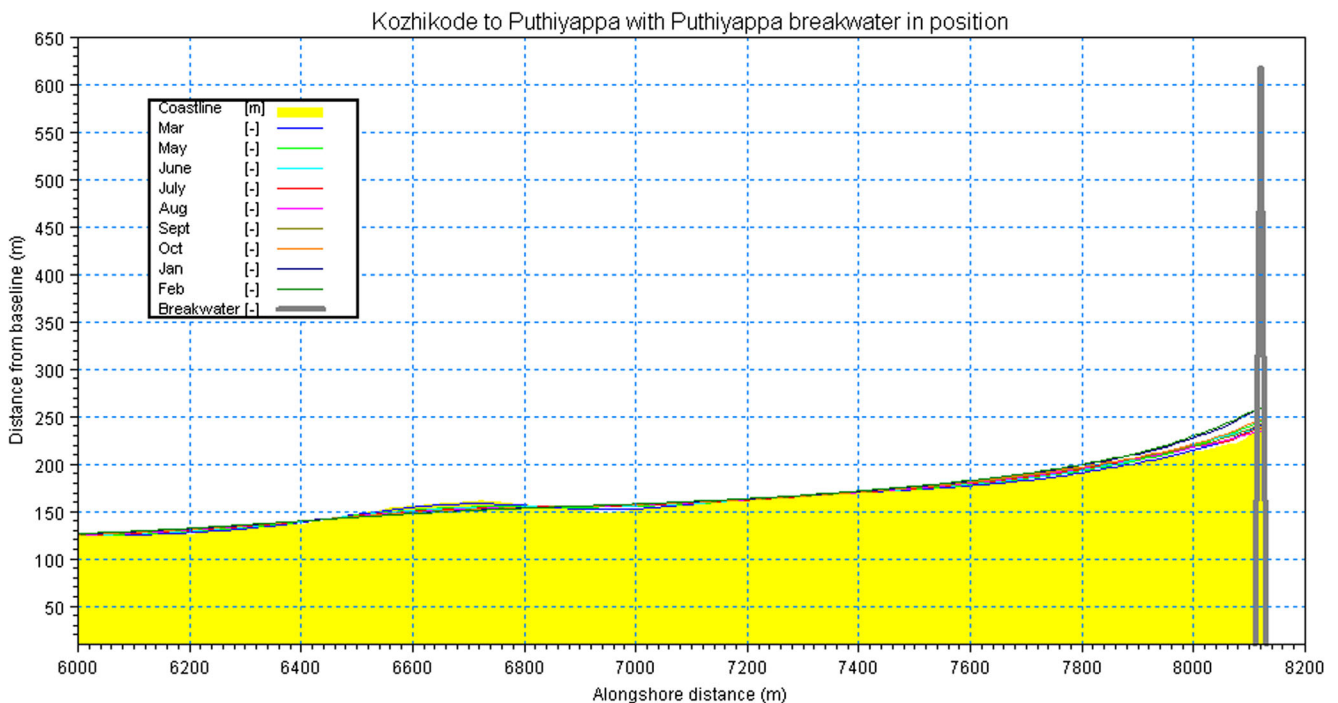

Fig. 10 Shoreline evolution close to Puthiyappa breakwater

in position and result is shown in Fig. 9. Major accumulation was observed upto 500 m towards south from Puthiyappa breakwater (Fig. 10). Beach advances from March to May and started to erode during the monsoon; and beach rebuilding starts by end of September.

Shoreline management plan

Coastal processes studies and various interventions and the associated impacts give an understanding of the extent of eroding coastal stretches which require management. The major settlements/investments which are affected by erosion have seawalls and groins. Except in Marad area these protection measures have frontal beaches during monsoon indicating fairly stable coast. Hence, the current status of erosion is not very serious warranting major interventions as the existing coastal protection measures are serving the purpose. These require only maintenance. Continuous monitoring of the protection measures are required to plan appropriate maintenance measures in advance. These areas include Beypore to Valiyangadi sector. Thoppayil, Puthiyakadavu and Puthiyangadi have beaches and are affected by only seasonal erosion during monsoon season. These require temporary management measures such as stacking of sand filled sacks. The occurrence of mudbanks in this region adds to the stability of this coastal stretch. Sand getting deposited at Puthiyappa could be used for the purpose. The same measure could be adapted to the coast immediately north of Valiyangadi where the possibility of end erosion exists. As an additional protection to the seawalls at Marad where no frontal beaches forms, a few short transitional groin fields are proposed. Transitional groins will reduce the erosion in downdrift side (Sundar and Sannasiraj 2006). This could develop frontal beaches and also trigger more sand deposit at Gotheswaram and south. The loss of beach sand to the coastal system due to mining of sand at Puthiyappa has to be controlled. Instead of mining sand for commercial purpose, the excess sand could be redistributed to the entire coastal area where there is deficiency of sand and to the existing and proposed groin cells so that the beach sand is made available for the waves and other coastal processes for redistribution.

Conclusion

Beypore to Valiyangadi has been an eroding coast which is now protected by seawalls and groins. No further intervention along this sector is required except for proper maintenance of the existing structures. Kozhikode to Puthiyappa is stable or accreting with the presence of mudbanks and beach build up south of Puthiyappa breakwater. Excess sediment available south of Puthiyappa harbour is being mined continuously and auctioned by Harbour Engineering Department. Thus

the sediment transported towards the breakwater is lost to the coastal system affecting the monsoon sediment redistribution processes. The sediments coming to the sector was estimated using numerical model and it is comparable with the field data. The shoreline evolution modelling results are also comparable with present observations. The results indicate that the sediment transport direction reported from earlier studies requires correction. Erosion at Vellayil and Puthiyangadi during monsoon could be addressed through temporary measures like stalking of sand filled bags prior to the onset of monsoon with continuous maintenance during monsoon. The excess sand available at Puthiyappa could be used to replenish beach sediment at Vellayil and Puthiyangadi and adjoining areas.

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