Conference Paper, Published Version

Nair, L. Sheela; Sundar, V.; Kurian, N. P.

Numerical Model Studies on Coastal Processes in a Critically Eroding Sector of South West Coast of India

NUMERICAL MODEL STUDIES ON COASTAL PROCESSES IN A CRITICALLY ERODING SECTOR OF SOUTH WEST COAST OF INDIA

L.Sheela Nair[1], V.Sundar[2] and N.P.Kurian[3]

Abstract: *The Kayamkulam-Arattupuzha sector of the SW coast of India has been an eroding coastline for the past two or three decades. Since 2000, there has been a drastic change in the erosion pattern and this is attributed mainly to the impact of two long breakwaters constructed as part of development of a fishing harbour at Kayamkulam. The breakwater construction, which started in the year 2001, was finally completed by 2007. Contrary to the pre-breakwater construction period, the coastal stretch to the immediate south of the breakwater has become an accreting beach whereas the region to the north of inlet continues to be an eroding site, with an increase in the erosion rate. The coastal processes and shoreline evolution in and around the Kayamkulam inlet and particularly the sector north of it over the years have been studied through numerical modeling using the various modules of MIKE21 modelling system and LITPACK. The environmental data used for the present study includes waves, wind, tide and sediment characteristics. The bathymetry data for the study area was obtained from CMAP and for the innershelf region this was further supplemented by the fine grid bathymetric survey data. The model calibration and validation were done by fine tuning the numerical model results by comparing with the available recorded data at selected locations along the coast for various parameters like nearshore waves, current and shoreline changes made during different periods. The study elucidates the fact that the construction of breakwater has aggravated the retreat of the shoreline of this coast particularly the region to the north of the breakwater. This also points out the need to have an integrated coastal management approach wherein shoreline management plans are also developed and implemented along with the execution of the project to counter the negative impacts whenever major projects like construction of breakwaters and other coastal structures are undertaken.*
Keywords: *breakwater; coastal processes; numerical modeling; shoreline evolution.*

INTRODUCTION

The Kayamkulam-Arattupuzha coastal stretch, which forms part of the Kayamkulam – Thottapally sector of southwest coast of India has been an eroding site for the last two to three decades (Sreekala et al., 1998). The Kayamkulam-Thottapally sector is a 22 km stretch of barrier beach of varying width located to the north of Kayamkulam inlet. It has the Lakshadweep Sea as boundary on the western side and the Kayamkulam backwater and Pallana river on the eastern side as boundaries. There is a perceptible variation in the width of this barrier beach as we move

1 Research Student, Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai 600 036, & Scientist, Marine Sciences Division , Centre for Earth Science Studies, Thiruvananthapuram 695 031, India, Email: sheela06@gmail.com
2 Professor, Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai 600 036, India, Email: vsundar@iitm.ac.in.(Member, IAHR).
3 Scientist, Marine Sciences Division , Centre for Earth Science Studies, Thiruvananthapuram 695 031, India, Email: npkurian@gmail.com

towards the north of Kayamkulam inlet with the narrow region near the inlet. The southern side of Arattupuzha coast which is about 5km to the north of Kayamkulam inlet consists of a few marshy and inter-tidal areas. Because of this the southern sector of Arattupuzha coast often gets inundated from both the sea and the backwater sides and it is all the more common during the monsoon season. As this region falls under the moderate wave regime, wave action is the primary source of energy available in the nearshore zone and this probably could be the main factor responsible for the coastal processes influencing this region. Kurian et al. (2007) have reported that severe erosion occurs in this stretch of the barrier beach during the southwest monsoon season when the wave activity is at its peak. However the Thrikunnapuzha coastal stretch which is having lesser number of intertidal/marshy and mangrove areas has a wider beach between the Pallana river on the eastern side and the sea. This stretch appears to be a stable coast except for occasional incidents of erosion reported during the monsoon period of high wave activity. In most of the cases this is directly linked to the formation of mudbanks further north of the region as the Thrikkunnapuzha-Thottapally sector is famous for the regular occurrence of mudbanks during monsoon. Applying the concept of sediment cell the Kayamkulam-Thottapally sector of 22km length, can be easily considered as a sediment sub-cell with prominent morphological features like tidal inlets as boundaries at both ends. Using this concept the observed variation in the shoreline changes over the years which could be either spatial, temporal or both can be assumed to be self contained. Hence for identification of the causative factors that are responsible for the observed changes in coastal processes it is enough to restrict the study to this sediment cell. The Kayamkulam-Arattupuza stretch being densely populated there is enormous pressure on this barrier beach and the high erosion rate seen in this region has always been a matter of concern particularly for the local people. At many places all along the backwater boundary the backwater has been reclaimed. Since the main livelihood of the local people is from fishing and related activities, their relocation is not a viable solution. The only option left is to have an appropriate shore protection measure that will ensure the development of a stable coastline with a sustainable beach. Although various protection measures like construction of seawalls had been adopted and implemented at various stages for the protection of the coast, none of these measures has been effective in the long run for controlling the erosion. This is mainly because the shore protection measures implemented so far have been done in a piece meal fashion without making any attempt to understand the coastal hydrodynamics. Anthropogenic activities like construction of breakwaters at Kayamkualm inlet as part of developing new fishing harbour and wide spread sand mining for heavy minerals within this sector also have contributed significantly to the deteriorating condition of the beach. The present study aims at understanding the coastal hydrodynamics of the region through numerical modeling using the state of the art modeling software like MIKE21. Based on the results of this study appropriate shore management plan for the entire sector can be recommended.

Study area

The study area is the Kayamkulam-Thottapally sector (Fig.1) of the southwest coast of India. The 25km coastal stretch extends from Azheekal (Lat. 9.9^{o}N, Long. 76.485^{o}E) located 2.5km to the south of Kayamkulam inlet to Thottapally inlet (Lat. 9.33^{o}N, Long. 76.375^{o}E) in the north, which is a seasonal inlet. To study the impact due to the newly constructed breakwaters of lengths 720m (southern arm) and 485m(northern arm) at the Kayamkulam inlet a small stretch of coast 2.5km to the south of the inlet also has been considered.

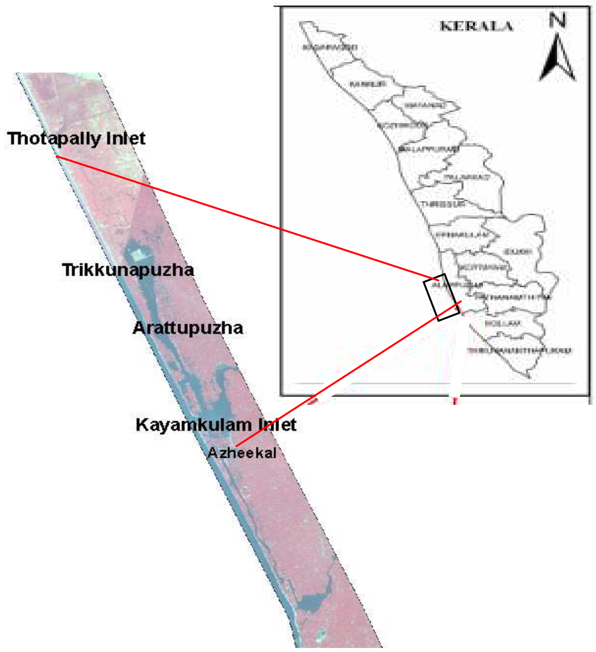


Fig.1. Location map of the study area

Methodology

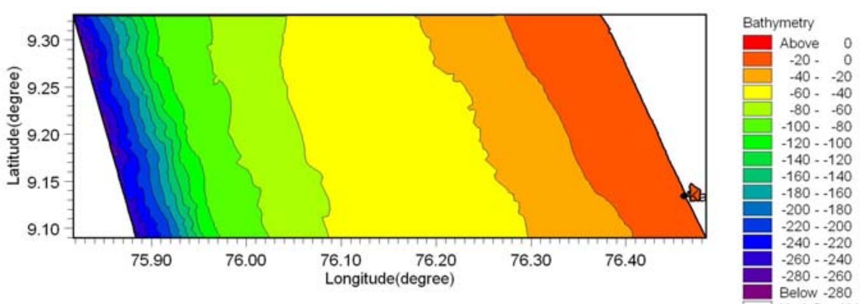
Numerical model studies have been carried out using the various modules of MIKE21 Numerical Modelling Suite. For computation of wave transformation from deep water to nearshore region the MIKE 21 Spectral Wave (SW) model was used. The model is capable of simulating the growth, decay and transformation of wind generated waves and swells in both offshore and coastal areas. MIKE21 SW is a new generation spectral wind-wave model based on unstructured meshes, which takes into account all the important phenomena like wave growth by influence of wind, non-linear wave-wave interaction, dissipations due to white-capping, bottom friction and depth-induced breaking. It can also model diffraction effects due to the presence of large structures which becomes increasingly important in the presence of coastal structures like breakwaters, groins etc. The effects of refraction and shoaling of waves due to depth variations and wave-current interaction are also considered in the model. The outputs from the model are the regular wave parameters which include the significant wave height, mean wave period, mean wave direction, directional standard deviation and also the wave radiation stresses required as input for running the hydrodynamic module.

The Hydrodynamic (HD) and Sand Transport (ST) modules of the MIKE21 Flow Model-Flexible Mesh(FM) series have been used for the modeling of the coastal circulation and nearshore sediment transport pattern along the Kayamkulam-Thottapally coast. The modelling system has been developed for complex applications within oceanographic, coastal and estuarine environments. It simulates the water level variations and flows in response to a variety of external forcing functions and includes features that accounts for the effects of flooding and drying, momentum dispersion, bottom shear stress, coriolis force, wind shear stress, tidal potential, wave radiation stresses, etc. It is based on the numerical solution of the two-dimensional incompressible Reynolds averaged Navier-Stokes equations subject to the assumptions of Boussinesq and of hydrostatic pressure. Thus, the model consists of continuity, momentum, temperature, salinity and density equations and it is closed by a turbulent closure scheme.

Coastline evolution analyses have been performed with the LITLINE module of LITPACK modeling system from DHI. LITLINE simulates the coastal response to gradients in the longshore sediment transport capacity resulting from natural features and a wide variety of coastal structures. LITLINE calculates the coastline evolution by solving a continuity equation for the sediment in the littoral zone. The influence of structures, sources and sinks are also included. The basic input data for running the model are the longshore relative coastline alignment, cross-shore profile description and bathymetry, active depth of transport and depth contour angles at each grid point, environmental data with wave properties, tidal currents and water levels position and size of structures etc.

Model Setup

Since the Kerala coast has a dominant presence of south-west monsoon (June-September) and the consequent seasonal variations, two separate models have been set up for simulating the wave and circulation pattern. The waves are predominantly in the westerly direction and are more vigorous during the monsoon season when compared to the non-monsoon season where the waves are mostly coming from the southwest direction. The bathymetry data for the model was



obtained using MIKE C-MAP digital charts. MIKE C-MAP works on the Global Electronic Chart Database CM-93 provided by Jeppesen Norway.

For the nearshore region, fine bathymetry grid data compiled from shallow water bathymetry survey of the region conducted by CESS under the various projects were used. The model domain (Fig.2) selected for the study is about 25km x 75km with a maximum water depth of about 280m. An unstructured mesh was created with local refinement in the nearshore region and also in the area adjoining the breakwater.

The model was set up with three open boundaries – north, south and west and a land boundary on the eastern side. For running the SW model, for the western open boundary, the offshore buoy data from National Institute of Ocean Technology (NIOT), which includes wave parameters like significant wave height, mean wave direction, peak wave period and directional standard deviation were given as input. The other two open boundaries – i.e. the northern and southern boundaries were defined as lateral boundaries.

For setting up of the Flow Model (Flexible Mesh –FM) the surface elevation or tidal variation at the open boundaries were given as input. The wind data for the region, sediment characteristics and output from the SW model which gives the wave radiation stresses were also provided.

The hydrodynamic data (tides, wind, wave, current, sediment characteristics) compiled by Centre for Earth Science Studies (CESS), Trivandrum under various projects were used for the present work. Since the data available with CESS is mostly confined to the nearshore region, the deep water met-ocean parameters required for defining the offshore boundary conditions were obtained from offshore buoys located in the Arabian Sea during the study period. NIOT, Chennai has provided data from the two deep-water buoys DS2 & DS7 for the year 2005.

The model calibration was done by fine tuning the model by adjusting the bottom friction parameter which is normally expressed in the form of seabed roughness. For this the simulated results from MIKE21 were compared with the corresponding measured values at Thrikunnapuzha, a coastal station located almost mid-way between Kayamkulam and Thottapally.

RESULTS AND DISCUSSION

Separate models have been set up using the various modules of the MIKE21 modelling system for the two distinct seasons of monsoon and post-monsoon to simulate the wave, current and sediment transport patterns. The results are analysed to bring out the seasonal variation in the nearshore coastal processes and their impact on the coastal area. The nearshore wave climates during the two seasons being entirely different there is a marked difference in the nearshore circulation and sediment transport pattern. The spatial and temporal impact due to various anthropogenic activities like the construction of breakwaters at Kayamkulam on the shoreline has also been critically analysed by conducting a one dimensional shoreline change study using LITLINE module of LITPACK modelling system.

The mean value of significant wave heights for the study area during the monsoon (Fig.3(a)) is between 1.2m and 1.35m and for the post-monsoon season (Fig.3(b)) it is in the range 0.75 to 0.9m. There is, however, a small reduction in the wave activity in the immediate vicinity of the breakwaters (particularly southern arm of the Kayamkulam breakwater) due to the shadowing effect. The mean wave direction during monsoon (Fig.4(a)) is in the range of 250-275^{o} indicating south -westerly to westerly waves and peak wave period is 11s whereas it is 240-280^{o} (Fig.5(b)) and 17s respectively during post-monsoon. There is also a noticeable change in the mean wave direction at the boundaries, adjacent to both the breakwaters, compared to the general trend. This apparently is due to the localized change in the wave pattern due to the presence of the breakwater and the related effects of diffraction and refraction. A less intense wave activity in the immediate vicinity of the breakwater followed by high wave activity at a distance of 1.5 to 2km on either side of the breakwaters is very conspicuous during both the seasons. The results clearly indicate the construction of breakwaters at Kayamkulam has certainly had an impact on the coastal processes of the area. These results are in confirmation with the field observations of high erosion reported along the Kayamkulam-Thrikkunnapuzha stretch.

The mean current speed during monsoon (Fig.5(a)) is in the range of 0.1-0.2m/s and there is a distinct increase in current speed (0.26m/s) observed at the tip of the Kayamkulam breakwater (Fig.6 (a)). The mean value of nearshore current varies between 0.07 and 0.2m/s on the northern side whereas the spatial variation in mean current speed is between 0.03 and 0.1m/s to the south of the breakwater. The results of the post-monsoon (Fig.5(b)) simulation show comparatively stronger currents. The mean current speed in the region to the north of Kayamkulam inlet varies between 0.11 and 0.14m/s whereas it is between 0.2 and 0.3m/s on the southern side. The mean current speed at the mouth (Fig.6(b)) of the inlet during post-monsoon is around 0.4m/s.

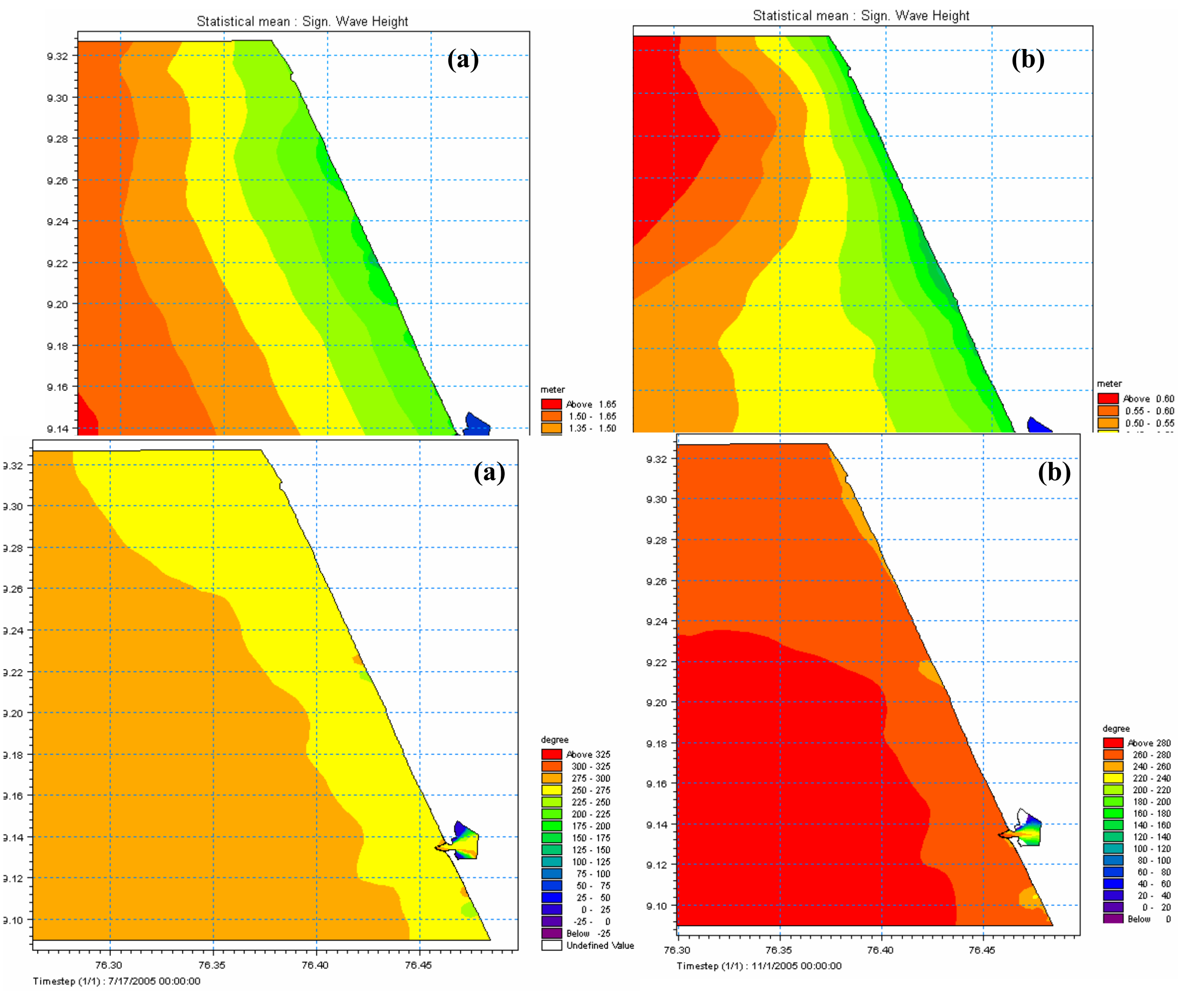
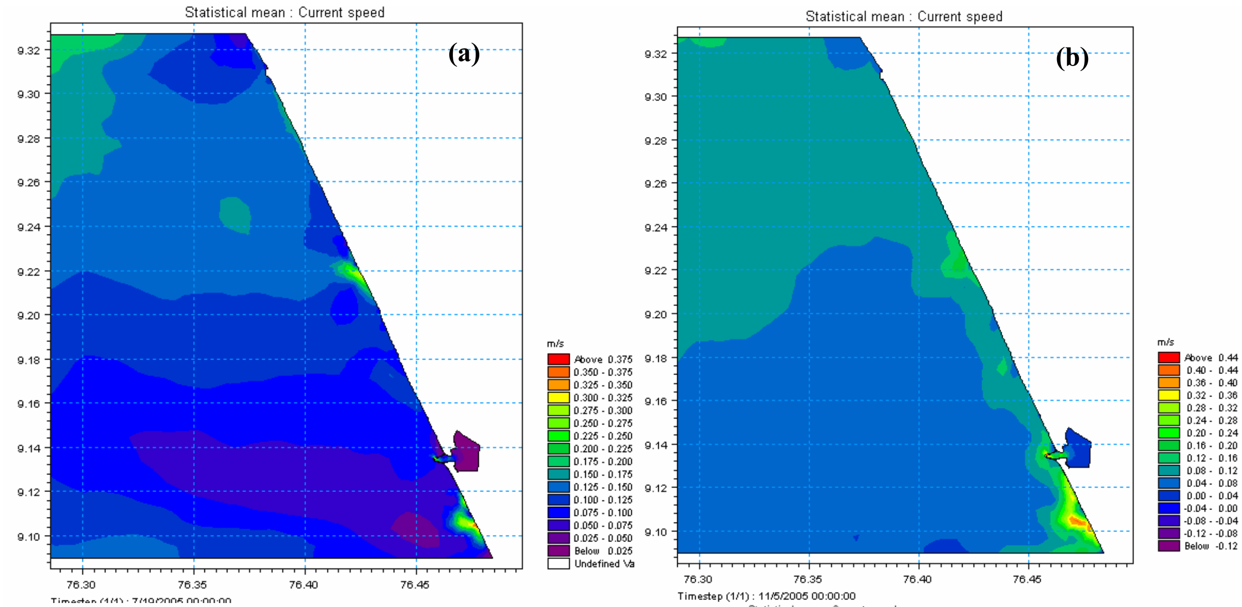
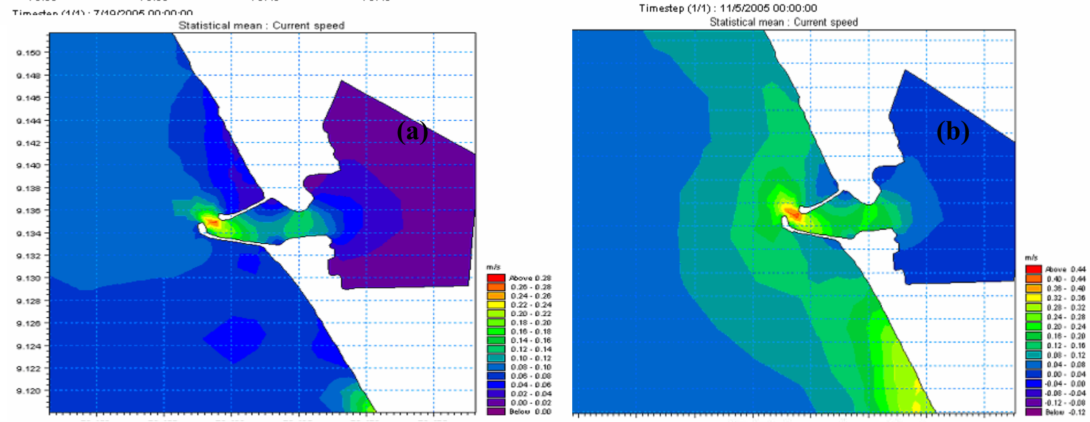


Fig.4. Mean wave direction during (a)monsoon and (b) post-monsoon





nsoon

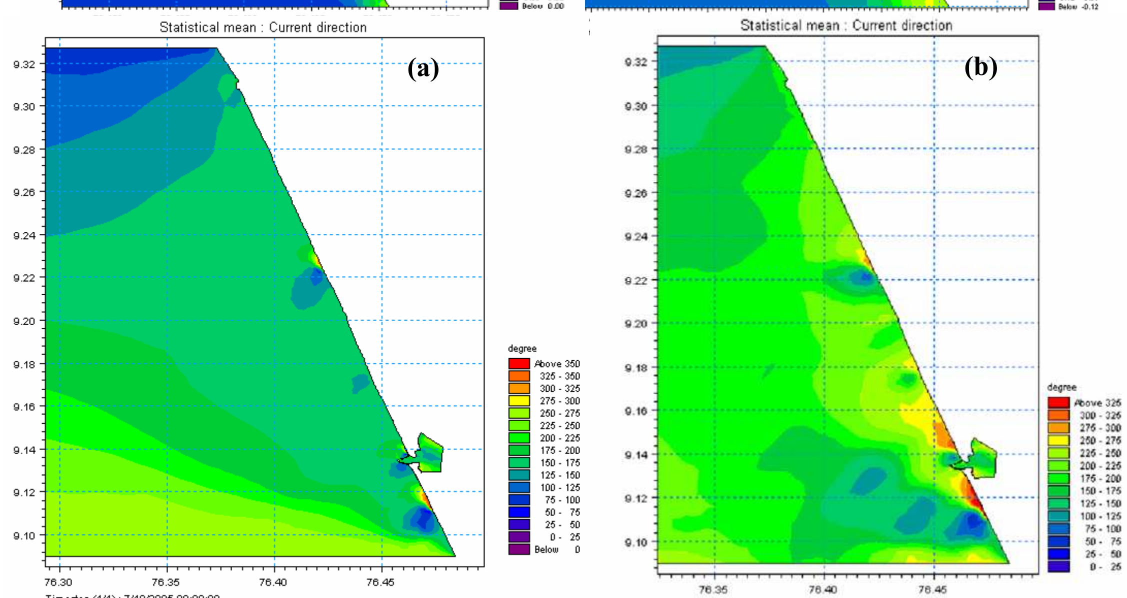


Fig.7. Mean current direction during (a) monsoon and (b) post-monsoon

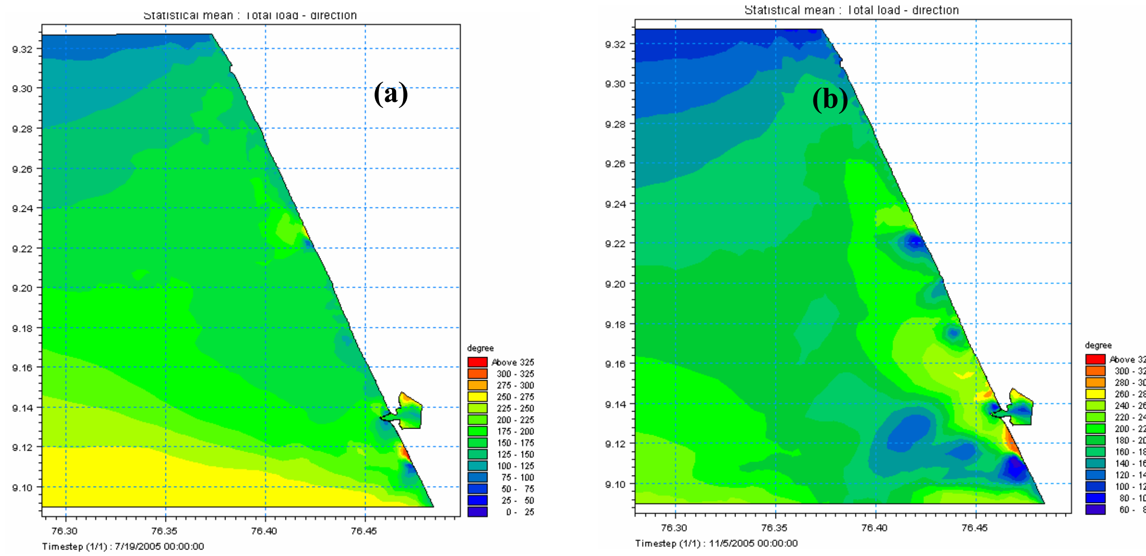


Fig.8. Mean total load direction during (a)monsoon and (b) post-monsoon

The nearshore mean current direction for the monsoon season (Fig.7(a)) is mostly in the West Southwesterly direction (250 - 275^{o}) except for the 1.5-2 km stretch south of Kayamkulam breakwater where the mean current direction ranges from 270^{o} to 300^{o}. This localized effect is clearly due to the recent accretion in the area that has developed as a result of the breakwater construction. The general current pattern indicates a predominantly southerly trend. During the post-monsoon season (Fig. 7 (b)) the mean current direction for the study area varies between 200^{o} and 240^{o} (SSW to WSW).The mean current direction during post-monsoon for the nearshore region immediate south and north of the breakwater is between 250^{o} and 300^{o}.

The sediment transport rates and the bed level changes for the two seasons also have been computed (figures not presented). The sediment transport rates in the nearshore region are relatively small and the direction is mostly southerly during monsoon (Fig.8(a)). For the post-monsoon season (Fig. 8(b)) an onshore movement is seen. The simulated bed level changes indicate an eroding tendency all along the coast during monsoon. The corresponding bed level changes for the post-monsoon season indicate a marginal increase in bed level. There are also indications of sediment deposition near to the tip of the southern arm and both sides of the breakwater.

Shoreline evolution

The shoreline evolution pattern for the Kayamkulam coast has been simulated using the LITLINE module of DHI's coastal sediment transport modeling system LITPACK. Shoreline change model was set up by giving the latest coastline and cross-shore profiles and the nearshore wave climate at depth of closure/nearshore region as inputs. The nearshore wave climate (Table 1) was derived from the measured wave data (Kurian et al 2007) at Thrikunnapuzha coastal station for the three seasons viz. pre-monsoon, monsoon and post-monsoon during 2004.

The simulated shoreline evolution pattern for 25 years with the breakwater is presented in Figs.9 and 10.The results (Fig.9) indicate that if this sector of the coast is left in the present condition, the area to the North of Kayamkulam inlet would be badly affected. The alongshore extent of erosion is observed up to 7.5 km from the inlet (i.e. from the northern arm of the breakwater). Of

Table 1. Input wave data for shoreline change studies

Season	Duration (% of year)	H_{rms} (m)	MWD°N	Tz (s)
Pre-monsoon	33.50	0.81	226	8.60
Monsoon	33.00	2.24	246	8.00
Post-monsoon	33.50	0.86	204	9.00

this the 4.5km coastal stretch, located at a distance of 0.75km to the north of the inlet has been identified as a critically eroding area experiencing very high rate of erosion especially in the first 10 years, after the construction of the breakwaters. At the same time an accreting tendency is seen over a very small coastal stretch of 100m adjoining the northern arm of the breakwater and this corroborates well with the field observations reported by Thomas et al. (2010) and the latest satellite imageries available for the area. The computed shoreline evolution pattern also indicates that this accretion would gradually extend to the northern side with the passage of time and the rate of accretion would be more once the sediment bypassing to the north of Kayamkulam breakwater starts. As per the trend in the shoreline change, a maximum 60m width of beach in the area adjacent to the breakwater would be lost in 25 years. The pattern of shoreline evolution predicted using LITLINE is strikingly similar to what is observed in the field as reported by Kurian et al. (2007). Even though the area of interest is the region to the north of Kayamkulam, a stretch of 2.5km to the south of Kayamkulam was also included in the model domain to have a complete study and assessment of the impact due to the construction of breakwaters on the adjoining coastline. Fig.10 gives the predicted shoreline changes over a period of 25 years along the coastal stretch to the south of the inlet. The simulated shoreline evolution pattern clearly indicates that there is an accreting tendency to the south of the inlet and is in agreement with field observations made by Thomas et al. (2010). But at the same time severe erosion is also seen at a distance of around 2km to the south of the inlet.

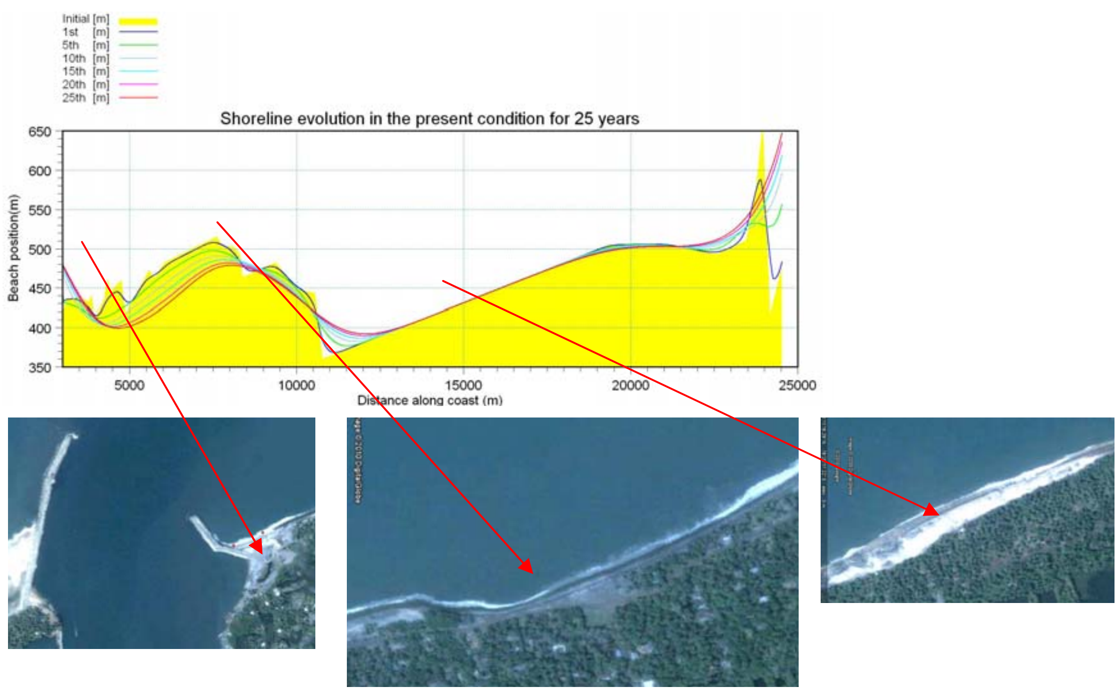


Fig.9. Simulated shoreline evolution pattern for 25 years in the present condition validated with satellite imageries

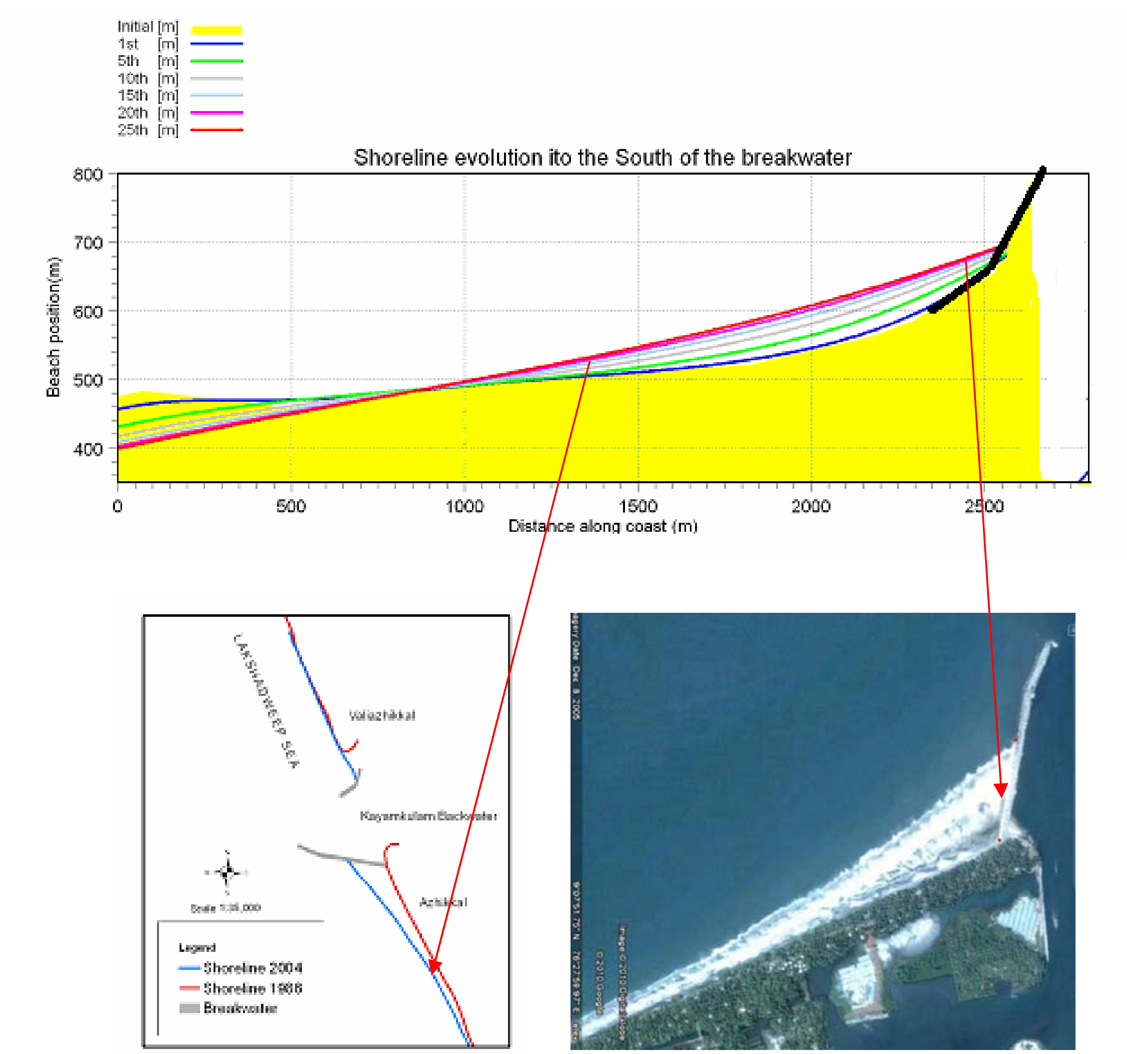


Fig.10. Validation of the simulated shoreline evolution for the region to the south of the breakwater with field observations (a) from Thomas et al. (2010) (b) Google image

Based on the results of the shoreline evolution pattern for 25 years, the most appropriate shore protection measure for the area under study can be recommended. The predicted shoreline changes for 25 years clearly indicates that only a small stretch of the coast, of approximately 5km length, to the north of the inlet needs immediate attention. Beach nourishment which is an environment friendly soft measure is recommended for the Kayamkulam-Arattupuzha stretch as the material required for nourishment is locally available. The sand deposited on the southern side of the breakwater can be used for nourishment as this material will have the same sediment characteristics as the one which is normally available during the post-monsoon season of beach formation. The nourishment rate can be gradually decreased when the sediment bypassing commences. In the present scenario this would be the most optimum and technically and economically viable option for the area. The region to the north of Arattupuzha appears to be stable and can be left as it is.

CONCLUSIONS

A critical examination of the results of the numerical modelling work for the two distinct seasons, clearly indicates that the Kayamkulam-Arattupuzha coastal stretch is a critically eroding site. The results of the numerical modeling studies clearly indicate accretion in the immediate vicinity of the breakwaters. The increased rate of erosion seen along the north of Kayamkulam inlet (a stretch of 6 to 7.5km from the inlet) is clearly due to anthropogenic activities like the construction of breakwater and mining in this area. Even though the post-monsoon results show some sediment deposition all along the coast the quantity that is coming to the area is not sufficient to maintain the balance. The increased rate of deposition seen along the southern arm of the breakwater is a clear indication of net northerly drift in this region. The moderate to high rate of erosion seen along the Kayamkulam-Arattupuzha stretch is likely to continue for a few more years till the bypassing of sediment to the north of the southern breakwater commences. Beach nourishment is recommended for the Kayamkulam-Arattupuzha stretch.

ACKNOWLEDGEMENTS

The Ministry of Earth Sciences is thanked for funding the Shoreline Management Project under which the data was collected. The authors are thankful to Dr. M.Baba, former Director, CESS, for the support and encouragement given for the work. The deep water data for the model study was provided by NIOT. The entire project team of the Shoreline Management Project is specially acknowledged for their involvement in field survey and data collection. Thanks are due to Arjun S, Kalarani, Praveen S.S, Shanavaz C.P. and Shamji V.R. for their support towards data collection and preparation of diagrms.

REFERENCES

Thomas, K.V., Kurian, N.P., Sundar, V.,Sannasiraj, S.A., Badarees, K.O., Saritha, V.K., Abhilash, S., Sarath, L.G., Srikanth, K. 2010. Morphological changes due to coastal structures along the southwest coast of India. *Proceedings on Joint Indo-Brazil Workshop*, 125-133 pp.

Kurian, N.P., Thomas, K. V., Shahul Hameed, T. S., Ramachandran, K.K., Sheela Nair, L., Ramana Murty, M.V., Subramonian, B.R., Pillai, A.P., Kalaiarasan, P., Rajith, K., Murali Krishnan, B.T., Indulekha, K.P., Sreejith, C., Anil, T., Asha, V., Shamji, V.R., Manjunath Bhat, Edwin Rajan. 2007. Shoreline management plan for Munambam-Kayamkulam sector, south-west coast of India , *Final Project Report, CESS, Trivandrum,* 149-151, 173 pp.

Sreekala, S.P., Baba, M. and Muralikrishna, M. 1988. Shoreline changes of Kerala coast using IRS data and aerial photographs. *Indian Journal of Marine Sciences,* V.27(1), 144-148pp.