SSRG International Journal of Civil Engineering
ISSN: 2348-8352/https://doi.org/10.14445/23488352/IJCE-V10I7P102

Volume 10 Issue 7, 29-44, July 2023

Original Article

Shoreline Changes around Three Estuarine Harbours on Kerala Coast in India

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Received: 18 April 2023 Revised: 22 June 2023 Accepted: 11 July 2023 Published: 31 July 2023

Abstract *- The shoreline, the land and water boundary is subjected to periodic changes due to different dynamic factors like, bathymetry, wave characteristics, currents, and coastal orientation. Coastline variation leads to erosion and accretion phenomena on the coast. In the present study, the coastal changes around three estuarine harbours along Kerala coast in India are analysed by using numerical method. The impact of harbour constructions on shoreline are assessed from this study. Mike 21 SW and LITPACK modules are used to predict the shoreline changes at these three estuarine harbour sites along Kerala coast. The analyses on coastline oscillations around three estuarine harbours show significant impact of harbour constructions on adjacent coast.*

Keywords *- Accretion, Breakwater, Erosion, Harbour, LITPACK, Shoreline.*

1. Introduction

The physical boundary between water and land is considered as the idealized definition for shoreline (Dolanet al.1980). Actually, the position of shorelines changes continually with time, due to the dynamic nature of water levels. So shorelines can be taken in a temporal frame, and the period of time considered depends on the necessity of the data. The water-land boundary at one point of time is the instantaneous shoreline at that point of time. As stated by many authors (Morton, 1991; List and Farris, 1999; Smith and Zarillo, 1990), the most potential wrong assumption in most of the shoreline survey is that the instantaneous coastline presents ‘‘average’’ or ‘‘normal’’ situations.

A shoreline can also be taken over a comparatively longer scale of time, like a tidal cycle, considering the features of the beach and prevailing wave climate. For a longer engineering scale of time, like 100 years, the shoreline location may vary by multiples of hundred meters or even more (Komar, 1998). As the coasts are subjected to varying wave climate with respect to time, they are most dynamic and also accretion and erosion take place on the coast (Balaji et al. 2014). Coastal ecosystems having numerous resources both living as well as non-living, are highly complicated (Constanza et al. 1997). As the coastal stretches are highly dynamic in nature and the changes on the coast leads to loss of land and life, threat to ports and harbours and loss of other resources on land. So, monitoring and protection of coastal area is extremely important for the development of any nation, for which it is essential to study the shoreline position (Rasuly et al. 2010). The important factors which influence the shoreline oscillations are sediment movement, sea-level variation and human interventions. The hydrodynamic factors on the near-shore, estuarine conditions, the types of landforms on the coast and storm surges also influence the shoreline position (Narayana and Priju, 2006; Scott, 2005; Kumar and Jayappa, 2009). Shoreline oscillation is directly related to coastal erosion or accretion. The probable coastline variations and the proper assessments of risk involved with different time spans are the major needs (Burgess et al. 2001).With regard to the supply of sediments, shoreline may be subjected to three varying situations like surplus condition, balanced, or deficit situation in sediment budgeting.

The tremendous change in the supply of sediments, with shorter or stretched time period, creates surplus or deficit sediment budget causing shoreline oscillations (Mukhopadhayaet al. 2012). Generally, the sea level rises due to storms, increase in global warming etc. will cause flooding on the coast and erosion/accretion phenomena takes place along the shoreline (Dattatri et al. 1997).

2. Study Area

The Kerala coast is having a total length of 590km. This coast is a low lying strip of land sandwiched with a chain of lagoons and backwaters on the east and the Arabian Sea on the west. These chains of water bodies have openings to Arabian Sea at various points. On this coast, the main economic activities, major industries and agricultural activities in Kerala are situated. This coast is constantly subjected to erosion and accretion phenomena. It is estimated that the erosion far exceeds the accretion, leading to loss of valuable land of Kerala. It is found that about 320 km length of this coast is subjected to severe erosion problems. In Kerala, there are forty one west flowing rivers. Most of these rivers are originating from Western Ghats and flow in westerly direction and join into the lagoons and backwaters along the Kerala coast. The lagoons or backwaters on the coast have 34 inlets into Arabian Sea. Among the 34 inlets, only 21 inlets will remain open throughout the year and the remaining inlets will open partially during the year that is they will open during the monsoon period and will remain closed during the rest of the year mainly due to the littoral movement (Kunhimammu et al, 1997). There are 25 harbour constructions on Kerala coast. All the harbours developed have breakwaters.

The construction of these harbours on Kerala coast has very high impacts. Three categories of fishery harbours are established on Kerala coast. The three types of harbours are: harbours established in river mouths/estuaries, harbours constructed in the existing bays in the coast and harbours developed on the open coast. They can respectively be named as estuarine harbours, bay harbours and sea harbours (Kunhimammu et al, 2007). Out of the 21 permanently open inlets in Kerala, many are observed to be naturally unstable. Due to the existing unstable natural conditions, safe navigational channels for vessels are not maintained at these coastal inlets (Kunhimammu et al, 2006, 2009, 2012). These inlets canals be classified as controlled (improved) or uncontrolled based on the existence or non-existence of artificial river training structures (Moni etal, 1973). The sediments which are supplied through river discharge from inlets or the sediments from the alongshore littoral movement influence the coastal inlets. Normally the artificial structures on the coastal inlets affect the shore stability on either sides of the inlets.

In Kerala coast, many fishery harbours are established in estuaries. For any estuarine fishery harbour, it is inevitable to have a pair of breakwaters. The breakwaters are planned and developed at twelve inlets on Kerala coast in connection with the establishment of fishery harbours or minor ports. The locations of coastal inlets are as follows: Muthalapozhy, Neendakara, Kayamkulam, Chethi, Munambam, Chettuva, Ponnani, Beypore, Azhikkal, Cheruvathur, Ksaragod and Manjeswaram. For the present study, three estuarine harbours at Azhikkal, Beypore and Munambam are considered. Figure 1 presents the location of these harbours on Kerala coast. At Azhikkal, a fishery harbour cum minor port was developed by constructing a pair of parallel breakwaters having 1070m (north) and 1150m (south) lengths. The centre to centre distance between the breakwaters is 370m. The construction was started in January 1995 and completed in March 2009. It is rubble mound breakwaters. It is located at $11^{o}94'$ N Latitude and 75^{o} 31’ E Longitude and constructed at Valapatnam river mouth (Kunhimammu et al, 2009). At Beypore, two parallel breakwaters with 860m (north) and 820m (south) lengths having centre to centre distance of 280m were constructed during the period 1982 to 1988.

Later the southern breakwater is extended by 300m during 2008-2009. At present lengths of northern breakwater is 860m and southern breakwater is 1120m. It is situated at $11^{o}10'$ N Latitude and 75^{o} 48’ E Longitude at Chaliyar river mouth (Kunhimammu et al, 2009). At Munambam inlet two breakwaters of 625m (north) and 360m (south) lengths were constructed with a centre to centre gap of 200m for establishing a fishery harbour. The construction was began during June 1992 and completed in January 1997. It is located at $10^{o}10'$ N Latitude and 76^{o} 10’ E Longitude and developed at Periyar river mouth (Kunhimammu et al, 2009).

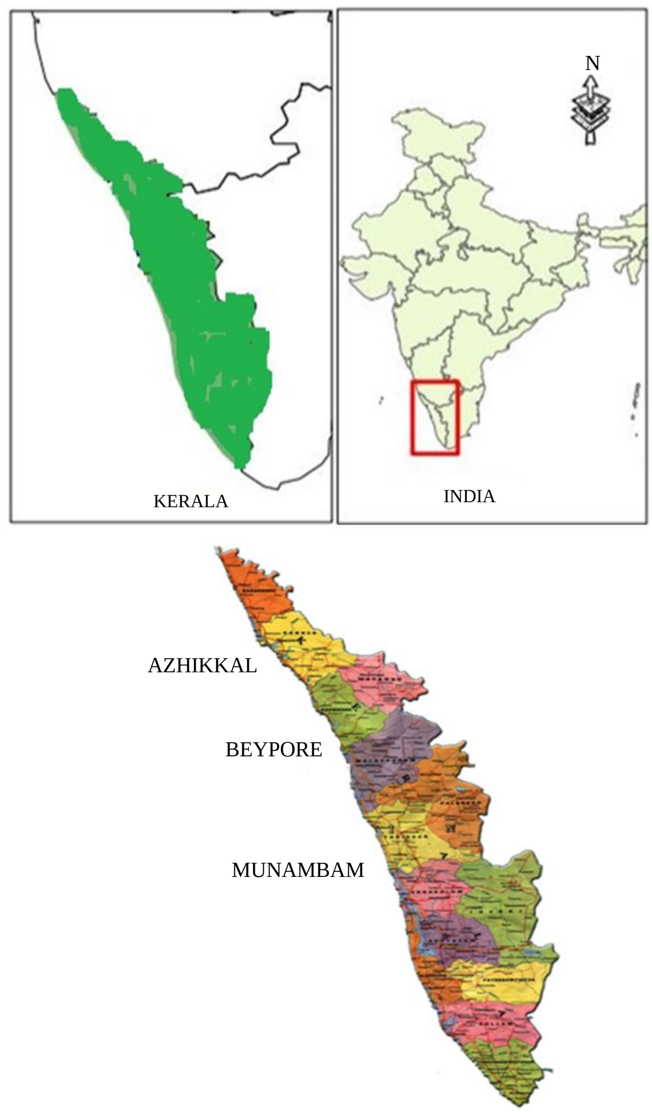


Fig. 1 Harbour locations on Kerala coast

3. Methodology

To study the shoreline oscillations following the construction of harbours/breakwaters, MIKE 21 Spectral Wave (SW) and LITPACK modules are utilized. The deep water waves are transformed to near shore region, by utilizing MIKE21 Spectral Wave (SW) module. The simulation of wind generated waves and its growth and decay can be carried out by this model. SW module of MIKE 21,which is spectral wind-wave module uses unstructured meshes, considering the important factors like wind influenced wave growth, dissipations due to white-capping, interaction between non-linear waves, bottom friction and breaking of waves. The model also considers the wave diffraction on the large coastal constructions like breakwaters, groins etc. In addition, the model takes into account the wave shoaling and refraction in near shore area and also interaction between waves and currents are taken in the model (DHI, 2011, 2017).

With the results from SW transformation, the shoreline changes are then predicted with the LITPACK module. LITPACK module simulation considers the response of coast to gradients in along-shore sediment movement capacity with regard to the natural conditions and existing coastal structures. LITPACK computes the shoreline evolution by adopting the technique of finding solution to a continuity equation for the sediments in littoral area. The impact of coastal constructions, the source of sediment and its sinks have also been considered. For running and obtaining the result from the model, the important input data are the relative alignment of the coastline, bathymetry, profile of cross-shore, active transport depth, contour angles, wave data, tidal currents, water level, and structure size, etc.(DHI, 2022)

4. Data Used

For bathymetric data in deep water regions, C-Map data has been utilized. The Hydro graphic Survey Wing of Kerala Government have bathymetry data for all coastal districts for depths ranging from 3m to 20m and this is utilized for the present analysis. In addition, Hydro graphic Survey Wing periodically draws bathymetric charts for all the developed fishery harbours in Kerala. Also, Harbour Engineering Department of Kerala Government carries out surveys and takes soundings at the harbour sites. The deep water wave data at 160km away from shore for two stations located off Thiruvananthapuram and Kasaragod districts are collected and used in the model.

The depth of this data collected is 10 years that is from 2007 to 2017. For the present analysis, flexible mesh is adopted. This mesh has a size of 20km at deeper water, a mesh size of 10km for water depths ranging from -1000m to -50m and 5km mesh size for -50m depth to shoreline. The abovementioned mesh size resolution was found suitable at different water depth ranges and obtained good results during model calibration and its further validations. Figure 2 shows the mesh diagram.

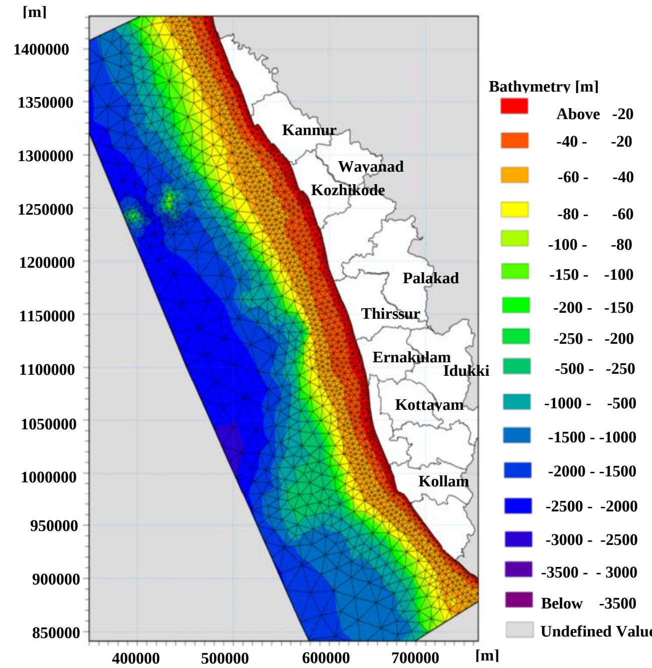
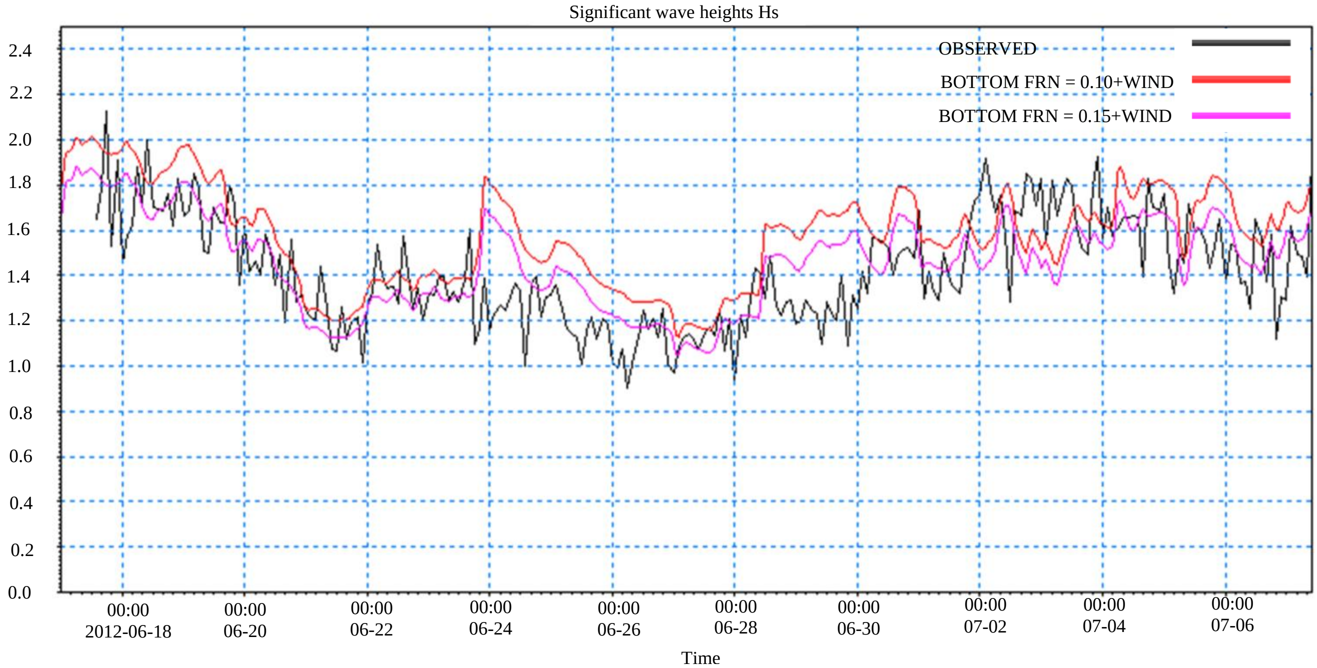


Fig. 2 Bathymetry and mesh adopted in model study

5. Results and Discussion

5.1. Model Calibration

Shallow water wave observation was done by Harbour Engineering Department of Kerala Government with Directional Wave Recorder (DWR) in 2012 at South Paravur in Kollam district in connection with the field studies for the establishment of a new mini fishing harbour at that location. The field wave data was observed at 8m depth and this collected data was used to calibrate and further validate the wave transformation results. Initially, wind data was not incorporated in model simulation. But after calibration trial with field data, the model was again simulated by incorporating the wind data. Now, the results obtained from simulation are found to be matching very well with the field data (Figure 3).It is found that the results of model calibration are best suited when wind data and a bottom friction of 0.15 are applied. This model setup is adopted for further analyses of shoreline oscillations at different locations. The field data on waves available during the year 2017 is adopted in the study. The model which is once calibrated is again validated with the observed field wave data available for 9th to 29th July of 2012 at Paravur. The predicted and observed data for Paravur site is in very good agreement. The results are presented in Figures 4 & 5. The model after calibration is again validated with the available observed field wave data for 2017 at Kozhikode. The predicted and observed data for Kozhikode site is found to be matching very well. The results are presented in Figures 6 & 7.



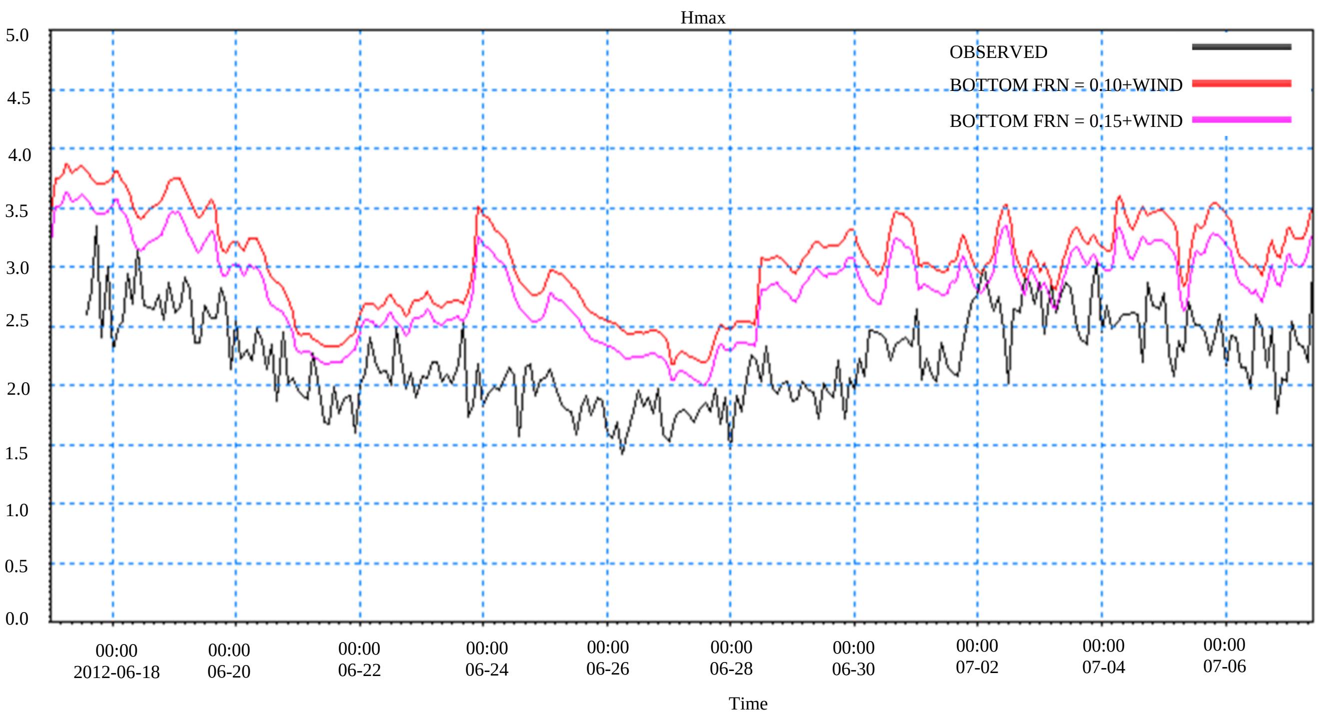


Fig. 3 Results of calibration for bottom friction 0.10 and 0.15

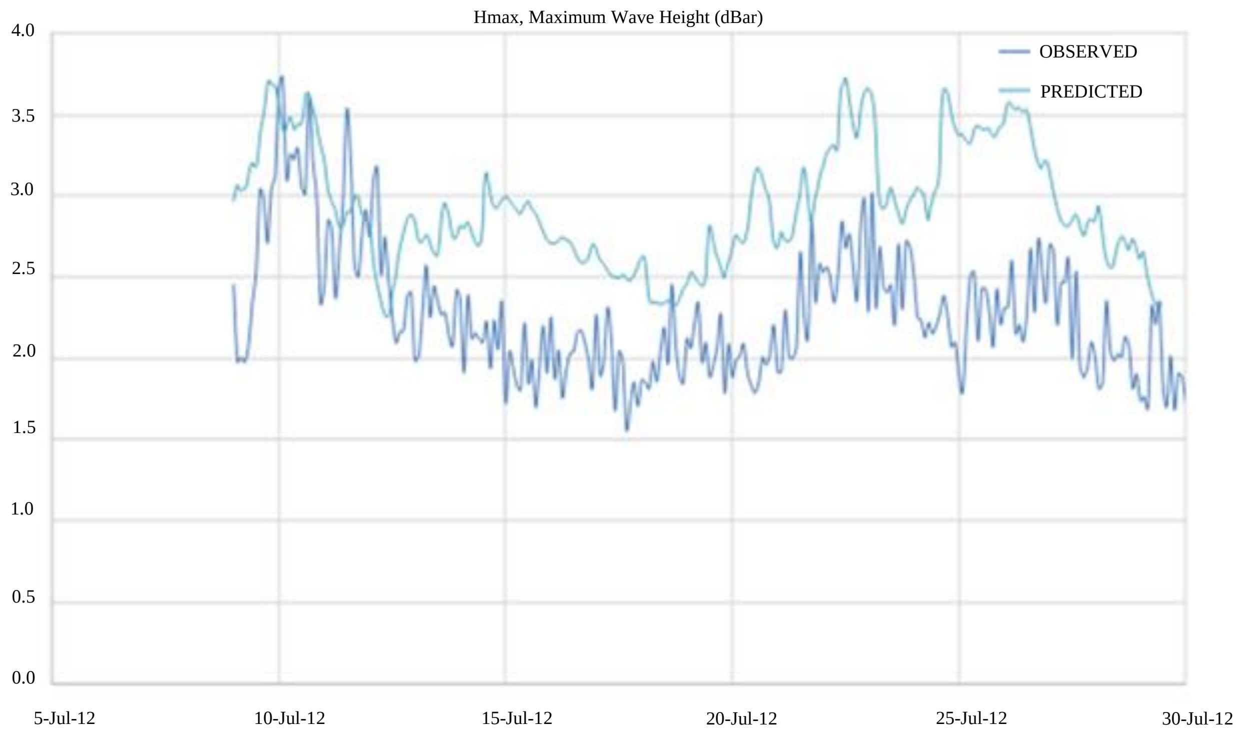


Fig. 4 Results of validation for Paravur site – Hmax

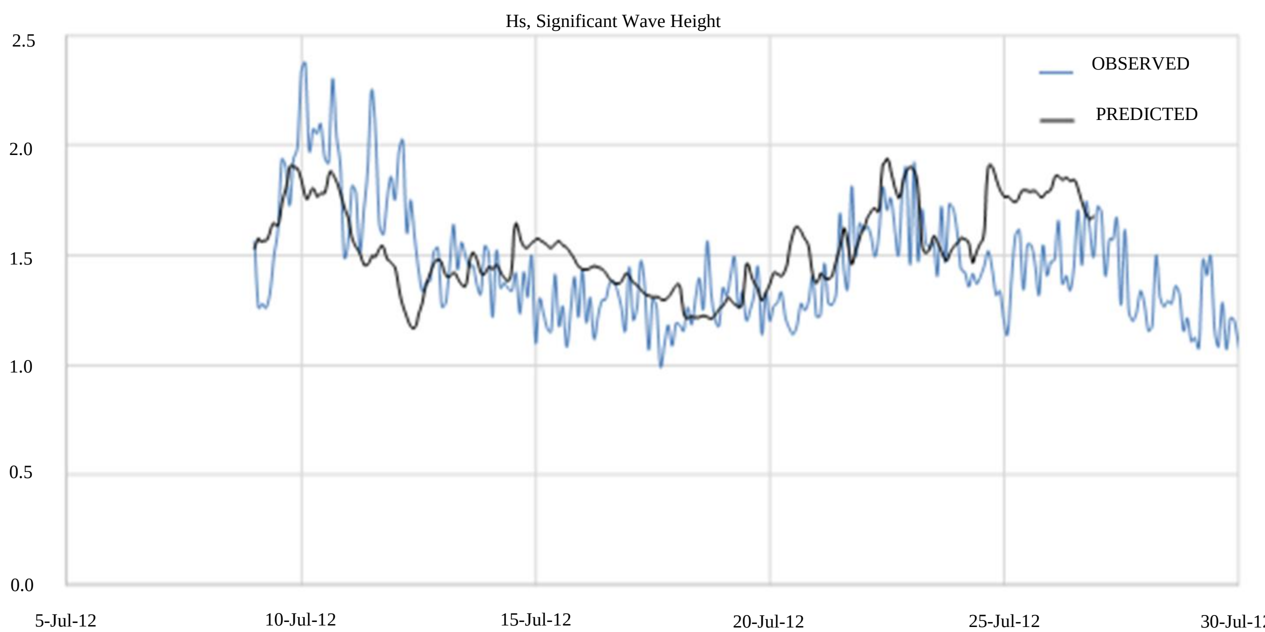


Fig. 5 Results of validation for Paravur site - Hs

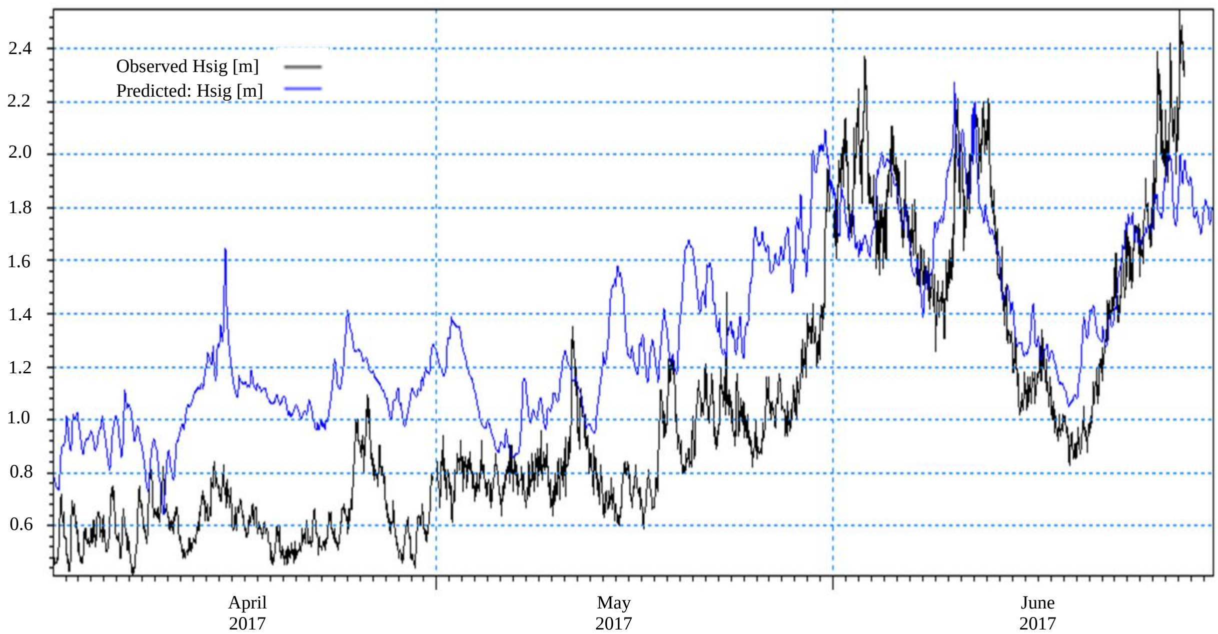


Fig. 6 Results of validation for Kozhikode site – Hs

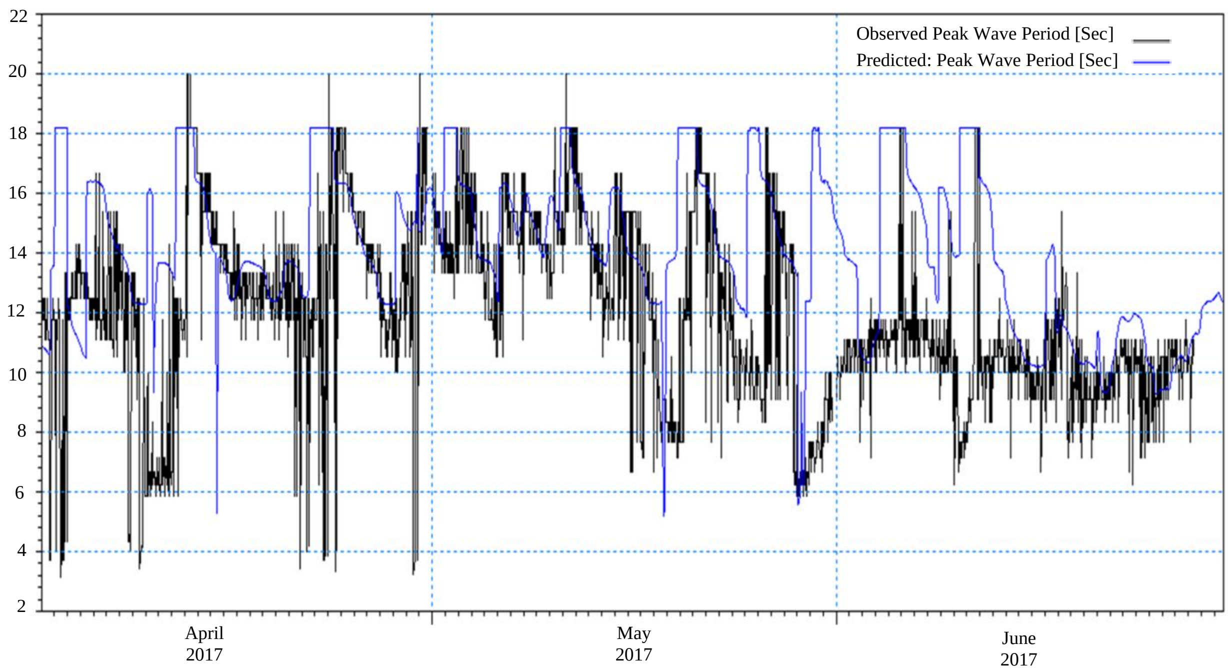


Fig. 7 Results of validation for Kozhikode site – peak wave period

The figure (Figure 8) below presents the results from SW transformation. The transformed wave climate is shown in the figure for monsoon period (July 2017). These results were adopted as the input data for running the LITPACK module to obtain evolution of shorelines.

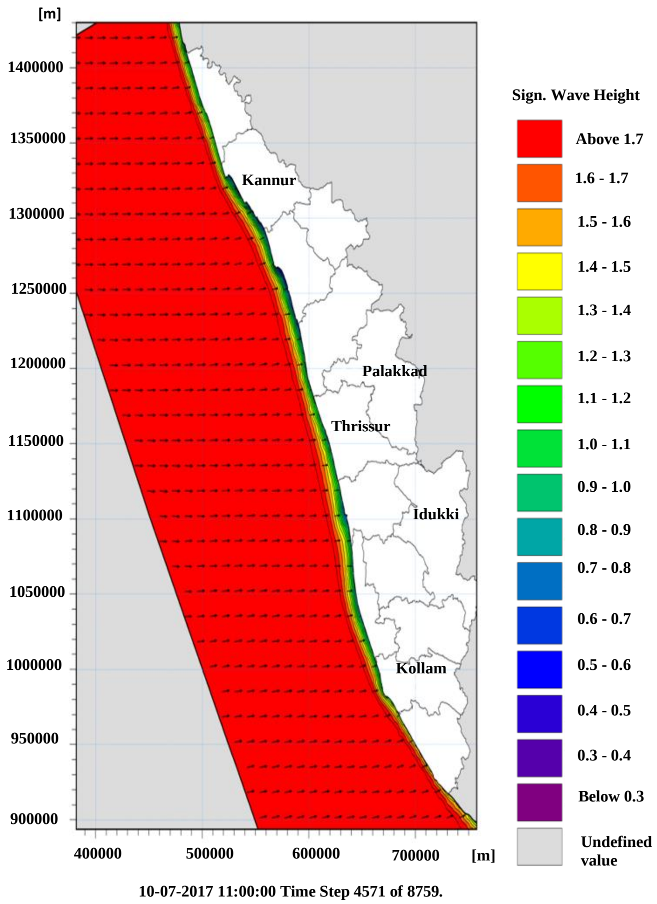


Fig. 8 Transformed wave climate for monsoon (July 2017)

5.2. Azhikkal Harbour

The shallow water wave data was extracted from SW transformation for Azhikkal harbour site. These extracted values are shown below (Figure 9). These values were used for running the LITPACK model. The model calibration is done by taking the shoreline of 1994 (base line), just before the commencement of breakwater works and calibration is done against 2017shoreline.

The predicted and observed shorelines of 2017 match very well. Both the northern side of north breakwater and southern side of south breakwater show accretion when compared to baseline (Figure 10). The calibrated model was used to predict the shoreline changes around the breakwaters constructed. The shoreline evolution was predicted after 5th, 10th and 15th years. The final output is presented in Figure 11.

From the predicted results it is inferred that both the north side of northern breakwater and south side of southern breakwater are showing considerable accretion during the period of prediction when compared to the base line. It has been observed that there is tremendous impact on the adjacent coast after the construction of breakwater at Azhikkal.

The predicted results show that the accretion is tremendous and net shoreline advance year after year on both the sides of the estuary. The accretion on either side of the breakwaters is due to the littoral movement on both sides. Figure 12 shows the aerial view of Azhikkal harbour.

5.3. Beypore Harbour

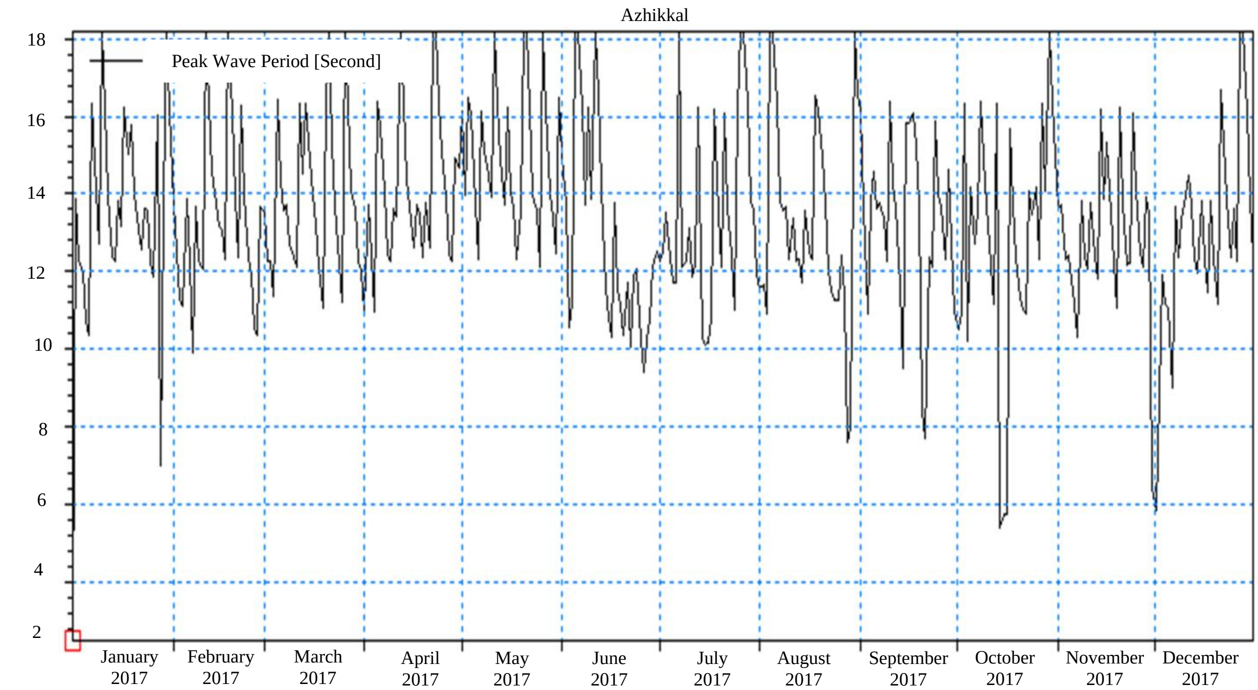
The near shore values were obtained from SW transformation for Beypore harbour site. The LITPACK model was then run with these extracted values to assess the shoreline changes. These values obtained are as shown below (Figure 13). The model calibration is carried out by considering the shoreline of 1982, just before the breakwater construction and is calibrated against 2017 shoreline.

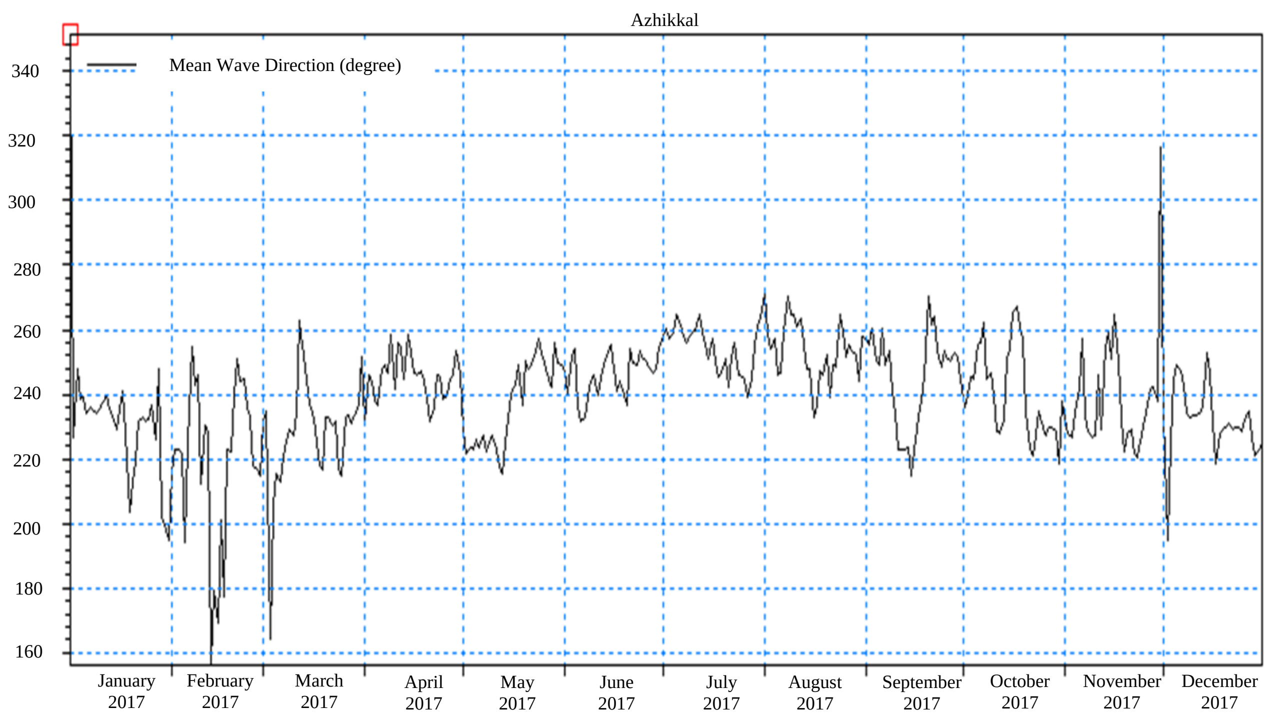
The predicted and observed shorelines show good agreement. North of north breakwater shows marginal accretion whereas south side shows considerable accretion when compared to baseline (Figure 14). There exists a rocky promontory on the south of the south breakwater. The model after calibration was used to predict the shoreline oscillations around the breakwaters constructed. The shoreline evolution was predicted after 5th, 10th and 15th years. The final output is presented in Figure 15. The predicted results show that the north side of north breakwater is having marginal deposition.

Tremendous accretion is observed on the immediate south side of south breakwater up to the promontory. But on the south of promontory, erosion trend is noticed. Tremendous effect on the coast is found after the construction of breakwaters at Beypore estuary. Considerable deposition and net shoreline advance on the south of south breakwater up to the promontory is observed from the detailed analyses.

As there is tremendous accretion and heavy deposition on the southern side, more area has been formed and this deposited area is utilized for the development of a defence project by Government of India. But on the south of promontory there is eroding trend and the coast is receding back. To arrest the further erosion and loss of land after the promontory, this stretch has been protected with sea wall.

The shoreline advance on the north of north breakwater can be attributed to the littoral transport from north to south. Also it can be inferred that the deposition between the south breakwater and the rocky promontory is mainly due to the riverine sediment supply and the erosion beyond the promontory is due to the arresting of littoral movement by the north breakwater and rocky promontory. Figure 16 presents the aerial view of Beypore harbour.


Azhikkal
Peak Wave Period [Second]
18
16
14
12
10
8
6
4
2
January 2017
February 2017
March 2017
April 2017
May 2017
June 2017
July 2017
August 2017
September 2017
October 2017
November 2017
December 2017


Azhikkal
Mean Wave Direction (degree)
340
320
300
280
260
240
220
200
180
160
January 2017
February 2017
March 2017
April 2017
May 2017
June 2017
July 2017
August 2017
September 2017
October 2017
November 2017
December 2017

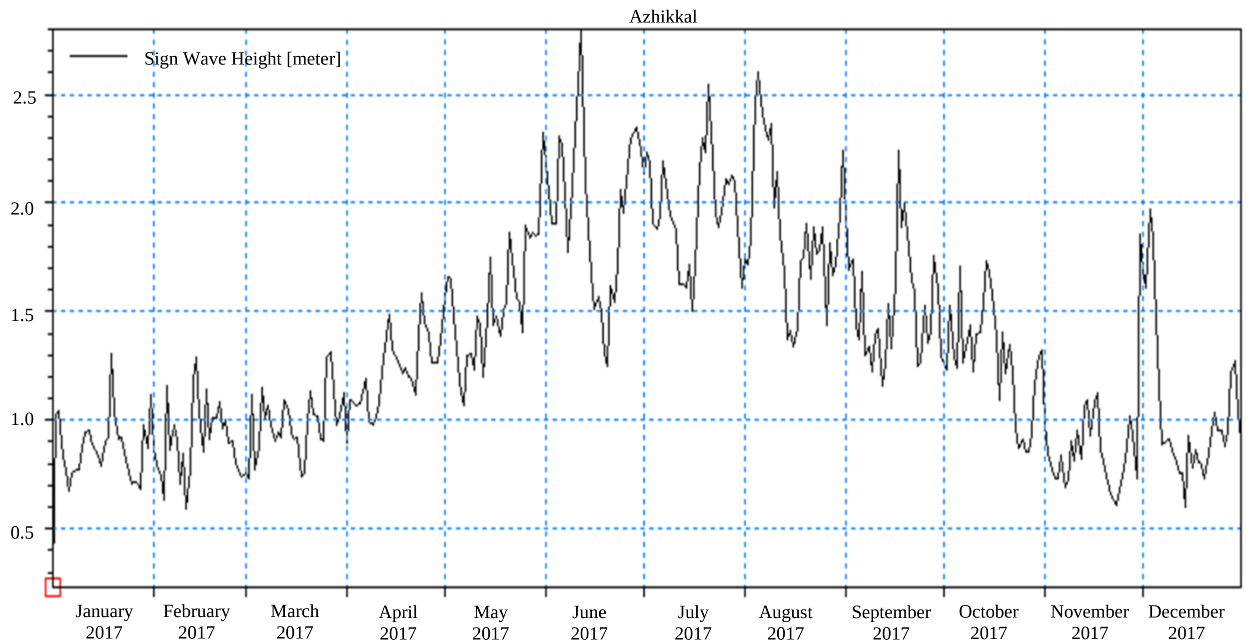


Fig. 9 Transformed wave climate from deep-water to 25m depth near Azhikkal harbour

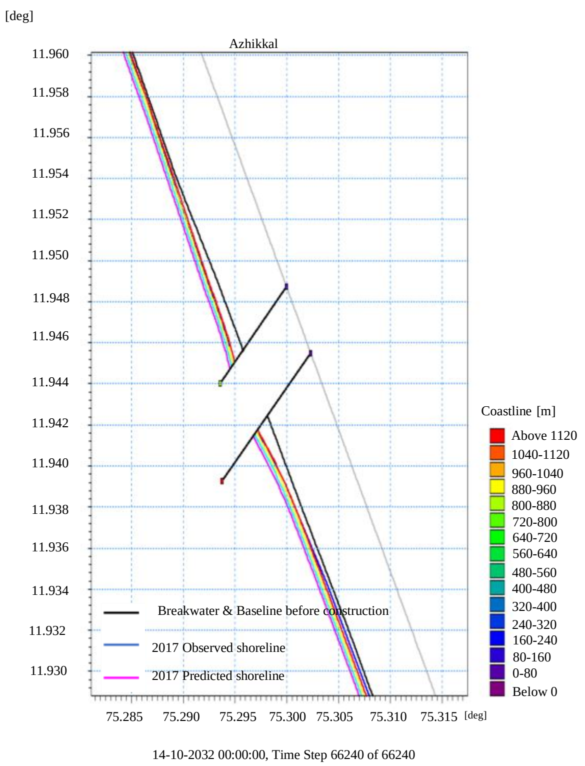


Fig. 10 Azhikkal model calibration

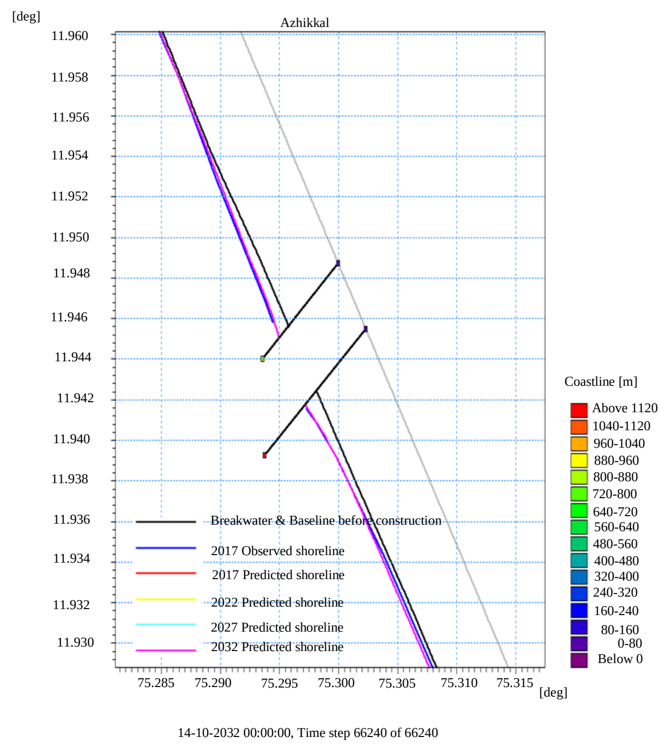


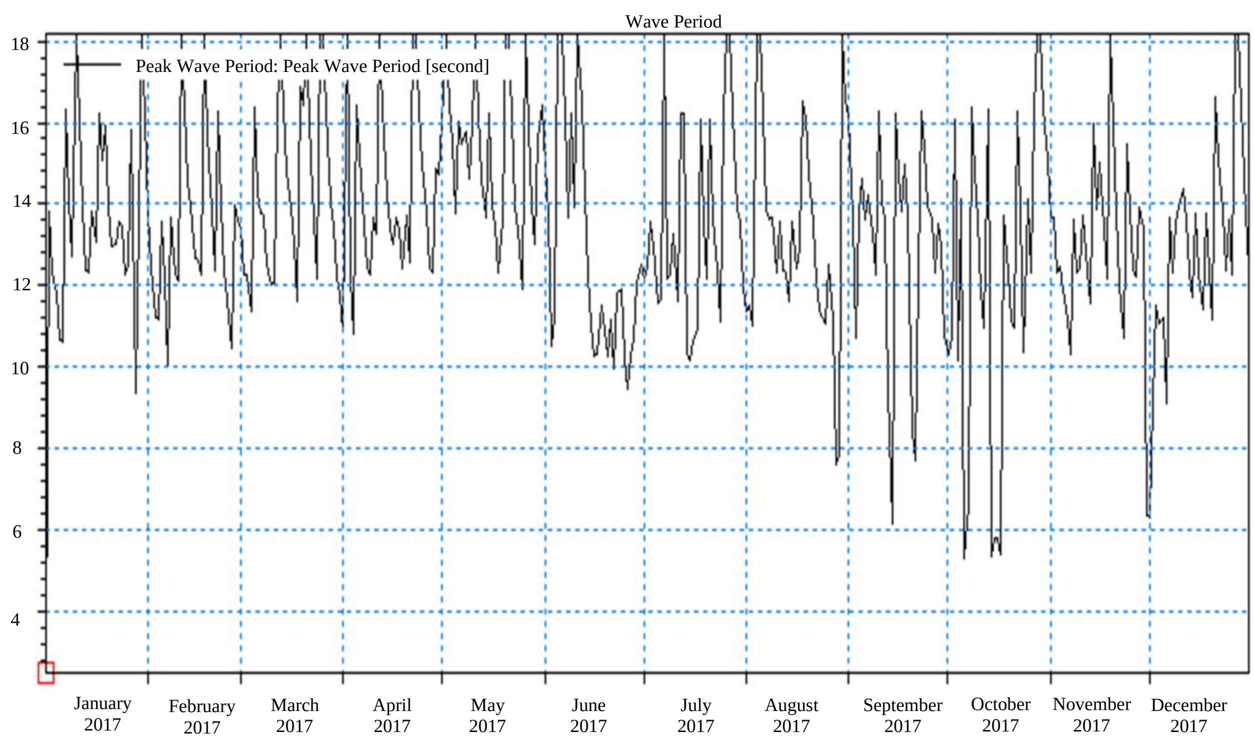
Fig. 11 Shoreline evolution at Azhikkal harbour

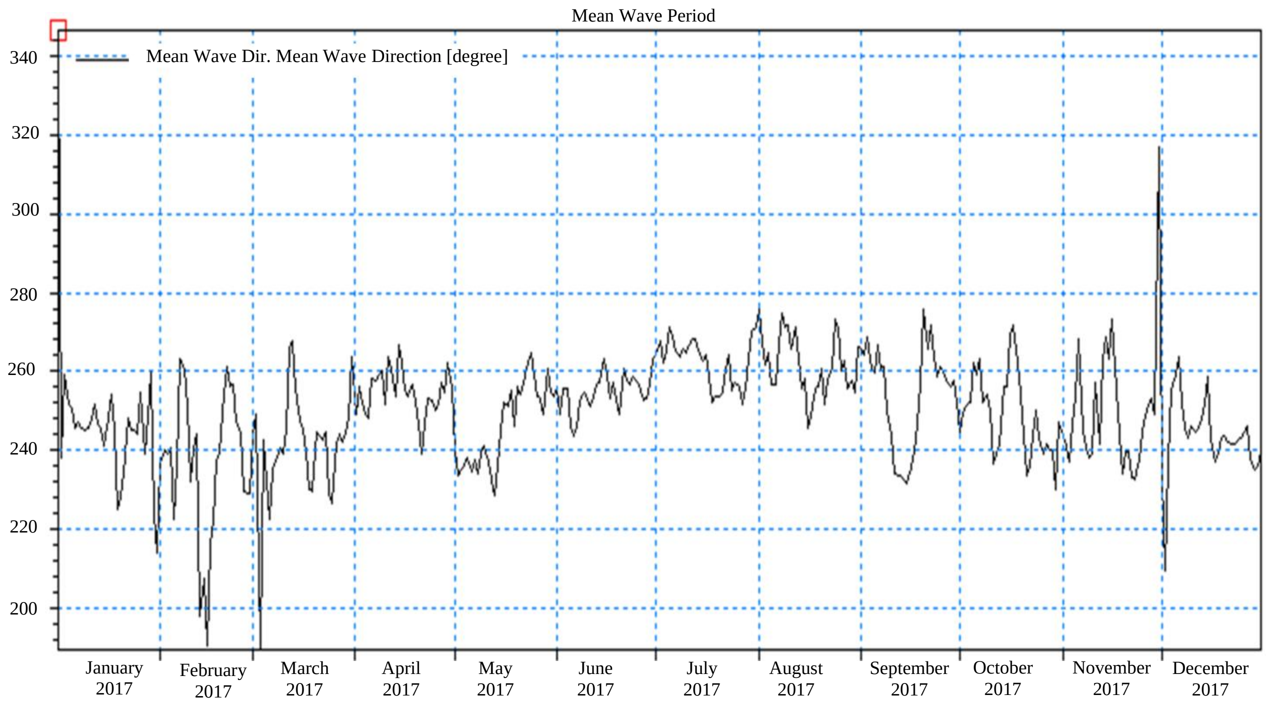
5.4. Munambam Harbour

The shallow water wave climate was taken from SW transformation for Munambam harbour site. The shoreline evolution was then found by running the LITPACK model utilizing these extracted values. These extracted near shore values are presented below (Figure 17). The calibration of is carried out by using the shoreline of 1992 (baseline), just before the construction of breakwater and calibration is done against 2017shoreline.

The predicted and observed shorelines of 2017 show good agreement. Northern side of north breakwater shows accretion and southern side shows erosion when compared to baseline (Figure 18).The model after calibrating and validation was used to predict the shoreline changes around the breakwaters constructed. The shoreline evolution was predicted after 5th, 10th and 15th years. The final output is presented in Figure 19.

Fig. 12 Aerial view of Azhikkal harbour





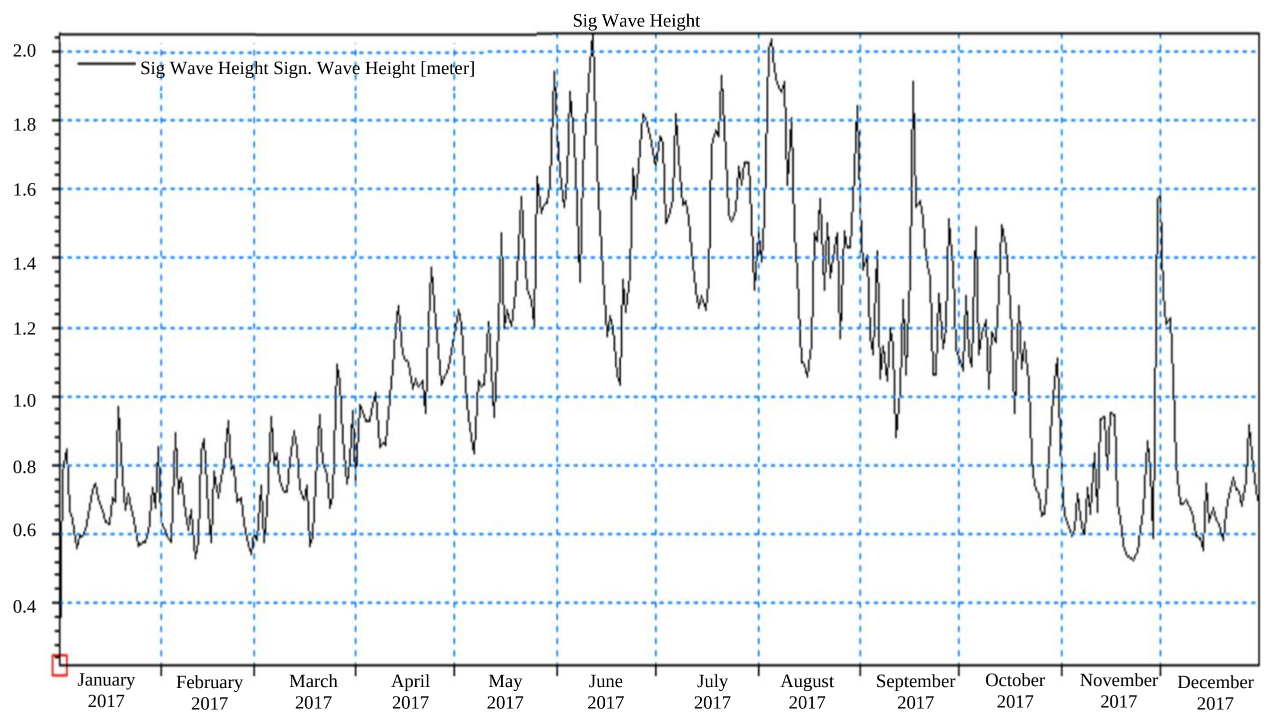


Fig. 13 Transformed wave climate from deep-water to 25m depth near Beypore harbour

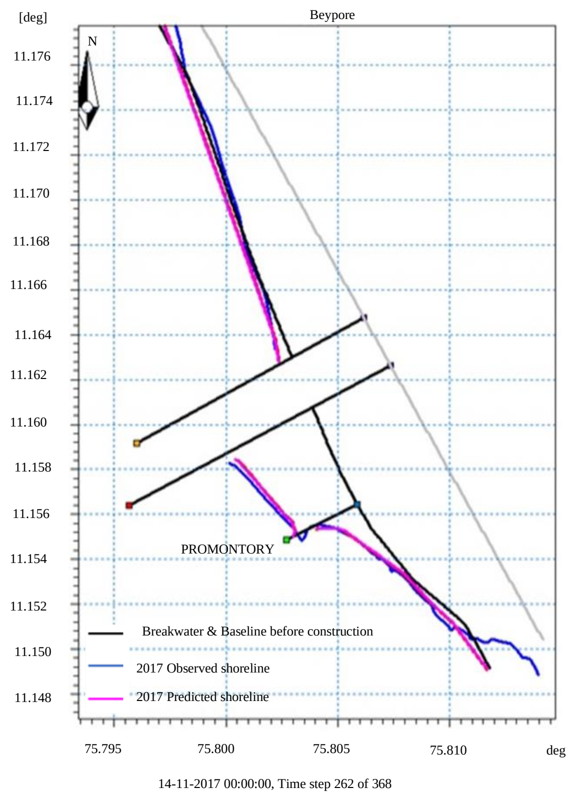


Fig. 14 Beypore model calibration

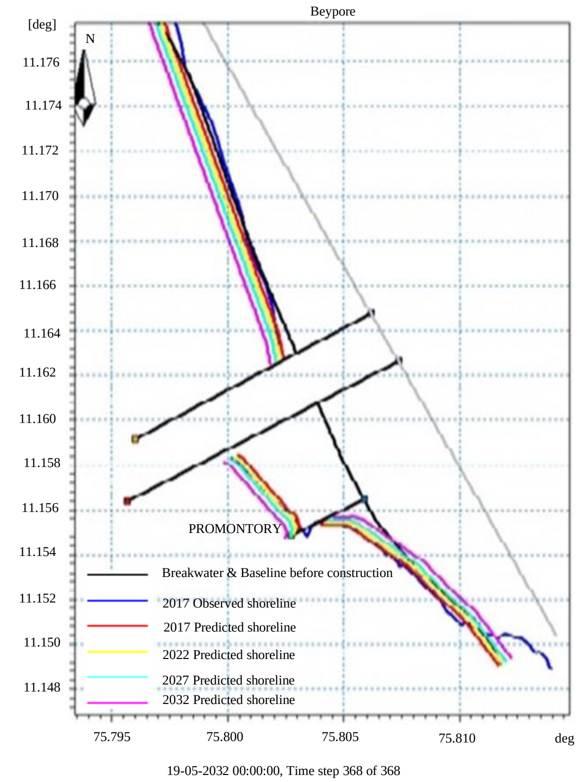
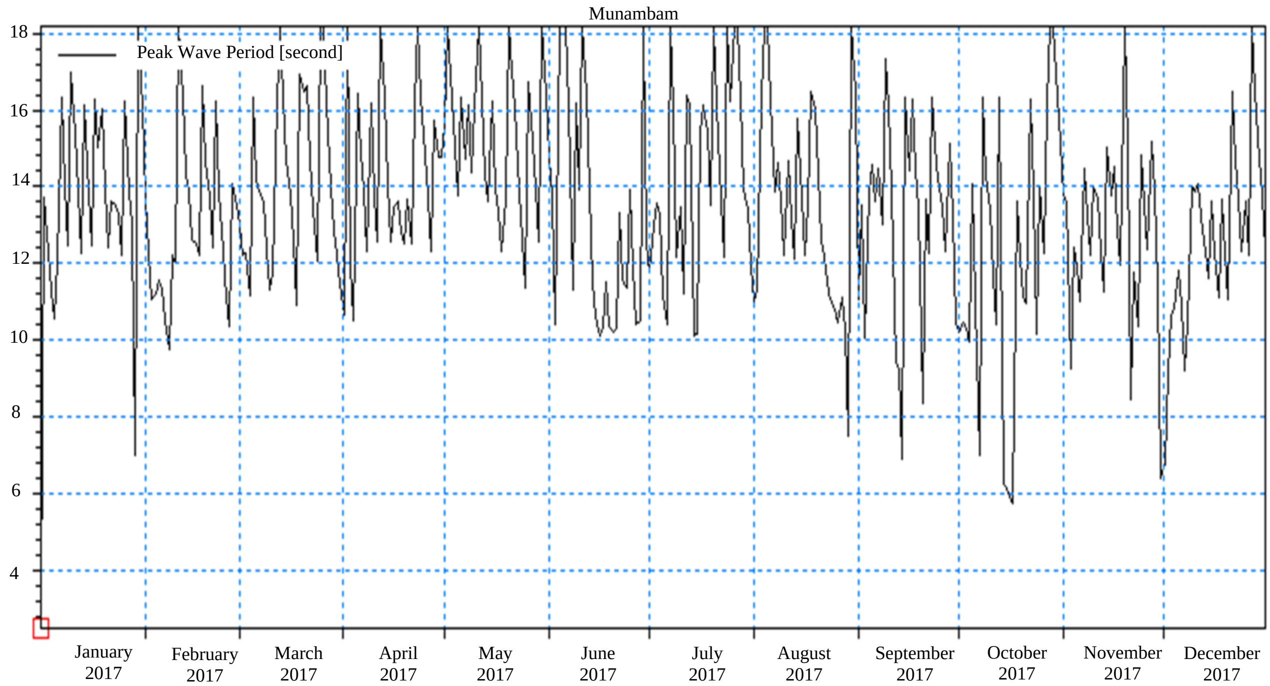
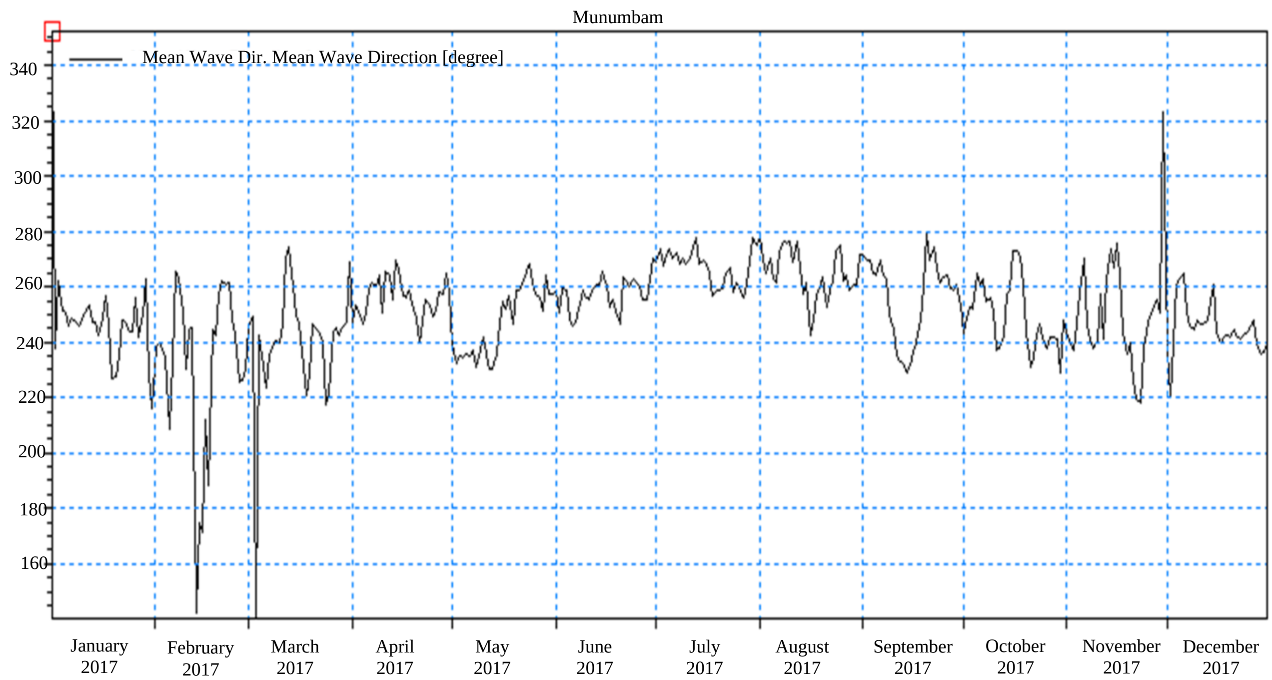


Fig. 15 Shoreline evolution at Beypore harbour

Fig. 16 Aerial view of Beypore harbour


Munambam
Peak Wave Period [second]
18
16
14
12
10
8
6
4
January 2017
February 2017
March 2017
April 2017
May 2017
June 2017
July 2017
August 2017
September 2017
October 2017
November 2017
December 2017


Munumbam
Mean Wave Dir. Mean Wave Direction [degree]
340
320
300
280
260
240
220
200
180
160
January 2017
February 2017
March 2017
April 2017
May 2017
June 2017
July 2017
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September 2017
October 2017
November 2017
December 2017

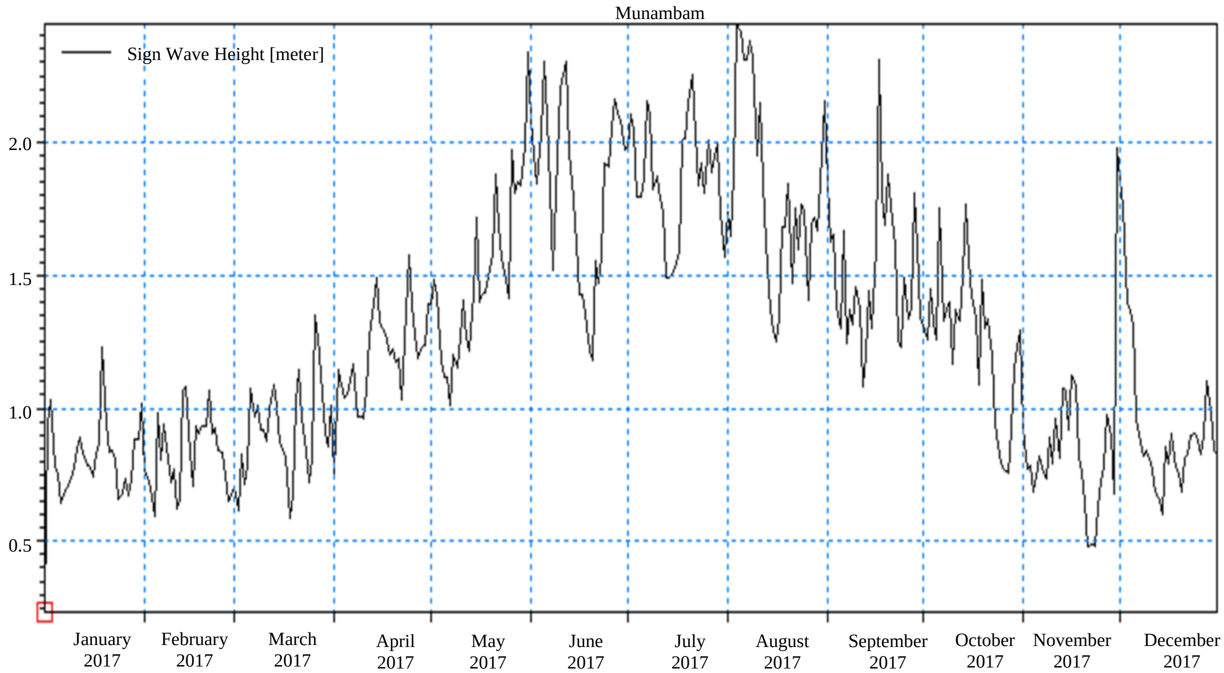

Fig. 17 Transformed wave climate from deep-water to 25m depth near Munambam harbour

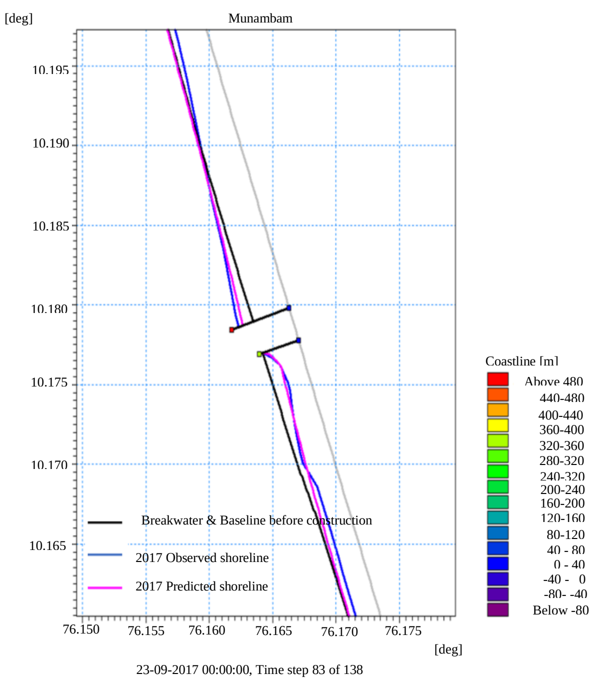

Fig. 18 Munambam model calibration

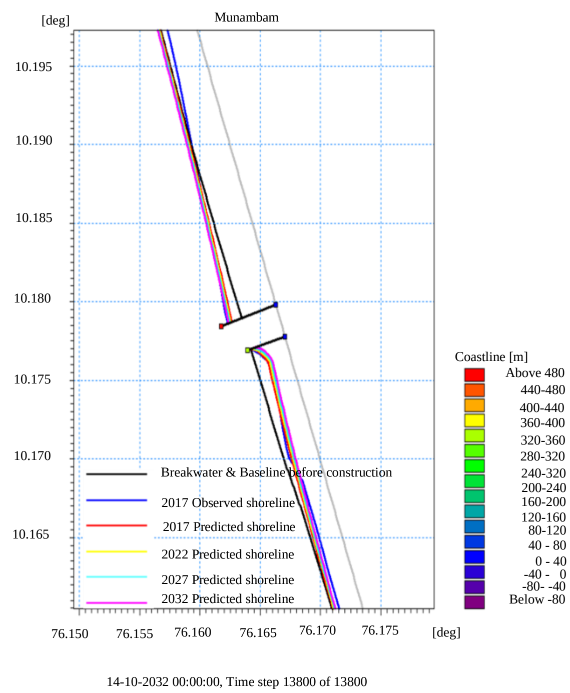

Fig. 19 Shoreline evolution at Munambam harbour

Fig. 20 Aerial view of Munambam harbour

The predicted results present that north of northern breakwater is having considerable accretion. But on the south of southern breakwater erosion trend is experienced. It has been found that there is considerable coastal impact due to the breakwater construction in Munambam estuary. The predicted results reveal that very high deposition and net coastline advance is evident on the north of north breakwater and on the south of south breakwater, net loss of land is seen. The accretion and erosion trends respectively on north and south sides of breakwaters are due to the arresting of littoral drift towards south. Figure 20 presents the aerial view of Munambam harbour.

6. Conclusion

The costal changes around three estuarine harbours constructed along Kerala coast in India has been assessed by using LITPACK Module Mike 21 software. The major conclusions drawn are:

- At Azhikkal harbour, on either sides of the estuary considerable accretion is observed;
- At Beypore harbour there is tremendous deposition on the south side up to the rocky promontory and also marginal accretion on the northern side;
- At Munambam harbour, tremendous accretion on the north side is noticed and net erosion on southern side; and
- The analyses on coastline oscillations around three estuarine harbours show significant impact of harbour construction on adjacent coast.

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