

Shoreline Change Studies Due to Construction of Breakwaters at Ariyankuppam River Mouth in Puducherry – a Union Territory of India, South India

P. Mohamed Rajab* and K. Thiruvenkatasamy

Department of Harbor and Ocean Engineering, AMET University, Plot No.135, East Coast Road, Kanathur, Chennai - 603112, Tamil Nadu, India; mohamedrajab.p@ametuniv.ac.in, swamy2667@gmail.com

Abstract

Objectives: In the present investigation, the shoreline change studies were carried out along the Puducherry coast using an online model such as DHI-LITPACK modules suite. **Methods/Statistical Analysis:** The study area covers 5 km on the southern side and 10 km on the northern side of the Ariyankuppam river port breakwaters. One year measured data off Puducherry coast at 15 m water depth was used for the estimation of littoral drift and to predict the shoreline changes along the Puducherry coast. The predicted shoreline changes using one-line model show good agreement with historical shoreline changes along the Puducherry coast. **Findings:** The shoreline change studies with existing coastal structures shows that, on the seawall northern end, the shoreline experiences erosion up to 10m, 20m, 35m, 45m, 55m and 60m after a period of 1, 2, 5, 10, 15 and 20 years respectively and the erosion is noticed for a distance of 1400m along the coast. The shoreline changes study with sand bypassing the net annual littoral sediment of 0.13×10^6 m³ from the southern side of the south port breakwater to the northern side of the north breakwater show that shoreline erosion is limited to 20 m and extends 500 m along the coast on the northern end of the seawall. In order to avoid shoreline erosion along the Puducherry coast, the initially implemented sand bypassing operation with beach nourishment has to be carried out with the sand bypassing volume of 0.13×10^6 m³ per year at the rate of 0.0188×10^6 m³ per month from March to September. **Application/Improvements:** After monitoring shoreline behavior with sand bypassing operation for few years, a long term arrangement can be worked out. Moreover, the study indicates that the DHI-LITPACK modules are suitable tools for the estimation of littoral drift and shoreline change studies.

Keywords: Breakwaters, DHI-LITPACK, Littoral Drift, One-Line Model, Puducherry Coast, Shoreline Change

1. Introduction

The impacts on the shoreline of Puducherry due to the construction of the breakwater in 1986 were studied¹ and estimated, shoreline changes using satellite imagery from 1986 to 2002, that the coastal area eroded is 335900 m² on the northern side of the port and the area accreted on the southern side is 307100 m². A seawall has been constructed for a length of nearly 8 km from the northern bank of the Ariyankuppam River. Without proper beach nourishment scheme, the erosion keeps on extending and resulting in the extension of shoreline erosion towards the coast of Tamil Nadu. The northern coastline

of Puducherry facing erosion has many economically important settlements and historically important monuments. On the southern side of the Ariyankuppam River accretions is reported over a distance of nearly 2 km. Puducherry union territory of India, a coastal state located along the Coromandel Coast, bordering the Bay of Bengal. Its coastline along the east coast of India, which extends 30 km in the north-south direction, lies between the latitudes 11° 46' w.r.t. North and 11° 57' w.r.t. North. The average orientation of the coastline in this region is nearly 15° w.r.t. North. The study area covers 5 km on the southern side and 10 km on the northern side of the Ariyankuppam river port breakwaters shown in Figure 1.

* Author for correspondence



Figure 1. Study region - Shoreline change model.

The objectives of the present investigation include, estimation of littoral drift using surfzone model (DHI-LITDRIFT module) and estimation of shoreline evolution using online model DHI-LITPACK-LITLINE module for two scenarios viz, i) with existing coastal features like the seawall, groins, fishing harbor breakwaters etc and ii) with structure and sand bypassing option. Among the several mathematical models², the DHI- LITPACK model suite is a convenient tool for studying the coastal processes related sediment transport in the wave breaking zone³. The different modules LITDRIFT and LITLINE, are used to study the non cohesive littoral drift and coastline evolution. The previous study on sediment transport rate along Ennore coast using LITDRIFT model found that the performance of the model is satisfactory and the model may be used successfully to study sediment dynamics along any coastline³. The study on littoral processes in the surf zone of Visakhapatnam, driven by longshore currents using a set of numerical models (MIKE-21 modeling system) show that the MIKE-21 suites of models bring out these phenomena in a regional scale and it is suitable for the application of prediction for management decision⁴.

2. Materials and Methods

The data collected during December 2010 by Institute of Ocean Management (IOM), Anna University, and National Institute of Ocean Technology (NIOT), Chennai, on bathymetry and sediment quality have been used in this study. The directional wave data measured at 15 m water depth, southeast of Ariyankuppam village, Puducherry (Latitude: 11.87°N and Longitude: 79.84°E), recorded at 3 hourly interval for a period of one year from July 2007 to June 2008, by Indian National Centre for Ocean Information Services (INCOIS), Hyderabad, was compiled and was used for the estimation of littoral drift and to predict the shoreline changes along the Puducherry coast⁵.

Measured Wave at 15 M Water Depth: The annual rose diagram for the available measured wave characteristics at 15 m water depth is shown in Figure 2 and it is observed that significant wave height vary between 0.2 m and 3.56 m, the peak wave periods are between 2.5 sec and 19.1 sec and the wave directions are between 36.6° and 179.1° w.r.t. North⁵. The annual measured wave in month wise is presented in Table 1 and show that the average significant wave heights vary from 0.56 m to 0.65 m from February to April, June and August and vary from 0.76 m to 0.88 m in May, July and from to September to November and January, and vary around 1.14 in December. The zero-crossing wave periods vary from 3.5 s to 9.9 s over the whole year. The predominant wave direction prevails around 115° during March and October, 120° to 150° in April to September, and 95° to 100° from November to February⁵.

Table 1. Monthly measured wave characteristics off Puducherry³

Month	Significant wave height H_s (m)			Zero crossing wave period T_z (s)			Wave direction w.r.t. North (Deg. N)		
	Min.	Max.	Mean	Min.	Max	Mean	Min.	Max	Mean
January	0.34	1.45	0.82	3.7	7.0	5.3	47.8	153.3	106°
February	0.35	1.09	0.62	3.7	7.0	4.7	75.9	149.1	104°
March	0.26	1.24	0.63	3.4	7.1	4.8	54.8	164.5	117°
April	0.30	1.19	0.56	3.5	8.1	4.9	60.5	175.8	130°
May	0.48	1.36	0.80	4.0	6.5	5.2	68.9	161.7	147°
June	0.11	1.14	0.62	3.4	7.6	4.9	73.1	174.4	136°
July	0.40	1.39	0.76	4.6	9.4	6.7	101.3	160.3	122°
August	0.34	1.45	0.65	4.2	9.2	6.3	95.6	165.9	126°
September	0.41	1.57	0.76	4.2	8.5	6.3	102.7	165.9	127°
October	0.30	1.64	0.70	3.9	9.2	6.3	54.8	158.6	117°
November	0.32	1.62	0.88	3.5	9.9	5.8	36.6	160.3	96°
December	0.48	2.97	1.14	4.2	7.2	5.6	61.9	129.4	100°

(Source: MohamedRajab et.al. 2014)

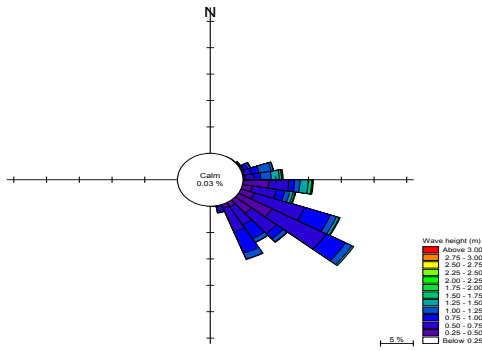


Figure 2. Annual rose diagram for measured waves at 15 m water depth³.

Source: MohamedRajab et.al. 2014

2.1 Surf Zone Model

In the present study, surf zone model (DHI-LITDRIFT module) was used for the estimation longshore sediment transport along the Puducherry coast.

2.1.1. Model Description

MIKE 21 LITDRIFT is a deterministic numerical model which consists of two major parts⁶, viz. i) a hydrodynamic model and ii) a sediment transport model (STP) (Figure 3). The hydrodynamic model includes propagation, shoaling and breaking of waves, calculation of the driving forces due to radiation stress gradients, momentum balance for the cross-shore and longshore direction giving the wave setup and the longshore current velocities. Having computed the longshore current by the hydrodynamic module, points are selected across the coast, which are representative for the long shore sediment transport calculations which is carried out by the STP module⁶. After computing the longshore current, the longshore sediment transport rate that includes bed load and suspended load transports, is computed taking into account the local conditions related to the energy dissipation, the percentage of un-breaking waves and the *rms* values of wave heights⁶⁻⁷. This gives the distribution of sediment transport across the profile, which is integrated to obtain the total longshore sediment transport rate^{6,8}. The annual drift is evaluated from the contribution, $Q_i T_i$, of each of the incident wave occurring over the year. Then the total annual drift Q_{an} is calculated as the sum of the contributions from all incident waves,

$$Q_{an} = \sum_{i=1}^{NS} Q_i T_i \quad (1)$$

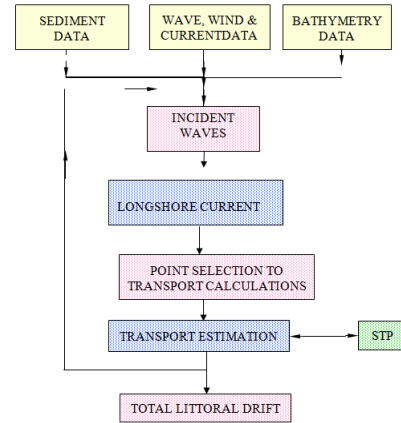


Figure 3. Flow diagram for littoral drift estimation - surf zone model.

(Source: DHI-LITPACK manual, 2010)

where NS is the total number of incident waves and T_i is the time intervals at which the wave data sets are specified. The annual drift is evaluated by the contribution of transport from each of the incident wave occurring over the year. When calculating the annual drift, the wave climate in LITDRIFT is described at specified intervals in a time series file where each set of items describes the characteristics of incident waves. The duration of the wave incident is given as a fraction of a year^{6,8}. The 3 hourly wave data measured at 15 m depth off Puducherry coast are used as input to the module.

Calibration of Surf Zone Model: The estimated annual littoral drift obtained from this surf zone model is validated with earlier estimates of annual net and gross long shore sediment transport rates based on ship reported wave data⁹ and based on measured data for Puducherry coast¹⁰⁻¹². It is observed that estimated annual net and gross transport rates based on the module has good agreement with earlier estimated annual net and gross transport rates for the Puducherry coast.

2.1.2 Results

The estimated monthly volume of littoral drift using surf zone model (DHI-LITDRIFT module) are given in Table 2. The highest northerly transport occurs in the month of May, followed by September, July, June and August is noticed. The highest southerly transport was observed in December followed by November. The net monthly transport is northerly from March to October and southerly during the remaining months. The transport rate is found to be low in February. The volume of annual

Table 2. Monthly volume of Littoral drift using Surf-zone model and estimation of sand bypassing quantity from south to north

Month	Southerly Transport (m ³ /month)	Northerly Transport (m ³ /month)	Net drift (m ³ / month)	Gross drift (m ³ /month)	Quantity of sand bypassing (m ³)
January	25425	-11550	13875	36975	-
February	4575	-5339	-764	9914	-
March	2330	-12429	-10099	14759	18875
April	2542	-23602	-21060	26144	18875
May	1505	-54785	-53280	56289	18875
June	2035	-26958	-24923	28992	18875
July	24	-31983	-31959	32007	18875
August	42	-28273	-28231	28316	18875
September	11	-35260	-35249	35272	18875
October	8697	-20157	-11459	28854	-
November	41647	-9261	32386	50909	-
December	44231	-5581	38650	49813	-
Total	133065	-265178	-132113	398243	132125

(+) = Net southerly drift

(-) = Net Northerly drift

gross transport is estimated as $0.398 \times 10^6 \text{ m}^3/\text{year}$ and the volume of annual net transport is $0.132 \times 10^6 \text{ m}^3/\text{year}$ (towards north). Based on the monthly net and gross drift estimates, the monthly sediment bypassing quantity from south to north are estimated which equally distributed from March to September and presented in Table 2.

2.2 Prediction of Shoreline Change

In the present study, the shoreline change of Puducherry coast were carried out using one line model i.e. DHI-LITPACK-LITLINE module developed by Danish Hydraulic Institute, Denmark for two scenarios viz., i) with existing costal features like seawall, groins, fishing harbor breakwaters etc and ii) with structure and with sand bypassing option.

2.2.1 Model Description

LITLINE calculates the coastline position based on input of the wave climate as time series. This model is based on a one-line theory⁶, in which the cross-shore profile is assumed to remain unchanged during erosion/accretion. The coastal morphology is solely described by the coastline position (cross-shore direction) and the coastal profile at a given long-shore position. LITLINE calculations are based on a coordinate system in which the x axis is a baseline that runs parallel to the primary coastline orientation, while the y-axis runs from the baseline in offshore direction. Coastal line profile is used to denote the variation of y_c in the longshore (x) direction,

while the cross-shore profile denotes the water depth as a function of the cross- shore position relative to the coastline position y_c .

The main equation in LITLINE is the continuity equation⁶ for sediment volumes expressed by,

$$\frac{\partial y_c(x)}{\partial t} = -\frac{1}{h_{act}(x)} \frac{\partial Q(x)}{\partial x} + \frac{Q_{sou}(x)}{h_{act}(x)\Delta x} \quad (1)$$

Where $y_c(x)$ is the distance from the baseline to the coastline, t is the time, $h_{act}(x)$ is the height of the active cross-shore profile, $Q(x)$ is the longshore transport of sediment expressed in volumes, X is the longshore position, Δx is the longshore discretization step and $Q_{sou}(x)$ is the source/sink term expressed in volume/ Δx .

Model Input: The following inputs are given to the one-line model:

- The cross-shore profile from the measured bathymetry has been incorporated in the model.
- The measured wave data at 15 m water depth for the period of one year is considered.
- The existing seawall extends to 8.5 km on the northern side of the Ariyankuppam river are given in the model.
- The digitized coastline from satellite imagery along the Puducherry coast for a stretch of 30 km is given as initial shoreline.
- The measured d_{50} - median size of nearshore seabed sediments is used.

- The existing structures along the Puducherry coast are considered in the model (Table 3).

Table 3. Details of structures existing along the Puducherry coast (Groins are numbered from north to south)

Sl. No.	Structure details	Location in WGS 84		Length (m)
		Latitude	Longitude	
1.	Seawall	11° 54' 25.92" N	79° 46' 46.49"E	8550
2.	North Breakwater	11° 54' 25.92" N	79° 46' 46.49"E	150
3.	South Breakwater	11° 54' 12.32" N	79° 49' 50.59"E	270
4.	Piled Jetty	11° 55' 22.86" N	79° 50' 01.42"E	280
5.	Groin 1	11° 58' 19.82" N	79° 50' 42.02"E	170
6.	Groin 2	11° 58' 09.25" N	79° 50' 37.71"E	100
7.	Groin 3	11° 57' 51.73" N	79° 50' 33.62"E	63
8.	Groin 4	11° 57' 45.82" N	79° 50' 31.44"E	35
9.	Groin 5	11° 57' 29.82" N	79° 50' 26.96"E	36
10.	Groin 6	11° 57' 26.76" N	79° 50' 26.77"E	35
11.	Groin 7	11° 57' 17.79" N	79° 50' 24.73"E	18
12.	Groin 8	11° 57' 14.20" N	79° 50' 23.96"E	16
13.	Groin 9	11° 56' 25.30" N	79° 50' 14.03"E	40
14.	Groin 10	11° 56' 22.71" N	79° 50' 13.44"E	55
15.	Groin 11	11° 55' 23.89" N	79° 50' 02.66"E	70

(Source: Google earth imagery dated March 22, 2010)

Validation of One Line (1D) Model Results: The predicted shoreline changes using one-line model is validated which have good agreement with previous shoreline changes studies along the Puducherry coast¹³.

2.3 Shoreline Changes with Existing Structure

Model Setup

The one-line model setup with all existing coastal structure is shown in Figure 4. The orientation of the profiles is taken as 105 deg. N (shore normal off Puducherry coast). The grid spacing based on the length of the profile is selected to be 10 meters. The study area covers 5 km on the southern side and 10 km on the northern side of the Ariyankuppam river port breakwaters. The coastal orientation is prepared for one line (1D) model with existing structures like breakwaters, seawall and groins in the graphical running setup shown in Figure 5.



Figure 4. Model setup - LITLINE module.

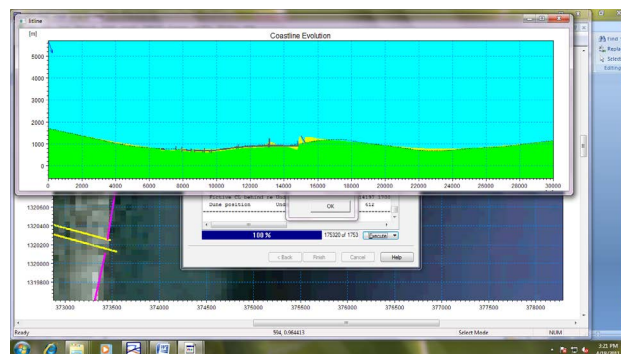


Figure 5. Shoreline one line model with graphical running setup with presence of existing structures.

The shoreline changes with presence of existing coastal structures after 1, 2, 5, 10, 15 and 20 years are shown in Figure 6 and presented in Table 4. The simulation shows that, the shoreline close to the southern breakwater on its southern side advances into the sea by 15 m, 30 m, 60 m, 120 m, 180 m, and 200 m after a period of 1, 2, 5, 10, 15 and 20 years respectively and the accretion on the southern part extends to 1800 m along the coast. On the northern end of the seawall, the shoreline experiences erosion up to 10m, 20m, 35m, 45m, 55m and 60m respectively after a period of 1, 2, 5, 10, 15 and 20 years respectively and the erosion is noticed for a distance of nearly 1400m along the coast.

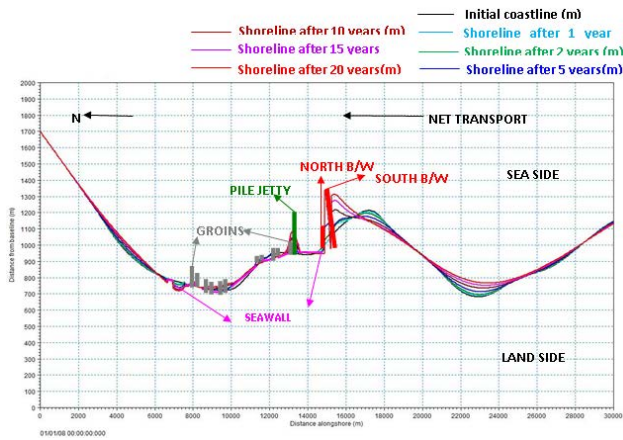


Figure 6. Shoreline changes after 1, 2, 5, 10, 15, 20 years with presence of existing structures and without sand bypassing.

Table 4. Shoreline changes with existing structure and without sand bypassing

Years	Accretion on southern side (m)		Erosion on northern side (m)	
	Offshore direction	Alongshore direction	Offshore direction	Alongshore direction
	After 1 year	15	800	10
After 2 year	30	1000	20	800
After 5 years	60	1200	35	1100
After 10 years	120	1400	45	1200
After 15 years	180	1600	55	1300
After 20 years	200	1800	60	1400

2.4 Shoreline Changes with Sand Bypassing System

During the planning of the construction of breakwaters in 1986, a sand bypassing system was initially developed to control the shoreline erosion¹. The system was designed to dredge sand from a sand trap designed south of the breakwater and pump $0.4 \times 10^6 \text{ m}^3$ of sediments per year to the northern side and dispose it at various points along the beach. But, the present computations estimates the volume of sediments to be bypassed to the northern side of the coast is only $0.13 \times 10^6 \text{ m}^3$ per year. This bypassing operation has to be carried out at the rate of $0.0188 \times 10^6 \text{ m}^3$ per month from March to September as presented in Table 4. The shoreline changes with presence of existing

coastal structures with sand by passing system after 1, 2, 5, 10, 15 and 20 years are shown in Figure 7 and presented in Table 5. In the case of sand bypassing system, results show that the maximum retreat of the shoreline along Puducherry coast is estimated to be 20 m after 20 years and extends 500 m northern end of the seawall.

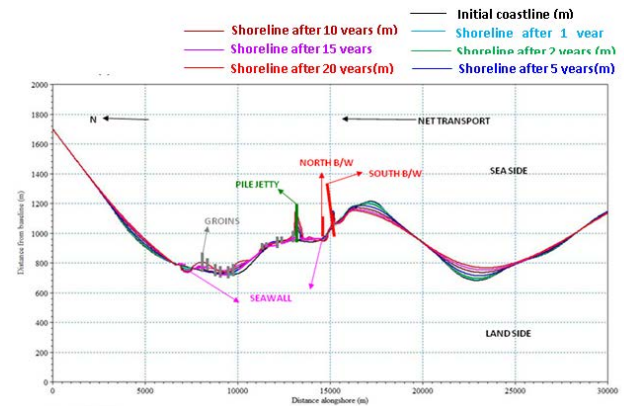


Figure 7. Shoreline changes after 1, 2, 5, 10, 15, 20 years with presence of existing structures and with sand bypassing.

Table 5. Shoreline changes with existing structure and with sand bypassing

Years	Accretion on southern side (m)		Erosion on northern side (m)	
	Offshore direction	Alongshore direction	Offshore direction	Alongshore direction
	After 1 year	-	-	-
After 2 year	-	-	-	-
After 5 years	10	50	5	100
After 10 years	15	100	10	250
After 15 years	20	100	20	400
After 20 years	20	100	20	500

3. Discussion and Conclusion

The present study shows that in order to avoid shoreline erosion along the Puducherry coast, the sand bypassing operation with beach nourishment has to be carried out at the rate of $0.0188 \times 10^6 \text{ m}^3$ per month from March to September. Such operation can be planned initially for a short period (say 2 to 3 years) and after monitoring its behavior, a long-term arrangement can be worked out.

Moreover, the study indicates that the DHI-LITPACK modeling tools can be used suitably for the estimation of littoral drift and shoreline change studies.

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