

Wave Climate and Nearshore Sediment Transport Pattern Along the SE Coast of India



V. Ranga Rao, Akhil Kolli, K. Stephen Raju and D. Kumaresan

Abstract Wave climate along five selected transects covering 580 km length of the SE coast of India was studied based on National Institute of Ocean Technology (NIOT) wave atlas. The wave height of 90% of the waves ranged from 0.5 to 0.8 m whereas for 10% of the waves the wave height varied from 1.5 to 2.0 m along the coast. The wave period usually varied between 4 and 6 s. During the NE monsoon season (January), the wave direction was predominantly ESE whereas during the SW monsoon the predominant direction was SSE. The wave climate data was utilized to estimate the sediment transport rates at 0.8, 2, 5, 10, 30 and 50 m depth contours across each of the five selected transects of the SE coast. The required wave parameters at these depths were calculated using Linear Wave Calculator of parabolic mild slope wave model of Danish Hydraulic Institute (DHI), Denmark. The calculated wave parameters at the different depth contours were given as input to simulate the sediment transport rates at the same depth contours using LITSTP model of LITPACK package of DHI. The remarkable feature identified in the present investigation is that most of the sediment transport was confined to nearshore waters within 10 m depth contour, i.e. within 5 km from the shoreline. The simulated results indicate that the sediment transport rate usually varied between a minimum value of 975 m³/month and a maximum value of 73,967 m³/month. The sediment transport rates along the coast is relatively higher during the NE monsoon season as compared to those during the SW monsoon.

Keywords Wave climate · Nearshore sediment transport · LITSTP SE coast of India

V. Ranga Rao (✉) · D. Kumaresan
ICMAM-PD, NIOT Campus, Pallikaranai, Chennai 600100, India
e-mail: vrrao@icmam.gov.in

A. Kolli · K. Stephen Raju
Department of Applied Mechanics & Hydraulics, NITK, Surathkal, Mangalore 575025, India

© Springer Nature Singapore Pte Ltd. 2019
K. Murali et al. (eds.), *Proceedings of the Fourth International Conference in Ocean Engineering (ICOE2018)*, Lecture Notes in Civil Engineering 23,
https://doi.org/10.1007/978-981-13-3134-3_12

1 Introduction

The littoral sediment transport pattern along a particular coast usually takes place due to the action of breaking waves [1–4]. The breaking waves result in the pile-up of water along the coast which in turn leads to the generation of littoral currents and moves the sediment either in alongshore or offshore/onshore direction. The onshore/offshore and alongshore movement of sediment is usually dependent on several factors such as beach slope, wave period, current direction and bottom friction [5, 6]. Both the strength and direction of sediment movement varies with season and location [3, 7–13]. Chandramohan et al. [14] revealed that the sediment transport pattern along the east coast of India takes place northward for 8 months (March–October) and southward for the remaining four months (November–February) of the year. According to Chandramohan and Nayak [15], the net annual sediment transport along the east coast is northward whereas along the west coast it is southward except for the south Gujarat Coast. In the present study, an attempt was made to study the nearshore wave climate and associated sediment transport pattern along the SE coast of India.

2 Study Area

The 580 km length of the study area (SE coast of India) starting from Kavali in Andhra Pradesh to Nagapattinam in Tamilnadu has three major ports (Ennore, Chennai, and Thoothukudi) and two medium ports (Cuddalore and Nagapattinam). Natural factors like cyclones, coastal flooding, coastal sediment deposition, tsunami, etc. and the anthropogenic factors such as domestic and industrial sewage due to urbanization and industrialization play a major role on the sediment dynamics along the coast. The material inputs from industries, aquaculture, tourism sector, petroleum products, fertilizer, pesticides, etc. enter the nearshore waters affecting the mangroves and related coastal environments [16].

3 Data and Methodology

In order to study the spatial as well as temporal variations of the sediment transport along the SE coast of India, five cross-shore transects (A–E) were fixed as shown in the Fig. 1. Each transect covers the distance from shoreline to 50 m depth contour offshore and the details of the physiographic characteristics of each transect are given in Table 1.

For each transect, the data on cross-shore bathymetry (from 0 to 50 m depth) was extracted by re-analysis of the bathymetry data from ICMAM database and by combining online bathymetry data, c-map and ICMAM field data. The directional wave

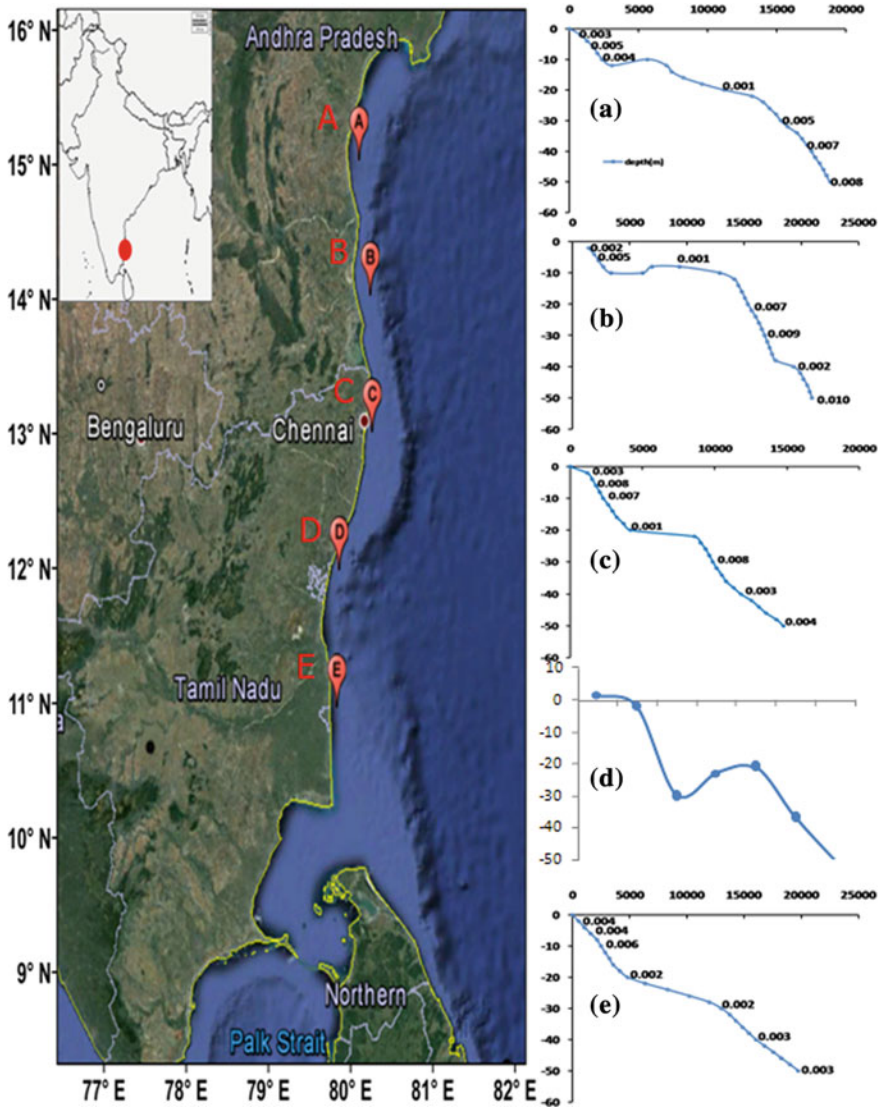


Fig. 1 The study area showing the five transects (A, B, C, D and E) with cross-shore bathymetry profiles (values on each profile indicate the ‘bed slopes’ at corresponding depth contour)

data needed at the offshore depths were collected from the wave atlas (1998–2012) of the Indian Coast prepared by NIOT [17]. The offshore location at which the wave parameters of the NIOT wave atlas represents is around 24–26 m depending on the transect. The extracted data from the NIOT wave atlas was used to calculate the wave parameters at 0.8, 2, 5, 10, 30 and 50 m depth contours using Linear Wave Calculator

Table 1 Details of the five transects along the SE coast

Transect Id	Transect origin at shore	Shoreline orientation (°N)	Mean slope along the transect	Transect length up to 10 m depth contour (km)	Transect length up to 50 m depth contour (km)
A	15.000N 80.192E	20	0.0047 (1:213)	6.1	25.8
B	14.000N 80.334E	10	0.0051 (1:196)	12.9	22.1
C	13.000N 80.357E	15	0.0038 (1:263)	2.7	15.2
D	12.000N 79.969E	25	0.0095 (1:105)	6.7	23.5
E	11.000N 79.935E	5	0.0034 (1:294)	3.3	19.8

(LWC) of DHI (2005). The calculated wave parameters at 0.8, 2, 5, 10, 20, 30 and 50 m depth contours for each of the five transects were later utilized as input for the LITSTP model of LITPACK [18].

The LITSTP is a one-dimensional model that includes the hydrodynamic processes and the intra-wave sediment transport mechanisms. The input data for the LITSTP module are the wave period (T), wave height (H), wave direction (θ), current speed and direction, shoreline angle, seabed slope and the mean sediment size. The wave direction alpha (α) is the angle between the wave orthogonal and the coast orthogonal (i.e. α is 0° if the wavefronts are parallel to the coast). The g value taken as $9.82 \text{ m}^2/\text{s}$ and the density as $1028 \text{ kg}/\text{m}^3$. While simulating the model the depth and the bed slope values were specified at each calculated location. Both current speed and direction were specified at each of the simulated location and the sediment size (0.2 mm) was represented as the mean grain diameter d_{50} . The uniformly graded sediment process was considered and the related fall velocity and the specific gravity were adopted as 0.022 m/s and 2.65 respectively. The model simulations to derive sediment transport rates along the SE coast were carried out for January and August months representing NE and SW monsoon wave climatic conditions respectively.

4 Results and Discussion

4.1 Wave Climate

January (NE Monsoon): The percentage distribution of wave height, wave period and wave direction at an offshore location derived from the NIOT wave atlas for each of the five transects (A–E) are shown in Fig. 2. In January the transects C, D and E

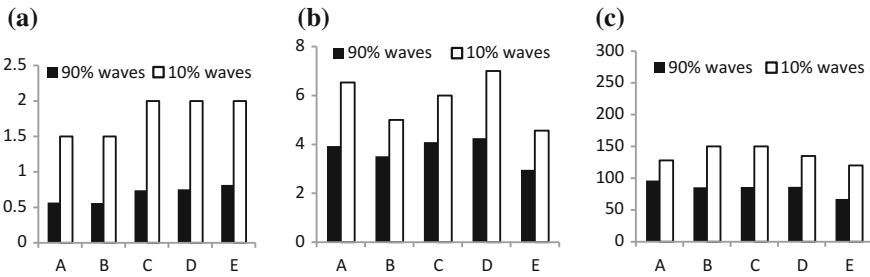


Fig. 2 Deepwater wave parameters—**a** wave height (m) **b** wave period (s) and **c** wave direction (deg) derived from NIOT wave atlas for the offshore region (around 22.8 and 30.4 m) for the five different transects (A–E) along the SE coast for January representing NE monsoon conditions

showed higher wave strengths of around 2.0 m whereas transects A and B showed comparatively lower strengths of around 1.5 m. Overall, the occurrence of higher strength waves in the offshore area (NIOT buoy location) comprised only 10% of the total waves and were within the range of 1.5–2.2 m. However, the lower strength waves which is a regular phenomena comprised 90% of the waves and ranged from 0.5 to 0.8 m height.

The wave period of 90% of the waves (Fig. 2b) along the SE coast usually falls within the range of 4–5 s whereas the remaining 10% fall within 5–7 s. The wave direction in January (NE monsoon) at the different transects (Fig. 2c) indicates that, in general, the waves approach the coast between 75 (ENE) and 155 (SSE) direction. However, 90% of the waves approach the shore between 75 and 90 (ENE and E) and the remaining 10% of the waves from 125 and 155 (ESE and SSE). Thus, during the NE monsoon season about 10% of the waves having higher strengths approach the coast from the SE direction while 90% of the waves approach the coast from ENE direction.

August (SW Monsoon): In August, the transects C and D (Fig. 3a) showed higher wave strengths of around 1.5 m whereas the transects A, B and E showed lower strengths of around 1.0 m. About 90% of the waves with strengths of 0.4–0.7 m and periods of 4–5 s (Fig. 3b) approach the coast from SE and SW direction (Fig. 3c).

Overall, it is observed that there is a clear demarcation in the approach direction between higher and lower strength waves along the SE coast. The higher strength waves (1.0–1.5 m) even though they are of less percentage approach predominantly from the S and SE directions during both the seasons. The lower strength waves approach the coast from ENE in NE monsoon and S and SSE in SW monsoon. Further, the NE monsoon is characterized by higher strength waves as compared to that of during the SW monsoon season. The lower strength of waves in the SW monsoon season may be due to the shadowiness of Sri Lanka peninsula for S wave propagation originating from the equatorial Indian Ocean region.

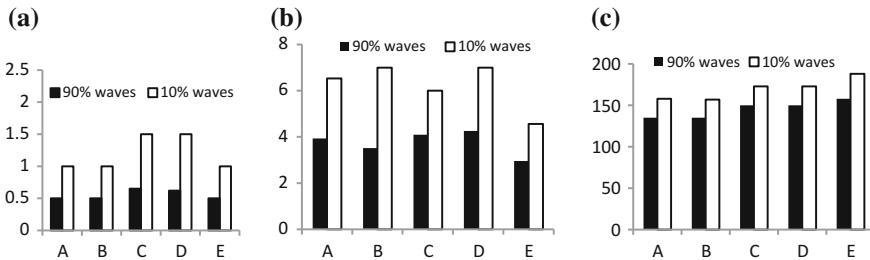


Fig. 3 Deep water wave parameters—**a** wave height (m), **b** wave period (s) and **c** wave direction (deg) derived from the NIOT wave atlas for the offshore region (around 22.8 and 30.4 m) for the five different transects (A–E) along the SE coast for August representing SW monsoon conditions

4.2 Wave Transformation in Shallow Water

January (NE Monsoon): The calculated wave height (H), wave period (T) and wave direction (θ) at the different depth contours (0.8, 2, 5, 10, 20, 30, and 50 m) based on LWC for each of the five transects (A–E) for January representing NE monsoon conditions are shown in Table 2. At transect A, 90% of the wave heights varied from 0.6 m (in deep water areas) to 0.5 m (in shallow waters near shoreline), whereas the wave direction vary from 96° in deep water areas to 88° in shallow waters areas. However, 10% of the waves with heights vary between 1.6 m (in deep water areas) to 0.7 m (in shallow water areas close to shoreline) and the directions vary from 125° to 123° as the waves approach from deep water areas to shallow water areas. More or less similar trend of wave transformation was noticed along transect B.

Along transects C–E the deep water wave heights at these three transects varied between 0.7 and 2.0 m whereas the shallow water wave heights varied between 0.7 and 0.8 m. Similarly, the directions varied between 135 and 81 in deep water areas and between 105 and 78 in shallow water areas (close to the coast). On the whole, the waves transformed from greater heights (around 0.7–2.0 m) to lower heights (0.7–0.8 m) as the waves approach the shore. This kind of wave transformation in January representing NE monsoon conditions may lead to southward sediment transport along the coast.

August (SW Monsoon): The calculated wave height (H), Wave period (T) and wave direction (θ) at different depth contours (0.8, 2, 5, 10, 20, 30, and 50 m) utilizing NIOT wave atlas data based on LWC along the five transects (A–E) for the month August representing SW monsoon conditions are shown in Table 3. At transect A, 90% of wave heights varied from 0.5 m (in deep water areas) to 0.6 m (in shallow waters near shoreline), whereas the wave direction varies from 135° in deep water areas to 121° in shallow waters areas. However, 10% of waves with heights vary between 1.0 m (in deep water areas) to 0.64 m (in shallow water areas close to shoreline) and the directions vary from 158° to 121° as the waves approach from deep water areas to shallow water areas. More or less similar trend of wave transformation was noticed along transect B.

Table 2 Transformed wave parameters at different depth contours covering deep water areas (50 m) to shallow water areas (0.8 m) across transects A–E in January (NE monsoon)

Depth	0.8 m		2 m		5 m		10 m		NIOT wave atlas		30 m		50 m	
	%occurrence	90%	10%	90%	10%	90%	10%	90%	10%	90%	10%	90%	10%	90%
<i>Transect A</i>														
H (m)	0.6	0.7	1.6	0.5	1.5	0.6	1.4	0.6	1.5	0.6	1.5	0.6	1.5	0.6
T (S)	4	5	7	4	7	4	7	4	7	4	7	4	7	4
θ (deg)	88	123	123	95	122	96	124	96	125	96	125	96	125	125
<i>Transect B</i>														
H (m)	0.6	0.7	1.5	0.5	1.3	0.6	1.4	0.6	1.5	0.6	1.5	0.6	1.5	0.6
T (S)	4	5	5	4	5	4	5	4	5	4	5	4	5	4
θ (deg)	74	135	135	80	147	81	151	81	151	81	151	81	151	151
<i>Transect C</i>														
H (m)	0.7	0.7	1.6	0.7	1.7	0.7	1.7	0.7	1.9	0.7	1.9	0.7	1.9	0.7
T (S)	4	6	6	4	6	4	6	4	6	4	6	4	6	4
θ (deg)	93	110	115	83	123	81	134	81	135	81	135	81	135	135
<i>Transect D</i>														
H (m)	0.7	0.7	1.6	0.7	1.9	0.7	1.8	0.7	1.9	0.7	1.9	0.7	1.9	0.7
T (S)	4	7	7	4	7	4	7	4	7	4	7	4	7	4
θ (deg)	105	119	119	87	119	84	120	84	120	84	120	84	120	120
<i>Transect E</i>														
H (m)	0.8	0.7	1.6	0.7	1.7	0.8	1.8	0.8	1.9	0.8	1.9	0.8	1.9	0.8
T (S)	4	5	5	4	5	4	5	4	5	4	5	4	5	4
θ (deg)	78	101	96	66	103	64	106	64	107	64	107	64	107	107

Table 3 Transformed wave parameters at different depth contours covering deep water areas (50 m) to shallow water areas (0.8 m) across transects A–E in August (SW monsoon)

Depth	0.8 m		2 m		5 m		10 m		NIOT wave atlas		30 m		50 m	
	%occurrence	90%	10%	90%	10%	90%	10%	90%	10%	90%	10%	90%	10%	90%
<i>Transect A</i>														
H (m)	0.6	0.64	1.0	0.5	0.9	0.5	0.9	0.9	0.5	1.0	0.5	1.0	0.5	1.0
T (S)	4	7	4	7	4	7	4	7	4	7	4	7	4	7
θ (deg)	121	122	127	132	137	134	142	135	158	135	158	135	158	158
<i>Transect B</i>														
H (m)	0.6	0.7	1.1	0.5	0.9	0.5	0.9	0.9	0.5	1.0	0.5	1.1	0.5	1.1
T (S)	4	7	4	7	4	4	7	4	4	7	4	7	4	7
θ (deg)	120	121	136	132	138	135	146	135	157	135	157	135	157	161
<i>Transect C</i>														
H (m)	0.7	0.7	1.1	0.6	1.1	0.7	1.2	1.2	0.7	1.5	0.7	1.7	0.7	1.7
T (S)	4	6	6	4	6	4	6	6	4	6	4	6	4	6
θ (deg)	133	121	132	145	155	150	160	150	173	151	176	151	176	176
<i>Transect D</i>														
H (m)	0.7	0.7	0.9	0.6	1.0	0.6	1.1	1.1	0.62	1.5	0.6	1.5	0.6	1.5
T (S)	5	6	5	4	7	4	7	5	7	5	7	5	7	7
θ (deg)	127	133	136	144	143	148	183	150	173	149	173	149	173	173
<i>Transect E</i>														
H (m)	0.4	0.7	0.4	0.6	0.6	0.4	0.8	0.8	0.5	1.0	0.4	1.0	0.4	1.0
T (S)	3	5	3	5	3	3	5	3	3	5	3	5	3	5
θ (deg)	116	133	137	144	162	152	178	158	188	152	189	152	189	189

Along transects C–E the deep water wave heights at these three transects varied between 0.4 and 1.7 m whereas the shallow water wave heights varied between 0.4 and 0.7 m. Similarly, the directions varied between 179 and 189 in deep water areas whereas in between 116 and 133 correspondingly in shallow water areas close to the coast. On the whole, the waves transformed from greater heights (around 0.5–1.5 m) to lower heights (0.4–0.7 m) as the waves approach the shore. Such wave transformation in August representing SW monsoon conditions may lead to northward sediment transport especially along the southern part of SE coast.

4.3 Nearshore Sediment Transport—LITSTP

After obtaining the transformed wave parameters at the required depth from LWC, the sediment transport rate at that depth was simulated using LITSTP model for each of the five transects as described in Sect. 3. To study the nearshore sediment transport pattern along the SE coast simulations for the months of January and August representing the NE and SW monsoon conditions respectively were carried out and the results were plotted as shown in Fig. 4.

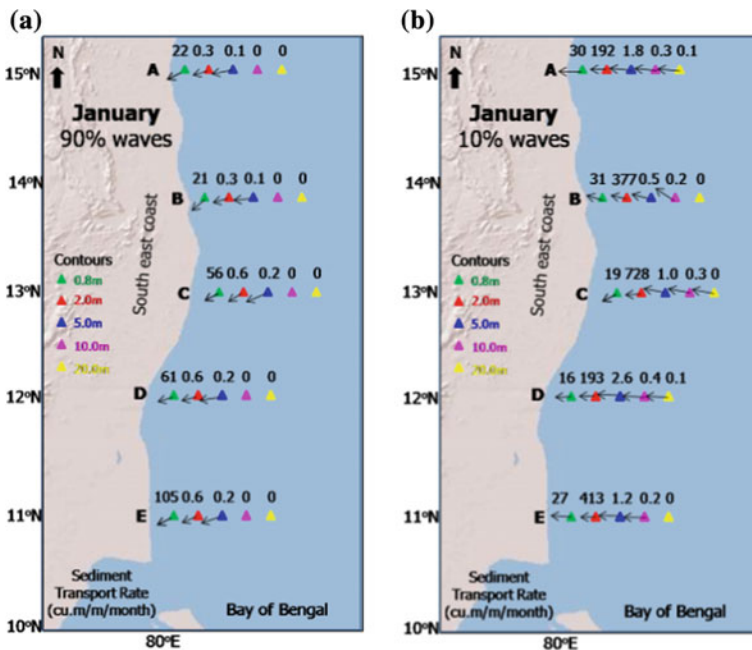


Fig. 4 Simulated sediment transport rate at different depth (0.8, 2.0, 5.0, 10.0 and 20.0 m) contours along each of the five transects (A–E) under the wave conditions of January (NE monsoon). Values on the figure represent the magnitude in $m^3/month/m$ while the arrows indicate the direction of sediment transport

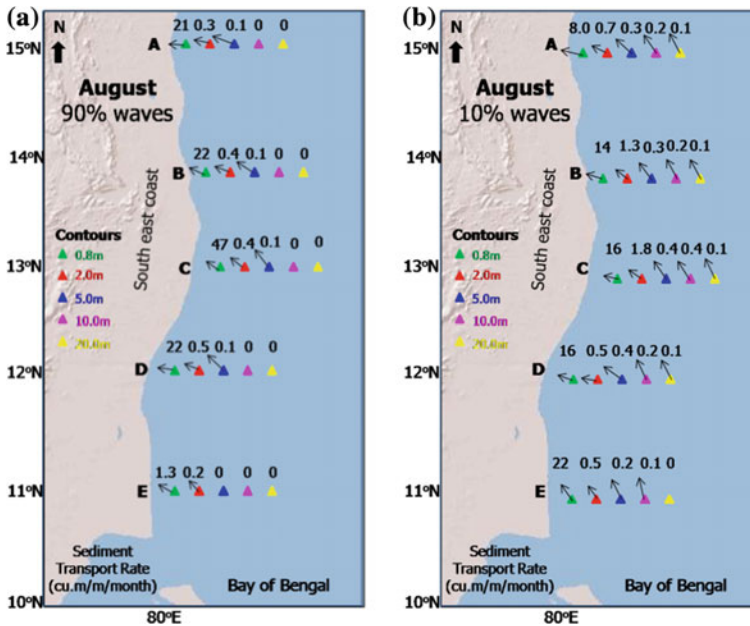


Fig. 5 Simulated sediment transport rate at different depth (0.8, 2.0, 5.0, 10.0 and 20.0 m) contours along each of the five transects (A–E) under the wave conditions of August (SW monsoon). Values on the figure represent the magnitude in $\text{m}^3/\text{month}/\text{m}$ while the arrows indicate the direction of sediment transport

In general, it is observed that the rate of sediment transport in January (NE Monsoon) is higher close to the coast and gradually decreased towards the offshore area up to 20 m depth contour. Sediment transport was negligible beyond 20 m depth at almost all the five transects studied. The sediment transport rate due to 90% of the waves is low (21–105 $\text{m}^3/\text{month}/\text{m}$) (Fig. 4a). High sediment transport rate of 192–798 $\text{m}^3/\text{month}/\text{m}$ (Fig. 4b) occurs at 2 m depth contour due to 10% of the waves.

More or less similar features were observed in August (SW monsoon) as that of January (NE monsoon) but the direction of sediment transport was predominantly northward with lower sediment transport rates. The sediment transport rate during the SW monsoon is relatively lower than that of during the NE monsoon (Fig. 5). The highest sediment transport rate of 1.3–47 $\text{m}^3/\text{month}/\text{m}$ (Fig. 5a) was seen due to 90% of the waves while 8–22 $\text{m}^3/\text{month}/\text{m}$ (Fig. 5b) due to 10% of the waves representing SW monsoon conditions.

From the simulated sediment transport rates as mentioned under Figs. 4 and 5, the computed gross sediment transport rate along each of the five transects due to 90% wave occurrences for the months January (NE monsoon) and August (SW monsoon) is given in Table 4. It is clearly noticed that the sediment transport rate during the SW monsoon is low (975–42,251 m^3/month) when compared to that of during the NE monsoon (13,319–73,967 m^3/month) at almost all the transects. The highest

Table 4 Sediment transport (ST) rate (m^3/month) due to 90% of wave occurrences along the SE coast

Transect Id	January (NE monsoon)	August (SW monsoon)
	ST due to 90% waves	ST due to 90% waves
A	13,319	12,643
B	21,143	21,664
C	50,618	42,251
D	42,959	15,573
E	73,967	975

Table 5 Sediment transport (ST) rate (m^3/month) due to 10% of wave occurrences along the SE coast

Transect Id	January (NE monsoon)	August (SW monsoon)
	ST due to 10% waves	ST due to 10% waves
A	67,297	5436
B	144,517	14,201
C	206,890	15,442
D	53,031	12,249
E	164,225	15,337

sediment transport rate of $73,967 \text{ m}^3/\text{month}$ was noticed during the NE monsoon season while the lowest sediment transport rate of $975 \text{ m}^3/\text{month}$ was noticed during the SW monsoon along the SE coast.

The gross sediment transport rate along each of the five transects due to 10% wave occurrences for the month of January (NE monsoon) and August (SW monsoon) is given in Table 5. It is noticed that the sediment transport rate during the SW monsoon is low compared to that of during the NE monsoon season at almost all the transects.

For validation, the simulated sediment transport rates were compared with published studies for this region [15, 19–21]. The simulated sediment transport rates reasonably matched well with the values obtained from the past studies as shown in Fig. 6.

5 Conclusion

Along the SE coast of India, 90% of the waves have wave heights ranging from 0.5 to 0.8 m whereas 10% of the waves have heights of 1.5–2.0 m. The wave period usually varies between 4 and 6 s. During the NE monsoon season (January) the wave direction is predominantly ESE whereas during the SW monsoon it is SSE. A remarkable feature identified in the present study is that most of the sediment transport is confined to the nearshore waters within 10 m depth contour i.e. within

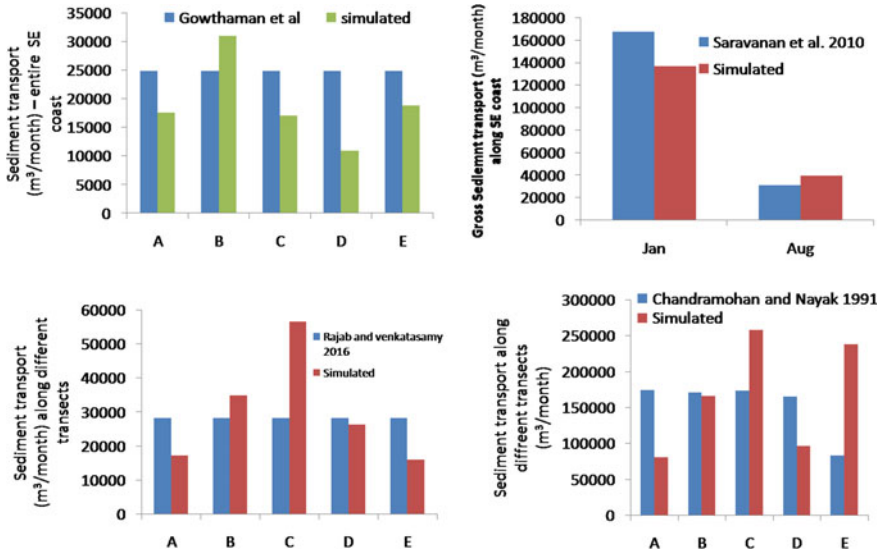


Fig. 6 Comparison between the simulated sediment transport rates and studies reported for the study area

5 km from the shoreline. The simulated results indicated that the sediment transport rate usually varied between a minimum value of 975 m³/month and a maximum value of 73,967 m³/month. The sediment transport rates along the coast are relatively higher during the NE monsoon season as compared to that of the SW monsoon. The direction of the sediment transport is southward in January representing the NE monsoon wave climatic conditions whereas northward in August representing the SW monsoon wave climatic conditions.

Acknowledgements The authors wish to express their sincere thanks to Dr. M. Rajeevan, Secretary, Ministry of Earth Sciences, and Dr. M. V. Ramana Murthy, Head, ICMAM, for their keen interest and encouragement. The authors (Akhil Kolli and Stephen Raju K.) express their gratitude to Dr. Subba Rao, NITK, Suratkal and Dr. P. Madeswaran, of ICMAM, Chennai for providing the necessary permissions and facility to carry out internship at ICMAM in the field of nearshore sediment dynamics. The authors are thankful to NIOT for providing the wave atlas of Indian coast for the present study.

References

1. Zheng J, Li R, Yu Y, Suo A (2014) Influence of wave and current flow on sediment-carrying capacity and sediment flux at the water—sediment. *Water Sci Technol* 338:1090–1099
2. Baldock TE, Manoonvoravong P, Pham KS (2010) Sediment transport and beach morphology-dynamics induced by free long waves, bound long waves and wave groups. *Coast Eng* 57:898–916

3. Eaton RO (1950) Littoral processes on sandy coasts. In: Proceedings of the first conference of coastal engineering, pp 140–154
4. Johnson DK (1919) Shore processes and shoreline development. Wiley, p 584
5. Daily JW, Stephen SC (1951) Characteristics of solitary waves. Proc Am Soc Civil Eng 77:107
6. Munk WH (1949) The solitary wave theory and its application to surface problems. Ann N Y Acad Sci 51:396–424
7. Manohar M (2017) Sediment movement at south Indian ports. Coast Eng 359–405. <https://journals.tdl.org/icce/index.php/icce/article/view/1911/1170>. Accessed 3 June 2017
8. Gilbert GK (1890) Lake Bonneville. Monographs of U. S. Geological Survey I: 584
9. Johnson JW (1953) Sand transport by littoral currents. In: Proceedings of the fifth hydraulic conference, vol 34, pp 89–109
10. Johnson JW (1957) The littoral drift problem at shoreline harbours. Proc Am Soc Civil Eng 83:1–37
11. Johnson JW (1956) Dynamics of near shore sediment movement. Bull Am Assoc Pet Geol 40:2211–32
12. Johnson JW (1953) Engineering aspects of diffraction and refraction. Trans Am Soc Civil Eng 118:617–652
13. Kuenen H (1950) Marine geology. Wiley, pp 221–251
14. Chandramohan P, Nayak BU, Raju VS (1990) Longshore-transport model for south Indian and Sri Lankan coast. J Water Way Port Coast Ocean Eng 116:408–423
15. Chandramohan P, Nayak BU (1991) Longshore sediment transport along the Indian coast. IJMS 20:110–114
16. Ramesh R, Nammalwar P, Gowri VS (2008) Database on coastal information of Tamilnadu. Environmental Information System Centre, Department of Environment, Government of Tamilnadu, Institute of Ocean Management, Anna University, Chennai
17. NIOT (2017). http://moes.gov.in/writereaddata/files/press_release_atlas_on_wave_related_information.pdf. Accessed Aug 2017
18. DHF (2005) DHI Water & Environment, MIKE Zero, Denmark
19. Gowthaman R, Sanil Kumar V, Siddaramaish G, Shanias DR, Jena BK, Jai Singh (2015) Nearshore waves and longshore sediment transport along Rameshwaram island off the east coast of India. Int J Nav Archit Ocean Eng 7:939–950
20. Rajab PM, Thiruvenkatasamy K (2016) Shoreline change studies due to construction of breakwaters at Ariyankuppam river mouth in Puducherry—a union territory of India, south India. Indian J Sci Technol 9:45
21. Saravanan S, Chandrasekar N (2010) Potential littoral sediment transport along the coast of south eastern coast of India. Earth Sci Res 14:153–160