IJBPAS, January, Special Issue, 2022, 11(1): 675-690

ISSN: 2277–4998

International Journal of Biology, Pharmacy and Allied Sciences (IJBPAS)

'A Bridge Between Laboratory and Reader'

www.ijbpas.com

INFLUENCE OF THE WAVE ENERGY SPECTRA AND OTHER COASTAL PROCESSES ON SEDIMENT TRANSPORT ALONG THE COAST OF INDIA

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Received 10th June 2021; Revised 11th July 2021; Accepted 20th Aug. 2021; Available online 15th Jan. 2022

https://doi.org/10.31032/IJBPAS/2022/11.1.1082

ABSTRACT

The morphometric changes in coastal landforms can be related to the seasonal and spatial variation in wind velocity, wave energy, storm surges, and cyclonic phenomena along the coast of India. The west coast is marked with a broad and shallow continental shelf. It is subject to high storm surges, but smaller waves along the coast of Karnataka and Kerala in early monsoons, maximum morphological changes take place with high wave energy. During this period, most of the sediment material gets transported along the shore and gets preserved during the post-monsoon season. The gross sediment transport is low ($5x10^5 m^3$) along the west coast. While, the east coast of India with a narrow and steep shelf, produces high and powerful waves. Rivers, along their mouth region, discharge water and sediment explicitly as well, higher along east coast. The northeast monsoon brings high wave activity along the east coast, increasing the rate of sediment transport (15-20 $x10^5$ m^3). Meanwhile, the stretches of the east coast are subjected to severe storm surges and cyclonic storms during October-December. The calculated wave energy spectrum was used to identify the different wave systems present in the study areas. The present study determines the distribution of wave energy along the Indian coast and the associated coastal conditions.

Keywords: Wave energy spectra, Indian Monsoon, tidal energy and Sediment transportation

INTRODUCTION

Coastal sediment transport is the result of energy released by the surface gravity waves, longshore currents and monsoon along Indian coast (Aboobacker, 2010). The wave propagation in shallow waters of west coast transforms wave energy due to reflection, refraction, and friction. Irregular coastline and seasonal weather contributes oblique wave propagation near the shore. The study of irregular waves are often described by wave energy spectra which indicate the amount of wave energy at different wave frequencies (Devananth *et al* 2020).

The significantly long coastline of India experience a unique trend in a wave-driven sediment transport mechanism along with monsoon winds (Bird, 2010). The wave energy spectrum is the amount of wave energy at different frequencies, affected due to sea waves, tidal currents, wave refraction, siltation of inlets and river mouths, stream outflow, storm surges, and cyclones is constantly working in the coastal zone (Rao, 1989; Purnachandra Rao & Wagle, 1997; Pillai & Kathia, 2004; Schwartz, 2006; Suresh *et al* 2010). Dissipation of energy (due to tide, wind, waves, and current) is often provided by the beaches, mudflats, marshes, and mangroves. Wind velocity and wind direction also show definite trends during seasonal anomalies, which are subjects to the transportation of sediment along and near the shores of the Indian coastline (Kumar& Nair, 2017).

Estimation of beach sediment volume changes on the annual scale reveals that the transport of the sediment is dynamic but gradual throughout the Indian coast (Jayyappa and Subrahmanya, 1989). Wave energy variations create an alongshore deviation in surf zone beach types where low energy dissipative in the south-west Indian coast, moderate energy intermediate in the central areas, while moderate to high energy dissipative in the north. The dominant southerly waves drive alongshore gradient in wave energy from south to north, and nearshore/surf zone sediment transport increases from south to north (Jose *et al* 1997).

The previous studies indicate that the wave energy spectra along west coast are bimodal due to the presence of prevailing winds, swells, and wave-seas (Kumar and Nair, 2015; Sheng and Li, 2017). In India, many attempts have been made to study coastal processes and their influences. Earlier attempts were made with observations and surveys by Rao (1989) under the guidelines of the Geological Survey of India. Further, Purnachandra Rao (1997) classified the Bay of Bengal and the Arabian Sea coast based on the observation of storm surges, wave heights, and tidal ranges. Parallel studies were conducted for every coastal area along the Indian coastline. With the establishment of the National Institute of Oceanography (NIO), in the 1970s, and the Survey of

India (SOI) empirical study on coastal areas in India started with the zest. Murty (1983) along the east coast of India. Several studies are carried out to estimate the general pattern of longshore sediment transport near Goa and western coast of India by Chandramohan *et al*. (1993) and Kumar (2013, 2015 and 2017). Chandramohan and Nayak (1991) developed a sediment transport model based on the longshore energy flux equation. Wave energy along the Indian coast is multi-peaked and shifts with the onset and offset of monsoon was explicitly marked by Rao and Baba (1996).

The role of remote sensing and satellite data in predicting and assessing coastal storm impacts was adopted in India in the late 1990s. Kunte (2003; 2003a; 2008; 2013) and Rajawat *et. al.* (2005) quantitatively assessed suspended sediments movement by digitally analysing various satellite data. While, Kumar and Nair (2017) reported the significance of SW monsoon winds in sediment transport. Sundar *et al*. (1999) used tide-gauge data for testing numerical models of sea-level rise estimation. Aboobacker (2010) implemented the 3D Hydrodynamic model 'COSMOS' successfully inpredicting tidal currents variation, residual currents, sea surface temperature, and salinity distribution in the high tide.

The assessment of sediment transport has great importance concerning sustainable development and coastal zone management. Within a decade, more than 7% of the Indian coastline gets eroded due to tremendous development activities of which protective coastal constructions contribute the most (Pillai and Kathia, 2004). There is a need to understand the sedimentation and circulation processes occurring in the region because of several development activities taking place along the coast of India.

The motivation of this study is to examine the relationships between the wave energy generated by all coastal processes, bathymetry of the Indian coast, and sediment transportation (Rodriguez, 2012). The main objective of the study is to understand the process of coastal sediment transportation along both the coasts of India and determine the effect of wave energy and other processes on sediment transportation. The other objective is to understand the effect of the most significant weather phenomena along the Indian sub-continent i.e. monsoon, on wave energy and simultaneous sediment transportation.

Study area

The Indian coastline along with Andaman and Nicobar Islands in the Bay of Bengal and Lakshadweep Islands in the Arabian Sea is 7517 km in length. The peninsular topography and bathymetric variations divides the coast into west coast with broad and shallow coastline and east coast with the narrow and steep coastline. The study area experiences seasonal monsoon winds, which flow from northeast during post –monsoon period and southwest during monsoon period. During monsoon winds, the wave climate is dominated by sea-swells coming from southeast and influence land –sea breezes. The breezes affect wave generation and weakens sediment deposition (Kumar and George, 2016).

The eastern coast is composed of alluvial, deltaic, gently indented, and extensively developed. The east coast lies amongst the Eastern Ghats and the Bay of Bengal. The shelf area of the east coast varies between 100to130 km. The deltaic systems of the east coast experience a high sedimentation rate and periodic cyclones which results in extensive floods.

Rivers draining coastal plains and deltas are Mahanadi, Godavari, Kaveri, and Krishna and bring large quantities of water and sediment. These coastal plains are from the Mahanadi delta, the southern Andhra Pradesh plain, the Krishna-Godavari deltas, the Kanyakumari coast, the Coromandel Coast, and the sandy coast. The east coast generally becomes active during the cyclones of the northeast monsoon period (October – November). The Annual Gross sediment transport rate is estimated as15-20 x 10^5 m^3 (Chandramohan and Nayak, 1991). The west coast of India differs from the east where practically no deltas are formed and are highly irregular, cliffed, and wave eroded (Purnachandra and Wagle, 1997). The region stretches from Gujarat, Maharashtra, Goa, Karnataka, and Kerala. Major rivers flowing into the sea are the Tapi, Narmada, Mandovi, and Zuari. The coastline here is modified by headlands, bays, and lagoons at irregular intervals. There is distinct evidence of the effect of non-tectonics in some sections (Bird, 2010).

The western coast is divided into three regions named Konkan, the Kanara, and the Malabar Coast. The Continental shelf is very wide on the west coast with about 340 km in the north, tapering to less than 60 km in the south (Fig.1). The coastline on the west receives southerly winds that bring high waves during the monsoons (June - September). The Annual Gross sediment transport rate is comparatively less than that of the east coast viz.5-10 x 10^5 m^3 (Kunte, 2008).

DATA AND METHODOLOGY

The wave and hydrodynamic data was acquired from DHI's (Danish Hydraulic Institute) MetOceanmodelling portal, ESSO-INCOIS marine repository and Regional Maritime Board data. From the continuously recorded time series data, 24 hours duration were taken as one record obtained from Met Ocean portal. The wave data analysis is similar to the method presented in Chandramohan and Nayak (1990) and Kumar and George (2016). Significant wave height (H_s) and mean wave period (T_m) were obtained from Met Ocean modelling portal. Spectral peak period (T_p), maximum spectral energy density (E_{max}) and wave spectrum (λ) were estimated following Kumar and George (2016). Mean wave direction (D_m), wave period (T_m) data, tidal range (T_r) and storm surge data were obtained and averaged from Met Ocean modelling portal. Swell (S_w) and swell period (S_{wp}) and wind data were estimated from ESSO-INCOIS marine repository. The sediment transport rate analysis was obtained following Chandramohan and Nayak (1991). The wave and tide data from 1980 to 2010 and 2013-2020 were used in the study. Since the data from year 2011-2012 is discrete and vague, it was not included in the present study. The wave energy spectrum was calculated at a resolution of 0.1 to 0.5 Hz frequency. Normal flow of the tidal current generates a tidal energy ranging from 0.04 to 1 KWm^{-1}at various tidal ranges.

Tidal energy can be calculated with the formula as mentioned in Wei *et al.*, (2016),

$$\boldsymbol{E = \frac{1}{2} A\rho g h^2}$$

Where,

E = Tidal energy in KWm^{-1},

A = Horizontal energy of an area (m^2),

ρ = density of water (it is taken to be 1025.81 Kgm^{-3} when the sea surface temperature

is averaged to 32^{o}C and salinity as 33 ppm for study areas),

g = gravity due to acceleration (9.81 m/s^2),

h = vertical tidal range in meters (observed tidal range of Vaitarna (3.9 m), Revdanda (2.8 m) and Mumbri region (1 m).

Nair *et al* (1986), Rajamanickam & Gujar (1997) and Wei *et al* (2016) has investigated the general tidal environment and wave characteristics along various parts of the Indian coasts. In present study an attempt has been made to determine and calibrate the tidal fluxes based on the calculated tidal energy, by statistical means using Insitu observations.

RESULTS AND DISCUSSION

The sediments along the southwest coast of India are fine sands (0.25 mm), and further north they are confined from fine to medium sand (0.5 mm) category. They form a relatively narrow band confined to <50 m water depth and within a distance of 25 to 35 km

from the coast. It has been found that the reduction in wave height is the minimum presence of coarser sediments at the surface. Surface samples in this area comprise of mainly calcareous sands with little fine-grained sediments (Rao, 1989).

The inner shelf region is carpeted with a mosaic of sand and silty sand with minor amounts of clay rather than continuous seaward fining. In general, the low mud contents (0-4%) suggest a relatively higher energy regime that prevents sedimentation of fine-grained particle Carbonate sands is distributed along the west coast confined within a distance of 35 to 70 km from the coast. Though carbonate sand is resistive, it forms a compact layer over the continental shelf and shallows it. Further, terrigenous sands are dominated along the Gulf of Kachchh and rocky beaches along the Indian coast. These areas are subject to erosion and dissipated by the wave refraction process. (Rajamanickamand Mohan, 1998).

Wave energy spectra, associated winds and sediment transport

Spectral characteristics of waves are usually studied due to significant seasonal variation in the wave height, wave period, and wind along the coast. Wave energy (E) can be calculated by determining kinetic (KE) and potential (PE) energy as $E = KE + PE$. It is measured as depth integrated wave energy in J/m^2. The wave energy over an area is averaged and expressed as Joules (J).

Waves are small during the pre-monsoon season (February to March), north-east winds are relatively weak, and significant wave height (Hs) along the entire coast is stable which is around 1 m, incapable to transport the sediment. Hence, the gross sediment transport is low (5x10^{5}m^3) along the southern Tamil Nadu and Maharashtra coast (Fig.2) (Rajamanickamand Mohan, 1998). The sediment transport direction is from north to south (Fig.4). Though, due to semi-diurnal tides sediments show the trend of southward shifting (Kumar *et al*, 2013) those results in two peaks of wave energy spectra.

Wave energy show an increasing trend during the SW monsoon (June to September) season from north to south (Porbandar to Thiruvananthapuram). Along the west coast, an increase in Hs (2 to > 3 m), pre-dominant offshore movement of sediments, and SW winds do not help increase sediment transport (Chandramohan and Nayak, 1990). This offshore transport leads to steep waves that occur during May. (Jayyappa and Narayana, 2009). Thus despite high wave energy, waves dissipate and transport of sediment is low. The gross rate of sediment transportation is higher (15-20

$x10^5$ m^3) as compared to the west coast along the east coast due to peak wave energy spectra (Fig. 3). Hs increases slightly than the pre-monsoon season (>2 m) (Aboobacker – 2010).

Due to narrow continental shelf and low-pressure conditions during extreme events, the east coast is subject to storm surges, which causes an increase in wave heights and onshore movement of the sediments. Besides, extreme events, the supply of a load of sediments by Indian's major rivers like Ganga, Godavari, Krishna, and Kaveri also contribute to a volume of sediment transportation (Bird, 2010). During the post-monsoon season (October to January), the Indian coast is stable by balancing the offshore and onshore movement indicating 'beach recovery after monsoon'. (Kumar and Anand, 2004). The rate decreases towards the north. Hs (>1 m) along the west coast of India, becomes 'normal' until the next SW monsoon winds arrive (Fig. 3). Thus the transportation occurs from north to south. Along the east coast, longshore drifts transport the sediments from the south towards the north enriching the Sunderban area.

Storm surges amplitudes and tidal range

Storm surges are oscillations of the water level in a coastal water body due to tangential wind stresses and cyclonic conditions. (Selvaraj and Ram Mohan, 2003). Surges onshore are affected by the configuration and bathymetry of the ocean bottom. Along the east coast, a narrow continental shelf subsequently produces deep water near the shoreline tends to produce a lower surge, but a higher and more powerful wave (Chowdhury *et al* 2021). Thus, the east coast isconfined with a very high tidal range (between 1 to 30 m). The coastline from Tiruchendur (0.75m) to Pondicherry (0.5m), Puri (10m), and Sunderban (20–30m) are subject to high surges but smaller waves. This difference is because, in deeper water, a surge can be dispersed down and away from the cyclone. Hence longshore drifts along the east coast are the major sediment transporters.

However, along the west coast, storm surges are uncommon and limited to coast Gujarat (5-10m) and south Tamil Nadu (>1 m). By entering a shallow, gently sloping continental shelf, the surge cannot be dispersed but is driven away from the shore by the wind stresses of the cyclone. Recently, progression and dissipation of low pressure area over Arabian Sea during annual cycle of tropical cyclone along North Indian Ocean took place. The onset of Tauktae cyclone on 15 May 2021 near

Kerala coast was identified where the significant wave height increased more than 5 m. The cyclone was marked to be one of the extremely severe cyclone by IMD. Maximum winds were recorded as 185 km/h (average winds for extremely severe cyclone is 166-220 km/h). It intensified steadily into a cyclonic storm by the evening of 16 May and moved parallel to the west coast of India. Finally dissipated along the coast of Gujarat on 20 May (significant wave height 2.5 m).(Fig 5). Meanwhile, the tidal range is comparatively lower along the west coast. (1 to10 m). This drives offshore drifts which can transport the sediments for a limited distance (Table 1).

CONCLUSION

Sediment transportation is, exclusively, controlled by coastal processes like waves, tides, storm surges, and winds. It is an outcome of a combination of these coastal processes. The energy created during these outcomes results in the movement of sediments. Along the west coast, the coastline is shallow and long and is subject to erosion due to the NE monsoon. Besides this, the supply of sediments by the rivers along the west coast is very less. The annual gross sediment transportation rate is comparatively low (5-10 x 10^5 m^3) except Gulf of Kachchh (15 x 10^5 m^3). On the contrary, the east coast yields more sediment from sediment-laden rivers. This ample supply is transported during SW monsoon winds, along with > 15m high storm surges, towards the north. Despite the low net transportation rate, the east coast altogether has more sediment transportation rate (15-20 x 10^5 m^3) than the west coast.

REFERENCES

[1] Aboobacker, V.M. (2010). Seasonal response of coastal waves along the Indian coast: spectral approach, Digital Repository Service. 76 – 123.

[2] Aboobacker, V.M. (2014).Sediment transport and model results, Digital Repository Service, National Institute of Oceanography. 129 – 150.

[3] Aboobacker, V.M.(2012).Wave transformation along open coasts and semi-enclosed regions, Digital Repository Service, National Institute of Oceanography.126 – 161.

[4] Bird, E. (2010). Encyclopaedia of the World's Coastal Landforms I, Springer, New York. 556 -560.

[5] Chandramohan, P. V Sanil Kumar, Nayak, B. U. and Pathak, K.C. (1993). Variation of longshore currents and sediment transport along the South Maharashtra coat, West coast of India. Indian Journal of Marine Sciences. 22:115 – 118.

[6] Chandramohan, P and Nayak, B. U. (1991). Longshore sediment transport along Indian Coast. International Journal of Marine Sciences. 20:110 – 114.

[7] Chowdhury, M.S., Rahman, K.S., Selvanathan, V. Nuthammachot, N., Suklueng, M., Mostafaeipour, A., Habib, A., Amin, N., and Techato, K. (2021). Current trends and prospects of tidal energy technology. Environment, Development and Sustainability, 23:8179–8194.

[8] Devananth R., Anto, J., Kannan, V.S., Manju, S. and Sujatha, S. (2020). Experimental Analysis of wave energy spectrum interaction on sea wall structures along Puducherry coast. Journal of Critical Reviews.7 (4):1214-1218.

[9] Jayyappa, K.S. and Narayana, A.C.(2009). Coastal Environments: Problems and Perspectives**.** I K International Pvt Ltd. 172 - 190

[10] Jose, F., Kurian, N.P., and Prakash, T.N., (1997). Longshore sediment transport along the southwest coast of India., Proceedings. Second Indian National Conference on Harbour and Ocean Engineering, Thiruvananthapuram. 1047 – 1053.

[11] Kumar, V. S. and Anand, N. M. (2004).Variations in wave direction estimated using first and second order Fourier coefficients. Ocean Eng.31:2105–2119.

[12] Kumar, V.S. and George, J. (2016). Influence of Indian Summer monsoon variability on the surface waves in the coastal regions of eastern Arabian Sea. Annales Geophysicae.43:871-885.Doi: 10.5194/angeo-34:871-2016.

[13] Kumar, V.S. and M. Anjali Nair. (2015).Inter-annual variations in wave spectral characteristics at a location off the central west coast of India.33:159-167.Doi: 10.5194/angeo-33-159-2015.

[14] Kumar, V.S. and M. Anjali Nair.(2017).Wave spectral shapes in the coastal waters based on measured data off Karwar on the western coast of India. 13:365-378.doi: 10.5194/os-13-365-2017.

[15] Kumar, V.S., Dubhashi, K.K., Nair, T.M.B., and Singh, J.(2013).Wave power potential at a few shallow water locations around Indian Coast.104(9):1219-1224.

[16] Kunte, P. (2008). Sediment concentration and bed form structures of Gulf of Cambay from remote sensing. International Journal of Remote Sensing. 29(8):164-175. Doi: 10.1080/01431160701422221

[17] Kunte, P., Alagarsamy, R. and Hursthouse, A. (2013) Sediment fluxes and the littoral drift along northeast Andhra Pradesh Coast, India: Estimation by remote sensing. Environmental Monitoring and Assessment 185(6):5177-5192. Doi: 10.1007/s10661-012-2934-0.

[18] Kunte, P., Wagle, B.G. and Sugimori, Y. (2003). Sediment transport and depth variation study of the Gulf of Kutch using remote sensing. International Journal of Remote Sensing. 24(11):316-322. Doi: 10.1080/01431160210164316

[19] Kunte, P.D. (2003). Study of Sediment Transportation in the Gulf of Kachchh, using 3D Hydro-dynamic Model Simulation and Satellite Data. A report submitted to National Institute of OceanographyDona Paula, Goa. 1-118.

[20] Murty, T.S (1983). Storm surges in the marginal seas of the North Indian Ocean. A report submitted to World Meteorological Organization (WMO), Sun- a forum on Natural Disaster Reduction. 130 – 139.

[21] Nair, R.R.., Hashimi, N.H., Purnachandra Rao, V. (1986). On the possibility of high-velocity tidal streams as dynamic barriers to longshore sediment transport: Evidence from the continental shelf off the Gulf of Kutch, India. Current Science. 56(2):215 – 116.

[22] Pillai N.G.K and Kathia, P.K. (2004). Evolution of fisheries and Aquaculture in India, Central Research Fisheries Research Institute, Kochi, India. p.240.

[23] Purnachandra Rao V. and Wagle B. G.(1997). Geomorphology and surficial geology of the Western continental shelf and slope of India: A review., Current Science. 73(4):333.

[24] Rajamanickam, G.V. and Gujar, A.R. (1997). Grain size studies on the nearshore sediments of Jaigad, Ambwah and Varvada Bays, Maharashtra. Journal of the Geological Society of India. 49:567-576.

[25] Rajamanickam, G.V. and Mohan, P.M. (1998). Depositional environments: inferred from grain size along the coast of Tamil Nadu. Journal of the Geological Society of India. 52(1):95-102.

[26] Rajawat A.S., Gupta M., Pradhan Y., Thomaskutty A.V., and Nayak S. (2005) Coastal processes along the Indian coast- Case studies based on synergistic use of IRS-P4 OCM and IRS-1C/1D data. Indian Journal of Marine Sciences, 34: 459-474.

[27] Rao, P. S.(1989). Sonograph patterns of the central-western continental shelf of India. Journal of Coastal Research, 5(4):727-729.

[28] Rodriguez, S. (2012). 'The Challenged Coast of India' a report released during Conference of Parties-Convention on Biological Diversity in Hyderabad. From the Tata Institute of Social Sciences, Deonar. 1-3.

[29] Schwartz, M. (2006).Encyclopaedia of Coastal Science I, Springer, New York. p.555

[30] Selvaraj, K. and Ram Mohan, V. (2003). Textural Variation and Depositional Environments of Inner shelf Sediments, off Kalpakkam, Southeast Coast of India., Journal Geological Society Of India., 61:451.

[31] Sheng, W. and Li, H. (2017). A method for energy and Resources Assessment of Waves in Finite Water Depths.Energies.10:1-17.

[32] Sundar D., Shankar D. and Shetye S. R. (1999). Sea level during storm surges as seen in tide-gauge records along the east coast of India. Current Science. 77(10):155-175.

[33] Suresh, R. R. V., Annapurnaiah, K, Reddy, K. G., Lakshmi T. N., and. Balakrishnan, Nair T.M., (2010). Wind sea and Swell Characteristics off East coast of India During Southwest Monsoon. International Journal of Oceans and Oceanography.4 (1): 35-44

[34] C.M. Thakar, S.S. Parkhe, A. Jain etal., 3d Printing: Basic principles and applications, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2021.06.272

[35] Khan, R. M. I., Kumar, T., Supriyatno, T., &Nukapangu, V. (2021). The Phenomenon of Arabic-English Translation of Foreign Language Classes During The Pandemic. IjazArabi Journal of Arabic Learning, 4(3). https://doi.org/10.18860/ijazarabi.v4i3.13597

[36] Sajja, G., Mustafa, M., Phasinam, K., Kaliyaperumal, K., Ventayen, R., &; Kassanuk, T. (2021). Towards Application of Machine Learning in Classification and Prediction of Heart Disease. 2021 Second International Conference On Electronics And Sustainable Communication Systems (ICESC).https://doi.org/10.1109/icesc51422.2021.9532940

[37] Veluri, R., Patra, I., Naved, M., Prasad, V., Arcinas, M., Beram, S., & Raghuvanshi, A. (2021). Learning analytics using deep learning techniques for efficiently managing educational institutes. Materials Today: Proceedings.

https://doi.org/10.1016/j.matpr.2021.11.416

[38] Wei, Z., Fang, G., Susanto, R. D., Adi, T. R., Fan, B., Setiawan, A., Li, S., Wang, Y., and Gao, X. (2016). Tidal elevation, current, and energy flux in the area between the South China Sea and Java Sea. Ocean Science. 12:517–531. https://doi.org/10.5194/os-12-517-2016.

Table 1: Geographical location of gauging stations and Sediment Transport Rate in 10^5 m^3 / yr*(after Chandramohan and Nayak, 1991)*

Gauging Stations	Location		Net STR	Gross STR
	Latitude (N)	Longitude (E)		
Porbandar West	21.6417°	69.6293°	10.18	15.00
Daman	20.3974°	72.8328°	1.5	1.8
Bhavnagar	21.7645°	72.1519°	1.5	2.00
Mumbai	19.0760°	72.8777°	1.18	1.47
Vengurla	15.8514°	73.6389°	0.53	1.20
Ratnagiri	16.9902°	73.3120°	0.95	1.20
Panajim	15.4909°	73.8278°	1.60	1.60
Kasarkod	12.4996°	74.9869°	0.40	0.77
Maravanthe	13.7258°	74.6488°	2.53	0.29
Kannur	11.8745°	75.3704°	0.19	5.16
Kozikode	11.2588°	75.7804°	1.14	2.56
Allapuzha	9.4981°	76.3388°	0.16	0.62
Thiruvananthapurm	8.5241°	76.9366°	0.99	12.31
Tiruchendur	8.4946°	78.1219°	0.64	0.87
Puducherry	11.9416°	79.8083°	1.34	2.37
Gopalpur	19.2647°	84.8620°	8.30	9.49
Chennai	13.0827°	80.2707°	1.27	0.68
Puri	19.8135°	85.8312°	7.35	9.26
Kolkata	22.5726°	88.3639°	0.27	1.52

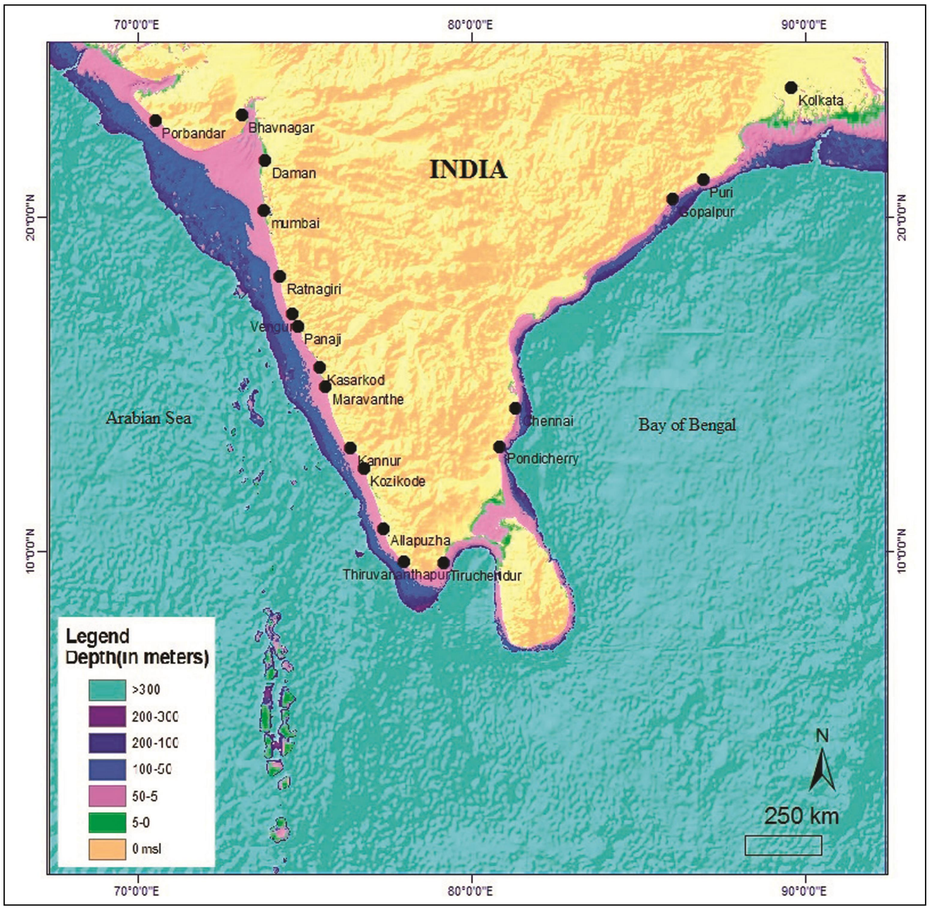

Fig.1: Study area showing gauging stations and GEBCO bathymetry

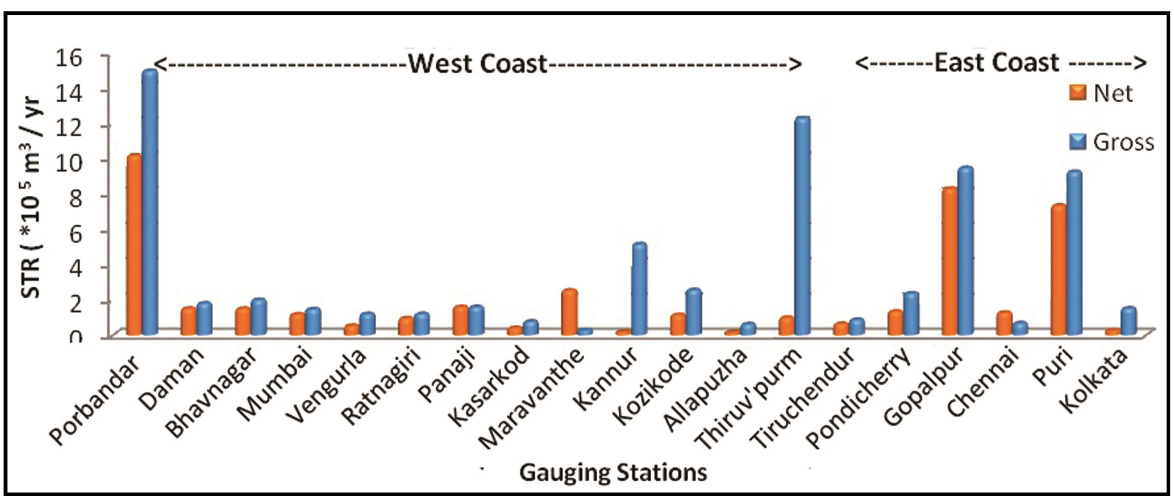

Fig.2: Gross and Net Sediment Transport Rate along the Indian Coast

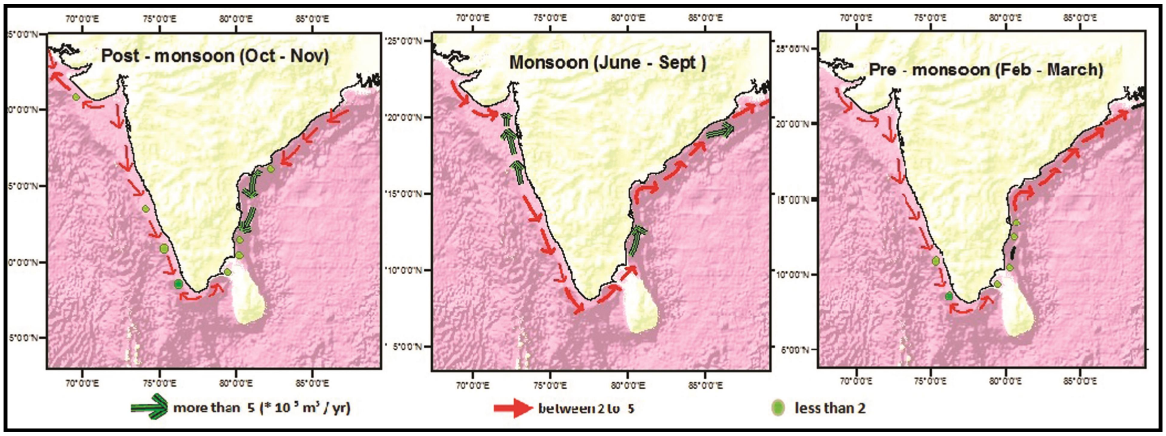

Fig. 3: Seasonal variation in the sediment transportation rate

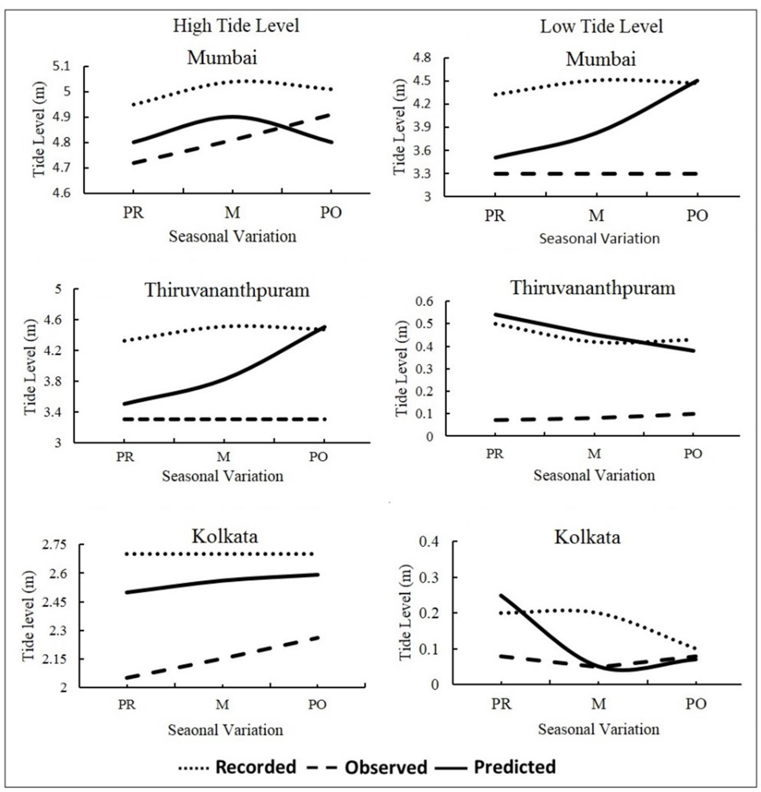

Fig.4: Graphical representation and comparison of observed tidal records for pre-monsoon (PR), monsoon(M) and post-monsoon(PM) for the year 2021

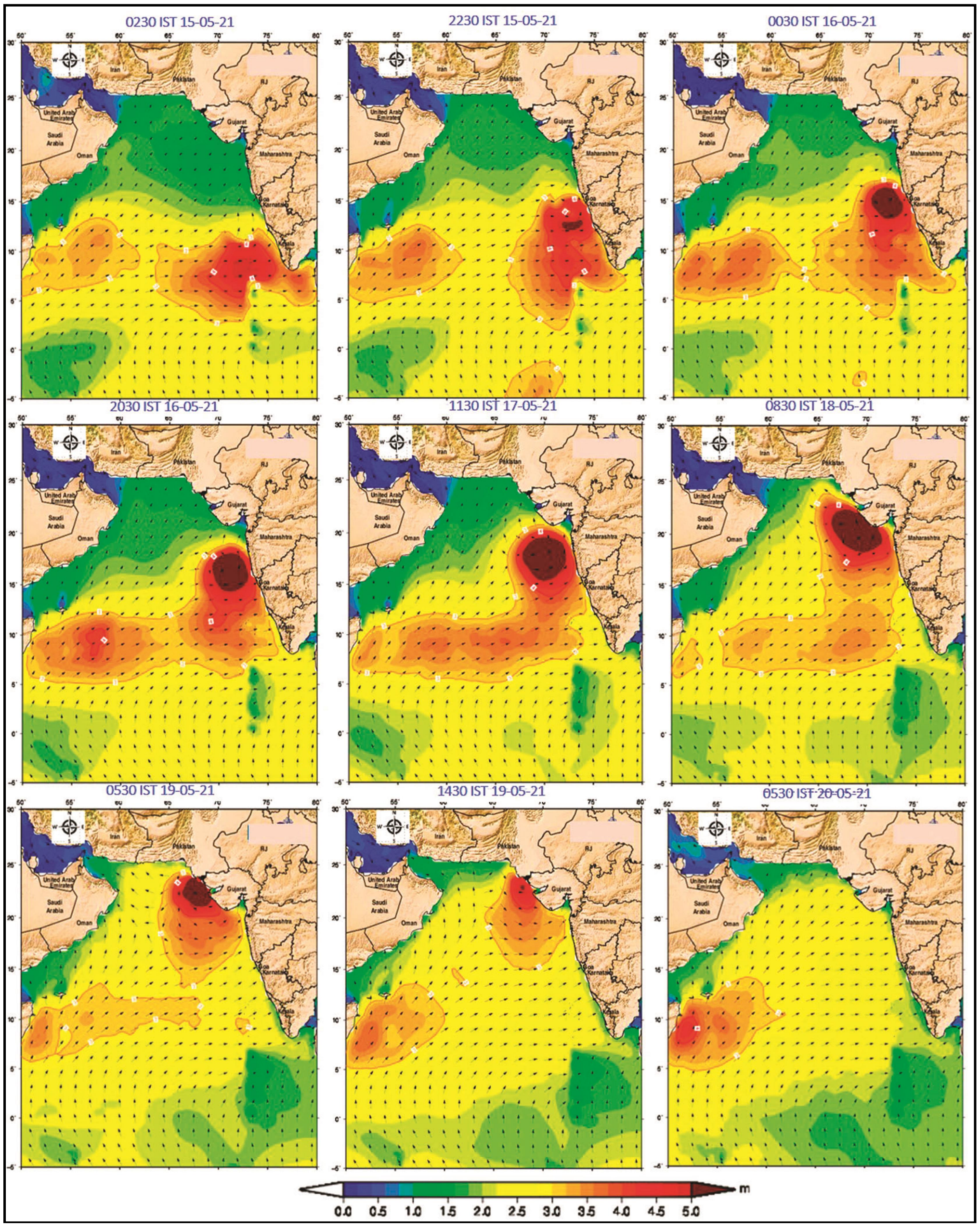

Fig.5: .Progression and dissipation of low pressure area over Arabian Sea during annual cycle of tropical cyclone along North Indian Ocean. The top-left image indicate the onset of Tauktae cyclone on 15 May 2021 near Kerala coast where the significant wave height increased more than 5 m (brown). It intensified steadily into a cyclonic storm by the evening of 16 May and moved parallel to the west coast of India. Finally dissipated along the coast of Gujarat on 20 May (significant wave height 2.5 m, yellow)

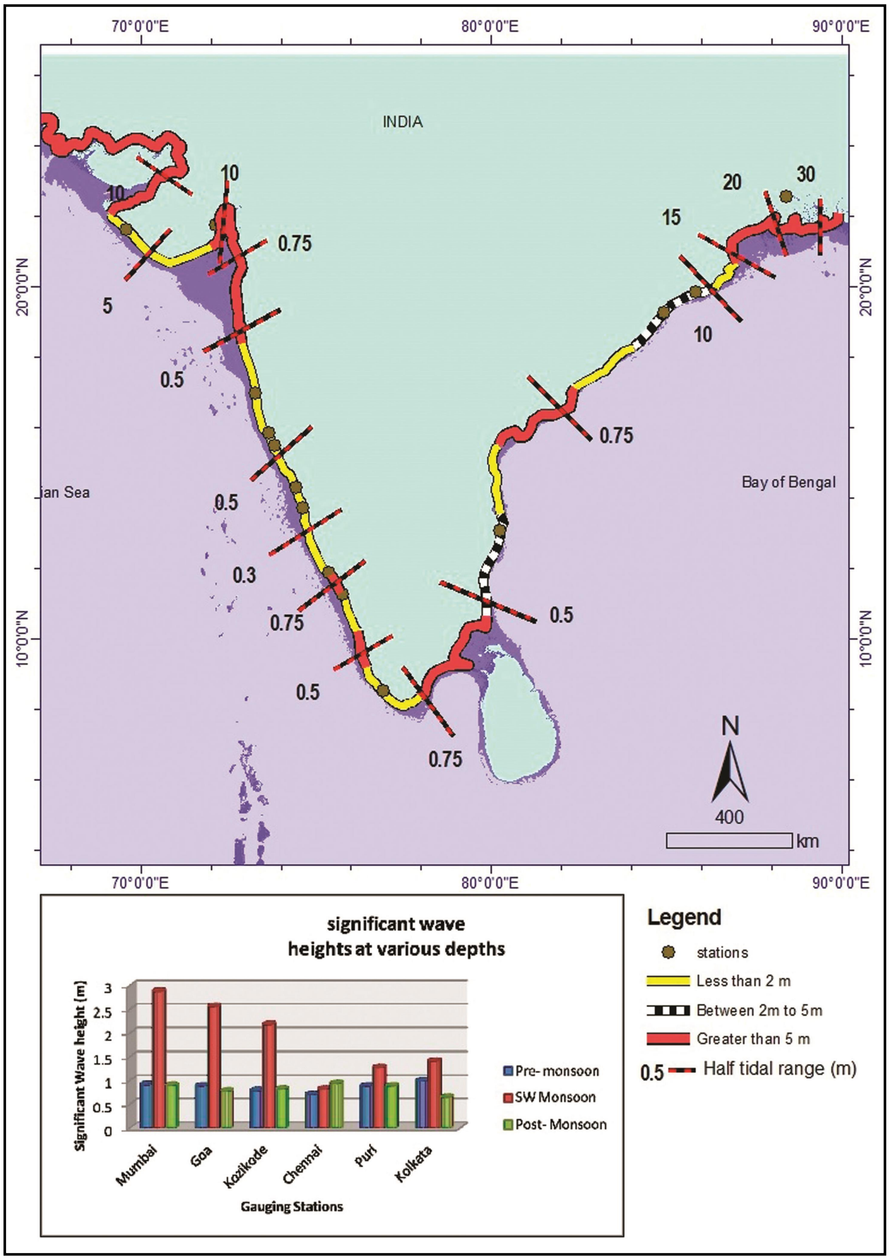

Fig.6: Proportionate relation between storm surges amplitudes and tidal range along with the coast of India (after Kumarand George, 2016)