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Observed Tidal characteristics along the near shore Coast off Kanyakumari, Southeast Coast of India

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Abstract: Tidal elevation and tidal constituents are studied by using short term tide gauge observations along Kanyakumari coast during north-east and South-west monsoon period of 2011. The tidal elevation was decreased L1 to L3 and highest high tide was observed in L1 (1.2 m). Tidal analysis has been made to understand the astronomical and residual-tidal variations. The harmonic analyses have been carried out using MIKE-21 IOS method to resolve the principal tidal constituents (M2, S2, K1 and O1). From the tidal constituents it is evident that the Kanyakumari coast has mixed semidiurnal. For the M2 tides, highest tidal amplitude was observed to be 0.1904 m (SW), 0.1888 m (NE) and the respective phases 38.62°, 48.82°. The role of wind and wave influences on water level variation has been studied well. Significant correlation was observed between residual tides and wind speed ($p<0.01$) along the coast have shown the meridian wind dominated by Northeastward and zonal wind dominated (except L3) by Southwestward blowing wind in 2011. The trends of residual tidal variations ($p<0.01$and $p<0.05$) are influenced by significant wave height and are observed in L2 and L3 in NE monsoon period only. The total Water level variation along the Kanyakumari coast is due to the tidal signal.

Keywords: *Tidal characteristics, harmonic analysis, tidal constituents, Kanyakumari, Bay of Bengal*

1. Introduction

Tide gauge measurements have much more attention to study the sea level rise [15], but the accurate estimation of long term sea level trend is still complicated [22]. Therefore, the short term measurements are made within the period is more valuable for fore coming years. A proper knowledge of tidal dynamics is necessary to understand the many general oceanographic phenomena at any station [27]. In this view, southern tip of India (Kanyakumari) has a special concern because of the confluence of three water bodies and also a major international tourist spot in the southwest coast of India. This particular region attracted by Vivekananda rock memorial and Thiruvalluvar statue, which is located in centre of the study area. Therefore, the understanding of tides in this coastal region is necessarily fundamental to the foremost oceanographic studies. The precise observation and analysis of tidal properties is indispensable to understand the processes of coastal dynamics of the ocean. The tides show great variability on day-to-day time scales [18] by various forces. The residual forces are one of the fundamental issues in coastal waters because the tidal dynamics are weak and commonly distributed in the deep basin while they are strong and intricate towards the shelves regions [37] especially in the near shore region. These processes not only affect water movements, it also affects the transport properties associated with water masses. The Non-linear interactions of Tidal flow with variable bathymetry [17] have also induces the non-tidal variations but the tides varies mainly with their attractive forces. The Tides and tidal dynamics of non-tidal activities have a potential ability to modify the flow through topographic interaction of the coast [14][16]. A number of studies on tides and tidal-flow variation over the different time scales are increasing substantially due to the daily rise and fall of the water. It causes a periodic change of the mean tidal range with the amplitude of about 4% [24].

In around the world, tidal propagation and its amplitudes has been studied by Fliegel [23] in California; Leesa et al [11] in Brazil; Lessa [12] in Ausralia; Mehra et al [28] in India. Regarding to the Indian coast, statistical model for monthly mean sea level along the west and east coast of India has been studied by Srinivas et al. [21]. Srinivas and Dinesh Kumar [19] have studied the tides and non-tidal sea level variations in Cochin and Beypore along west coast of India. The maximum tidal ranges of about 3 m are observed at Mumbai High offshore region has been investigated by Joseph et al [1]. The recent attempt on tidal current from south to north shelf off Mumbai has been investigated by Subeesh et al [26].

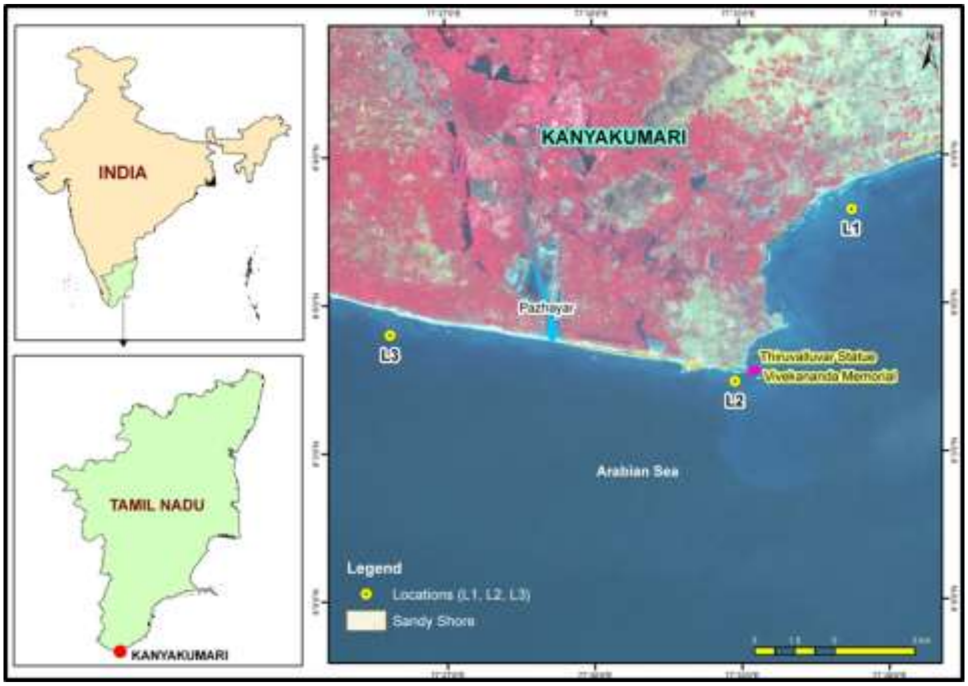

Figure 1 *Study area*

The observed characteristics on Tidal variations in Sundarban Estuary are dealt by Meenakshi et al [6]. They showed that the magnitude of semi-diurnal tides higher than the other tidal constituents. Antony and Unnikrishnan[5] using a simple model to study the tides-surge interaction along Bay of Bengal. For the most part, studies on the tidal characteristics in the Kanyakumari coast are scarce; a few workers have made efforts to understand the tides [27], but no one study the characteristic of tides in Kanyakumari coast. Chandrasekar et al [40] has prepared a Coastal vulnerability map for southern tip of India. Therefore, the present investigation have special interest because of the region receives the water from BoB (Bay of Bengal), AS (Arabian Sea) and IO (Indian Ocean). The main intention of the present study is to investigate the observed tides and tidal amplitudes along Kanyakumari Coast. A comprehensive knowledge about tide is the basis and necessary for all the oceanographic studies.

2. Description of study area

Kanyakumari, is located (11° 29' N and 79° 47' E) on the southern extremity of Indian peninsula. The coastal water has influenced by the confluences of Bay of Bengal (East), Arabian Sea (west) and Indian Ocean (South), which is formed to southern-eastern (Gulf of Mannar) and southern-west boundaries (Arabian Sea and Indian Ocean) where, meets in the study area. Sampling locations for tidal gauges were set up in the east, west and center of Kanyakumari coastal region. Figure 1 shows the systematic measurement location of water level and it is marked into L1 (Vattakottai), L2 (Tip) and L3 (Pallam). The local mean tidal level along the coast is 0.5 m [31][33]. SW monsoon (May – October) currents flow shows towards the NE and in NE monsoon (November to February), the flow is southward direction [34]. A climatic intension to the coast is receives rain mutually [9] SW and NEwith an annual average of 168.5 mm and the temperature range from 23- 33°C. Admirable feature of the sandy shores are located in the Koodankulam, Vattakottai, pallam and rocky shoreline are located in the tip of Kanyakumari. The drainage systems of the coast are mainly controlled by the rivers along with creeks and streams.

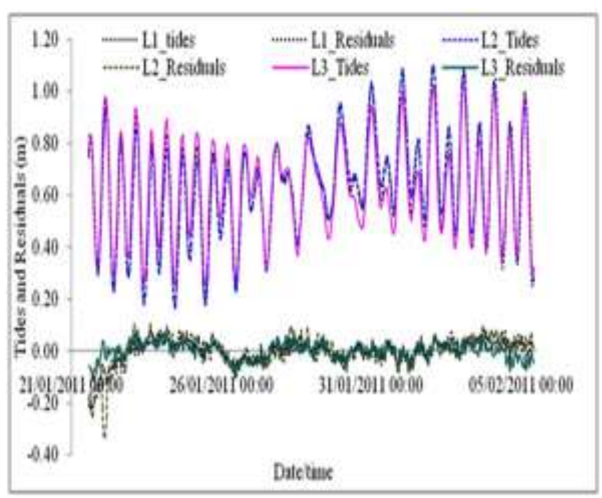

Figure 1 *Observed time series of Tides and residual tides at L2, L3 and L4 during NE monsoon season*

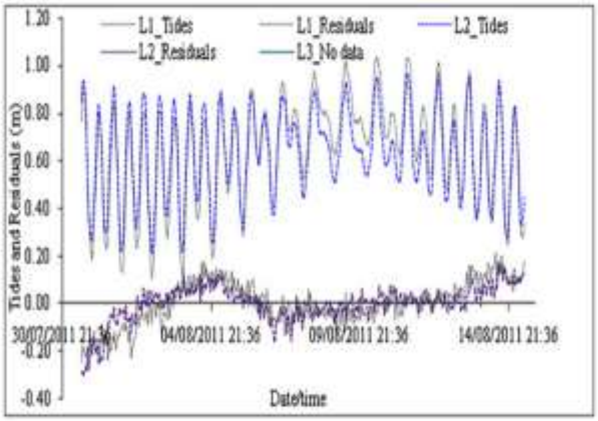

Figure 2.*Observed time series of Tides and residual tides at L1, L2 and L3 during SW monsoon season*

3. Data Collection and Methodology

Oceanography of the Kanyakumari coastal region is dominated by three seasons. The data was collected in two monsoon started from middle of Northeast monsoon which is beginning of fair weather period (January to February) and Southwest monsoon (August). Three MIDAS tide gauge (by Veleport) instruments were deployed along the coast of Kanyakumari. The measurements are used to collect the water level and wave data during the measurement period of 16 days for NE monsoon (January 21 to February 05, 2011) and SW (July 31 to August 15, 2011) monsoons. Measurements were made every 10 minutes and Details of these measurements are summarized in Table 1. These tide gauge instruments were continuously acquired the water pressure level by the sampling rate of 2 Hz with the accuracy of ±0.01%, to enumerate the more absolute measurement. Detailed analyses were made by observed data to understand the tide and non-tidal variability [20]. Pearson correlation (2-tailed) for residual tidal variation (Residual rides- wind speed; Residual rides- Significant wave height) was carried out using SPSS software to find the significance between the parameters.

Tide gauge data were subjected to harmonic analysis of tides which extract the amplitudes and phase from the water level records. The amplitudes and phase lag of the tidal height are derived by standard software package of MIKE 21 (Danish Hydraulic Institute). The MIKE 21 tidal tool box is performed based on least squares analysis method. It has reproduced the tidal constant and it can be solved explicitly in certain frequency domain with default Rayleigh criterion value of 1. The time series of tide were performed by the following formula,

$$x(t) = a_0 + \sum_{i=1}^{\infty} a_j \cos(\omega jt + Vjo - gj)$$

Where,

a_j, Vj^oandg_j are the amplitude,
(ω_j) phase lag with frequency and
($t=0$) time origin.

The Pre-determined frequency; Harmonic analysis techniques are followed as by Godin, [10] and Foreman, [25] using IOS method in the MIKE 21 tidal tool. It is widely used by Kankara et al. [31]; Misra et al. [36]; Mirfenderesk and Tomlinson, [13] to describe and to estimate the tidal constituents.

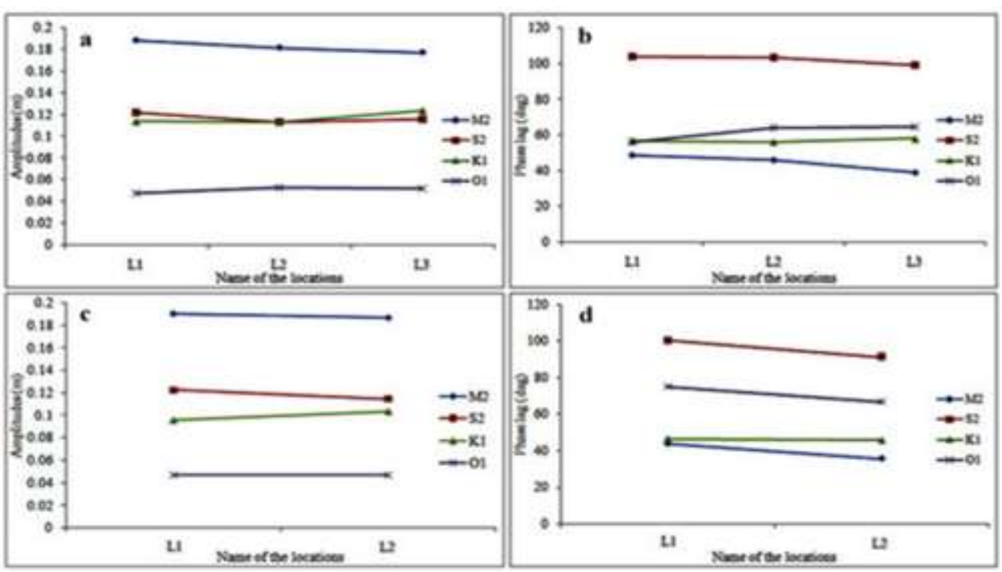

Figure 4 *Shows the amplitudes and phase lag of the constituents for both NE and SW monsoon season. a and b indicates the NE monsoon, c, d indicates for SW monsoon season of the amplitudes and phase lag*

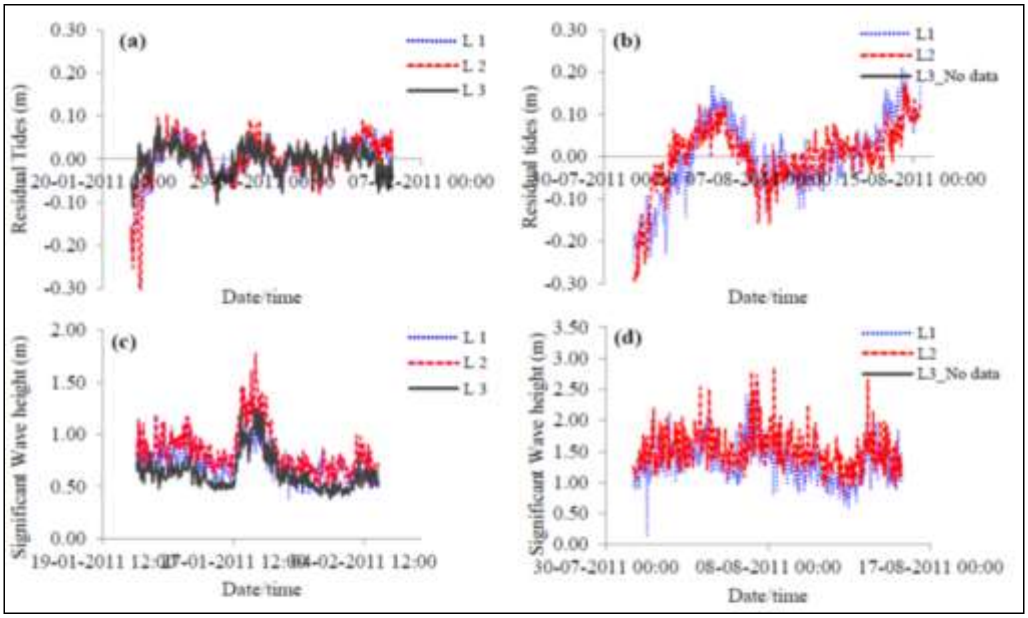

Figure 5 *Non-Tidal sea levels a, b and c, d indicates significant wave height respectively NE and SW monsoon season*

As the length of the tide gauge records is more sufficient to resolve 17 constituents though the world's most important major semi-diurnal, diurnal constituents (M2, S2, K1 and O1) and Shallow water constituents (M4, M6, S4, M8, M_{S4}) is found to be insignificant in this study were obtained by applying harmonic tidal analysis. Basedon the constituents, tidal characteristics [29] of the coast were also analyzed.

4. Results and Discussion

The present observation shows the water level variation during NE and SW monsoon seasons along Kanyakumari coast. Han and McCreary [42] studied the salinity distribution in the Indian Ocean. They reported that the salinity varies due to the Ganges- Brahmaputra river discharges in to the Northern Bay ofBengal, because significant amount of water reaches the southern tip of India directly through the passage. Even though discharged amount of water is reduced by the distance to reach the southern tip of India. Therefore maximum water level is observed during NE monsoon (1.15 at L1) period. It is slightly higher than SW monsoon (1.13m at L1) period due to the Northeast water flows towards Southern tip of India. Jyothibabu et al [30] have also studied the water exchange between Gulf of Mannar and Palk Bay. The observed tides and residual tides are shown in figure 2 and 3. From the figures, it is observed that the tidal elevation were decreased westward (L1-L3) in both NE and SW monsoon period. The highest high tides occurred with the maximum range of 1.095 m and 1.032 m at L1 for NE and SW monsoon, the lowest low tides were observed with minimum range of 0.107 and 0.167 m in L1 and L2 for SW and NE monsoon period respectively.

The residual tides primarily driven by barometric pressure (present study the barometric pressure are not measured), wind effect and storm surges. Although in shallow coastal water, wind and wave are the short periodic driving forces [11]. Perhaps, the significant relationship between pressure, wind and waves in non-tidal fluctuation were considered to identify the tidal/sea variation [3]. For the present study, wind speed exceeding 2 m/s is needed to observe the effect of winds on the recorded sea level [38] variation. The residual tidal elevations varied between -0.222- 0.077 (L1), -0.324- 0.100 (L2), -0.108- 0.081 (L3) and -0.233- 0.209 (L1), -0.292- 0.165 m (L2) for NE and SW monsoon, ranged from minimum- maximum. It is in contrast to the correlation and significance level shown for both measured residual tidal elevations and wind speed.The correlation between residual tides and wind speed (U and V) are negatively correlated in NE monsoon period and positively correlated in SW monsoon period (Table. 1) with the significance level of about $p<0.01$ at 95% confident level in L1 and L2 for both monsoon periods (except L3). The negative coefficient implies that there is an inverted response of the sea level to atmospheric pressure [35]. Along the Indian coast, seasonal sea level changes due to atmospheric pressure variations (3- 13 cm) vary from Colombo to 13 cm at Paradip [7]. The Seasonal wind pattern along the coastal region shows, the U component wind dominated in SW and V component wind dominated in NE monsoon period.Wind generated sea waves can also affect the water level [41]. Subsequently, the temporal Relationship between Significant wave height and residual tides are studied and shown in figure 5. The residual tides vary with the increase / decrease of significant wave height, which are observed clearly during NE monsoon period only. The correlations between residual tides and significant wave height have also shown the correlation with significant level of $p<0.01$ and $p<0.05$ in L2 and L3 respectively in the NE monsoon period. Such a considerable effect for the mean sea level variation, Wijeratne [8] has been observed along the southern side of Adams Bridge during SW monsoon period. Continental shelf waves are found to exist on along the east and west coast of Australia. Hamon [4] suggested that these waves areenergized by atmospheric pressure variations.

Table 1: *Pearson Correlation coefficients (2 tailed)*

Name of the locations	Parameter Pearson		
	Wind speed		Significant wave height (r)
	U component (r)	V component (r)	
NE monsoon			
L1	-0.141**	-0.156**	-0.058
L2	-0.158**	-0.194**	0.140**
L3	0.03	0.060	0.129*
SW monsoon			
L1	0.246**	0.091	0.052
L2	0.303**	0.198**	0.028
L3	No data		

4.1. Amplitude and phase lag variation

The amplitudes and Phase lag for the four major tidal constituents at three locations for NE and SW monsoon are shown in figure 4. The shallow water constituents (M4, M6, S4 and M8) are not shown because of the less impact with very low amplitudes. The harmonic analysis of tides reveals that the amplitude and phase lag among three locations are varying with position. Tides in the Bay of Bengal are amplified from south to north [32]. From the results, a fundamental characteristic of tidal form factor in Kanyakumari coast was identified as mixed mainly semi-diurnal tide enhancing with K_1 tides. The form ratio (F) values of 0.518, 0.562, 0.599 for NE monsoon and 0.458, 0.50 m for SW monsoon were observed with the small inequalities in range and time, which are increases gradually from L1 to the L3 primarily due to the nonlinear shallow water effects. The minimum of inequalities occur whenever the moons declination has passed its minimum values.

The most dominant M_2 amplitudes are found to be consistent around the world. Murty and Henry [39], UKHO [40]and Mukherjee et al [2] have observed the dominance of M_2 tide along BoB and found to be more energetic than S_2, K_1 and O_1. Similar results are observed for the SW monsoon (L1-L2) but for the NE monsoon the tidal component K_1 dominates over S_2 at two locations L2 and L3. The dominance of K_1 component is due to the flow of water from Arabian Sea during NE monsoon. Srinivaset al [20] showed similar result obtained along Cochin and Baypore. The distributions of most dominant M_2 amplitudes are higher in L1 than the L3 with the strongest amplifications occurring from South- North. The similar situation exhibited in S_2 tide (except at Pallam), as the shallow water constituent (e.g. S_4) increases. The maximum range of M2 amplitude reaches about 0.190 m in L1 (SW) and 0.188 m in L1 (NE), which reflects that the coast was strongly dominated by M_2 tides. While taking into the account along the Indian coast, Kanyakumari coast depicted as minimum amplitudes, which is observed from earlier studies along the BoB and AS. From figure 5, the Diurnal constituent (K_1) increases with their Phase lag of 57.97° in L3, which indicates that there is an increase in their amplitudes from L3 to towards the west coast (South-North), therefore K_1 tides are considerably higher at L3 (Pallam).

The Arabian Sea waters have more influence on the GoM hydrography. Murty and Varma [3] discussed the GoM waters influences the PB with limited extent of water. As a result of distribution of phase lines, M_2 phase only shows the tidal phase lag decreasing (L1-L3) towards SW ward direction. It is propagating by increasing the phase moving from M_2 to M_4 to M_6 amplitudes. The Coastal geomorphologic structure of L1 implies the S2 phase lag reaches maximum of 103.9° for NE and 100.4° for SW monsoon respectively. From L1- L2, coastal configuration reverts back to E-W direction and finally direct to the west coast in the trend of N-S direction [32].

5. Conclusion

The present study has elucidated tidal characteristics along the coastal region off Kanyakumari. The short term observation of tides for 16 days marked a gradual degrease towards south with increasing narrow slope of coast. Tidal height varied between 1.15 and 1.08 m during NE and SW monsoon respectively. The correlation between residual tides and wind speed ($p<0.01$) shows the meridian wind dominated by Northeastward blowing wind and zonal wind dominated (except L3) by Southwestward blowing wind during 2011. The response of sea level driven by wind is the dominant factor in the periods larger than 30 days [43] may be another reason for the minimum correlation/ deviation. A Relationship between residual tides and significant wave height ($p<0.01$ and $p<0.05$) shows only in L2 and L3 for NE monsoon period. The major tidal amplitudes and phase lag summarized above are used to find the spatial changes in the coastal environment. The tidal form factor indicates the coast is mixed mainly semi diurnal implying the diurnal inequalities. The Kanyakumari coastal region is dominated by M2 tides and decreases with the maximum amplitude from L1 to L3. The spatial distribution of Semi-diurnal and diurnal constituents suggested that the M2 tide continuously loses energy from North to South of Bay of Bengal and Arabian Sea. Subsequently, K1 tide started to gain energy from L3.

6. Acknowledgement

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