Tidal Dynamics along the Eastern Coast of the Red Sea

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Abstract

Understanding of tidal components is of paramount importance in assessing the influence of tides on coastal processes. The present study focuses on comprehensive tidal analysis in the eastern coast of the Red Sea, Saudi Arabia. The analysis carried out spatial and temporal scale to unravel the tidal dynamics along the coastal regions of the eastern coast of the Red Sea. Time series data from the seven coastal stations along the western coast of the Saudi Arabia were used for tidal analysis. T_TIDE analyses were performed for extracting the tidal constituents. The study reveals the variations of tidal constituent temporal and spatial basis. The analysis well predicted water levels and verified it with field data.

Subject Areas

Environmental Sciences

Keywords

Tidal Dynamics, Coastal Processes, Form Factor

1. Introduction

The Red Sea is connected to the Indian Ocean; no direct tidal waves enter from Indian Ocean to Red sea and hence the tidal range is less in the Red sea [1]. The Red Sea has more practical importance in connecting Arabian Sea and Mediterranean Sea. The tidal dynamics in the Red Sea have more importance, especially coral protected coastal areas. Even though the tidal range is small, the influence of the tide has a major role in the coral life and coastal protection. Hence, a comprehensive study on the dynamics of tides is lacking in this region. Since the area belongs to the micro tidal region the influence of tide and its associated currents are more prominent in the coastal areas, than the open ocean, where

anthropogenic activities are more. Since the eastern coast of the Red Sea is protected by coral reef, the coastal physical processes play a major role in the life span of coral reef [2].

Hence, a numerical modeling study was carried out to unravel the dynamics of tides in the eastern coast of the Red Sea, where such site-specific studies are few. The tidal analysis was carried out about the eastern coast of the Red Sea. The main objective of the study is to analysis the tidal dynamics along the eastern coast of the Red Sea using T-Tide tool and its related practical applications in this region. The study also focuses to bring out spatial variation of tidal constituents along the eastern part of the Red Sea and its practical importance. The present investigations have more importance that can be used in the field of academic research and developments. The present investigation was carried out with comprehensive field data collected from even distributed tide gauges data along the eastern coast of the Red Sea and hence the scope of the study is more. The study area, Red Sea is about 2250 km long and, at its widest point, 355 km wide [3] [4] [5]. The topography of the Red Sea is from north to south starting from the Gulf of Aqaba, with coastline with low cliffs and sandy beaches [6]. There are fringing reefs and reef-edged sharms (e.g. Sharm Obhur) are located along the coastline. Since the average tidal range is less in the Red Sea coast, the inter-tidal zones are narrow. The Farsan Islands consist of many reefs and emerged reef islands showing tectonic dislocation [7]. The present investigation carried out spatially along these environmentally varying coastal areas with time series data. The study also reveals the annual variations of observed water levels using location-specific tide gauge observations.

Red sea is characterised with different weather pattern; monsoon system affects the wind pattern over the Red Sea. By the effect monsoon, system NNW wind blows in the northern part and wind blows NNW in the summer and shifted to SSE during the winter [8]. This seasonal strong wind pattern and associated circulations will influence the tidal dynamics along the coastline of the Red Sea. The SST of Red Sea is very high during the summer and precipitation is very less all over the year. The sea level of the Red sea also changing with respect to wind associated circulation pattern [9] [10] [11] [12] [13].

2. Data and Methodology

The present study used time series data from seven stations along the east coast of Red Sea which were obtained from the General Commission for Survey (GCS), Kingdom of Saudi Arabia. The tide gauges distributed along the coastline are shown in **Figure 1**. The time series data are available from Sept. 2012-Aug. 2013 at 1-hour interval. The data were processed and used for analysis. The one-year data will almost cover all astronomical influences on water level. The study uses T-tide (developed by University of British Colombia, Canada) software for analysis. T-tide works in Matlab platform, can be used to perform classical harmonic analysis with nodal corrections, inference, and a variety of user

Figure 1. Study area and coastal stations.

specified options [14]. The T-tide derives tidal constituents due to astronomical forces and signal analysis which can carry out. The predication can be carried out using the same tool. The toolbox can be used to plot the analysed time series data with residual tide. The present investigation forces temporal variability of tidal constituents using the toolbox.

3. Results and Discussion

The one years of water levels in all the coastal stations processed using T-tide to derive the tidal constituents at seven coastal stations along the east coast of Red Sea. The amplitudes of resolved constituents are listed in **Table 1**. The important tidal constituents were derived to study their seasonal and temporal variations. Since tidal wave, propagates to shallow water subjected to different physical processes such as amplifications, distortion, etc. [15], coastal tidal dynamics are more complex than the open ocean. Since the geometry of the eastern coast of the Red Sea varies irregularly with complex nearshore topography, it reflects in the tidal amplifications in the nearshore area. The amplitudes of derived important tidal constituents are given in **Figure 2**. The analysis shows that the nature of the tides is of mixed and semi-diurnal type with less amplitude. Among all resolved constituents, M2 (Principal Lunar Semidiurnal) shows selective ampli-

fications at all coastal stations. The semi diurnal constituents M2 dominant is with more than double amplifications compared to other constituents. The amplification of M2 towards north and south from the Jeddah indicates the

Table 1. Amplitudes (m) of all derived constituents in the seven coastal locations.

Constituent	Jizan	Qunfudah	Jeddah	Yanmbu	Alwajh	Duba	Magna
Q1	0.004	0.004	0.004	0.004	0.005	0.003	0.004
RHO1	0.001	0.001	0.002	0	0.002	0.001	0.001
O1	0.016	0.009	0.016	0.014	0.011	0.01	0.009
M1	0.002	0.001	0.001	0.001	0.002	0.001	0.001
P1	0.006	0.01	0.01	0.009	0.008	0.008	0.01
S1	0.013	0.006	0.011	0.006	0.004	0.006	0.006
K1	0.021	0.023	0.032	0.028	0.03	0.027	0.023
J1	0.002	0.002	0.002	0.002	0.001	0.002	0.002
OO1	0.002	0.002	0.002	0.002	0.002	0.002	0.002
MNS2	0.001	0.002	0.001	0.001	0.001	0.002	0.002
2N2	0.019	0.016	0.006	0.011	0.015	0.015	0.016
MU2	0.013	0.01	0.002	0.006	0.007	0.009	0.01
N2	0.099	0.084	0.024	0.052	0.07	0.076	0.084
NU2	0.022	0.018	0.005	0.011	0.013	0.016	0.018
M2	0.317	0.274	0.071	0.163	0.23	0.248	0.274
LAM2	0.002	0.001	0.001	0.001	0.001	0.001	0.001
L2	0.01	0.008	0.003	0.005	0.006	0.008	0.008
T2	0.005	0.006	0.002	0.004	0.006	0.005	0.006
S2	0.102	0.083	0.017	0.044	0.071	0.071	0.083
R2	0.002	0.002	0.001	0	0.004	0.002	0.002
K2	0.028	0.022	0.006	0.015	0.021	0.022	0.022
2SM2	0.002	0.002	0.001	0.001	0.002	0.001	0.002
2MK3	0.002	0.002	0.001	0	0.001	0.002	0.002
M3	0.003	0.004	0.001	0.001	0.003	0.003	0.004
MK3	0.005	0.005	0.002	0.001	0.003	0.004	0.005
MN4	0	0.001	0	0	0	0	0.001
M4	0.003	0.001	0.001	0	0	0	0.001
MS4	0.003	0.001	0.001	0	0.001	0.001	0.001
S4	0.001	0.001	0.002	0.001	0.001	0.001	0.001
2MN6	0.001	0	0	0	0	0	0
M6	0.001	0	0	0	0	0	0
2MS6	0	0.001	0	0	0	0	0.001
S6	0	0	0	0.001	0	0.001	0

Figure 2. Variation of amplitudes of significant tidal constituents along the seven coastal stations: (a) Jizan (b) Qunfudah (c) Jed-dah (d) Yanbu (e) Al wajh (f) Duba (g) Magna.

presence amphidromic points in the central part of the Red Sea. The less amplification of the constituents M2 is quite evident from the tidal range from field signature (~ 20 cm). The other important constituents S2 (Principal Solar semi-diurnal) and K1 (Luni-solar diurnal) shows amplification compared to other important constituents. The S2 shows much amplification than K1 among all the stations except Jeddah, which is the central part of the Red Sea, having amphidromic feature. The other constituents (O1, 2N2, NU2, P1, N2, K2, and MU2) have also shows spatial variability in amplitudes along the eastern coast of the Red Sea. Other important features are the diurnal constituents which show increased amplifications from north and south towards the center of the eastern coast of the Red Sea, which is of the reverse pattern of the semi-diurnal constituents, which show in amplification along the coastal line. Among the diurnal and semi diurnal components, semi-diurnal components show much amplification than the diurnal components and well represent astronomical tidal characteristics along the eastern coast of the Red Sea.

The present study also made a detailed analysis of spatial variations of phase of important tidal constituents (O1 (Lunar diurnal constituent), K1, 2N2 (Lunar elliptic semi diurnal second-order constituent), S2, M2, P1 (Solar diurnal constituent), N2 (Larger lunar elliptic semi diurnal constituent), K2 (Lunisolar semi diurnal constituent), NU2 (Larger lunar evectional constituent), MU2 (Vibrational constituent)) to understand the tidal dynamics along the eastern coast of the Red Sea (**Figure 3**). It can be seen that the main semi-diurnal components have almost same phase along the eastern coast of the Red Sea except Jizan. The water depth and presence islands in the Jizan alter the phase of the tidal wave propagates from the central Red Sea. The K1 shows almost reverse phase than

Figure 3. Variation of phase of significant tidal constituents along the seven coastal stations.

the major constituents M2, where K1 has different phase for Jizan coast. The complex topography in the nearshore area and in the Red Sea will affect the phase distributions of important tidal constituents along the coastal line and is quite evident from **Figure 3**. Since there is no river discharge in the nearshore area, the possibility of nonlinear interaction between the tides and river runoff is very less and hence the nearshore topography act as main causative factor for nearshore tidal wave dynamics.

3.1. Water Level Predictions

The T-tide tool used to predict water level at the Yanbu coastal stations for 30 days during July 2015. There is reasonably good fit between the measurements and predicted in the selected location (**Figure 4**). The correlation coefficients are reasonably good (0.96) in the location and RMS value is 0.92. Hence, T-tide predictions are reasonably good and can be used as a prediction tool along the coastline.

3.2. Form Factor Study

The derived amplitude used to classify tide regime in the eastern coast of the Red Sea. The importance of diurnal or semi-diurnal tide and its classifications can be expressed in terms of form factor F [16].

$$F = (K1 + O1) / (M2 + S2) \quad (1)$$

where the symbols of the constituents indicate their respective amplitudes. The form factor calculated from derived constituents presented in **Table 2**. The values

Figure 4. Correlation between observed and predicted water level at Yanbu during July 2015.

Table 2. Form factors at different coastal locations.

Coastal Stations	Form factor
Magna	0.0896
Duba	0.1159
Alwaj	0.1362
Yanbu	0.2028
Jeddah	0.5454
Qunfuthah	0.0896
Jazan	0.0883

of form factor show tides in the all the coastal stations are in semi-diurnal nature except Jeddah, where tide mainly mixed semi-diurnal nature. The form factor is higher in the central coast and decreases towards south and north coastal stations. The study also points out the semi diurnal and mixed semi-diurnal characteristics of the tide along the eastern coast of the Red Sea.

4. Summary and Conclusion

Study shows tide plays important role in the near shore area of the eastern coast of the Red Sea. The one-year time series data were from the coastal stations along the eastern coast of the Red Sea used for the analysis. The compressive analysis of tidal data using T-Tide in the coastal areas unravels the spatial variations of tidal dynamics due to different environmental factors. The T-tide tool is used to compute the equilibrium tidal amplitude and phase from astronomical forces. From the analysis, semi diurnal constituents M2 dominant is with more than double amplifications compared to other constituents. The M2 plays a major role in the total tidal range in the region than other major constituents. The study phase variations of major constituents also show different tidal dynamics along the eastern coast of the Red Sea. The form factor study was also used to find the nature of tidal pattern along the coastal region.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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