Hydrodynamic Modelling Along The Eastern Coast Of The Saudi Arabia

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Abstract: Study on tidal dynamics is important for different coastal processes, biological processes, engineering and navigational purposes. The present study have carried out a hydrodynamic modelling study on tidal dynamics along the eastern coast of the Saudi Arabia, Gulf of Arabia. The analysis focuses on the spatial and temporal variation of tide along the coastal regions of the eastern coast of the Saudi Arabia. Time series data from the five coastal stations along the eastern coast of the Gulf of Arabia were used for tidal analysis. Delft 3D model used for the analysis and derived simulated water level along the eastern coast of the Saudi Arabia. The study reveals the variations of tidal constituents in temporal and spatial scale along the coastline. The important tidal constituents principal semidiurnal lunar (M2) shows selective amplification among the other important tidal constituents The simulated water levels were verified it with field data and can be used for many related applications.

Index Terms: Numerical modelling, Constituents, Delft 3D, Tidal dynamics, Form Factor

1. INTRODUCTION

The Gulf of Arabia is the extension to the Gulf of Oman in by the Strait of Hormuz. The effect of tidal waves from the Indian Ocean is less. The tidal dynamics along the eastern coast of the Saudi Arabia is more practically importance, since there more ports located along the coast. The physical changes of tidal waves will affect the biological processes of coral protected coast. Hence, a broad study on the physical properties of tides is required. Since the area belongs to the meso-tidal region the influence of tide and its associated currents are more prominent in the coastal areas, than the open ocean, where the coastal development activities are more. Hence, a numerical modeling study was carried out to unravel the physical dynamics of tides along the eastern coast of the Saudi Arabia, where such studies are very less. The main objectives of the present investigations to model the tidal dynamics along the eastern coast of Saudi Arabia using Delft 3D model and verify the simulations with field conditions and use the model for future applications. The present investigation was carried out with comprehensive field data collected from even distributed tide gauges data along the eastern coast of the Saudi Arabia and hence the scope of the study is more. The study area about 1000 km length and approximate width of 370 km. The mean depth in this region is 36 m [1]. The shamal (northwesterly wind) wind dominated in this region [2]. The evaporation rate is more is about 2 m/yr [3]. The river Shatt-AlArab is the major fresh water source in the Arabian Gulf [4]. The tidal pattern of the Gulf of Arabia is of different types of semi-diurnal, diurnal and mixed in characteristics (Reynolds, 1993). The diurnal and semi-diurnal components are equally prominent in this region [5]. The diurnal amphidromic points are found in the center part of the gulf of Arabia, whereas the semi-diurnal located in northwestern and southern ends of the Gulf of Arabia ([5] and [6]. The predicted tidal current is 0.9 m/s found in the Strait of Hormuz [5].

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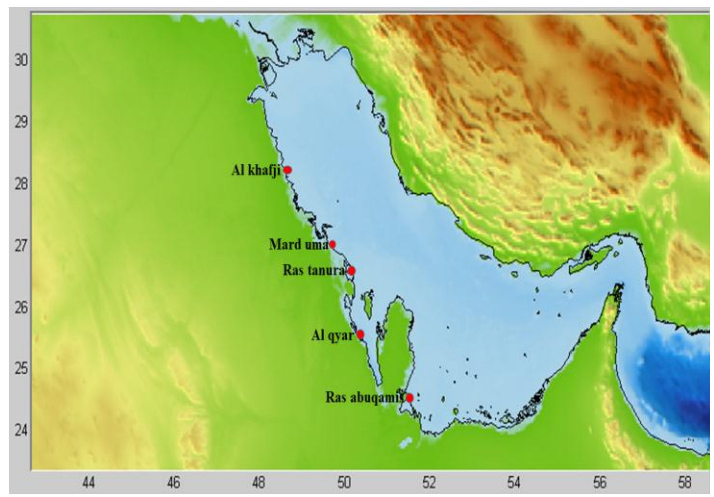

Figure 1. *Study location*

MATERIALS AND METHODS

The observed data from the five coastal station along the eastern coast of Saudi Arabia. The obtained from the tidal stations established by the General Commission for Survey (GCS), Kingdom of Saudi Arabia. The tide gauges distributed along the coastline are shown in Fig. 1. The time series data are available from Sept. 2012-Aug to 2013 at 1-hour interval. The raw data processed, analyzed and used for modelling study.

2.1 MODEL USED

The spatial model study were carried out means of the high-resolution tide-resolving model Delft3D model [9][10]. Among the different modules, hydrodynamic module Delft3D-FLOW used for the tidal simulation study. Navier Stokes equations for an incompressible fluid is used in Delft 3D model. The model solve the depth averaged shallow water equation. Delft3D-FLOW based on flooding and drying algorithm [9]. The grod were generated in the study location using GEBCO data. The boundary conditions were generated using Global Inverse Tide Model. The model simulations were carried for one year (2012 Sep to 2013 Aug). The simulated tidal elevation 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) soft- ware for analysis. T-tide works in Matlab platform, can be used to perform clas- sical harmonic analysis with nodal corrections, inference, and a variety of used for Navier Stokes equations. 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 study focus on spatial variability of tidal constituents in the coastal locations of the eastern coast of the Saudi Arabia, Gulf of Arabia through modeling study.

RESULTS AND DISCUSSION

The Delft 3 D model study carried out for one year to derive all astronomical tidal forces. The spatial study also shows the variations of tidal elevation along the Guf of Arabia. Northern region experience more tidal elevation than the southern region. Maximum average tidal range experience more than 2m. The spatial distributions of tidal elevations also reveals the importance of tidal forces in this Arabian Gulf environment. The study mainly focus on the tidal elevation along the eastern coast of the Saudi Arabia where tidal observations are available. The one-year tidal elevation derived at different coastal locations (as shown in Fig.1.). The data analyses using T-tide and derive important tidal constituents. The derived amplitudes of the five stations listed in Table 1. The tidal wave subjected different physical processes when it propagate from deep water to shallow water. Since the topography of Arabian Gulf is more complex and hence the tidal deformation will be more. The amplitudes of important tidal constituents given the Fig. 2. This show the spatial variability of tidal distribution in the eastern coast of the Saudi Arabia. The simulated and field analysis shows the nature of the tide is mixed and semi-diurnal characteristics with higher amplitudes. The study shows the tidal constituents principal semidiurnal lunar (M2) shows selective amplification among the other important tidal constituents [8]. The spatial variations of M2 also shows in the Fig.2 and also this amplifications quite evident from the filed signature too. The tidal elevation in this region is more than the other locations. The constituents M2 and K1 shows large amplitudes than other constituents in all locations [7]. The other important tidal constituents like S2 (Principal Solar semi- diurnal) and K1 (Luni-solar diurnal) also shows amplification in the eastern coast from the north to the south. The tidal constituent S2 shows comparatively less amplifications than the K1. In the southern coast near the Ras Abuqamis K1 shows, much amplification compared to S2, whereas Rastanura S2 shows much amplifications than K1. Most of the important tidal constituents shows much amplification in Ras -Abuquamis than other locations. The other constituents like O1 (Lunar diurnal constituent), P1 (Solar diurnal constituent) also shows spatial variation s along the eastern coast from south to north. The presence of amphidromic points also reflects the in the variability of amplifications of important constituents along the coastal areas. The other important constituents like N2 (Larger lunar elliptic semidiurnal constituent), M4 (Shallow water overtides constituent) have also shows spatial variability in their respective amplitudes along the coastline from south to north. Since the constituents derived from coastal stations shallow water components are also shows amplifications compared to other components. All the tidal constituents shows decrease in amplitude from north to south and then increases to further south.

TABLE 01: *AMPLITUDE OF DERIVED TIDAL CONSTITUENTS*

CONSTITUENTS	AMPLITUDE (M)				
Q1	0.055	0.023	0.024	0.027	0.095
O1	0.153	0.061	0.066	0.074	0.32
P1	0.047	0.018	0.024	0.019	0.123
K1	0.145	0.055	0.073	0.071	0.424
N2	0.051	0.023	0.047	0.015	0.189
M2	0.256	0.117	0.268	0.078	0.739
S2	0.112	0.071	0.143	0.04	0.308
K2	0.035	0.025	0.046	0.013	0.082
2MK3	0.014	0.025	0.019	0.006	0.071
M4	0.049	0.015	0.062	0.004	0.027

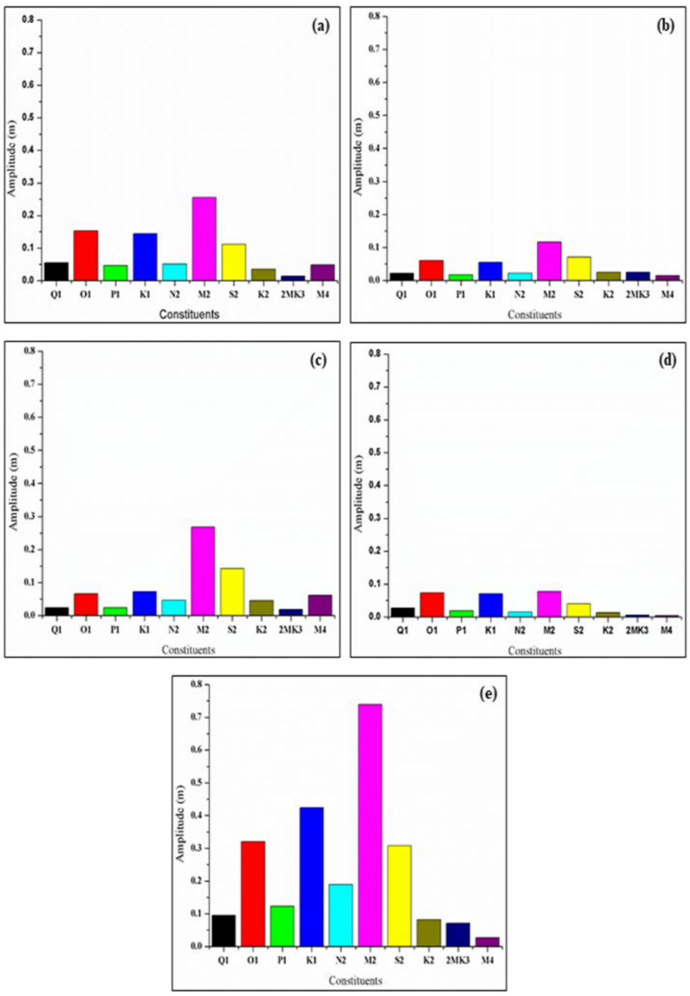

Fig. 2. Variation of amplitudes of significant tidal constituents along the seven coastal stations: (a) Al khafji, (b) Mard Uma, (c) Ras Tanura, (d) Al qyar, (e) Ras Abuqamis

The study also carried out the spatial variations of phase of the constituents along the coastal lines (Fig. 3). The important tidal constituents M2 shows variations from north to South (113 to 52 degree). It shows almost complete phase transformation from 0 degree to 360 degree. The S2 also shows variations in Phase change along the coastline. These phase changes also affect the amphidromic characteristics of the Gulf of Arabia and tidal elevations. The semi-diurnal componets N2, M2 and K2 are almost in same phase whereas Principal Solar semi-diurnal (S2) shows opposite phase. In diurnal constituents O1 (Lunar diurnal) and Q1 (Larger lunar elliptic diurnal) are spatially same phase whereas P1 and K1 are in opposite phase. It is a important things that two semi diurnal constituents having selective amplification along the coast having opposite in phases, that will cause the change in tidal elevations.

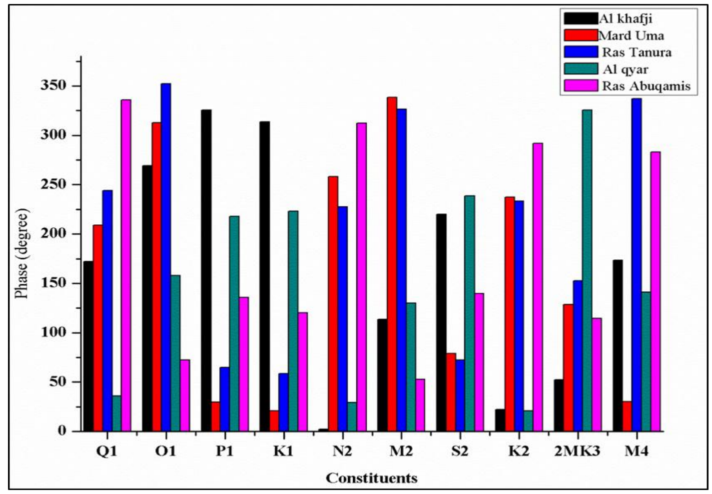

***Fig. 3**. Variation of phase of significant tidal constituents along the five coastal stations*

3.1 Form Factor Study

The tidal constituents amplitude derived by T-tide tool is used for form factor study. The derived amplitudes used for tidal regime study along the coastline. The role of diurnal or semi-diurnal tide and its tidal regime classification is given by form factor F [12].

$$F = (K1+ O1) / (M2 +S2) \text{ ----------------------- (1)}$$

The values of form factor shows the tides in the all the coastal stations are in semi-diurnal in nature [11] and is given in the Table 01. From factor varying along the coastline and is more in Ras Abuqamis, which is in the southern part. The form factor study and field data also shows the semi-diurnal characteristics of tide in the Gulf of Arabia.

***Table 01:** Form Factor Distribution*

Sl. No.	Coastal Locations	Form Factor
1	Al Khafji	0.809783
2	Mard uma	0.617021
3	Ras tanura	0.33820
4	Al qyar	1.228814
5	Ras abuqamis	0.710602

CONCLUSIONS

Study shows the importance of tidal elevation along the eastern coast of the Saudi Arabia. The one year comprehensive model simulations were carried in the Gulf of Arabia using Delft 3D and the tidal elevations were derived along the eastern coastline, where tidal observations available for long term. The T-tide tool used derive important tidal constituents along the coastline to unravel the spatial variability of tide tidal forces. The T-tide tool is used to compute the equilibrium tidal amplitude and phase from astronomical forces. From the analysis, semi diurnal constituents M2 and S2 dominant is with more than double amplifications compared to other along with diurnal components K1 and O1 constituents. The tidal constituents M2 shows selective amplifications in the south and shows comparative amplifications in the northern part also. The study phase variations of major constituents also show different tidal dynamics along the coastline, Principal Solar semi- diurnal

(S2) shows opposite phase characteristics than other diurnal component.. The form factor study shows mixed-semi diurnal characteristics of tidal pattern along the coastal region.

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