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SHORT COMMUNICATION

Shallow-water tidal analysis at Sharm Obhur, Jeddah, Red Sea

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Abstract Comprehensive field data was collected at Sharm Obhur. This data was processed and analyzed using different harmonic analysis techniques during the period of 2013. Since the measurement of the data was from a shallow-water creek, the data was full of noise and hence was filtered using the MATLAB code. Harmonic analysis techniques such as IOS and Admiralty methods were used for deriving major and minor tidal constituents. The variability in the shallow-water constituents and their selective amplifications were studied with derived constituents. The tidal regime classifications using form factor were carried out by using derived tidal constituents as applied and have been effectively tested in the field condition. The form factor study also shows the mixed semidiurnal nature of the tide in the creek and has been verified with field conditions. The contribution of sea-level variations of shallow-water constituents, Zo, was investigated and analyzed. The study has great practical potential for sea-level variation study and hydrographic-related applications in this region.

Keywords Tidal constituents · Harmonic analysis · Seal-level change

Introduction

Tides are the periodic rise and fall of the sea water level due to astronomical gravitational pull and the centrifugal force generated by the earth's rotation. A high tide may provide enough depth to enter or leave a harbor, while a low tide may prevent entering or leaving a harbor. Nowadays, tidal information is critical for ships due to their size and capacity as well as for biological productivity. Therefore, accurate tidal predictions are essential in tidal zone harbors and their approaches where depths and widths leave little narrow for error. Thus, precise tidal measurement and predictions are important for shipping safety, economy, and other physical and biological activities.

Tidal variations in the Red sea are spatially more dynamic and have more influence on the physical and biological processes. Saudi Arabia and Yemen lie in the eastern part of the Red Sea. A two-dimensional modeling study contributes the study of major semidiurnal and diurnal tidal constituents and existence of amphidromic system in the central part of the Red Sea (Madah et al. 2015). The scientific study of tidal analysis in the Red Sea is lacking (Madah et al. 2015). The lacuna is due to different factors such as uneven distribution of tide gauges over the Red Sea coast and lack of data resources. The theoretical study of tides of the Red Sea has been done by several investigators during the last century, which provides a dynamical explanation of actual tides. Hence, comprehensive study on the dynamics of tides is lacking in this region. The historical work mainly concentrated on the coastal region (Saad 1997; Monismith and Genin 2004). Present investigations were conducted at the Sharm Obhur where a little study was carried out. The study focuses on shallow-water tidal analysis using different tide analysis techniques with availability of data. The study area has more academic and scientific importance. The study area is within the premises of the faculty of Maritime Studies, King Abdulaziz University.

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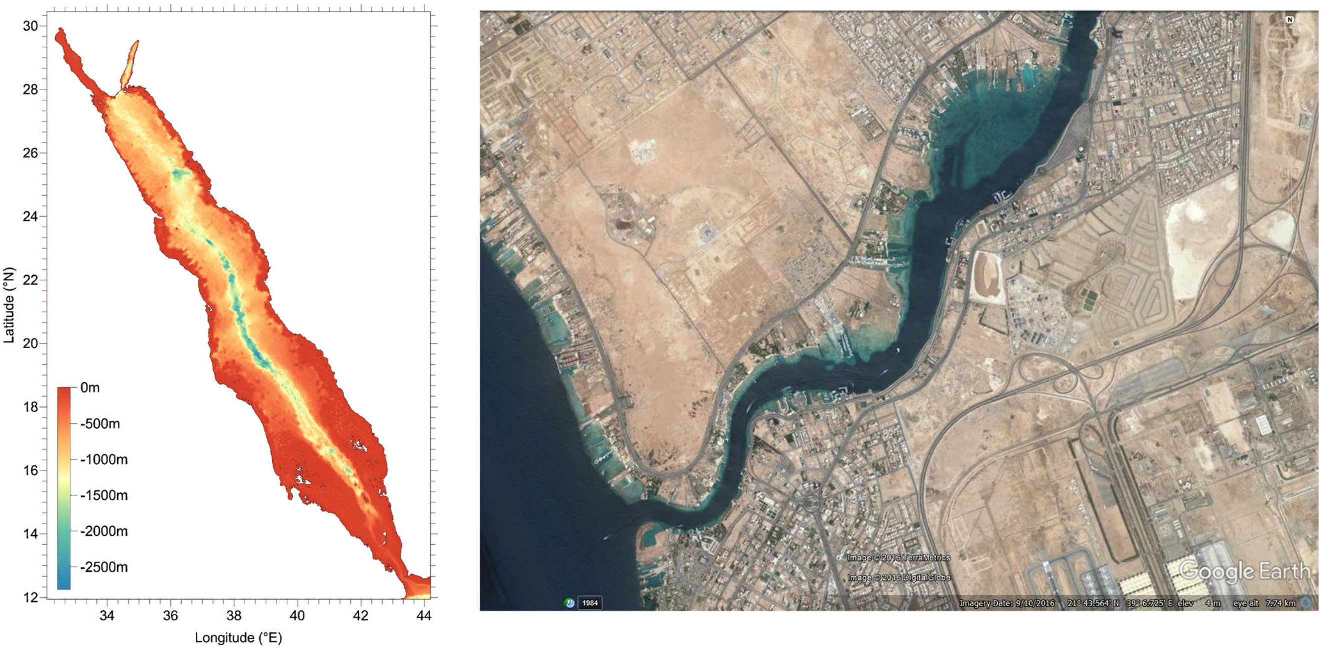

Fig. 1 Study area, Sharm Obhur, Jeddah

The faculty mainly conducts maritime courses and hydrographic surveying courses, and hence, the tidal information from the Sharm Obhur is useful for their academic and research activities. The study area's practical importance lies more in its recreational and fishing activities. The Sharm Obhur can be developed as a mini port for fishing as well as tourism activities, and hence, the information about tide in this region has more practical importance. These studies can yield a detailed analysis of shallow-water tidal constituents. The studies were carried out using the numerical modeling approach and its applications. The specific model used for the study is the MIKE 21 modeling system developed by Danish Hydraulic Institute (DHI 1998). Comprehensively collected 1-year field data at Sharm Obhur was also used for the study.

Fig. 2 Data collection at tide gauge station

Study area

The study area Sharm Obhur is located about 35 km north of Jeddah and is approximately 10 km long and 500 m wide (Al-Barakati 2009) (Fig. 1). The depth varies along the bay with an average depth of 30 m (Behairy et al. 1983). The Sharm Obhur is extended to inland by coralline limestone, and temperature varies from 24.4 °C in winter to 32.2 °C in summer and generally increases toward the head of the Sharm (Basham and El-Shater 1994a, b). The diurnal water exchange takes place at the mouth of the bay due to the tidal cycle. Due to complex bathymetry, the tide becomes more dynamic as has been brought out through this study. For monitoring the complete tidal cycle, a tidal station is established near the inlet to the Sharm Obhur and 1 year of comprehensive data was collected and analyzed for the study.

Material and methods

The data was collected near the maritime study, Sharm Obhur, Jeddah. The location of the tide gauge is at 21° 42′ 33″ N 39° 5′ 45″ E (Fig. 2). The tide gauge is attached to weather stations, and hence, the tide data was collected along with the other environmental parameters like atmosphere temperature, wind speed and direction, atmosphere pressure, humidity,

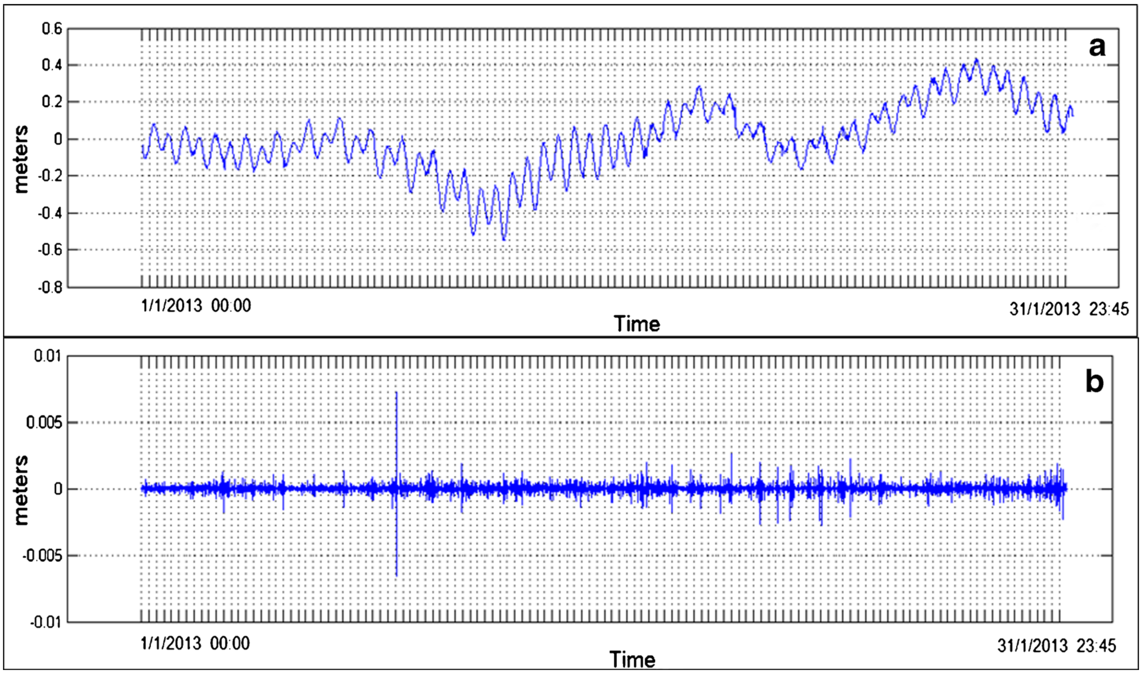

Fig. 3 **a**, **b** The time series tide data and filtered noises in the month of January 2013

irradiance, etc. These environmental parameters were supplemented to the study in order to know other varying environmental forces, which affect tidal dynamics in the Sharm Obhur. The tide data was collected using a pressure-type tide gauge in 15-min intervals with all astronomical tidal influences. The pressure-type tide gauge is an established part of the weather station, owned and operated by the Faculty Marine of Science, Obhur campus. The frequency of data logging is 15 min, which is stored on a flash memory with data being downloaded every month. The water-level gauge

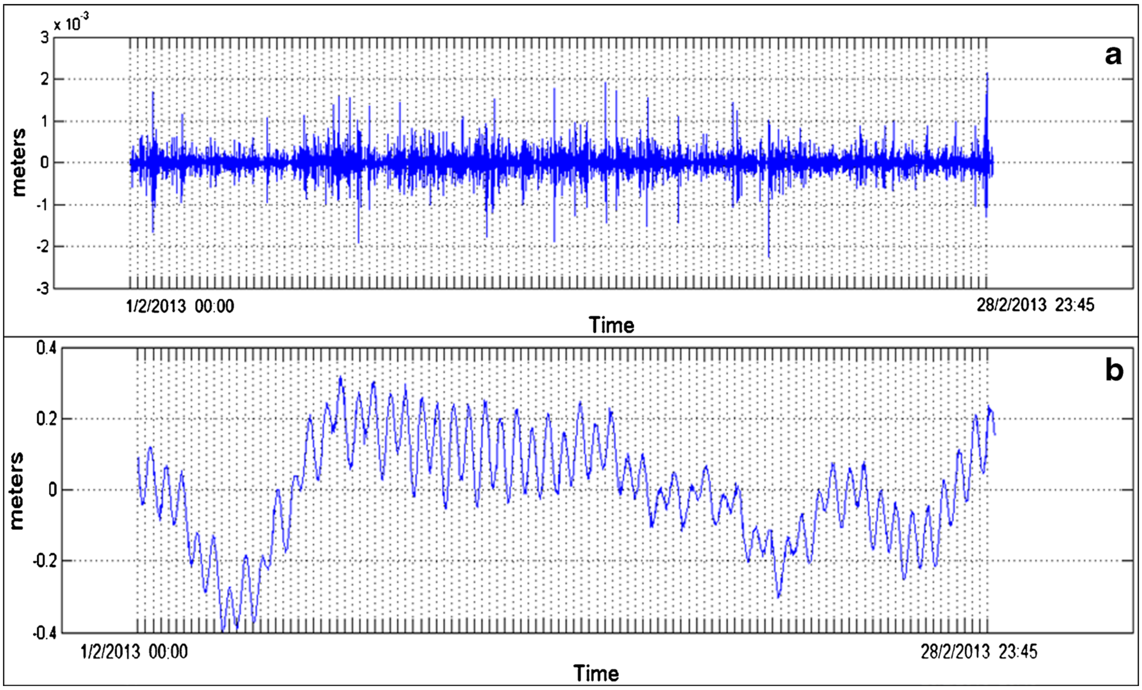

Fig. 4 **a**, **b** The time series tide data and filtered noises in the month of February 2013

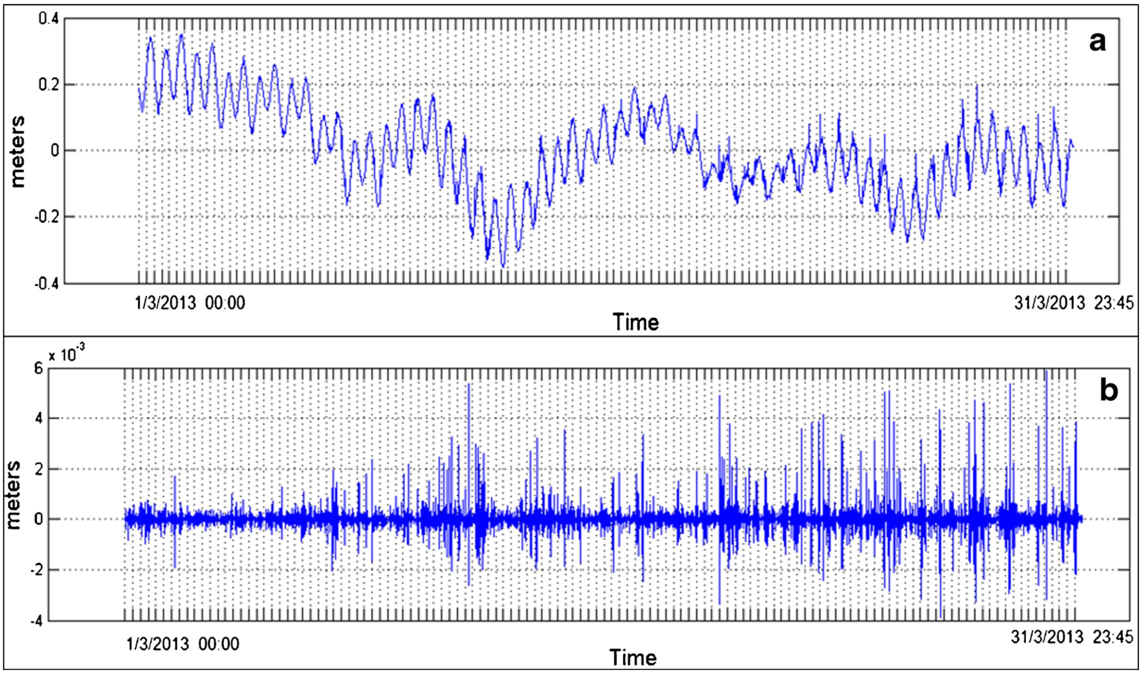

Fig. 5 **a**, **b** The time series tide data and filtered noises in the month of March 2013

used part of the weather station is pressure-type gauge, which is deployed on the bottom of the Sharm Obhur. Raw data was collated for the whole year of 2013, which was processed and analyzed. Since the raw data was collected in the lake, the noises were filtered using the MATLAB program. The filtered data was subjected to harmonic analysis to derive major tidal constituents, and the Institute of Ocean Sciences (IOS) method (Foreman 1977) was used for deriving standard constituents, which include 45 astronomical main constituents and 24 shallow-water constituents.

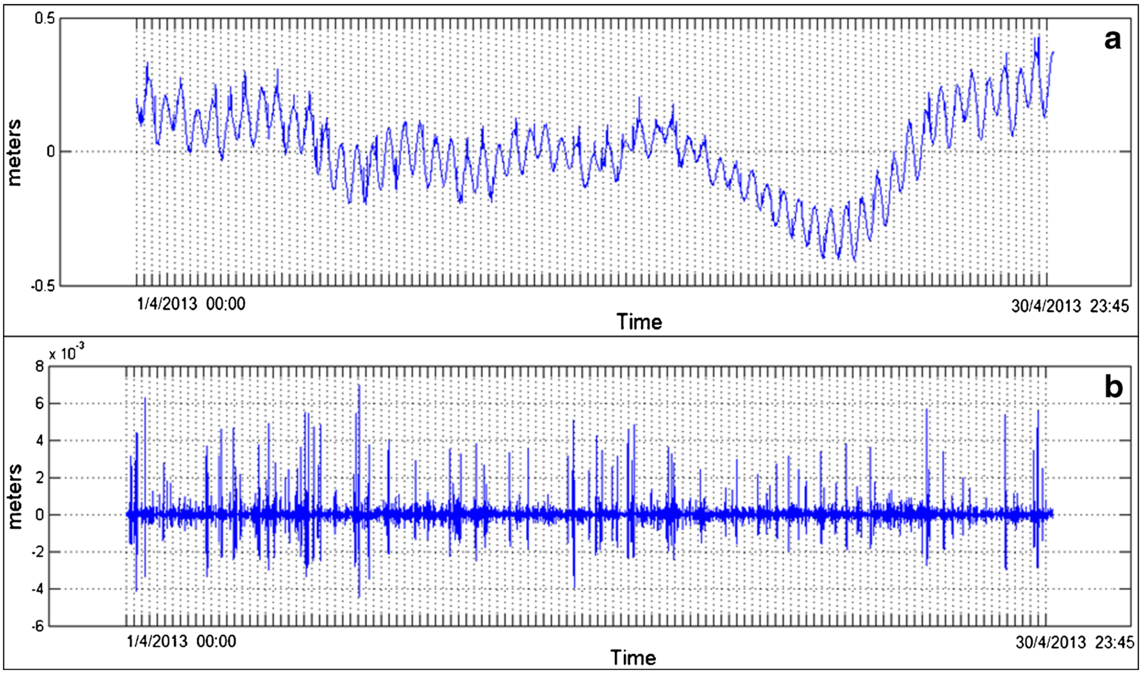

Fig. 6 **a**, **b** The time series tide data and filtered noises in the month of April 2013

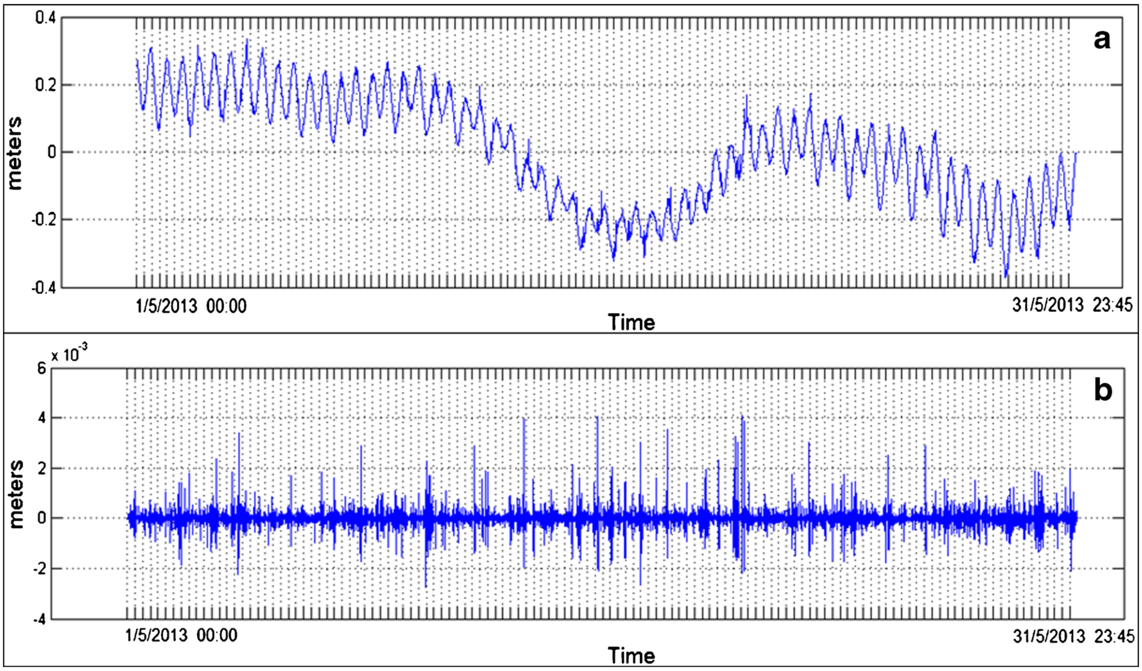

Fig. 7 **a**, **b** The time series tide data and filtered noises in the month of May 2013

Results

Noise filtering

The data was collected inside the creek; therefore, the effects of shallow-water tidal constituents were prominent; the selective amplifications of the shallow-water tidal constituents were more prominent in this region. Since the data was collected near the inlet, the data mixed with lots of noise due to other environmental factors and other non-trend signals. Most of the mixed-noise residual variation may depend upon atmospheric pressure variations, wind forces, density variation, etc. (Al-Subhi 2010). The tidal data can be filtered using standard high, low, and bandpass filtering techniques. In the present

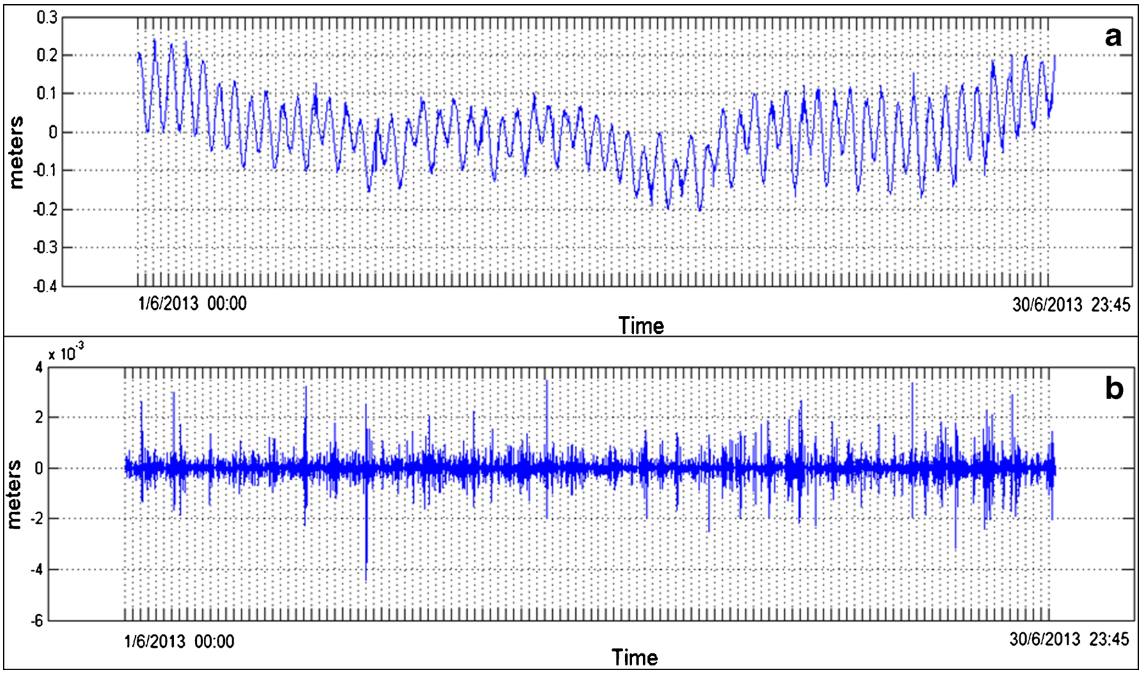

Fig. 8 **a**, **b** The time series tide data and filtered noises in the month of June 2013

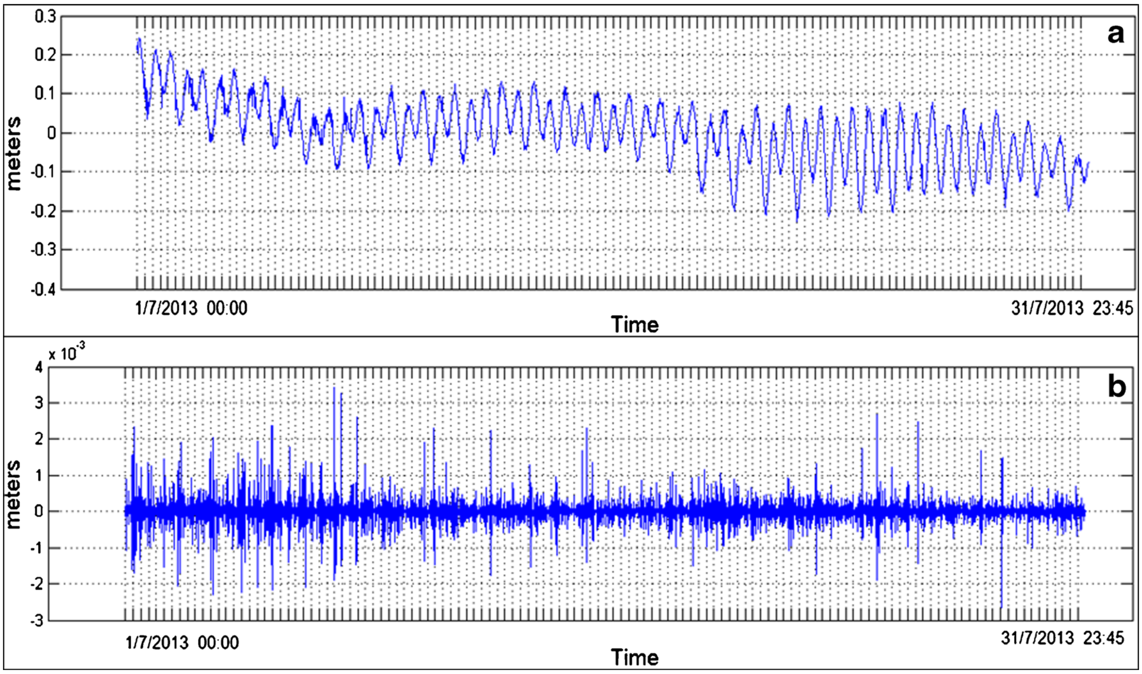

Fig. 9 **a**, **b** The time series tide data and filtered noises in the month of July 2013

study, the MATLAB code was used to filter the tidal data and the code was written using the Butterworth high-pass filter techniques. The Butterworth filter techniques are the best compromise between attenuation and phase response, and it is a maximally flat filter. The data filtering processes were carried out for each month in the year 2013 with same-frequency band.

The tidal data, mixed with other environmental forces, are filtered and presented in Figs. 3a, b, 4a, b, 5a, b, 6a, b, 7a, b, 8a, b, 9a, b, 10a, b, 11a, b, 12a, b, 13a, b, and 14a, b. In some month, it shows maximum noise or non-trend signals. The trend need not be linear and non-linear, which may be because of seasonal and temporal variations of environmental forces. Since the environmental data is not available, the

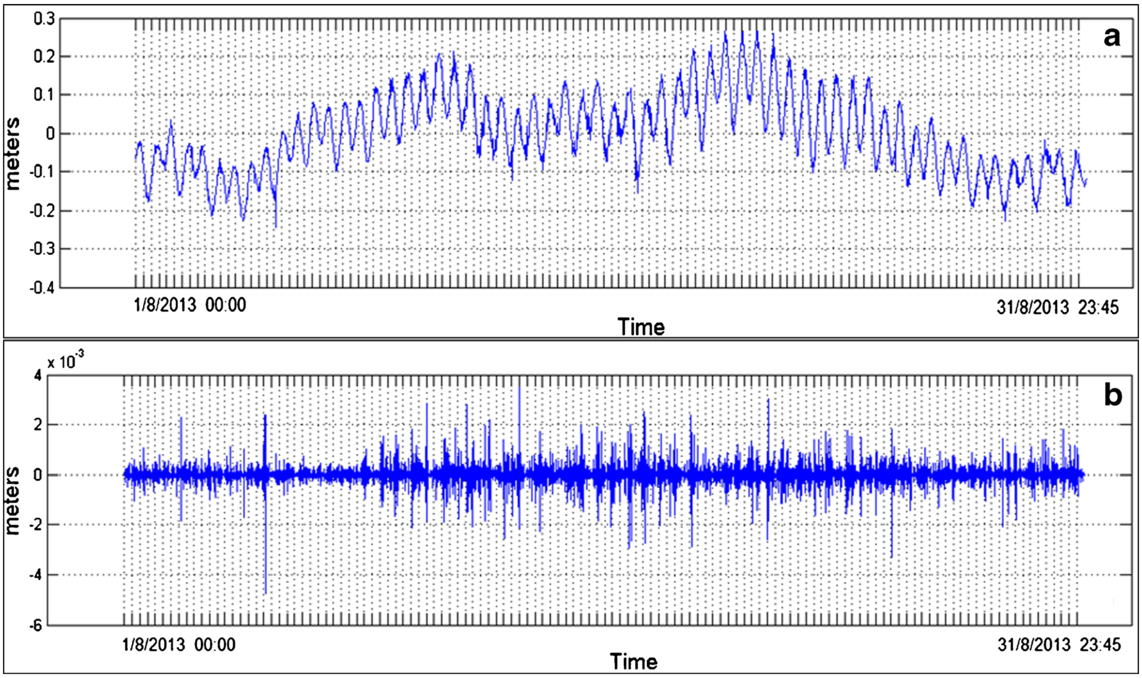

Fig. 10 **a**, **b** The time series tide data and filtered noises in the month of August 2013

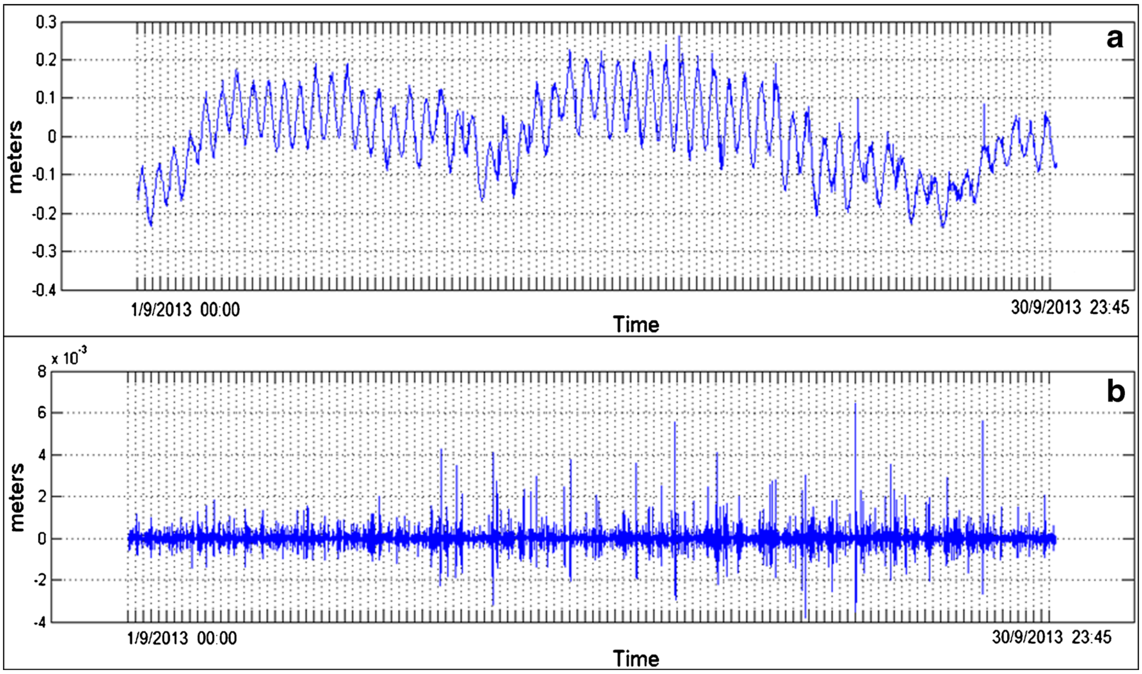

Fig. 11 **a**, **b** The time series tide data and filtered noises in the month of September 2013

establishment of such relationships could not be performed. Other factors may be topographical or geological and may be subject to further study and investigation. The analysis of data shows more noise in certain months than in other months, and this is mainly due to the impact of seasonal and temporal effects of environmental forces. In the Red Sea during the northeast monsoon (November to March), strong southeasterly wind prevails in the southern part of the Red Sea (Jiang et al. 2009); this is quite evident from Figs. 3b, 4b, 5b, 13b, and 14b where the tidal data shows more noise, whereas, during the summer season (June to September), weaker northwesterly wind prevails over the Red Sea, and hence, the tidal data shows less noise (Figs. 8b, 9b, 10b, and 11b). The mesoscale variations of other meteorological factors

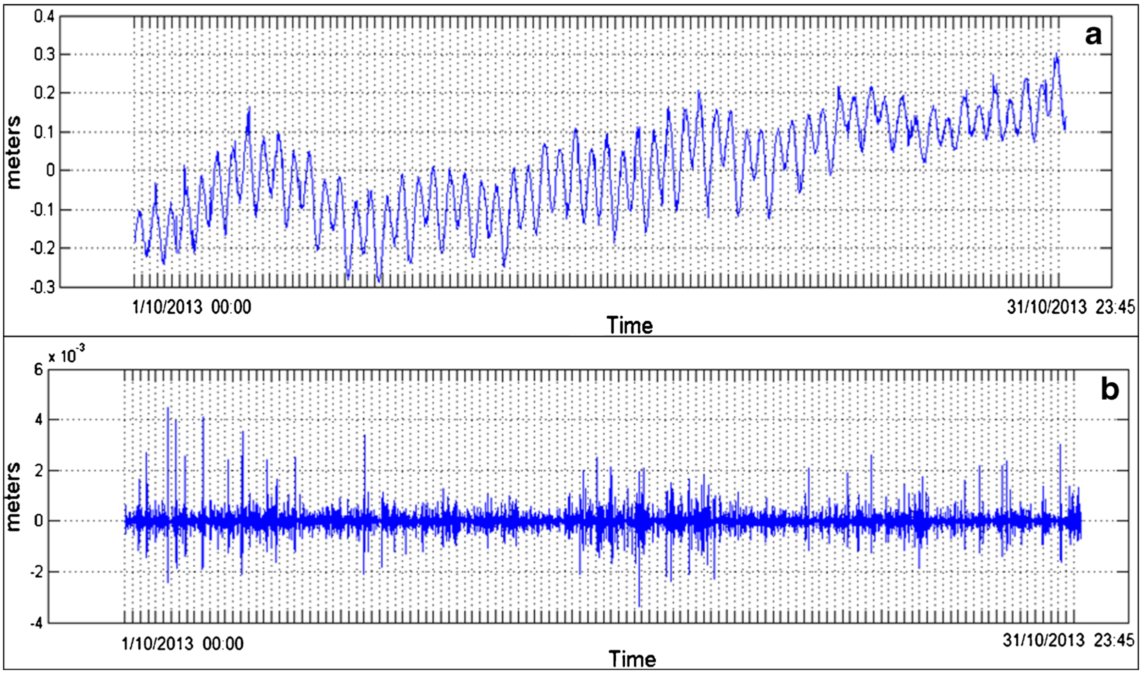

Fig. 12 **a**, **b** The time series tide data and filtered noises in the month of October 2013

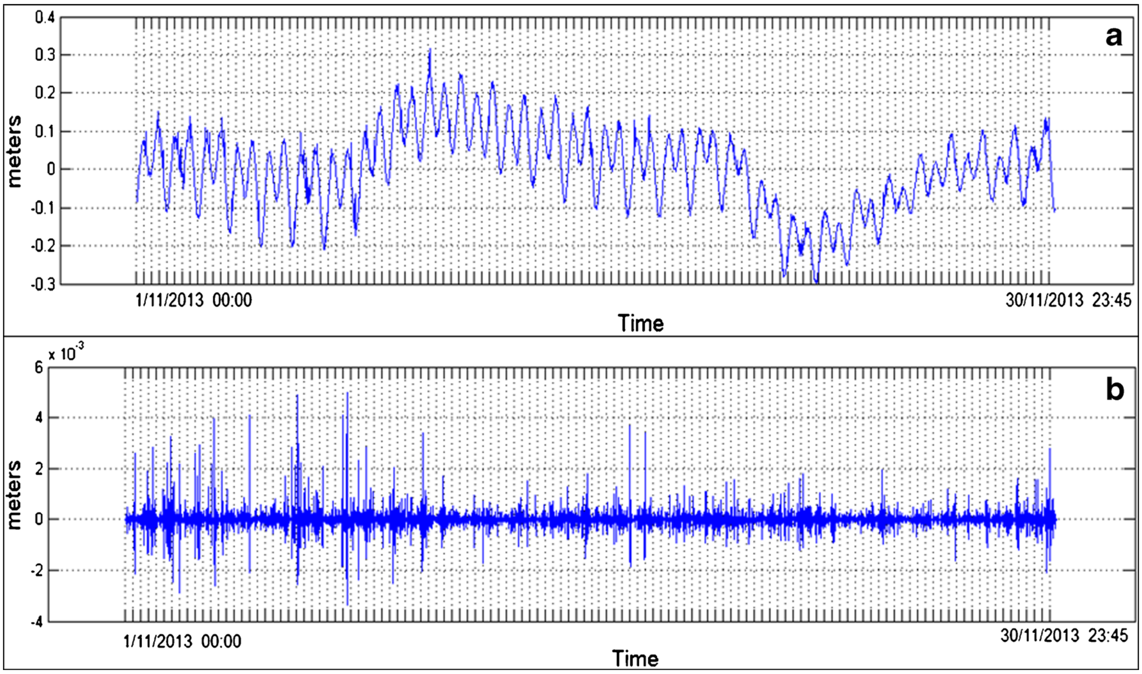

Fig. 13 **a**, **b** The time series tide data and filtered noises in the month of November 2013

also affect the tidal data. The analysis also shows the impact of seasonal and temporal variations in wind pattern, which also cause noises in the data. During high-pressure summer, the prevailing wind pattern over the Mediterranean will be toward northwesterly direction.

Tidal constituent analysis

Understanding of tidal components is of paramount importance in assessing the influence of tides on a wide range of tidal processes. Hence, different methods were adopted to

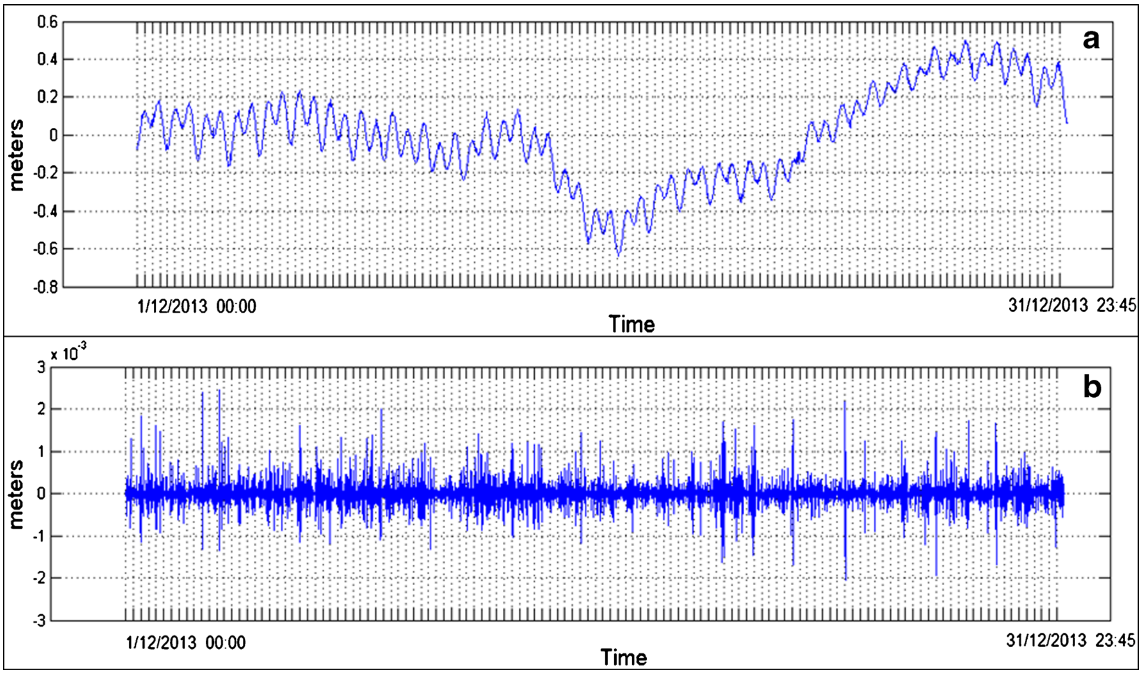

Fig. 14 **a**, **b** The time series tide data and filtered noises in the month of December 2013

Table 1 Major tidal constituents at Sharm Obhur

Sl. no.	Constituents	Amplitude	Phase
1.	M2	0.0647	−159.47
2.	S2	0.0118	−127.43
3.	K1	0.0292	−148.62
4.	O1	0.0178	−144.78
5.	F4	0.2349	−155.95
6.	F6	0.5095	4.29

derive major and minor tidal constituents. The tidal constituents can be used for tidal predictions and related processes. More importance was given to analysis of shallow-water tidal constituents. The different techniques adopted for derivations of major and minor constituents were discussed in the following sections:

Harmonic analysis

The tidal constituents were derived using the harmonic analysis method. The derived tidal constituents were used for tidal analysis of Sharm Obhur. One year of data was used to calculate major tidal constituents via this method. The observed tide can be decomposed into its diurnal constituents (K1, O1, and P1) and semidiurnal constituents (M2, S2, N2, and K2). The tidal constituents can be derived monthly to study their seasonal and temporal variations. The primary tidal constituents were derived and are presented in Table 1.

Table 1 presents tidal constituents derived by harmonic analysis in the year 2013. The derived constituents and overall analysis show that the tides are of the mixed semidiurnal type with less tidal amplitude. The field studies also show less

Table 2 Tide constituents by the IOS method in January 2013

Sl. no.	Name	Amplitude	Phase
1.	Z0	2.104	0
2.	MSf	0.0481	133.34
3.	2Q1	0.0059	242.78
4.	Q1	0.0093	239.18
5.	O1	0.0224	263.51
6.	NO1	0.015	195.13
7.	K1	0.0362	287.03
8.	J1	0.013	115.72
9.	OO1	0.0135	249.93
10.	UPS1	0.0053	258.19
11.	N2	0.0409	259.04
12.	M2	0.0418	5.13
13.	S2	0.03	31.35
14.	ETA2	0.0071	8.63
15.	MO3	0.0009	357.93
16.	M3	0.0012	292.08
17.	MK3	0.001	74.13
18.	SK3	0.0006	223.73
19.	MN4	0.0006	266.43
20.	M4	0.001	223.99
21.	MS4	0.0013	257.74
22.	S4	0.0005	176.2
23.	2MK5	0.0006	326.53
24.	2SK5	0.0005	197.78
25.	2MN6	0.0004	274.22
26.	M6	0.0007	329.74
27.	2MS6	0.0007	74.51
28.	2SM6	0.0002	234.22
29.	3MK7	0.0004	325.36
30.	M8	0.0007	318.12

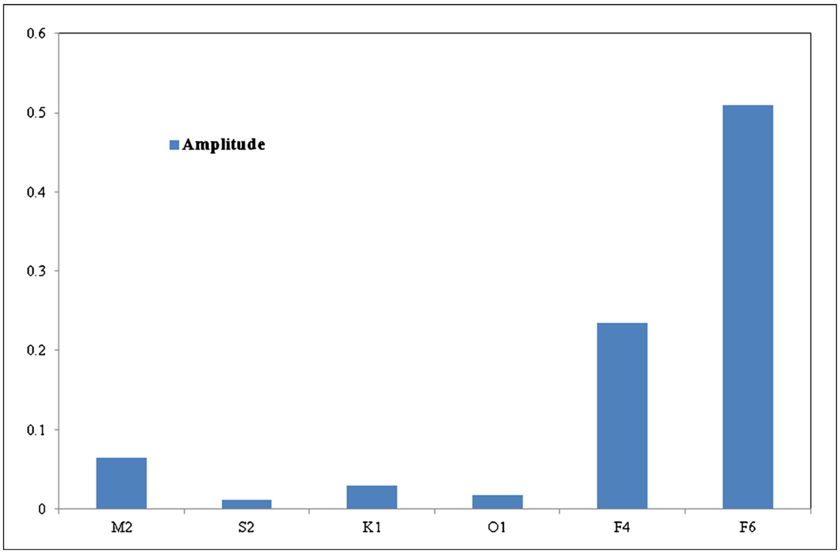

Fig. 15 Distributions of major tidal constituents for the year 2013

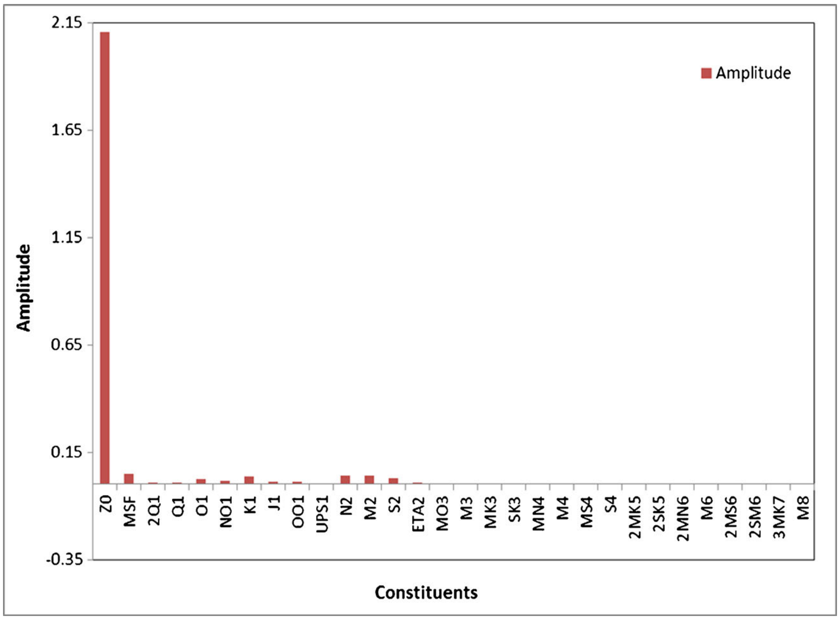

Fig. 16 Distributions of minor tidal constituents in the month of January 2013

Table 3 Tidal constituents for form factor

Sl. no.	Constituents	Amplitude	Phase
1	M2	0.0647	−159.47
2	S2	0.0118	−127.43
3	K1	0.0292	−148.62
4	O1	0.0178	−144.78

amplitude of tide in agreement with tidal constituent's analysis results. The semidiurnal constituents show much amplification than diurnal constituents. The tidal constituents F6 and F4 show selective amplifications than other constituents (Fig. 15) and have more importance in the shallow-water correction. The application of this method is of great practical importance for the study of the tidal constituents in the creek.

IOS method

The IOS method is potentially the most detailed description of the tide at a specific location. This method developed by Foreman (1977) IOS, Victoria, British Columbia, Canada (IOS), and is used for locations where the tide data was available for several months. This method is more effective to study shallow-water tidal constituents. This method, having the standard constituents, includes 45 astronomical main constituents and 24 shallow-water constituents. This method was mainly used to derive shallow-water tidal constituents for the present investigation where the study location is a shallow-water creek. Using this method, the 30 tidal constituents, including shallow-water constituents are derived.

A well-defined important shallow-water constituent can be seen at the location from the analysis. The shallow-water constituent Z0 (Table 2) shows a significant amplification and is related to mean sea-level variation. The sea level shows more variations during summer in the central area of Red Sea (Ahmad and Sultan 1993; Sultan et al. 1995a, b; Maghrabi 2003). The long-shore wind stress shows more contribution than cross-shore stress for sea-level variations during summer (Zubier 2010). From the analysis study, it is very clear that among the constituents, the Z0 and MSf components are showing more selective amplifications than other constituents (Fig. 16). The tidal constituent MSf (lunisolar synodic fortnightly) shows its significant presence in all months with amplitudes greater than the equilibrium amplitude. Globally, the presence of the tidal constituent MSf reported only few places

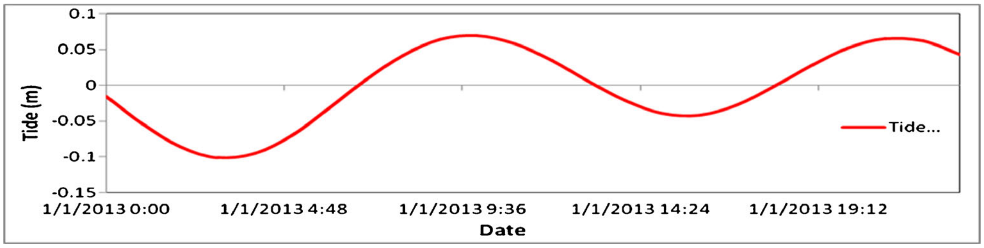

Fig. 17 One-day time series plot of tide at Sharm Obhur

(Rose et al. 2015). Even though the presences of MSf tidal constituents are relatively weak, they play an important role in the low-frequency ocean dynamics (Rose and Bhaskaran 2016). The shallow-water constituent Z0 is dominating among all other constituents irrespective of seasons, which refer to mean sea level. The constituents Z0 and MSf show seasonal variations. During northeast monsoon (November to March), Zo and MSf show relatively higher amplifications than the summer seasons and this may be due to meteorological influence. The monthly variations of Zo and MSf due to meteorological influence should be investigated. The shallow-water constituent Z0 is mainly shaping the tidal range in the Sharm Obhur; the constituent Zo can be used for the long-term sea-level variation study. The constituents Z0 and MSf generated by the IOS method can be used for tidal study in the Sharm Obhur.

Classifications of tidal regime

The nature of tide and classifications of tidal regime at Sharm Obhur were carried out in terms of form factor, *F* (Boon 2004). The importance of diurnal or semidiurnal tide and its classifications can be expressed in terms of form factor.

$$F = \frac{K_1 + O_1}{M_2 + S_2} \tag{1}$$

The derived major tidal constituents (Table 3) were used to calculate form factor (*F*). The form factor, *F* ~0.614, is mixed semidiurnal with a result in close agreement with field data (Fig. 17) (Al-Subhi 2010).

Conclusion

This paper discusses the tidal analysis at Sharm Obhur, Red Sea, using different tidal analysis techniques from which the major and minor tidal constituents were derived and analyzed along with their importance. The objectives were achieved with limited resources. The shallow-water constituent Zo shows ample practical importance in the Sharm Obhur with more selective amplifications along with MSf than other tidal constituents. The derivations of the shallow-water constituents from 1 year's data can be contributed to the study of long-term sea-level variations. The major tidal constituents show less amplification than the minor constituents and have proven lesser importance in the Sharm Obhur creek. The credibility of the constituents was tested in the field conditions using form factor and has been verified in the field conditions. The derived tidal constituents have much practical importance for analysis and predictions. The study area has more practical importance in the field of hydrography and its applications.

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