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Characteristics of the tidal wave in Khor Abdullah and Khor Al-Zubair Channels, Northwest of the Arabian Gulf

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Abstract - The characteristics of the tidal wave propagates along Khor Abdullah and Khor Al-Zubair were studied based on comprehensive field measurements of water level at three locations by using harmonic tidal model. The results revealed that there is a gradual increase in the amplitude of tidal wave when it propagates towards an inland direction due to the convergence nature of the study area. Also, the results of harmonic analysis led to estimate 28 tidal constituents that contribute to water level fluctuations, and M_2 was the main contributor, followed by K_1, S_2, O_1, and N_2, and the astronomical tide is responsible for about 96% of these variations. The ratio between the amplitudes of the principle diurnal to the principle semi-diurnal constituents gave the tide a form number of 0.68, 0.48 and 0.44 in Khor Abdullah, Umm Qasar and Khor Al-Zubair port stations, respectively. Hence the tide is characterized by mixed, predominantly semi-diurnal. Based on the tidal wave deformation due to the nonlinear tidal interactions, the study area is classified as a flood dominant which suffers from a continuous deterioration in their depths. The results provide useful information for understanding the general behavior of tidal wave and will be significant in the future assessments of coastal developments in this region

خصائص الموجة المدية في خور عبدالله وخور الزبير شمال غرب الخليج العربي

علي عبد الرضا لفته[1]، سامر عدنان الطائي[1] و نوري حسين الهاشمي[2]
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المستخلص - تم دراسة خصائص الموجة المدية المنتشرة على طول خور عبد الله وخور الزبير استنادا على قياسات ميدانية لتذبذب مستوى المياه عند ثلاثة مواقع باستخدام الموديل التوافقي. أوضحت النتائج ان هناك زيادة تدريجية في سعة الموجة المدية عندما تنتشر بالاتجاه الشمالي بسبب طبيعة التقارب في منطقة الدراسة. كذلك توصلت نتائج التحليل التوافقي الى حساب 28 مقومة مدية تساهم في حدوث التذبذب في سطح البحر بحيث ان المساهمة العظمى تعود للمقومة M2 وتأتي بعدها كل من K1، S2، O1 و N2 وان ظاهرة المد الفلكية تكون مسؤولة عن حوالي 96% من حدوث هذا التذبذب. ان النسبة بين سعة المقومات اليومية الاساسية الى المقومات نصف اليومية الاساسية تعطي قيمة لعدد الشكل مساوية 0.68 ، 0.48 و 0.44 في محطات خور عبد الله، ام قصر وخور الزبير على التوالي، لذلك فان منطقة الدراسة تصنف على انها ذات مد مختلط ولكن المد نصف اليومي هو السائد. كذلك واستنادا على التشوه الذي تعاني منه الموجة المدية فان منطقة الدراسة تصنف على انها من النوع ذي طور المد المهيمن والتي تعاني من التدهور المستمر في الاعماق بسبب هذه الخاصية. ان نتائج هذه الدراسة تعطي معلومات مهمة لفهم سلوك الموجة المدية ولها أهمية للدراسات المستقبلية المتعلقة بالتطويرات الساحلية في هذه المنطقة.

كلمات مفتاحية: الموجة المدية، الموديل التوافقي، اللاتماثل المدي، طور المد المهيمن، المد المختلط

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Introduction

The tidal generating force is produced by the combination of the gravitational attraction between the earth, moon and sun, and the centrifugal force due to the rotation of the earth-moon and earth-sun systems, and lead to creat two bulges on both sides of the earth's surface, one that corresponds moon or sun, and the other in the opposite direction to them. So the tide is defined as a periodic vertical motion of the sea surface due to mutual attractive forces of the sun, moon, and earth, and due to these forces, a very long wave generates in the ocean basin and propagate towards the coastal areas. This wave which is known as a tidal wave is a shallow water wave propagates under the influence of the celestial body (sun or moon) that caused it (Boon, 2013).

The characteristics of the tidal wave undergo many variations when it propagates towards shallow coastal water such as bays, lagoons, and estuaries due to many physical factors which are geometry, bottom friction, and tidal flats extensions (Woo and Yoon, 2011). These changes include an increase in wave amplitude, a decrease in wave propagation speed, and deformation in their shape, i.e. the wave crest and trough move at different speeds.

Then, the characteristics of tidal waves are determined according to the dimensions of these coastal water bodies. The hydrodynamics of tidal waves are responsible for determining how large the tide range will be and when the high and low waters will occur, and how fast the tidal currents will flow and when slack waters will occur and determine the frequencies that tidal energy transmitted through it (Parker, 2007).

Khor Abdullah and Khor Al-Zubair are part of the Iraqi marine water situated at the northwest of the Arabian Gulf and have important aspects for the country including economics, industrials, fisheries, and oil transportations. The tidal characteristics in the Iraqi marine water are influenced by the tide of the Arabian Gulf. However, the tide of the Arabian Gulf is complex and shows a heterogeneous distribution between purely semi-diurnal or diurnal tide in some places and a mixed tide in other places (Reynolds, 1993). There are several studies of the tidal characteristics in the Arabian Gulf, distributed between field measurements (Hunter,1982; Reynolds, 1993; Sultan *et al.*, 1995; Sultan *et al.*, 2000; Alothman *et al.*, 2014; Siddig *et al.*, 2019), and numerical modeling studies (Sadrinasab and Kämpf, 2004; Kämpf and Sadrinasab, 2006; Elshorbagy *et al.*, 2006; Elhakeem *et al.*, 2007; Elhakeem *et al.*, 2015; Akbari *et al.*, 2016). However, despite the great importance of the Iraqi marine waters, there are a few studies highlighting the tidal wave characteristics in this region (Baker *et al.*, 1989; Salman and Baker, 1990; Al-Shammary, 1999; Abdullahh, 2002). The objective of this study was to investigate the general characteristics of a tidal wave propagated along the Iraqi marine waters and quantify the important tidal frequencies and tidal asymmetry in this region.

Materials and Methods

Study Area:

The Iraqi marine waters are situated at the northwestern tip of the Arabian Gulf and consist of Shatt Al-Arab Estuary and several open lagoons such as Khor Al-Kafka, Khor Al-Amaya and Khor Abdullah (Al-Mahdi *et al.*, 2009). Khor Abdullah is a shallow water body (depths ranged from 7 to 14 m and averaged about 10 m) characterized by its funnel shaped and extended towards the northwest direction, and surrounded by the Al-Faw peninsula on the east bank and Bobian island on the other bank, with wide intertidal zones on its banks (Mohamed *et al.*, 2002). The total length of Khor Abdullah channel is about 40 km and its width is about 17 km at its confluence with the Arabian Gulf and reduces to about 6.5 km south of Warba island when it forms Khor Bobian that connects it with Khor Al-Subia and Khor Al-Zubair which extends to the inland of Iraqi territory

(Fig. 1). While, Khor Al-Zubair channel is an extension of Khor Abdullah and they connected through Khor Shytana (Fig. 1).

The average area of Khor Al-Zubair that covered by water is approximately 60 km^2 and with a mean tidal range exceeds 4 m at the spring tide (Al-Ramadhan, 1988). The depth of the navigation channel in Khor Al-Zubair ranges between 10 and 20 m. The northern part of Khor Al-Zubair is composed of several irregular shallow tidal lagoons with complex geometry that formed a characteristic shape like a tree fronds (Fig. 1). The climate of the region is characterized by an arid desert climate with two distinct seasons, the summer which is a hot and long that reaches about 230 days and winter that represent a cold and rainy season. There are two types of prevailing winds in the study area, northwest winds, which causes dust storms in the summer, and locally known as Al-Shammal and it is a characteristic of
the region and southeast winds mostly during autumn and winter that is relatively warm and moist and brings rainy clouds occasionally (Zakaria *et al.*, 2013).

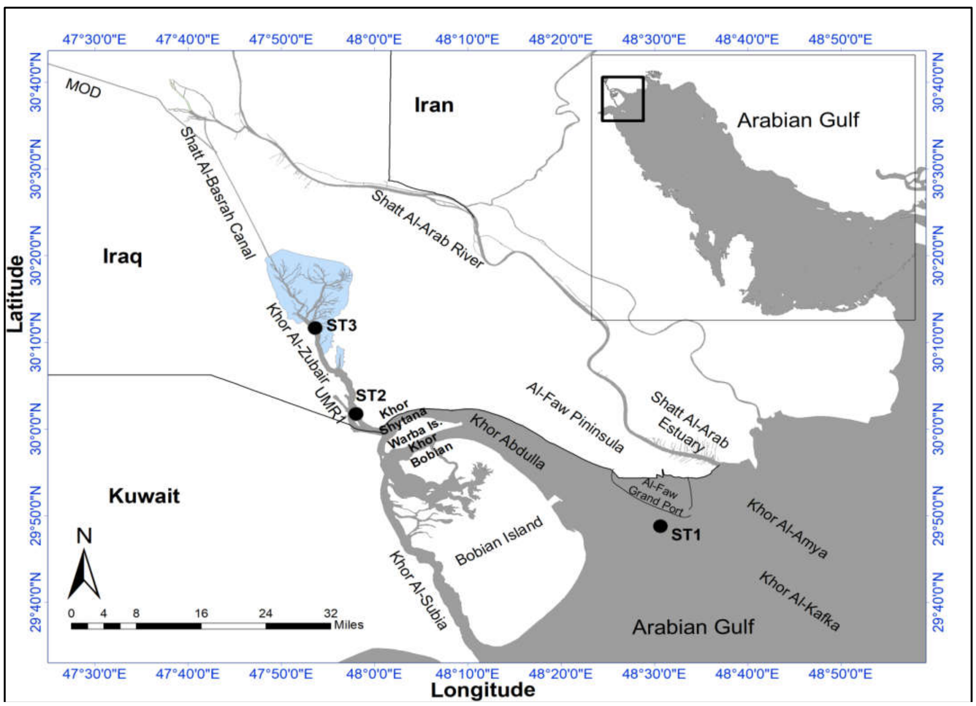

Figure 1. Location map showing the study stations.

Harmonic Model of Tide:

The transmission of tidal wave energy through certain frequencies is expressed by the sum of a series of simple harmonic terms (called tidal constituents). Each term represents a sine wave with a known frequency associated with the periodic movement of the celestial body of the earth-moon-sun system.

The main objective of the harmonic model is to determine the tidal constants, which are the amplitude and phase of each sine wave that contributes to the sea surface fluctuation at a certain location. The equation of the harmonic model is given as (Boon, 2013).

$$h(x,t) = h_\circ + \sum_{j=1}^{m} f_j\, H_j \cos(\mathrm{w_j t + u_j - k_j^*}) \qquad 2.1$$

where *t:* time in serial hours, *h(x,t)* : estimated water level , f_j: lunar node factor of jth constituent, H_j: amplitude of jth constituent, h_0 : mean water level in that location, u_j: nodal phase of jth constituent, κ_j*: phase of jth constituent, ω_j:: frequency of jth constituent and *m*: number of constituents.

For purely solar constituents, $f_j = 1$ and $u_j = 0$. There are many tidal frequencies, including, diurnal, semi-diurnal, and long periods, which have an astronomical origin, as well as frequencies that generated as a result of shallow water effects which known as overtides and compound tides (Kowalik and Luick, 2013).

The earth takes about 24 solar hours to rotate around its axis relative to the sun which is known as the solar day, and since there are two bulges on the earth surface due to gravitational force of the sun, so the energy of the tidal wave generated by this force will be transmitted through a semidiurnal frequency called the principal solar semidiurnal constituent S_2, and has a duration of 12 hours and a frequency of 2 cycles per day (CpD) and an angular speed of 30 degrees per hour (360°/12). Meanwhile, the moon rotates around the earth in the same direction as the earth's rotation, so when the earth is rotating within 24 hours, the moon has moved a short distance in its orbit around the earth, about 12 degrees, so at any point on the Earth surface, after 24 hours it takes an additional 50 minutes to return and faced the moon again.

Hence the lunar day is longer than the solar day and equal to 24.48 solar hours. And, since there are two bulges on earth surface because of the moon's gravity, the resulting tidal wave energy will transmit through a semidiurnal frequency, called the principal lunar semidiurnal constituent M_2, with a period of 12.42 solar hours and frequency 1.93 cycles per day with an angular speed of 28.98 degrees per hour.

However, the tidal generating forces inversely proportional to the cube of the distance between the earth and the moon or the earth and the sun, thus, although the moon is 27 x 106 times smaller in mass than the sun and the moon is only 389 times nearer to the earth than the sun, the moon is 2.16 times more effective in causing the tide than the sun, and hence M_2 is greater than S_2 in most location around the globe (Hicks, 2006). However, if both the orbit of the moon around the earth and the orbit of the earth around the sun are completely circular, and both in the earth equatorial plane, the tidal energy will be transmitted at only two frequencies, M_2 and S_2. But, according to Kepler's first law, both orbitals are elliptical, so the distance between the earth and the moon is varied monthly and the distance between the earth and the sun varies yearly.

Furthermore, the plane of the moon orbit is declined relative to the equator, the moon appears to an observer on Earth to move north of the equator and then south of the equator and back north of the equator over roughly a month. Similarly, the sun appears north of the equator half of the year (summer in the Northern Hemisphere) and south of the equator in the other half of the year (winter in the Northern Hemisphere). These changes in the orbitals of the moon and earth mean that the energy of tidal waves will be transmitted through additional frequencies rather than M_2 and S_2.

The monthly variation in distance between the earth and the moon is expressed by an additional two semidiurnal tidal constituents, the Larger Lunar Elliptic semidiurnal constituent N_2 (12.69 hours), when the moon at the nearest distance from the earth at lunar perigee, and Smaller Lunar Elliptic semidiurnal constituent L_2 (12.19 hours), when the moon at the farthest distance from the earth at lunar apogee. Similarly, the yearly modulation of S_2 due to the effects of the elliptical orbit of the Earth around the sun (the perihelion-aphelion effect) produces two additional semidiurnal tidal constituents around S_2, T_2 (12.06 hours) when the earth at the nearest distance from the sun at perihelion and R_2 (11.98 hours) when the earth at the farthest distance from the sun at aphelion.

However, the declination of the moon orbit plane relative to the equator leads to generate inequality in the elevation of the two high water formed by the tidal bulge at any latitude. The declination of the moon orbit plane puts energy into the diurnal tidal frequencies, which expressed by two diurnal constituents, the Luni – solar Declinational diurnal constituent K_1 (23.93 hours), and the Principal Lunar Declinational diurnal constituent, O_1(25.81 hours). Similarly, the declination of the earth orbit plane around the sun relative to the equator is expressed by two diurnal constituents, K_1 which represent the solar part of The Luni-solar Declinational diurnal constituent and P_1(24.0658 hours) (Parker, 2007).

Another effect on the tidal energy distribution is due to the long periods which is known as the lunar nodal regression, because the intersection location of the moon's orbital plane with the ecliptic varies during 18.6 years, and this has an important impact on the tidal range. So the water level data required for tidal analysis must be long enough, actually equal or more than 18.6 years, to capture this effect. Practically, it is difficult to get such long records of data, so the theoretical method was proposed to capture this effect by including multiplying factors of amplitude and phase for lunar constituents which are known as nodal factors as shown in equation (2.1) (Parker, 2007).

Shallow water effects are another important processes responsible for transmitted the tidal energy through various nonlinear processes, to new frequencies, creating overtides and compound tides (especially in the semidiurnal band). Shallow water, however, can deform the shape of the tidal wave, making it very asymmetric, and make its rise and fall (and its flood and ebb) no longer equal. The significant shallow water impact mechanism is caused by bottom friction, which can have asymmetric and symmetric effects (Parker, 2007).

The asymmetric effect produced since friction has a greater effect in shallow water than in deep water, and so it slows down the trough of the wave more than the crest, leading to the deformation of the tidal wave and the generation of the second harmonic, called M_4 constituent, which has half the period and double frequency of M_2 respectively. The symmetric effect results due to the energy loss by friction is proportional to the square of the current speed.

Consequently, there will be much more energy loss during times of maximum flood and ebb than near times of slack water. This is leading to the generation of another higher harmonic, M_6, which has one third the period of M_2. Higher harmonic tidal constituents such as M_4 and M_6 are called overtides, M_4 is the first overtide, and the second harmonic of M_2, M_6 is the second overtide and the third harmonic of M_2 (Parker, 2007).

Another shallow water effect is the generation of compound tides, which can be generated from the interaction of two or more constituents. compound tides and overtides can produce a tidal asymmetry which can affect the long term distribution of sediments and hence the stability of the waterways in their depth and shape (Aubrey and Speer, 1985).

Data Collection:

A continuous record of water levels at three locations (Fig. 1) is carried out, the first is located at the entrance of Khor Abdullah (ST1), these data for one year (1^{st} March/2018 to 1^{st} March/2019) as shown in Figure (2, A) are obtained from Daewoo Engineering and constructing company, that constructed the western breakwater of Grand Al-Faw port.

The water levels data in the second station that locate in Umm Qasr town (ST2) are collected by installing a Valeport TideMaster Portable Tide Gauge for one year (1^{st} March/2018 to 1st March/2019) as shown in Figure (2, B), While the water level data at Khor Al-Zubair port station (ST3) is acquired from Khor Al-Zubair Port. Authority for three months (March, April and May/2018) (Fig. 2, c). All these data are hourly records and referenced to the local chart datum (Lowest Low Water) in this region. It is worthy to mention that there are interruptions in recordings the water level for two months (December/2018 and January/2019) in Khor Abdullah station and twenty days through April/2018 in Khor Al-Zubair port station.

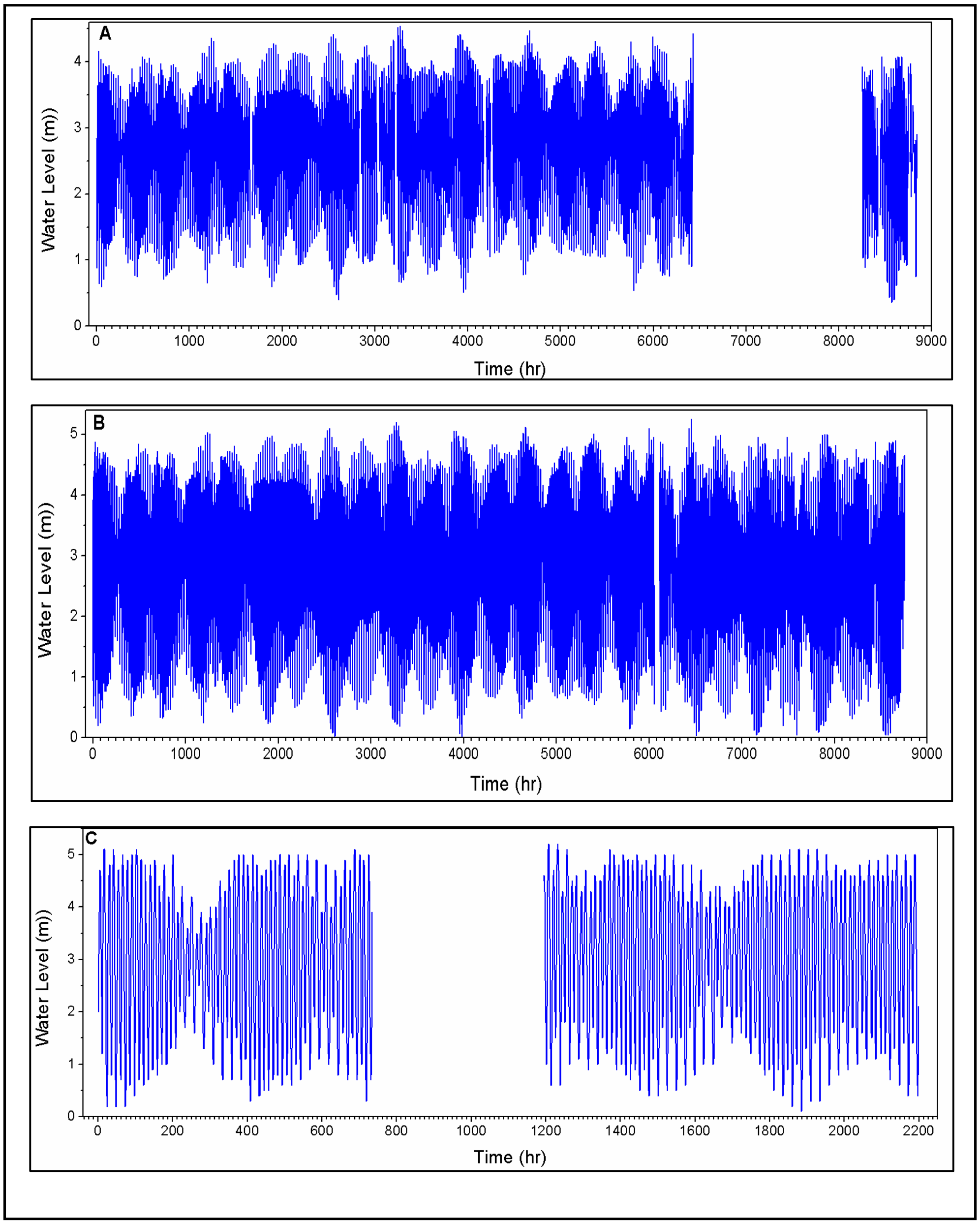

Figure 2. Water level fluctuations at (A: Khor Abdullah inlet, B: Umm Qasar, and C: Khor Al-Zubair Port)

Results and Discussion

The characteristics of the tidal wave are investigated by using the harmonic model for water level records in the study stations (Fig. 2) which performed by World Tide package, a Matlab application for the harmonic analysis and prediction of tides (Boon, 2013). The results of the harmonic analysis are shown in Table (1).

The harmonic analysis leading to estimate 28 tidal constituents that contribute to the water level fluctuations in the study area, while Abdullah (2002) estimated 34 constituents in the Shatt Al-Arab Estuary. The astronomical tides generated by estimating 28 tidal constituents have accounted for 96.74%, 96.09% and 96.6% of the total variations in Khor Abdullah, Umm Qasar and Khor Al-Zubair port stations respectively.

Table 1. Amplitude and phase of the main tidal constituents in the study area.

Seq.	Constituent Symbol	Frequency (CpD)	Khor Abdullah		Umm Qasar		Khor Al-Zubair Port	
			Amp. (m)	Phase (degree)	Amp. (m)	Phase (degree)	Amp. (m)	Phase (degree)
1	O1	0.9295	0.339	207.8	0.351	221.64	0.353	226.97
2	M1	0.9664	0.016	321.67	0.022	327.56	0.049	333.83
3	P1	0.9973	0.15	307.52	0.152	320.37	0.204	329.95
4	S1	1	0.029	245.58	0.038	273.29	0.138	289.37
5	K1	1.0027	0.526	295.84	0.561	307.79	0.584	317.14
6	MNS2	1.8283	0.006	186.68	0.033	205.04	0.06	214.06
7	2N2	1.8597	0.029	24.33	0.04	45.96	0.129	54.22
8	N2	1.896	0.184	154.59	0.247	189.59	0.258	209.33
9	M2	1.9323	0.947	270.91	1.409	297.83	1.591	309.18
10	L2	1.9686	0.042	292.63	0.093	298.76	0.075	303.92
11	T2	1.9973	0.023	25.9	0.021	69.23	-	-
12	S2	2	0.321	26.73	0.46	65.27	0.528	85.98
13	R2	2.0027	0.004	328.82	0.011	333.07	-	-
14	K2	2.0055	0.111	179.65	0.152	215.45	0.174	221.11
15	2SM2	2.0677	0.015	304.16	0.04	326.16	0.036	349.05
16	2MK3	2.8618	0.038	43.67	0.086	86.84	0.109	103.77
17	M3	2.8984	0.008	286.48	0.006	299.75	0.029	308.16
18	MK3	2.935	0.043	135.62	0.059	195.2	0.017	206.06
19	MN4	3.8283	0.013	329.38	0.038	343.36	0.062	351.21
20	M4	3.8645	0.037	87.63	0.087	94.99	0.124	106.9
21	MS4	3.9323	0.026	204.9	0.065	222.81	0.097	229.91
22	S4	4	0.001	252.39	0.014	284.59	0.031	291.07
23	2MN6	5.7605	0.003	1١0.37	0.013	120.22	0.017	194.98
24	M6	5.7968	0.005	109.93	0.02	238.19	0.03	314.29
25	2MS6	5.8645	0.005	215.89	0.021	305.2	0.036	324.5
26	S6	6	0.002	164.86	0.001	179.31	0.004	204.58
27	M8	7.7291	0.001	27.64	0.004	79.7	0.009	95.1
28	3MS8	7.7968	0.002	54.48	0.006	188.86	0.019	204.63
	Maximum Amplitude		2.926		4.052		4.763	

Consequently, the astronomical tides are responsible for about 96% of the total variations in the water level in this region of the Arabian Gulf, while the 4% residual water level are likely attributed to other factors such as non-tidal meteorological forcing, a similar result was observed in the Kuwait Bay (Alosairi *et al.*, 2018). The maximum tidal amplitude was 2.926, 4.052 and 4.763 m in Khor Abdullah, Umm Qasar and Khor Al-Zubair port stations, respectively. M_2 was the main contributor to the total variation of water levels, followed by K_1, S_2, O_1, and N_2, in addition to P1 which has an important contribution in total water level variation in the Arabian Gulf regions as depicted by Pous *et al.* (2012), when they determined the important tidal constituents in the Arabian Gulf. The phase differences for M_2, the largest constituents that contribute to water level variations, which governed the time of high and low water, between Khor Abdullah and Umm Qasar is 27 degrees and between Khor Abdullah and Khor Al-Zubair port is 39 degrees. However, since the speed of M_2 is equal to 28.98 degrees/hour, i.e. the high water will be arriving after about 55 minutes to Umm Qasar and after about 78 minutes to Khor Al-Zubair port relative to Khor Abdullah station.

The results revealed that there is a significant increase in the amplitudes of the principle semidiurnal constituents (M_2, S_2 and N_2) and a slight increase in the amplitudes of the principle diurnal constituents (K_1 and O_1). The amplitude of the constituents increases by about, 48%, 68% for M_2, and 43%, 64.4% for S_2, and 34%, 40% for N_2, and 6%, 11% for K_1, and 3.5%, 4.1% for O_1 in Umm Qasar and Khor Al-Zubair port stations compared to their amplitudes in Khor Abdullah station. However, the increase in the amplitude of the tidal constituents are attributed to the convergence nature of the study area (the gradual reduction in the cross-sections when we move towards the upper reaches of the study area), which leads to the energy of the tidal wave to concentrate at a small area and hence an increase in the tidal amplitude (Parker, 2007). Additionally, the results indicate that there is an increase in the contribution of the semidiurnal frequencies (MNS_2, $2N_2$, N_2, M_2, L_2, T_2, S_2, R_2, K_2 and $2SM_2$) in the total energy of the tidal wave when it propagates towards the inland direction with a notable decrease in the contribution of the diurnal frequencies (O_1, M_1, P_1, S_1 and K_1) as shown in Figure (3). Meanwhile, there is a notable increase in the participation of the quarter-diurnal (MN_4, M_4, MS_4 and S_4), six-diurnal ($2MN_6$, M_6, $2MS_6$ and S_6) and the eight-diurnal (M_8 and $3MS_8$) frequencies along the study area due to the increase of shallow water effects.

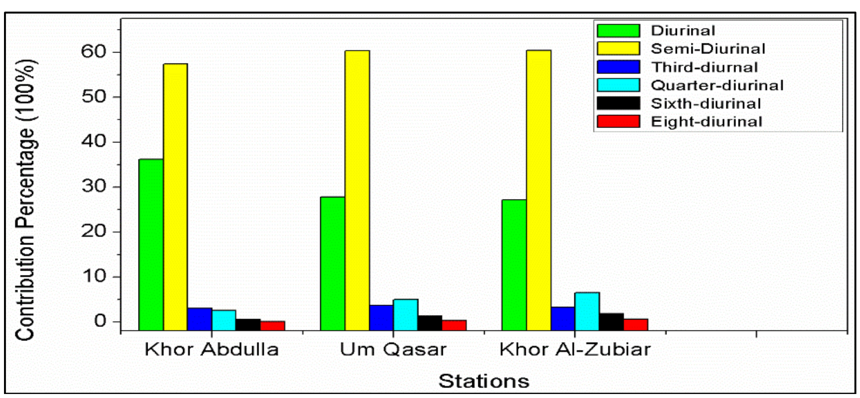

Figure 3. The contributions of tidal frequencies in tidal wave energy.

Table (2) shows the important tidal factors, it is obviously that there are clear variations in the mean tidal range between spring and neap phases at the study stations. The waterways with a mean tidal range exceed 4 m is classified as a macrotidal, and less than 2 m is classified as a microtidal, while those with mean tidal ranges between 2 and 4 m are classified as a mesotidal (Boon, 2013).

These classifications have an important role to determine the main forces that govern the physical processes. Generally, the tidal forces are responsible for the major processes at macrotidal as well as mesotidal waterways.

The mean tidal ranges were between 2.536 and 4.238 m at the spring tide, and between 1.252 and 2.126 m in the neap tide, hence there are pronounced changes in the classification of the study area between spring and neap phases, but it can be classified in general sense as mesotidal, which agree with the study of Al-Mahdi *et al.* (2009).

The form number in the study area was 0.68, 0.48 and 0.44 in Khor Abdullah, Umm Qasar and Khor Al-Zubair port stations, respectively compared to 0.85 in Shatt Al-Arab Estuary (Abdullah, 2002). However, according to the tidal type classification of Defant (1961), areas with form number in the range of 0.25 to 1.5, are classified as mixed tides, predominantly semidiurnal, i.e. tidal wave transmission will be through mixed frequencies, but the major contribution is due to the semidiurnal frequencies.

Table 2. Tidal Factors (H_x is a constituent amplitude (m)) (Parker, 2007).

Parameter	Formula	Value		
		Khor Abdullah	Um Qasar	Khor Al-Zubair Port
MSR (m)	$2(H_{M2}+H_{S2})$	2.536	3.738	4.238
MNR (m)	$2(H_{M2}-H_{S2})$	1.252	1.898	2.126
Form Number	$(H_{O1}+H_{K1})/(H_{M2}+H_{S2})$	0.68	0.48	0.44

Another significant property observed is a tidal asymmetry, i.e. there is inequality in ebb and flood duration. However, the asymmetry of the tide can be described as the distortion of the dominant principle lunar semidiurnal M_2 by the higher-frequency overtides M_4, based on the relation of relative phase $(2g_{M_2} - g_{M_4})$ (Wang *et al.*, 2002), where g_{M_2} and g_{M_4} are the phases of M_2 and M_4, respectively.

The relationship between the amplitudes of the M_4 to M_2 (M_4/M_2) is also used to indicate the magnitude of the tidal wave distortion, when this ratio increases, it indicates an increase in the tidal wave distortion (Guo *et al.*, 2019). The results indicate that there is an increase in the ratio (M_4/M_2) as shown in Figure (4), i.e. the wave experience more distortion when it propagates towards the upper reaches of the study area.

According to tidal asymmetry classification (Aubrey and Speer, 1985), waterways with $(2g_{M_2} - g_{M_4})$ between o° and 180° are classified as flood dominant, and between 180° and 360° are classified as ebb dominant. The flood dominant waterways are characterized by the duration of the ebb phase being longer than the flood duration, i.e. water rise quickly and fall slowly, and the flood currents are higher than the ebb currents.

Conversely, waterways with ebb duration shorter than flood duration and with stronger ebb currents than the flood currents are ebb dominant. However, the tidal asymmetry has an important effect on both geological evolution and navigation channels in shallow waterways.

The flood dominant waterways are characterized by the net sediments transport will be towards it's upper reaches, i.e. it is unable to flush sediments and experienced continuous deterioration in their shape and depths, compared to the ebb dominant which may maintain a more stable configuration due to their ability to flush sediments.

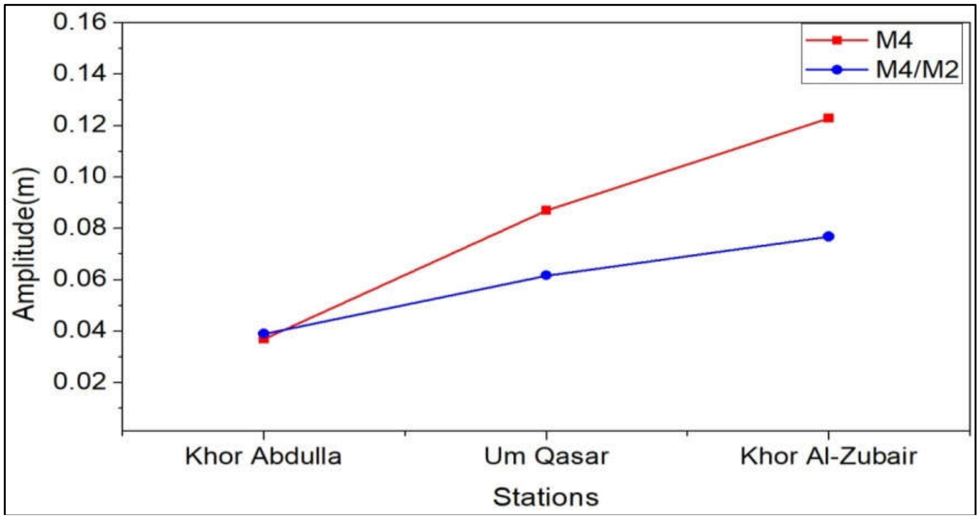

Figure 4. The amplitude of M_4 and the amplitude ratio (M_4/M_2) in the study area.

Table (3) shows the average durations of the flood and ebb phases. The relative phase values are 94.19, 140.67 and 151.46 degrees in Khor Abdullah, Umm Qasar and Khor Al-Zubair port stations, respectively. Consequently, the study area is classified as a flood dominant, since the ebb duration is longer than the flood duration and the flood currents are higher than the ebb currents (Al-Ramadhan, 1988; Al-Mahdi *et al.*, 2009; Al-Mahdi and Mahmood, 2010; Lafta *et al.*, 2015; Al-hasem, 2018; and Al-Taei *et al.*, 2018). Consequently, since the Iraqi marine waters represents an estuarine environment, characterized by large quantities of sediments whose main source is from the Tigris, Euphrates and the Karun Rivers, which reach the Iraqi marine waters through the Shatt Al-Arab Estuary, hence a large part of these sediments are moving towards Khor Abdullah and Khor Al-Zubair causing deterioration in their navigation channel depths as well as in the depths of the important Iraqi ports basins.

Table 3. Average flood and ebb durations in the study area.

Stations	Duration (hours)	
	Flood	Ebb
Khor Abdullah	6	7
Umm Qasar	5.6	7.4
Khor Al-Zubair Port	5.4	7.6

Conclusions

Based on the comprehensive field measurements of water level fluctuations, we observed that there is a gradual increase in the tidal wave amplitude when it propagates towards the inland direction due to the convergence nature of the study area. The results of the harmonic analysis led to estimate the 28 tidal constituents that contribute to water level variations, and the astronomical tide is responsible for about 96% of these variations. The type of tide was mixed a predominantly semidiurnal, i.e. tidal wave energy transmitted through mixed frequencies, with most of the contributor are due to a semidiurnal. And due to the shallow water effect, there is a deformation in the tidal wave form which indicated by the increase of the ratio M_4/M_2 along the study area. Consequently, and based on the tidal asymmetry, the study area is classified as a flood dominant which is characterized by longer period of ebb phase than the period of flood phase and stronger flood currents than ebb currents.

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