DOI: http://doi.org/10.32792/utq.jceps.10.01.01

Calculation of Tidal Constituents Using a Numerical Model in the Shatt al-Arab River Estuary

Adel Jassim Al-Fartusi, **Sadiq Salim Abdullah**

adel.mohammed@uobasrah.edu.iq **sadiq.abdullah@uobasrah.edu.iq**

Physics Department, Marine Science Center, Basrah University

Received 14/8/2023 **Accepted 29/8/2023,** **Published 21/9/2023**

Abstract:

To calculate the tidal constituents in the Shatt al-Arab River estuary and determine the nature of the dominant tides in the research area, a numerical model in one dimension using the Mike 11 software package was created. After calibration and model verification, it was discovered that there was a good match between the model's results and field measurements in terms of water discharge and sea level rise.

The model's findings revealed that the values for the key dominant constituents K1, O1, M2, and S2, are 0.3374, 0.2154, 0.4763, and 0.1434, respectively.

Knowing the tidal regime in the study area, which turns out to be of a mixed type, semi-diurnal dominant, is made possible by studying the analysis of the main constituents.

Keywords: Hydrodynamic, tide, Shatt al-Arab, estuary.

1. Introduction:

Studies on aspects of tides in canals and gulfs are numerous, but there are few studies on how tides and river flow interact. The harmonic analysis of the observed sea level rise can accurately represent, the tides produced by astronomical forces.

The tides and the flow of freshwater in the rivers determine how much the water surface changes at the mouths of rivers that are directly connected to gulfs. Higher discharge slows the tide, which raises the average water level along rivers, according to records of water levels (Suphat and Phairot, 2006). Through analysis of the tidal signal change resulting from sea level rise in the Coomera estuary in southeast Australia (Hamid, and Rodger, 2009). The results of the harmonic analysis showed that the Coomera Estuary responds to the influence of the tides a non-linearly and manifests through frictional forces. It has been proven through a study (W.R. Crawford, 1982) that it is possible to extract tidal constituents from sea level records on a biweekly and monthly basis. It also demonstrated that due to the noise imposed by meteorology, recording for a year is insufficient to find these components, through examined data from four ports in western Canada and described ways to lessen this noise. Utilized (Hamid et al., 2008) a numerical model of Mike 11 in one dimension, after that developed (Hamid and Rodger, 2014) the Mike 21 numerical model in two dimensions to measure the tidal constituents of the Coomera Estuary. (Lafta, 2019) used field measurements to examine the physical properties (tidal wave, tidal currents, and residence time) in Iraqi marine waters and how they might change in response to sea level rise. Where he found that the water level fluctuations are caused by 28 harmonic components. The results also indicated that the water level has risen in the study area. (Lafta, 2022) utilized water level records going back about a year to investigate the tidal dynamics and tidal asymmetry at the Shatt al-Arab River estuary. Two techniques, harmonic and tidal skewness, were used there. The measurements of the river's water level showed that tidal waves attenuated as they moved farther inland. To enable a more detailed analysis of the hydrodynamic behavior of the investigation area, a numerical model was set up using the program Mike 11(DHI, 2007). The study aims to provide an understanding of the dynamics and nature of tides constituents. Because the Shatt al-Arab River has recently experienced considerable stress, due to its location in a significant economic development area.

2. Data and Methods

2.1 Study Area:

The characteristics of the hydrodynamics of the river resulting from the flood and ebb are significant because of their influence on salinity intrusion, water quality, and sedimentation problems. The Shatt al-Arab depends on the hydrodynamics of the resource of fresh water supplied to it (Tigris, Euphrates, and Karun) in addition to the water coming from the Arabian Gulf. In other words, the rate of change of the water level in the Shatt al-Arab basin is affected by the discharge of the river first, and second by the daily change of water by the action of the tides in the Gulf. The change in the water level (the tidal range) in this process at the estuary is about (2 m) (Husain et al., 1991). The south side of the river is impacted strongly by tides from the sea. The Arabian Gulf is characterized by the dominance of the tidal force, as the kinetic energy of the tides, which work on the movement of water, is ten times greater than the kinetic energy of the winds, (Reynolds,1993). Figure (1) exhibits the extent of the study area. The length of the river is 204 km from the confluence of the Tigris and the Euphrates Rivers north of the city of Basrah to its mouth in the Arabian Gulf. The depth of the River varies, the deepest point is located near the island of Sindbad north of Basrah, reaching up to (29 m) as mentioned (Al-Mahdi and Al-Asadi, 2007).

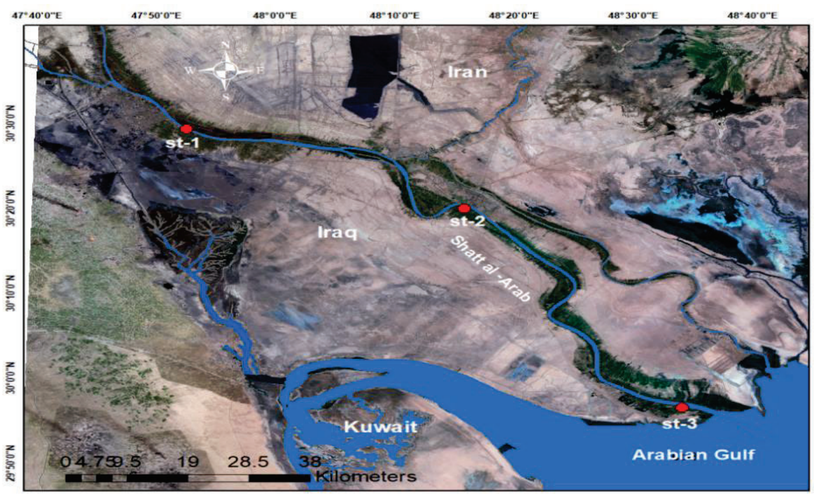


Figure (1): Study area and approximate positions of the measurement stations

2.2. Water Level Measurement:

A scientific team from the Department of Marine Physics gathered the data after conducting the measurements at the stations listed in Table (1).

Table 1: Measurement Stations

Station Number	Name	Distance from mouth
S1	Alashar	1٠٠
S2	Siba	30
S3	Faw	10

The water discharge was measured in each of the three stations (S1, S2, and S3), in addition to that, the water level (water pressure) was measured in station S3 only due to installing the tide gauge there. The measurement recording period was set to 15 minutes with an average interval of 10 seconds. The data recording period was (31 days). These gauges measure pressure, so after the data was downloaded from the gauge, it was necessary to adjust the water pressure readings for variations in atmospheric pressure. The outcome is a time series that represents the variations in the ratio of the water surface elevation relative to the mean sea level.

2.3. Current Measurement:

Utilizing Using a field device Acoustic Doppler Current Profiler (ADCP) type Rio Grande 600 HZ connecting with a boat moving at a constant speed to cross the two banks of the channel in a straight line back and forth, the device draws the shape of the cross-section of the river and provides us with information on the discharge through the measured section, the speed of the water currents, and the area of the water body. ADCP measurements were performed for a full tidal cycle (13 h) in three cross-sections at stations S1, S2, and S3 (Fig. 2a, b, c).

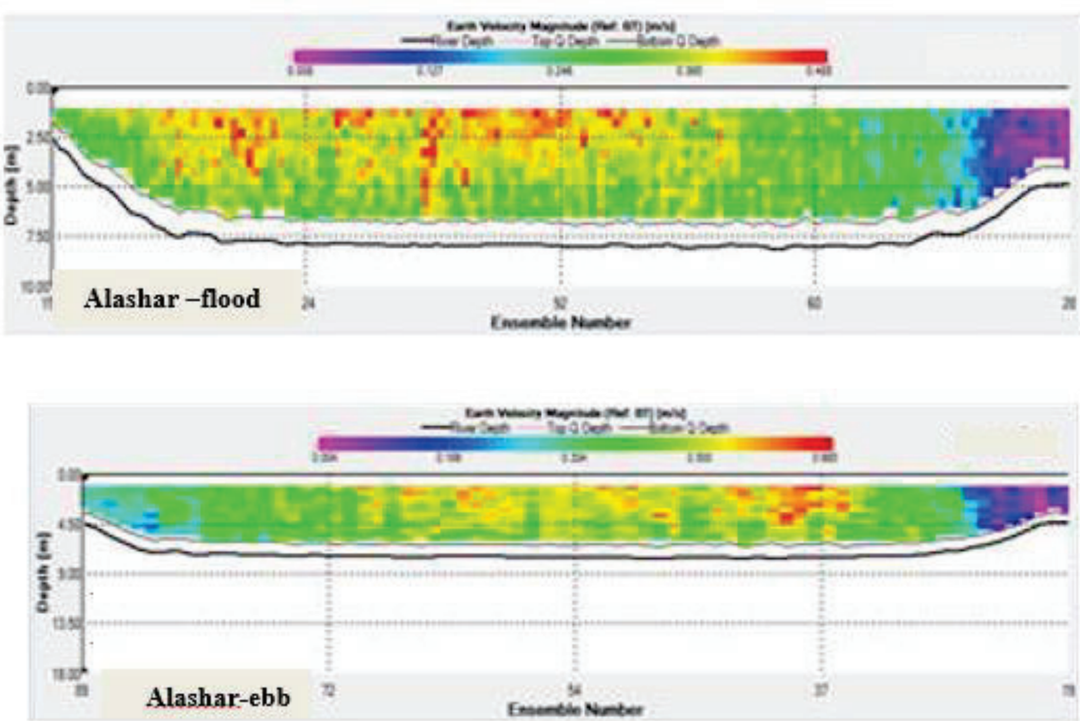


Figure (2a): Flow Velocity Distribution During Flood and ebb tide at measuring station S1

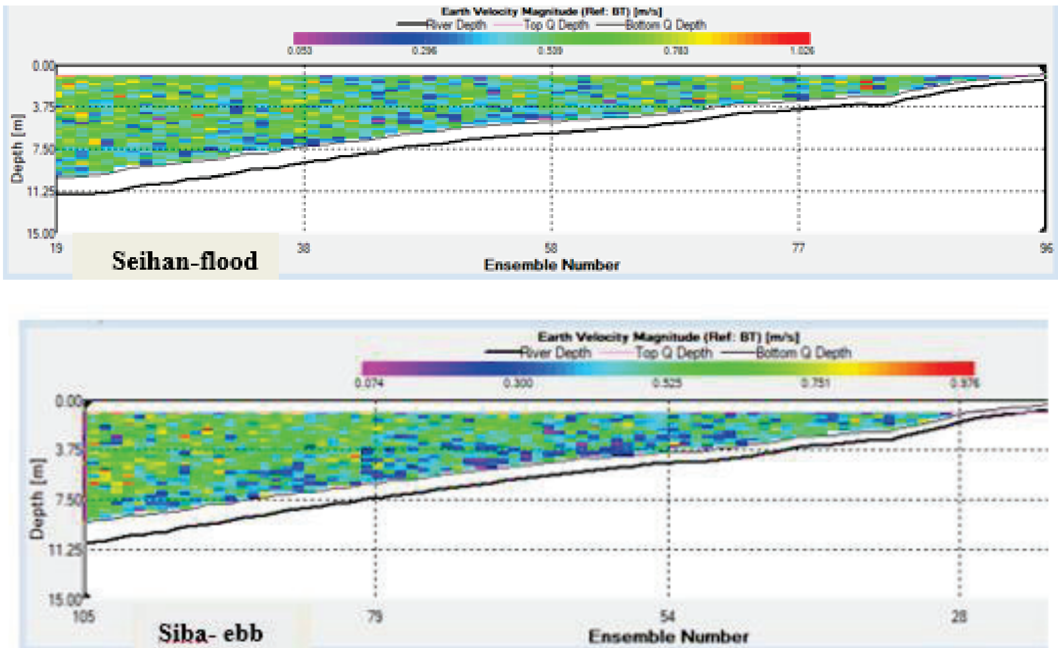
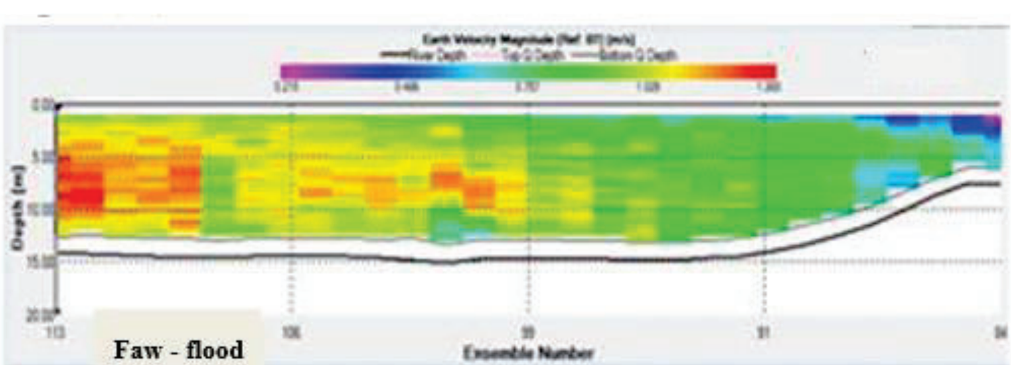
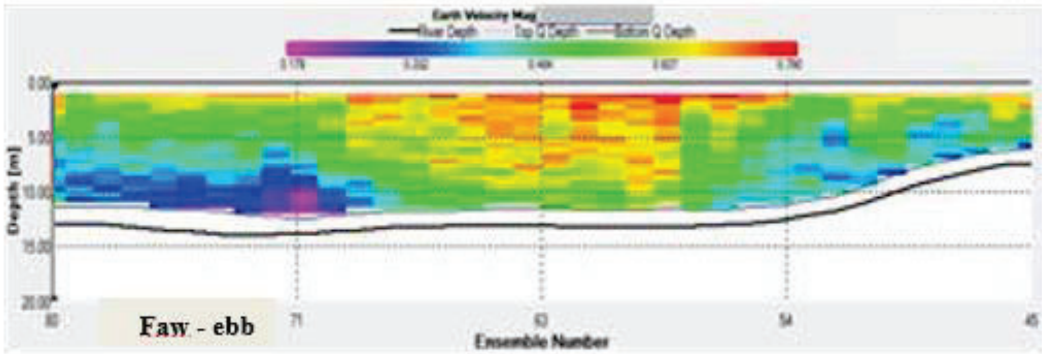


Figure (2b): Flow Velocity Distribution During Flood and ebb tide

at measuring station S2





Figures (2c): Flow Velocity Distribution During Flood and ebb tide at measuring station S3

At measuring stations S1, S2, and S3, the average horizontal velocity distribution during the ebb and flood tide was (0.41, 0.32), (0.58, 0.52), and (0.95, 0.49) m s^{-1}, respectively.

2.4. Numerical Modelling:

A numerical hydrodynamic model was created for the Shatt al-Arab River Estuary to simulate tidal flow (using the Mike11 package), Mike11 uses implicit finite difference techniques to solve the equations of mass and momentum conservation (Saint Venant equations). The solution of these equations is based on the presumption that the wavelengths are large to the water depth, which implies that flow is parallel to the bottom, vertical accelerations are disregarded, and pressure change along the vertical is hydrostatic. The model can be utilized for looped and branched networks and quasi-two-dimensional flow simulations on floodplains. Given that the estuary of Shatt al-Arab is a natural system, this modeling tool is believed to be appropriate for this paper. To achieve stability and obtain a fit between reality and mathematical results, climatic factors like wind (wind shear stress) are entered into the model. Expresses the shear stress of wind by relationship. (Hsu, 1988).

$\tau_w = t_{fac}\, c_w\, \rho_a\, v^2_{10}$

c_w = wind friction factor (24 x 10^{-4})

t_{fac} = factor dependent on the surrounding topography and its value is (1) for open water

V_{10} = velocity, perpendicular (10 meters) above the water (Basrah Weather Station,2018).

ρ_a = air density.

As the maximum recorded value of wind speed during the study period was (9 m s^{-1})

Also, by entering a variable value of Manning's Number (n) for various parts of the model, depending on the variance of roughness at different sections of the Shatt al-Arab River (Al- Taei et al,2019) shown in Table (2).

Table (2) Manning Coefficient value of the measurement stations

Station name	Manning Coefficient
Alashar	0.0130
Siba	0.0262
Faw	0.0460

2.5. Calibration of Model:

The model is validated, by comparing the outputs of the mathematical model and the empirically measured river discharge at three stations (S1 to S3), Figures (3, 4, 5) show a comparison between the model's predictions and the actual discharge. These findings demonstrated a good match between them.

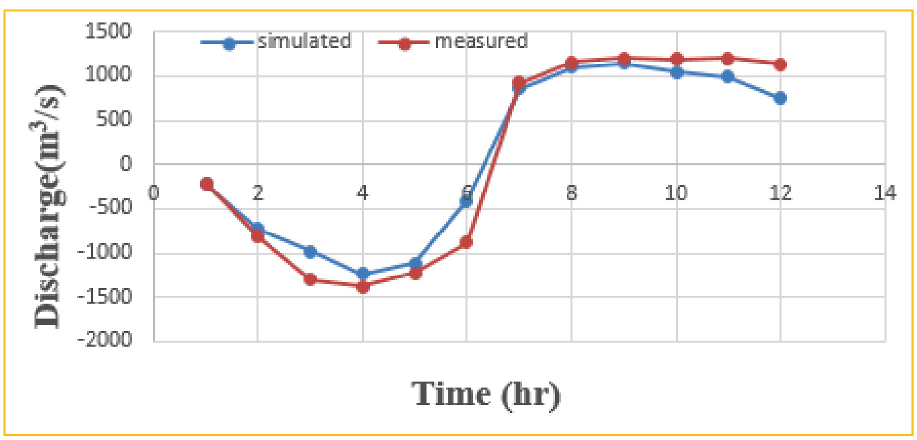


Figure (3): Comparison of Simulated and Measured Discharge in Station 1

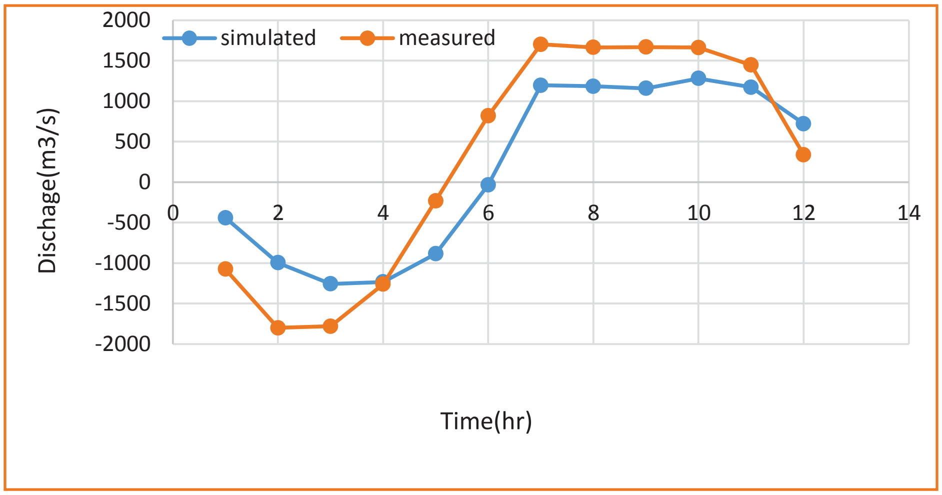


Figure (4): Comparison of Simulated and Measured Discharge in Station 2

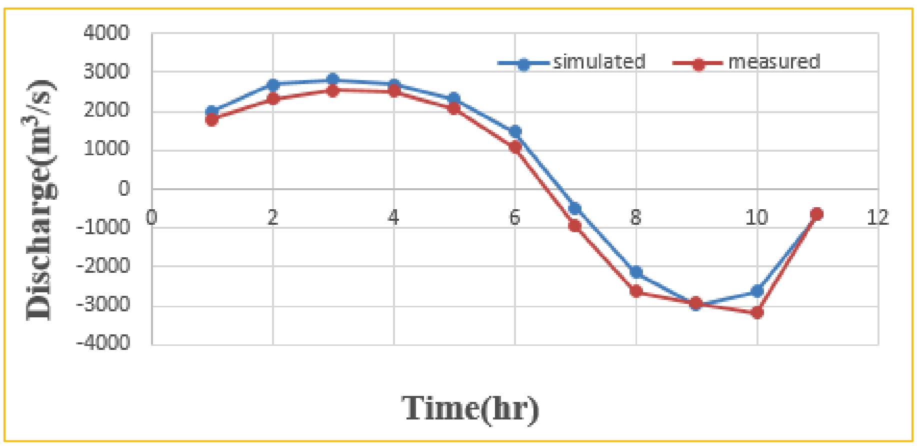


Figure (5): Comparison of Simulated and Measured Discharge in Station 3

2.6. Coefficient of Efficiency:

The efficiency factor for each measurement station was calculated using the below relation to estimate the accuracy of the model created using Mike 11.

$$\text{Coefficient of Efficiency} = 1 - \frac{\sum_{i=1}^{N}\left(o_{i-p_i}\right)^2}{\sum_{i=1}^{N}\left(o_{i-\tilde{O}}\right)^2}$$

whereas: O_i = measured values, p_i = model values, Õ = average measured values, N = number measurements.

Found that the efficiency factor is equal to (0.85) for discharge, and it is a good value, as the closer, the result is to the number (1), the closer the efficiency of the model will be to 100%.

3. Results and Discussion:

To appreciate the tidal properties of the study region. Harmonic analysis of water level was done using the Mike11 (DHI, 2007) software programs package developed by the Institute of Ocean Science (Danish). Figure (6) represents the time series of the tide and residual variations in station S3 through 31 days, covering periods of both spring tide and neap tide.

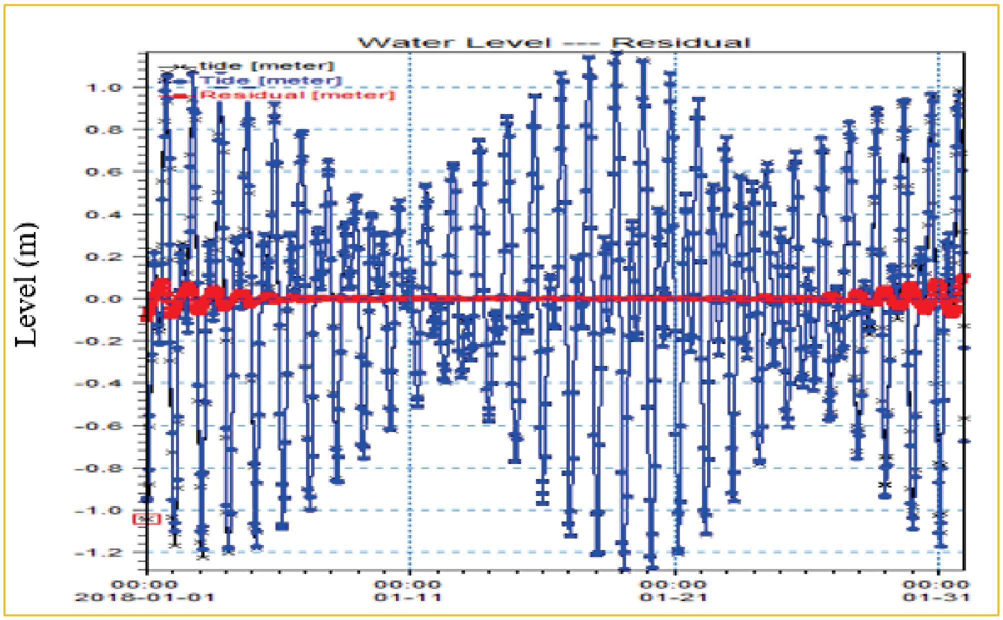


Figure (6): Tide and Residuals Variation at the Shatt al-Arab Estuary (station 3)

Along with the aforementioned, the model was calibrated using the tidal water level, which was measured at station S3 for a minimum of 31 days, and by the discharge at three stations for the tidal cycle (13 hours) inside the study region in January 2018. Figure (7) depicts a comparison between the model's prediction and the actual water level for a typical station at the lower Shatt al-Arab River.

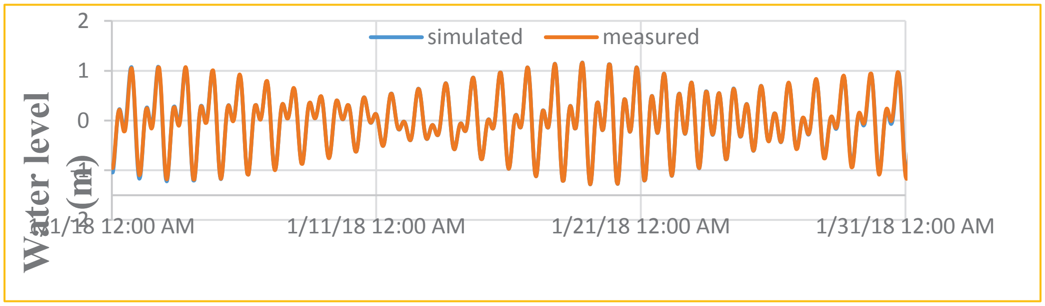


Figure (7): Comparison of Measured and Simulated Water level in Station 3

The prepared model determined the amplitude and phases of the tidal constituents, and the results were depicted in Figure (8), which demonstrates the amplitude for the 30 tidal constituents at Station S3, as long as K1, O1, M2, and S2 are the principal constituents of shallow water (M. Foreman,1979). So focus on it. Table (3) shows the Model results for the major four Tidal Constituents. The constituents K1 and O1 represent the dominant diurnal tides, with K1 having a larger amplitude than O1, while M2 and S2 are the dominant semi-diurnal constituents, with M2 having a greater amplitude than S2 (the second largest semi-diurnal constituents).

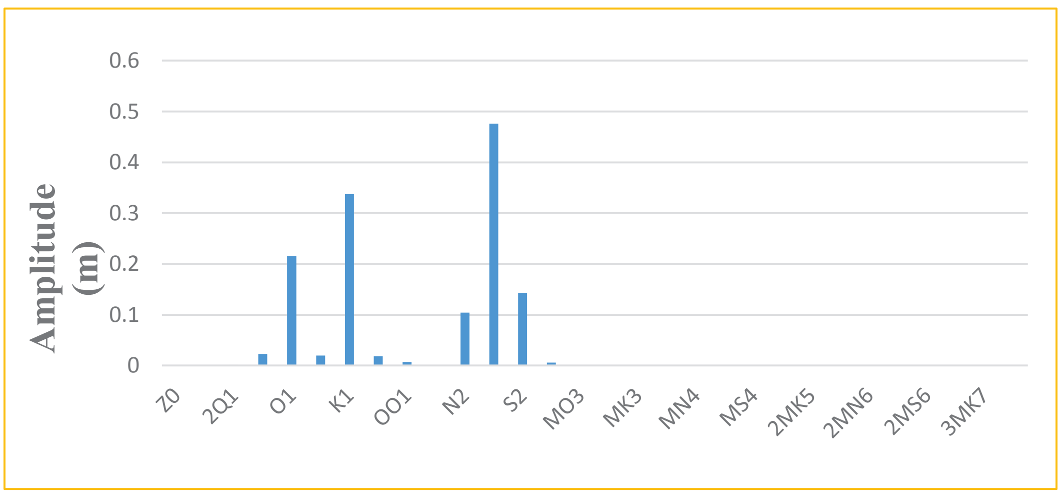


Figure (8): Tidal level constituents at Station S3

Table 3: Model results for Tidal Constituents

Tidal Constituents	Amplitude (meter)	Phase (degree)
K1	0.3374	254.8
O1	0.2154	201.7
M2	0.4763	194.3
S2	0.1434	243.14

To determine the type of tides in the study area, values for the four constituents were entered into the below equation (Pugh, 1987).

$$N = \frac{O1+K1}{M2+S2}$$

Since (N=0.892) is the equation's value for the Shatt al-Arab River estuary, the tide is mixed but semi-daily dominant, where value N is within the range (0.25 - 1.5), according to (Pugh, 1987).

4. Conclusions:

A one-dimensional tidal model was developed, calibrated, and verified using collected data. The model's findings revealed that the values for the key dominant constituents K1, O1, M2, and S2, are 0.3374, 0.2154, 0.4763, and 0.1434, respectively. Harmonic analysis of the data shows a mixed tidal regime and dominantly semi-diurnal within the Shatt al-Arab River estuary.

5. Acknowledgments:

The author would like to express his thanks to DANIDA (Danish International Development Agency) for providing Mike11 Software, and also to the scientific team of the Marine Science Center / Basra University for their fieldwork.

6. References:

Al-Taei, Samer Adnan, Al-Fartusi, Adel Jassim, and Abdulhussein, Ihsan Abdulkareem (2019). Determination of Hydrodynamic Resistance Coefficient (Manning's Coefficient) in Shatt al-Arab River, Southern of Iraq-Basrah. Journal of Engineering and Sustainable Development,23(3):78-88.

Basrah Weather Station. (2018). Iraqi Meteorological Organization. unpublished data.

DHI, (2007). MIKE11 Flow Model, hydrodynamic module, Danish Hydraulic Institute, Copenhagen, Denmark.

H. Mirfenderesk, and R. Tomlinson. (2009). An Investigation of the Change in the Tidal Signal in an Estuary as a Result of Sea Level Rise and Development at Short -Medium Time Scale. Journal of Coastal Research special issue 56:641-645.

H. Mirfenderesk; R. Tomlinson, and L. Hughes. (2008). Tidal Analysis of the Coomera River Estuary, Engineers Australia, 9th National Conference on Hydraulics in Water Engineering Darwin Convention Centre, Australia 23-26.

H. Mirfenderisk, and R. Tomlinson. (2014). Numerical Modelling of Tidal Dynamic and Water Circulation at the Gold Coast Broadwater, Australia, Journal of Coastal Research Special Issue 50: 277 - 281

Hsu, S.A. (1988). Coastal Meteorology. Academic Press. Inc., New York, NY. p 260.

Hussein, Najah Abboud ; Karim, Hussein Hamid ; Al-Saad, Hamid Talib ; Youssef, Osama , and Al-Sabunji, Azhar (1991). Shatt al-Arab basic scientific studies. Marine Science Center publications (10). Basrah university. p392.

Lafta, Ali Abdulridha. (2019). Numerical Modeling for Field Study of Physical Characteristics in Iraqi Marine Water. A thesis Submitted to the College of Education of pure science. Basrah University, in partial fulfillment of the requirement for the degree of Doctorate of Philosophy of Science in Physics, in Arabic (unpublished)

Lafta, Ali Abdulridha. (2022). Investigation of tidal asymmetry in the Shatt al-Arab river estuary, Northwest of Arabian Gulf. Oceanologia 64: 376-386.

Al-Mahdi, Iyad Abdel-Jalil and Al-Asadi, Safaa Abdel-Amir. (2007). Some geomorphological characteristics of the Shatt al-Arab stream. Basra Research Journal for Human Sciences, Part (B), 32 (1:88-106.

Pugh, D. T. (1987). Tides surge and mean sea-level, J. Wiley, New York.

R. M. Reynolds. (1993). "Physical oceanography of the Gulf, Strait of Hormuz, and the Gulf of Oman: Results from the Mt Mitchell expedition," Mar. Pollut. Bull., 27: 35–59.

Suphat Vongvisessomjai, and Phairot Chatanantavet. (2006). Analytical model of interaction of tide and river flow Songklanakarin J. Sci. Technol. 28 (6):1150-1161

W.R. Craw Ford. (1982). Analysis of Fortnightly and Monthly Tides. International Hydrographic Review, Monaco, LIX (1),131-142.