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RESEARCH PAPER

Proposed treatment to reduce salinity intrusion into the Shatt Al-Arab estuary by using temporary storage in a convergent of channel in the context of tide

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ABSTRACT

The Shatt Al-Arab estuary is the lifeline of the Basrah city, as it is the source of water for various uses of irrigation, industry, agriculture and human use, in addition to being the navigational passage towards the Arabian Gulf throughout history. Nowadays, the estuary suffers from the deterioration of its water quality due to the increase in salinity values as a result of the intrusion of salinity from the Arabian Gulf due to the lack of freshwater flows from the Tigris and Euphrates rivers. To reduce the risks of water quality deterioration and the lack of natural solutions represented in the provision of freshwater, the idea of building an artificial structure to narrow the channel came to give the ability to resist the impact of the tide and the intrusion of marine salinity. Two hypothetical sites were chosen to build the structure: i.e. in Dweeb and Faw sites, to test the feasibility of this artificial estuary structure. A one-dimensional mathematical model was adopted, which is the Mike 11 software package. The model was run according to a set of scenarios using the critical water discharge values of 10 and 20 m^3/s. The results showed through simulation of the model for a period of six months that the structure is useful on improving the water quality by reducing salinity in the river, in addition, there is a delay in the time of arrival of the intrusion of salts.

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KEYWORDS
Convergent of channel; Shatt Al-Arab estuary; temporary storage; salinity intrusion

1. Introduction

The tidal rivers and their estuaries are the vital lung for the cities and villages which are located on the banks of these waterways. Population communities are increasing in it to provide the necessities of life such as the availability of freshwater, ports, fishing, agriculture, as well as coastal tourist areas. The increase in the population causes an increase in pollution resulting from human activities and others that cause damage to the estuary environment, as well as the consumption of large quantities of freshwater. On the other side, the natural conditions were represented by the decrease of freshwater coming from its sources as a result of water retention in the upper rivers through the construction of dams due to the climatic conditions represented by the decline of rainfall, what, allowed the sea salt to penetrate (Peng et al., 2021). This is what characterizes the Shatt Al-Arab estuary because drilling and maintenance operations have stopped for many years.

All of these combined factors were caused damage to the environment of the estuary and allow the tidal phenomenon to play the main role in the hydrodynamics of the estuary and the river that produced the intrusion of marine salts to the upward of river.

Thus, to mitigate the shortage of freshwater in the Shatt Al-Arab estuary, the reduction of salinity intrusion can be used in water quality protection and water resources management.

A lot of models were applied to large amounts of hydraulic structures (i.e. inverted siphons, culverts, gates, diversions, tunnels, gates, culverts, dams, bridges and aqueduct) to improve the water quality. However, there are some analytical studies presented to prevent the intrusion of salinity, (Brockway et al., 2006) submitted an analytical solution to prevent salt intrusion into a well-mixed funnel-shaped estuary. Gay and Donnell (2009) concluded that the narrowing of the channel may contribute significantly to alleviating the salinity intrusion. MIKE 11 could be considered a suitable tool for describing the salinity intrusion for complex flow through hydraulic structures (Cheng et al., 2006; Förster et al., 2008; Tang et al., 2014 Thompson et al., 2004; and Yujun et al., 2017).

Despite the use of the various hydraulic structures mentioned above, there is not yet an artificial estuary model within the real estuary that can be used to treat salinity intrusion.

This paper focuses on a one-dimensional model (MIKE 11) for simulating the salinity intrusion during the artificial estuary structure in the Shatt Al-Arab estuary. This model included a hydrodynamic (HD) model and an advection–diffusion (AD) model. The flow was simulated by using this model. Simulation results referred that it was a suitable model for describing the behaviour of salinity intrusion.

This study tries to answer the question, i.e. if the temporary storage in a convergent of Shatt Al-Arab estuary by using an artificial estuary structure inside the real estuary came to give the ability to resist the impact of the tide and the intrusion of marine salinity towards the upstream. Thus, the conducted study tries to submit a suitable treatment for reducing the risks of salinity intrusion and for the lack of natural solutions represented in the provision of freshwater.

2. Study area

The Shatt Al-Arab forms from the confluence of the Tigris and Euphrates rivers at the city of Qurna, 76 km north of

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Figure 1. Study area and the selected sites (i.e. Basrah, Abo Flous; Sihan; Dweeb and Faw) at Shatt Al-Arab estuary (Lafta, 2022b).

Basrah city. It flows in the south-eastern direction for a distance of 204 km to its mouth in the north of the Arabian Gulf, south of the Faw city. The Shatt Al-Arab estuary is supplied by a third river, i.e. Karun river, which comes from Iranian territory to meet with the Shatt Al-Arab estuary about 45 km south of the Basrah city (Lafta, 2022b), see Figure 1.

The Shatt Al-Arab river is considered a tidal river (Abdullah, 1990), it is affected by the tidal phenomenon coming from the Arabian Gulf, and its impact reaches the border of Basrah and Maysan provinces in the north (Abdullah, 2014). The type of tides in the river and its estuary is a mixed type, semidiurnal dominant (Abdullah, 2002; Lafta, 2022a). The length of the river is 204 km and its average width is 400 m, while its depths range between 8 and 20 m. The three rivers, Tigris, Euphrates and Karun, contribute large quantities of fresh water up to the Shatt Al-Arab, with an amount exceeding 1000 m^3/s during the years of the last century. The freshwater reaches several kilometres in the waters of the Arabian Gulf and this results in the formation of the Shatt Al-Arab estuary. According to these large water discharges, the river water is characterized by high quality, which made it a suitable source for human; agricultural and

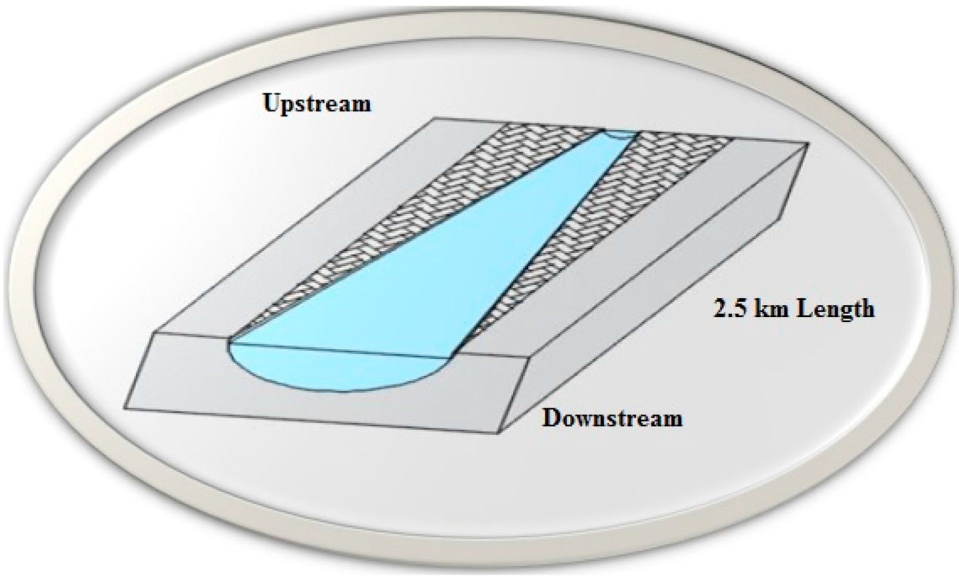


Figure 2. The proposed artificial concrete estuary structure.

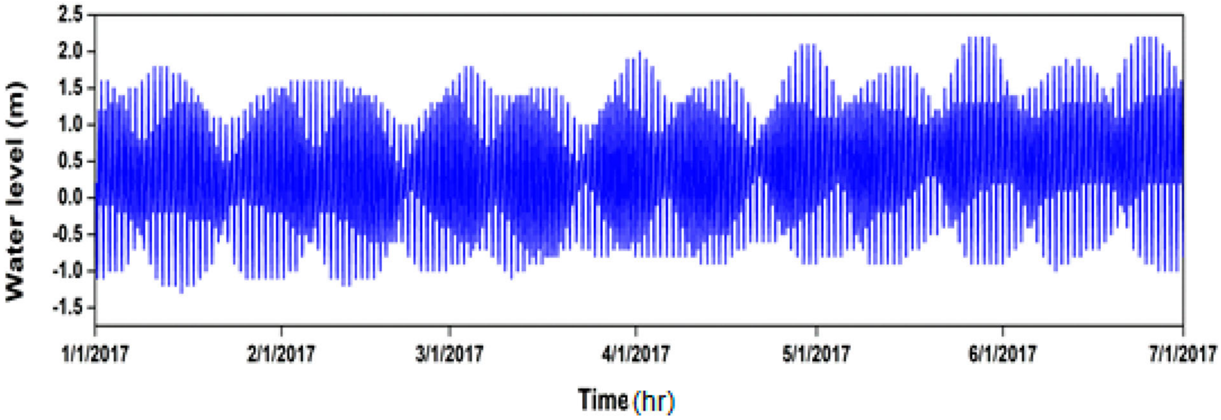


Figure 3. Water level (m) at Faw site.

industrial use. As the agriculture was flowering and the evidence for that is the forests of date palm and fruit trees that surrounded the two banks of the river from its formation point to its river mouth.

However, since of three decades ago, the gradual decline of freshwater was began in Shatt Al-Arab due to the construction of water reservoir dams in the upstream countries Turkey, Syria and Iran.

In addition to the bad water management in Iraq, that resulted in a decrease in the quantities of water to become 50 m^3/s, which is only from the Tigris river. Where the Euphrates river was completely closed. On the other hand, the Karun river opens when there is excess water in Iran. This led to the intrusion of marine salts beyond the northern city of Basrah several years ago, as a result of the overpowering of the tidal energy over the energy of freshwater discharge (Al-Taei et al., 2014), According to this case, the water quality of the Shatt Al-Arab estuary deteriorated and became unfit for human use, and this was reflected in the deterioration of agricultural activity in the areas surrounding the river, especially the southern ones.

To recover the river from its unhealthy state, and according to the field observations, it requires up to 200 m^3/s of freshwater so that the local community can rely on it for its various uses. However, this matter is difficult to provide this amount of water from the Iraqi side.

At the present time, attention is focused on thinking of making a regulatory dam to be built on the river to prevent

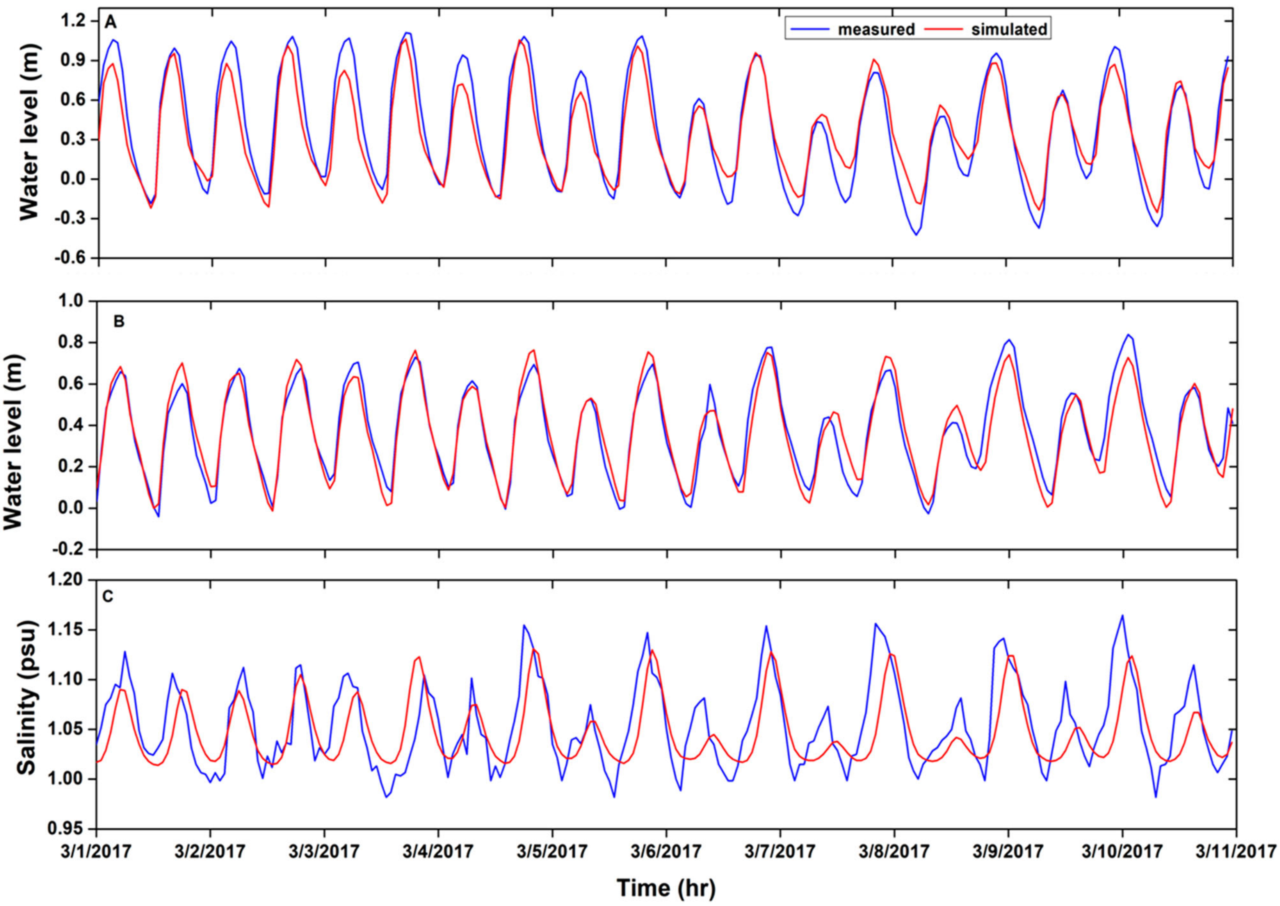


Figure 4. Comparisons between measured and simulated data of water level (m) and salinity (PSU) at (A& C: Sihan, B:Abo Flous) sites.

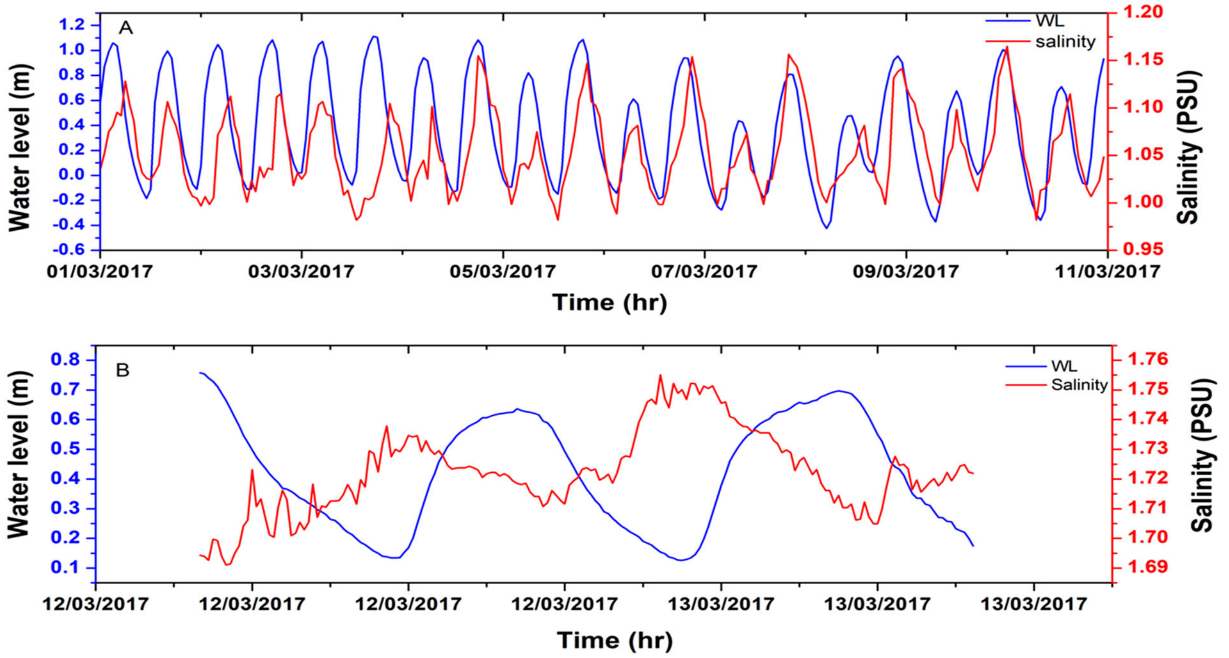


Figure 5. Relation of measured water level (m) and salinity of Shatt Al-Arab estuary at Sihan (A) and Abo Flous (B) sites.

the intrusion of marine salts up the river. The current study presents an artificial concrete estuary structure inside the real estuary to reduce the impact of tidal energy and conserve freshwater up the artificial structure with acceptable quality for some uses.

2.1. Artificial concrete estuary structure installation

The idea of the artificial model is a concrete structure built as a second estuary inside the river bed. It consists of two parts, each part is adjacent to the bank, and the two parts are separated by the natural river course. The length of the installation is estimated at 2.5 km, and the cross-sections of the structure start from the upstream at 50 m, and the width of the section of the structure increases by 100 m with every 500 me towards the downstream of the structure. Thus, the last width of the section becomes the same as the width of the natural section of the river. The depth of the water column in the structure is the same as the depth of the natural river at the top and bottom of the structure, see Figure 2.

This structure was used to replace the cross-sections of the river in two sites: Dweeb and Faw, Figure 1, which were the most nominated sites by researchers who

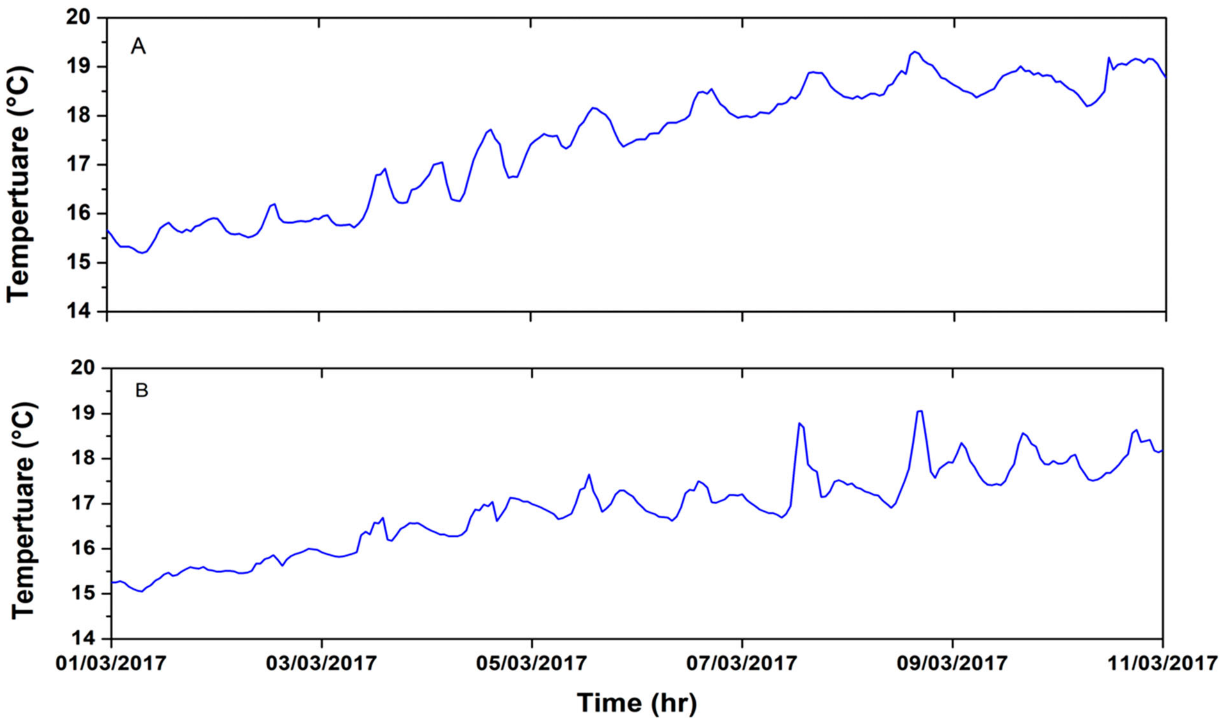
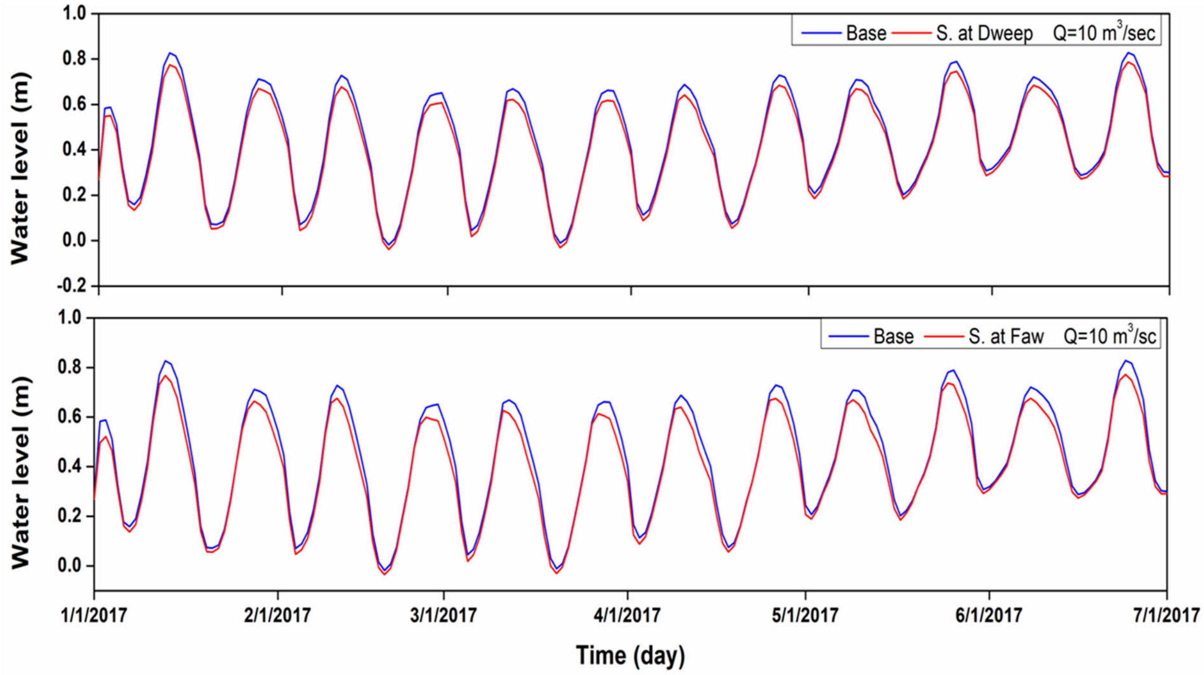
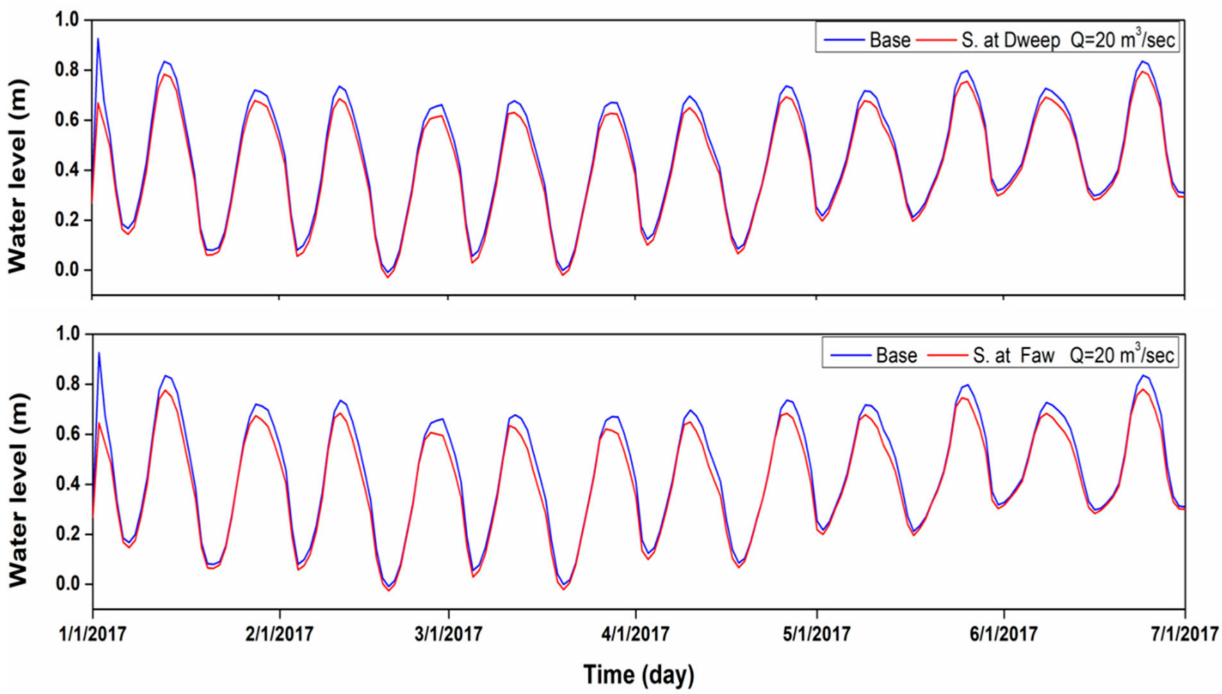


Figure 6. Fluctuation of sea surface temperature of Shatt Al-Arab estuary at Sihan (A) and Abo Flous (B) sites. (a) HD results at Basrah, structure at Dweeb and Faw sites. (b) HD results at Sihan, structure at Dweeb and Faw sites.



(a)



(b)

Figure 7. (a) HD results at Basrah, artificial estuary at Dweeb and Faw sites ($Q = 10$ m^3/s). (b) HD results at Basrah, artificial estuary at Dweeb and Faw sites ($Q = 20$ m^3/s). (c) HD results at Sihan, artificial estuary at Dweeb and Faw sites ($Q = 10$ m^3/s). (d) HD results at Sihan, artificial estuary at Dweeb and Faw sites ($Q = 20$ m^3/s).

recommended to be the place of the regulatory dam. Where, it is one of the artificial solutions to protect the river water from the influence of salinity intrusion.

3. Materials and methods

3.1. Mathematical model

A one-dimensional mathematical model was used, which is prepared by the Danish Hydraulic Institute (DHI), i.e. Mike 11, which is a software package for simulating flow; water level; water quality and sediment transport in the inland water bodies (Andersen et al., 2006). This model is based on nonlinear time-dependent Saint-Venant differential equations, which can be defined by continuity, momentum and AD equations as shown below (DHI, 2007):

HD model:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\alpha \frac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial h}{\partial x} + g\frac{n^2 Q|Q|}{AR^{\frac{4}{3}}} = 0 \tag{2}$$

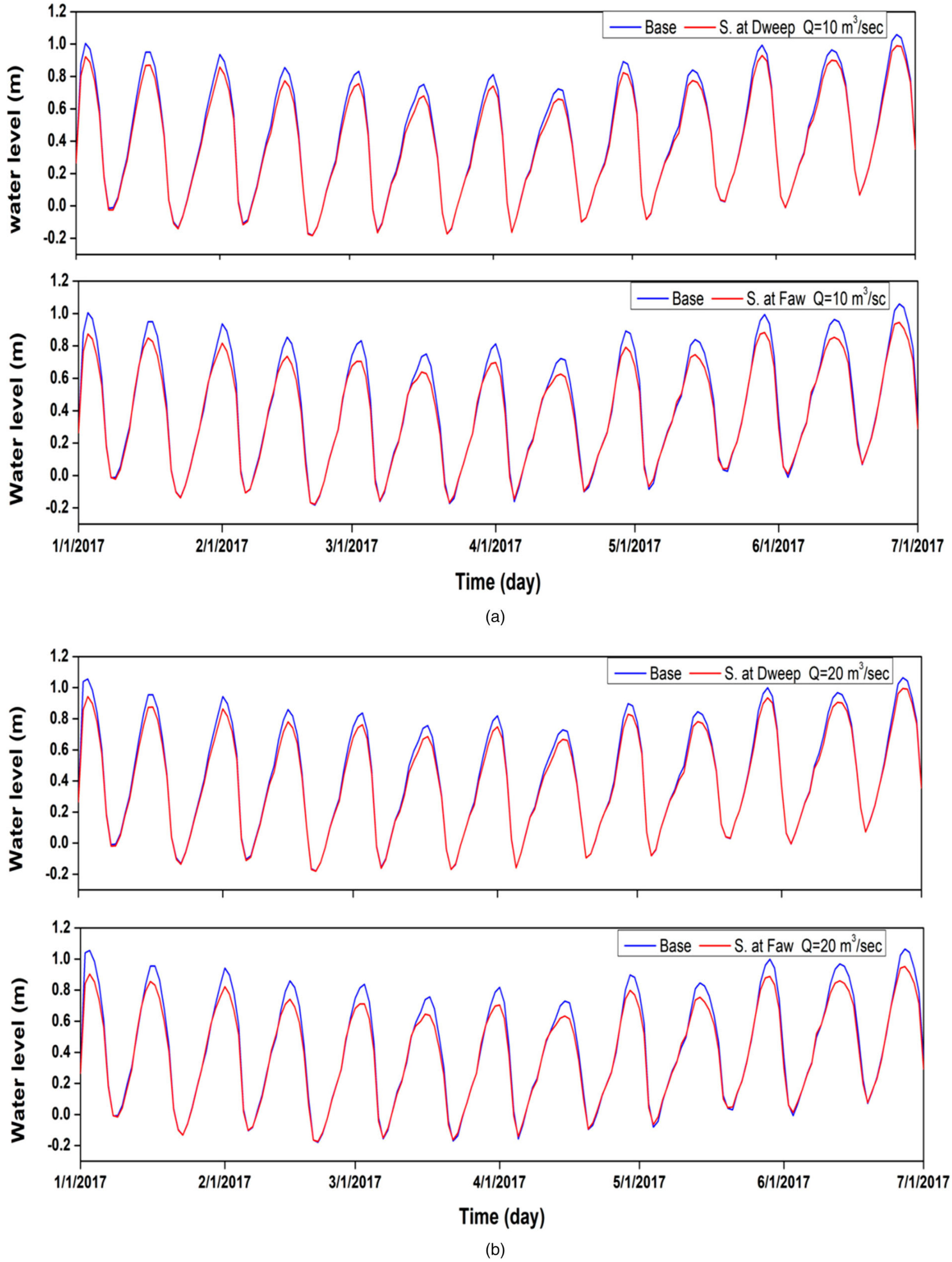


Figure 7 *Continued*

AD model:

$$\frac{\partial AC}{\partial t} + \frac{\partial QC}{\partial x} - \frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right) = -A\lambda c + c_2 \tag{3}$$

where Q is the discharge, A is the cross-sectional area, h is the water surface elevation above an arbitrary horizontal datum, n is Manning's coefficient of roughness, R is the hydraulic radius, g is the gravity acceleration, α is the kinetic energy coefficient, x is the distance along the watercourse and t is the time, C is the concentration, D is the dispersion coefficient, λ is the linear decay coefficient and C_2 is the source/sink concentration.

3.2. Data collection

The water level; bathymetry and salinity measurements have been used in the conducted research. The measurements of

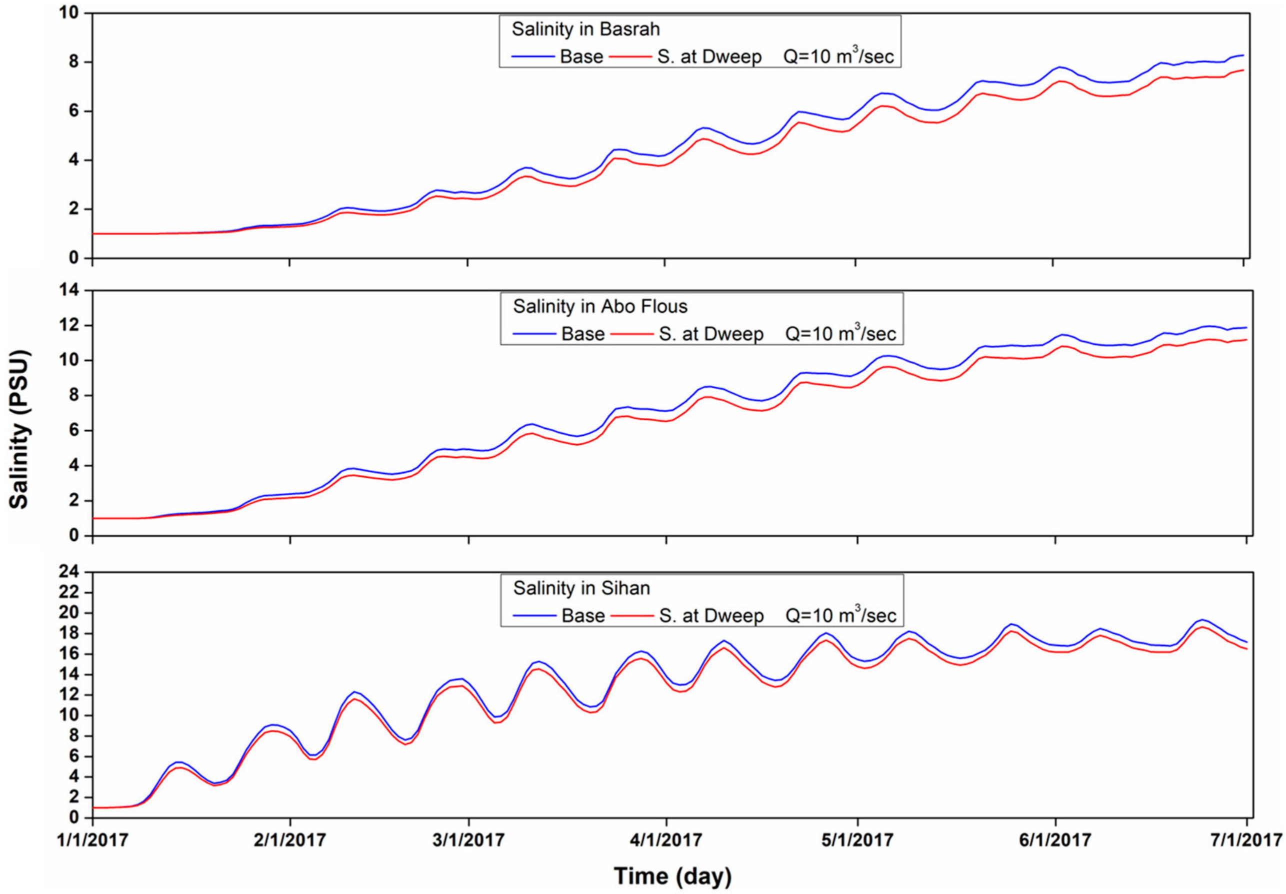


Figure 8. AD results at Basrah, Abo Flous and Sihan sites, artificial estuary at Dweeb site ($Q = 10\ m^3/s$).

water level and salinity were achieved by using a pressure water level diver and conductivity diver type Hopo in March 2017 at two sites: Abo Flous and Sihan, see Figure 1. Hence, the salinity could be estimated by multiplying the conductivity by 0.64. The local datum for water-level measurements was called: Faw 1979, which is a mean sea level at Faw. The measurements of the bathymetric and topographic survey along the Shatt Al-Arab and Tigris rivers were collected by the Marine Science Center–University of Basrah in 1998 and 2005 and used in the following research. Moreover, the measurements of the geometry of the Shatt Al-Arab river were carried out by the General Directorate of Water Resources-Basrah Province during 2012.

3.3. MIKE 11 model set up

The model of Shatt Al-Arab river consists of two parts, the main path of the Shatt Al-Arab river as well as its tributaries. The model boundaries (green points) are illustrated in Figure 1. At the Shatt Al-Arab river, the upstream boundary of the model was located in the Tigris river at its entry point in Basrah province. The choice of this location is due to the tidal effect that is completely vanished and water flows in downstream direction only. The discharge of Tigris river was used. The Euphrates (along 35 km), Karun (along 50 km) and Karmat Ali (along 18 km) rivers were added as branches in the preparation of the network file and the bathymetry file of the Shatt Al-Arab model. The upstream boundaries for Euphrates and Karmat Ali rivers were submitted as closed boundary conditions. In addition, the upstream boundary of Karun river proposed to be at Darkhovin. However, at Darkhovin the tidal effect could be damped and could represent the limit according to Adib and Jahanbakhshan (2013) and Adib and Javdan (2015). Hence, the discharge of the Karun river was used as an upstream boundary condition, in which this discharge affects the salinity intrusion in the Shatt Al-Arab estuary (Lafta 2022b). The downstream boundary of the Shatt Al-Arab model was located at Faw. Where, there is no data of water level data at the mouth which is about 10 away from Faw, the water level data were obtained from the Total Tide software (UKHO, 2003), see Figure 3. Along the main path of the model and its tributaries, the spatial discretization was 250 m. The initial conditions were equal to zero at the first time step of the simulation, for each of the water level and water speed. The span of model running was six months, i.e. from 1 January to 30 June 2017. According to the Courant–Friedrichs condition, the model stability was with a time step of 120 s. On the other side, the initial conditions of salinity at the downstream boundary was selected to be 35 PSU, however, about 1 PSU at the Shatt Al-Arab and Karun rivers upstream boundaries.

For the best accuracy of the model's work, the model was calibrated and this is clear from the comparison between the model results and field measurements of water level and salinity at two sites, i.e. Sihan and Abo Flous. The root mean squares error ($\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(M_i - C_i)^2}{N}}$) was applied to ensure the best performance of the model. Where M_i and C_i are a sum of measured and simulated values. N is a number of values. Several sensitivity analyses were conducted to reach the best match between measured and simulated

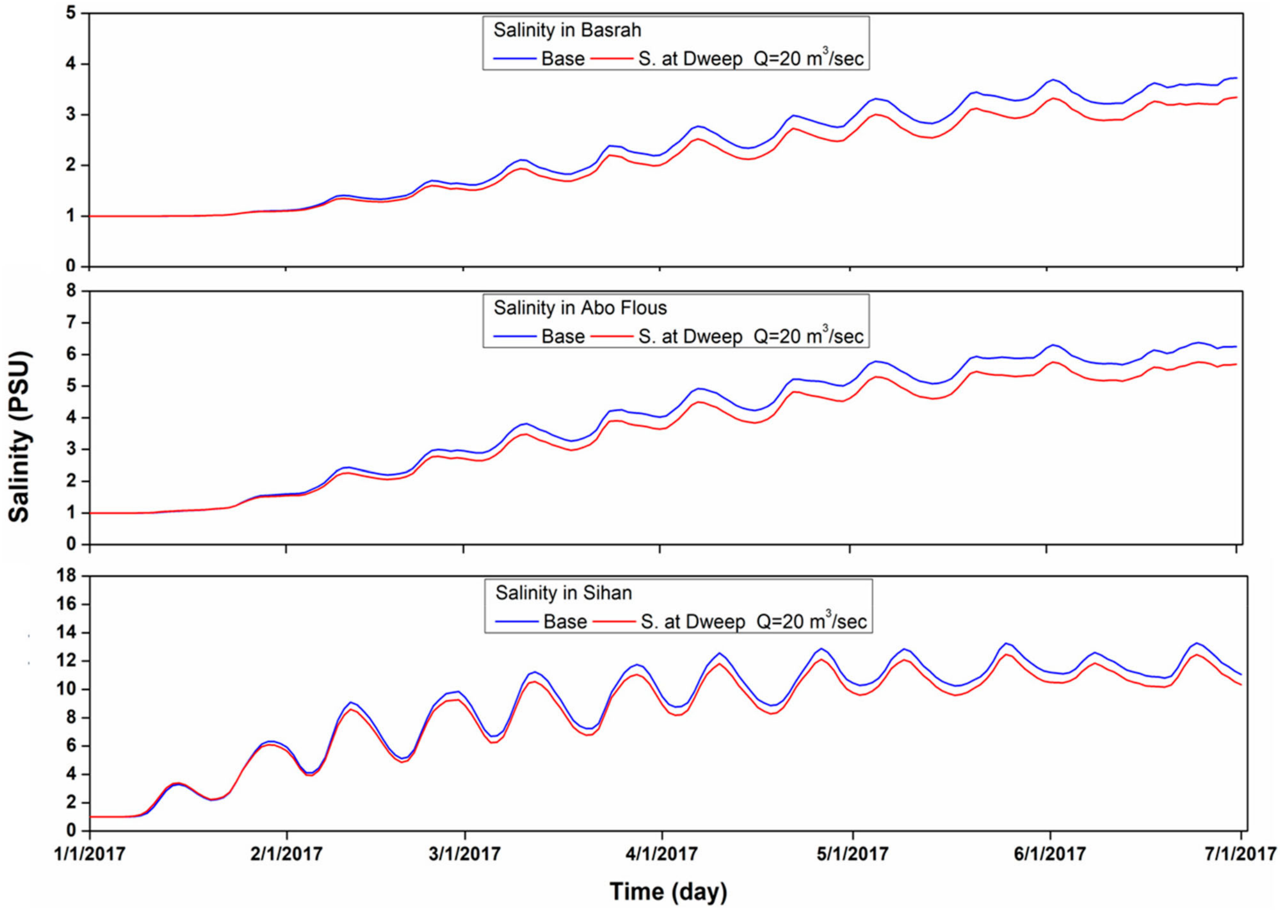


Figure 9. AD results at Basrah, Abo Flous and Sihan sites, artificial estuary at Dweeb site (Q = 20 m^3/sec).

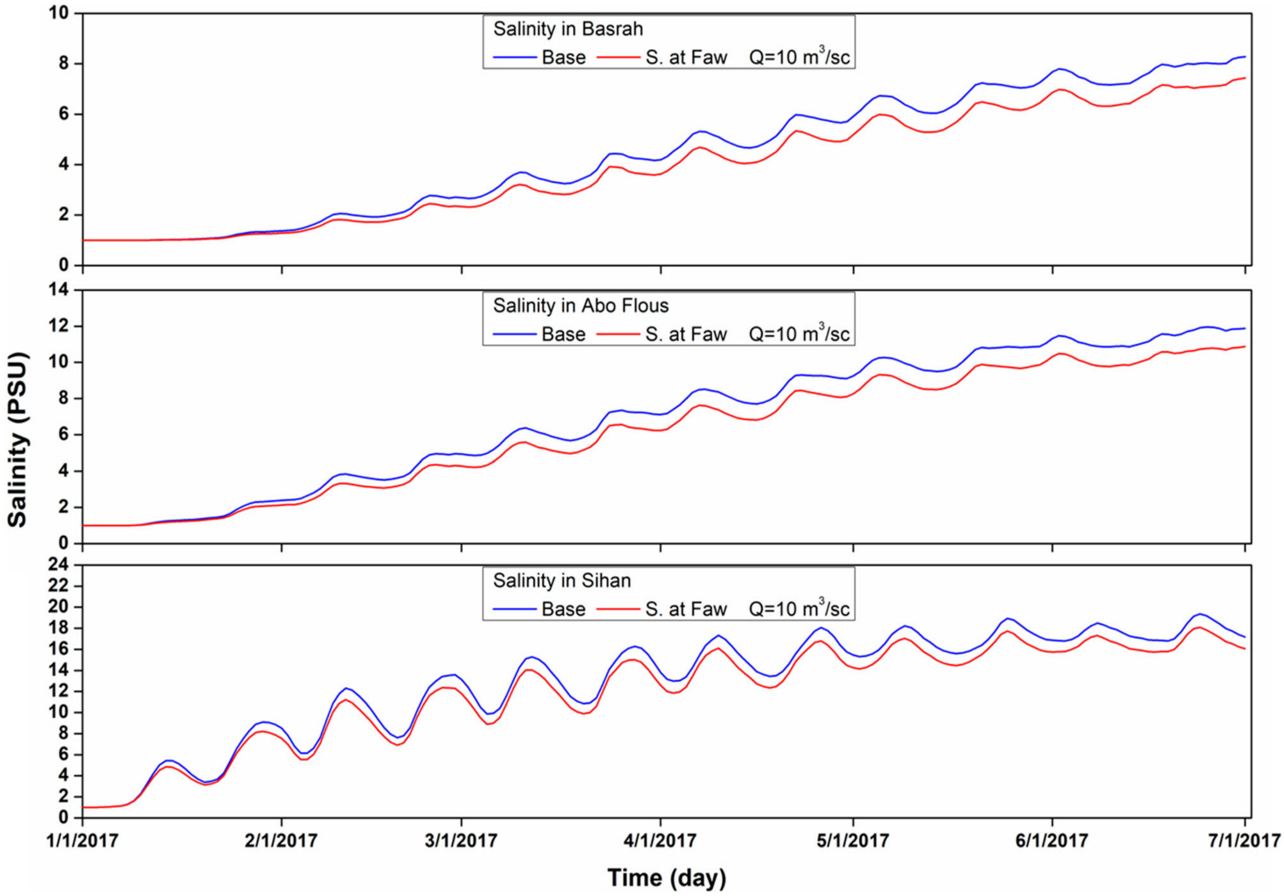


Figure 10. AD results at Basrah, Abo Flous and Sihan sites, artificial estuary at Faw site (Q = 10 m^3/s).

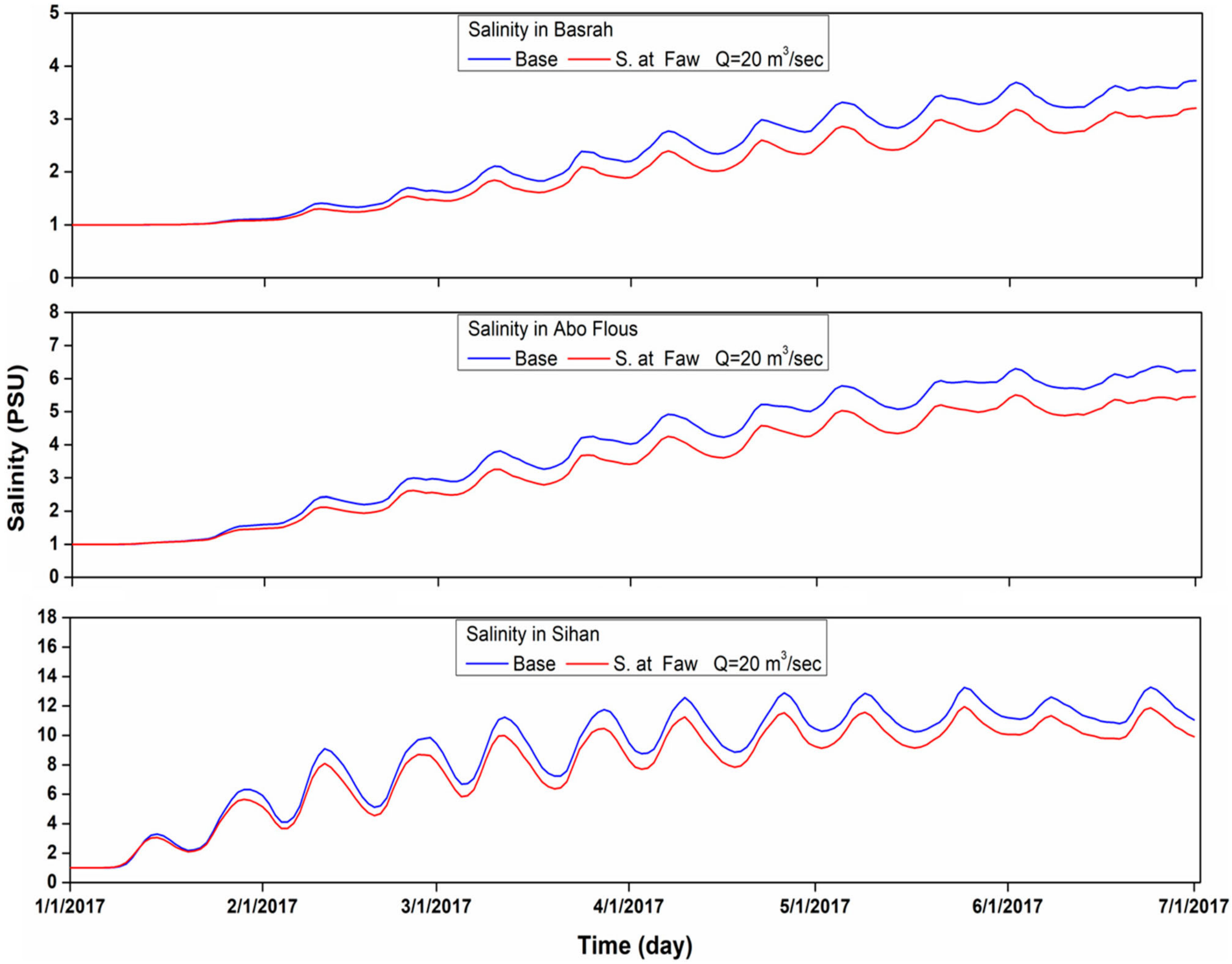


Figure 11. AD results at Basrah, Abo Flous and Sihan sites, artificial estuary at Faw site ($Q = 20$ m^3/s).

water-level series. A bottom roughness (manning number) of the value 0.17 m$^{1/2}$/s was chosen for the best performance of the model. The discharges of the Tigris river of 50 m^3/s and Karun of 5 m^3/s were used for upstream. Figure 4 shows the comparisons between the measured and simulated data of water level at the Sihan and Abo Flous, as RMSE of 0.13 and 0.06 m respectively. The qualitative matching was achieved between measured and simulated data of salinity at the Sihan site, in which it could be attributed to the low fluctuation range of salinity about 1.15 PSU or less. However, the fluctuations of salinity at Abo Flous were very low and the model was not capable to capture such low variations.

Following the relation of measured water level and salinity of Shatt Al-Arab estuary and fluctuation of sea surface temperature are shown in Figures 5 and 6.

The effects of the Karun river in Abo Flous site is more clear in both tidal cycles, while the influence of the sea is more pronounced in the Sihan site, as evidenced by the 90-degree phase difference between salinity and water level, see Figure 5.

On the other hand, the fluctuation of sea surface temperature at Sihan and Abo Flous sites subject to air temperature, see Figure 6.

4. Results and discussion

The HD model was run for a period of six months from 1/1/2017 until 1/7/2017 due to four cases: when freshwater discharges were about 10 and 20 m^3/s, with ignoring the impact of the artificial estuary. Next, the programme was run when a freshwater discharge was about 10 and 20 m^3/s with the presence of the artificial estuary in the Dweeb site once and in the Faw site again.

Figure 7(a–d) shows the values of water levels in Basrah and Sihan sites. Where, each figure contains two curves, one of which is for the natural state of the river (Base) and the other represents the water level in the presence of artificial estuary.

According to the results of salinity, which were obtained from running the AD model for six months from 1/1/2017–1/7/2017, the comparison of salinity values between the normal condition and the case of the artificial estuary was presented in three sites: Basrah, Abo Flous and Sihan. Figures 8–11 show these comparisons.

As shown, the temporary storage in a convergent of Shatt Al-Arab estuary by using an artificial estuary structure gives the ability to resist the impact of the tide and the intrusion of marine salinity towards the upstream.

The results of water levels at the Basrah site, Figure 7(a and b), showed differences in the values of water levels between the natural state of the river and the state of the artificial structure. That is, according to the value of freshwater discharge in addition to the location of the structure site. These differences are evident in the spring tidal phases, while they approximately disappear in the neap tidal phases. Moreover, for all scenarios, the difference between the two

Table 1. Water level values at study sites in terms of HD models.

Site Name	Structure position	Freshwater Discharge (m^3/s)	Date	Water level value at base (m)	Water level value at structure (m)	Difference value (m)
Basrah	Dweeb	10	13/01/2017	0.827	0.775	0.052
			26/05/2017	0.789	0.746	0.043
Basrah	Dweeb	20	13/01/2017	0.835	0.784	0.051
			26/05/2017	0.798	0.755	0.043
Basrah	Faw	10	13/01/2017	0.827	0.768	0.059
			26/05/2017	0.789	0.73	0.059
Basrah	Faw	20	13/01/2017	0.835	0.777	0.058
			26/05/2017	0.798	0.739	0.059
Sihan	Dweeb	10	17/01/2017	0.95	0.87	0.08
			28/05/2017	0.955	0.891	0.064
Sihan	Dweeb	20	17/01/2017	0.955	0.875	0.08
			28/05/2017	0.96	0.897	0.063
Sihan	Faw	10	17/01/2017	0.95	0.827	0.123
			28/05/2017	0.955	0.873	0.082
Sihan	Faw	20	17/01/2017	0.955	0.833	0.122
			28/05/2017	0.96	0.879	0.081

cases was about 0.06 m of water level. That means a drop in the water level occurs when the artificial structure is present in the river bed.

As for the Sihan site, Figure 7(c and d), presented differences in the values of water levels between the natural state of the river and the presence of the artificial structure as well. Where these differences appear in cases of spring tidal phases and disappear in cases of neap tidal phases, as similar as in the Basrah site. However, the recorded difference value in the Sihan site was greater than this value in the Basrah site. Where the difference was about 0.1 m. It could be referred to the fact that the location of the site has an effect on water levels. As the artificial structure reduced the effect of the tidal phenomenon, because the Sihan site is closer to the source of the tidal phenomenon in comparison to the Basrah site. Table 1 shows the differences between the water levels values in terms of two cases:

According to the results of salinity (Figures 8–11), the comparison of salinity values between two cases (i.e. the normal condition and the case of artificial structure) was pronounced in three sites: Basrah, Abo Flous and Sihan as clarified in terms of the following conditions.

The first condition: the location of the artificial structure was proposed to be installed in the Dweeb site as well as the suggested freshwater discharge was 10 m^3/s, in all three sites mentioned above. As shown in Figure 8, there were no differences in salinity values were recorded between the two cases in the first month from the start of the model's operation. However, the differences in salinity values were seen around the beginning of the second month. A comparison between salinity values during two days, i.e. Figure 8, showed that the differences were 0.57 and 0.62 PSU for the days of 28/5/2017 and 30/6/2017, respectively, at the Basrah site. This decrease in value is related to the installation of the artificial structure. Next, at the Abo Flous site, the differences were 0.64 and 0.70 PSU, respectively. In addition, at the Sihan site, the differences were 0.71 and 0.70 PSU, respectively. It is concluded that there is an increase in the difference values with time at Basrah and Abo Flous sites. However, and there is stability in the difference value at the Sihan site. Thus, the reason behind that could be the distance that separates the sites with respect to the location of the structure.

The second condition: in this condition, the suggested freshwater discharge value was about 20 m^3/s and the artificial structure was installed in the Dweeb site, Figure 9. At all sites, i.e. Basrah; Abo Flous and Sihan, there is no difference during the first month in salinity values between base and structure cases. The amount of the differences in the Basrah site were 0.34 and 0.39 PSU in the days of 28/5/2017 and 30/6/2017, respectively. As for the Abo Flous site, the differences were 0.56 and 0.57 PSU. In addition, at the Sihan site the differences were 0.74 and 0.55 PSU during the two days mentioned above, respectively. It can be concluded here that the difference increases with time in the Basrah site but the stability was in the Abo Flous site. However, the decrease in the difference was at the Sihan site. In general, the difference in salinity values between the base case and the case of the presence of the structure with the progression of time in all sites.

The third condition: the position of the structure should be installed at Faw site and the freshwater discharge could be about 10 m^3/s, Figure 10. As in the two previous conditions, there is no difference in salinity values between the

Table 2. The discharge, salinity and delay time for the arrival of salinity at some sites.

Site name	Structure position	Freshwater discharge (m^3/s)	Salinity value (PSU)	Recorded date at base case	Recorded date at structure case	Delaying duration (day)
Basrah	Dweeb	10	5.321	07/04/2017	21/04/2017	14
Abo Flous	Dweeb	10	8.503	07/04/2017	21/4/201	14
Sihan	Dweeb	10	15.403	07/04/2017	08/04/2014	1
Basrah	Dweeb	20	2.775	07/04/2014	22/07/2017	15
Abo Fious	Dweeb	20	4.916	07/04/2017	22/04/2017	15
Sihan	Dweeb	20	10.786	07/04/2017	08/04/2017	1
Basrah	Faw	10	2.75	07/04/2017	22/04/2017	15
Abo Flous	Faw	10	4.916	07/04/2017	04/05/2017	27
Sihan	Faw	10	15.403	07/04/2017	08/04/2017	1
Basrah	Faw	20	2.775	07/04/2017	22/04/2017	15
Abo Flous	Faw	20	4.916	07/04/2017	04/05/2017	27
Sihan	Faw	20	10.78	07/04/2017	08/04/2017	1

base case and the structure case during a period of about one month from the operation of the model. The amount of the differences in the Basrah site were 0.50 and 0.52 PSU in 28/5/2017 and 30/6/2017, respectively. As for the Abo Flous site, the differences were 0.86 and 0.81 PSU. In addition, at the Sihan site the differences were 1.31 and 1.15 PSU during the two days mentioned above, respectively. So, there is an increase in the amount of differences with time at the Basrah site. However, the opposite of that appeared as a little decrease in the amount of differences at Abo Flous and Sihan sites.

Fourth condition: the position of the structure proposed to be installed at the Faw site and the freshwater discharge could be about 20 m^3/s, Figure 11. As similar as in the three previous conditions, there is no difference in salinity values between the base case and the structure case during a period of about one month from the operation of the model. The amount of the differences at the Basrah site were 0.50 and 0.52 PSU in 28/5/2017 and 30/6/2017, respectively. As for the Abo Flous site, the differences were 0.86 and 0.81 PSU. Finally, at the Sihan site the differences were 1.37 and 1.19 PSU during the two days mentioned above, respectively. Here, there is a clear similarity in the values of the differences with the third condition. That means the freshwater discharge has no effect when it increases to 20 m^3/s.

On the other side, the highest values of salinity differences, i.e. during the all studied cases of the four conditions mentioned above, were recorded in the spring tidal phases. However, the lowest values were recorded in the neap tidal phases. That is the result of the effect of the tidal phenomenon during the spring tidal phases. Moreover, the effect of freshwater discharge occurs during the neap tidal phases and this causes a decrease in salinity values in neap phases.

Salinity values were tracked in the two cases (i.e. base and structure cases) of the four conditions. For example, at the Basrah site during the condition of freshwater discharge about 10 m^3/s and the installed structure at the Dweeb site: a salinity value that observed on the date 7/4/2017 was 5.321 PSU which is equal to its value what observed on the date 21/4/2017 in the case of structure, i.e. 5.324 PSU. This means that the concrete structure had a clear effect in delaying the arrival of salinity in the river, and the duration of the delaying was approximately 14 days. Table 2 shows the results for the other conditions.

Under this serious threat (i.e. the salinity intrusion), it is necessary to increase the monitoring and management of the water quality in Shatt Al-Arab estuary.

The proposed salinity intrusion treatment should be established and perfected to protect water resources safety and make full use of the freshwater.

5. Conclusions

The mathematical model Mike11 is suitable for simulation in the Shatt Al-Arab environment in natural cases, as well as in cases where artificial structures are used in the course of the river. The proposed artificial concrete estuary structure for narrowing the river channel is a suitable solution to prevent the intrusion of salts. It is possible to reconsider the shape of the structure in terms of the distribution of its sections and its length, to give better results. In general, the effect of the structure was clear in delaying the time of salinity intrusion. It also has an effect on reducing the amount of salinity slightly according to the place of the structure.

The proposed structure leads to attenuate the tidal energy coming from the downstream of the river, causing the drop of the water level in the areas above the structure. It also gave freshwater the ability to reduce salinity values, i.e. in the upstream, which may results in a saline stratification in the water column and formation of a stratified estuary in the areas above the structure. As for the nature of the estuary in the far areas below the installation, it will remain completely mixed estuary (i.e. in the downstream).

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