2D SEDIMENT TRANSPORT MODELLING TO THE SHATT AL-ARAB RIVER ESTUARY

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Abstract

This study is an attempt to determine the suspended sediment transport of Shatt Al-Arab estuary (North west Arabian Gulf).Two dimensional time dependent hydrodynamics model coupled with sediment transport model were applied and solved numerically by using the explicit finite difference method, computer program used to simulate the flow and suspended sediment transport which shows a good agreement with the satellite image .The two cases of tide (spring and neap tides) were applied to the estuary ,which shows that the spring tide case was more verified than the neap tide case regarding the situation at the time the satellite image was taken .

Keywords: Numerical model suspended sediment transport

1- Introduction

Shatt Al-Arab River forms the outlet of the two main rivers of Iraq, the Tigris and the Euphrates which meet at Al-Qurna. It flows south-east towards the Arabian Gulf. The monthly average discharge of Shatt Al-Arab River downstream of Karun was about 1189 m^3 /s and upstream of Karun was about 765 m^3 /s in 1960[1]. Another study found that the monthly average discharge of Shatt Al-Arab River downstream of Karun was about 1576 m^3 /s and upstream of Karun was about 761 m^3 /s in 1994-1995 ,i.e the discharge of Karun river contributes by 815 m^3/s [2].

Although Iran built a dam and transformed the flow of Karun to Bahamsher River which takes its way into the Arabian Gulf, a high quantity of discharge and sediment come from it to Shatt Al-Arab River.

The type of sediment which comes from Karun river is sand ,but a high rate of it settles in Shatt Al-Arab river before it reaches the estuary. Then the types of sediments which reaches estuary are silt , clay and sand in varying rates ,[2].

The width of Shatt Al-Arab River mouth is approximately 1700 m near Ra's Al- Bishah (south of Al-Faw). The sediment concentration in the Tigris and Euphrates always settle down in marshes due to low water velocity and slope [3]. The major source which contributes to the sediment in Shatt Al-Arab river is Al-Karun tributary [2].In the case of ebb, the velocity of flow increases from zero at the slack case to maximum at the middle period of the ebb tide then returns to zero at the end of the ebb period. This forms a phenomenon called a plume forward from the river mouth which can be seen easily in a satellite photo due to the difference in the color of the suspended sediment particles which come from the river , compared with the Arabian Gulf water color which contains a little quantity of sediment.The aim of this study is to determine numerically the sediment concentration (mg/l) in Shatt Al-Arab river estuary at the end of the ebb period.

2-Sediment Transport

The ability of a river to load the materials depends on the velocity of flow in the river and the discharge as well as the granular size of the material in the river which is called the river load . This load is divided into suspended and bed load. these loads are called sediment transport .The sediment transport can be defined as the average quantity of sediment which passes through the river section at a specific time period .

Sediment transport in the Shatt Al-Arab River contains mainly suspended rather than bed load materials . Therefore, this study , concentrates on the suspended sediment to study the dispersion in the estuary .

Suspended load is the most important of a river load which moves with the flow . The particles that compose the suspended load are different in their shapes . They could be spherical , elliptical ,disc or non uniform .

The weight and shape of the particles are the important factors that govern the settling of the particles . The particles in the liquid might be affected by a group of forces ,which are the gravity, lift force and draw force . The settling velocity of the particles was neglected in this research due to the high speed of flow in the estuary in the ebb case (according to the situation under study), and due to very fine materials, Settling velocity= $3.9*10^{-3}$ m/s [2].

The concentration of suspended matters (T.S.S) is variable dependent especially on the season , position from the surface and the case of tide (ebb or flood). In this study, we take an average which equals to 120 mg/l from a previous study at the river mouth in the season when the satellite image was taken [4&2] . Then it was taken as a boundary condition input data to the finite difference numerical model to evaluate the sediment concentration at every grid point and at any time during the ebb period downstream of Shatt Al- Arab River mouth .

3- The Models

a. The hydro-dynamical model

Two dimensional time dependent depth-averaged hydrodynamic model are described by the conservation laws of momentum and equation of continuity for mass. Navier– Stockes equations are solved in a Cartesian mesh by the explicit finite difference technique . Buoyancy effects due to fresh water outflow are considered by calculating density variations at each time step and point location in the mesh by solving the salinity equation .

The horizontal eddy viscosity coefficients are chosen first as 1000 m^2 /s as in some previous studies in the same estuaries .Then these coefficients were taken to equal zero ; no difference in the shape of the effluent was noticed . The same thing is true of the dispersion coefficients for equations of sediment transport and salt dispersion do not affect the shape of effluent. As a result ,in this study, the coefficients of eddy viscosity and dispersion were neglected.

Also, this study neglects the effect of wind , Coriolis force and ambient current in the sea .

Thus, The equations of momentum in x and y direction will be as follows:-

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + \frac{ku\sqrt{u^2+v^2}}{h1} = \frac{-1}{\rho_2} g \frac{h1}{2} \frac{\partial \Delta\rho}{\partial x} \quad ..1$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + \frac{kv\sqrt{u^2+v^2}}{h1} = \frac{-1}{\rho_2} g \frac{h1}{2} \frac{\partial \Delta\rho}{\partial y} \quad ..2$$

where ,

u, v : x and y components of depth averaged velocity .

t : time

k= k_i or k_b (as to the situation of flow)

k_i = interfacial shear coefficient which equals to $4*10^{-4}$ for arrested saline wedge case , as the situation under study [5].

$K_b = \frac{g}{c^2}$

g: acceleration due to gravity, c = chezy coefficient (c=50 ~60 $m^{1/2}$ /s).

$\Delta\rho$: the difference in density between the fresh water density and the receiving water density =($\rho_2 - \rho_1$).

h1=thickness of fresh water layer = $\frac{u^2}{g\frac{\Delta\rho}{\rho}}$

for the situation of salt wedge as in the case under study . [6]

b- The suspended sediment transport model

Sediment transport model used in this study mainly focuses on the problem of suspended sediment .

The sediment concentration in the Cartesian (Oxy) coordinate system is governed by the following equation [9] :-

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} = 0 \qquad \text{……..3}$$

Where:

C : depth averaged of suspended sediment concentration

u, v : x and y components of depth averaged of current velocity derived from the hydrodynamics model.

t: time

c- continuity equation of salt

Where turbulent mixing occurs in an estuary , the equation of continuity of salt flow can be expressed more usefully as ,

$$\frac{\partial s}{\partial t} + u\frac{\partial s}{\partial x} + v\frac{\partial s}{\partial y} = 0 \text{ ……………………4}$$

Where,

S: Salinity

u,v : x and y components of depth averaged of velocity derived from the hydrodynamics model.

t: time

The density of water ρ could be related to the salinity S by the following linear relationship [7].

$$\rho = \rho_f(1+e(s-s_f)) \qquad \text{……..5}$$

Where,

ρ_f and s_f are the density and salinity of fresh water respectively and **e** is a constant that equals 7.8×10^{-4} .

The importance of using equation 4 is to calculate the salinity at every point in the domain and at every time step then transforms it to density by using equation 5 , which needed in equations 1 and 2 .

4- Model Area and Simulation Design

Model area is Shatt Al-Arab River Estuary which is located at 29° 56' N and 48° 38 ' E, as shown in the Fig. (1). The domain of study is discritized into grids with size of Δx= 1000 m and Δy=500 m . Simulations were done for two tidal conditions i.e. spring and neap . which occur twice a month for each . And due to the high tidal range in spring tide in comparison with a neap tide , we can see the bed beside navigational channel during the end of ebb period downstream of the mouth.

a-Initial condition and boundary conditions for hydrodynamic model

The numerical solution of the two-dimensional momentum equations requires boundary as well as initial conditions to indicate , and then to advance the solution in time and space.The origin was taken at the center of the mouth , the x and y are selected at water surface , x positive towards the offshore and y is measured along a straight coastline .Then, a similarity with respect to x-axis was applicable to get a full shape of the effluent . Thus,

V=0 (at y=0) , $\frac{\partial u}{\partial y} = 0$

Also,

u=v=0 (at x=0 and y > B/2) [where B= width of river mouth]

The velocity variation with time can be represented as a harmonic sine wave ,

$u = u_{max} \sin \frac{2\pi t}{Tp}$ for x=0 and 0≤y≤B/2) …6

where ,

u_{max} maximum velocity.

t= the time from high water (HW)

Tp: tidal period

The initial condition for the velocities will be :-

u=v=o ,(for t=0) (Slack water)

The downstream boundary condition to the study area, i.e. the open sea ,will be as follows :-

u=v=0 (for x=y= ∞ and t>o)

b-Initial and boundary conditions for sediment transport equation

The continuity equation of sediment requires also initial and boundary conditions which are as follows ,

$C=C_o$ (for t=0 , and for t >0 at x=y=∞ and x=0 , y> B/2

$C= C_r$ (for x=0 and 0≤y≤B/2)

$\frac{\partial C}{\partial y} = 0$, at y=0

Where,

C_o= suspended sediment concentration of the sea water.

C_r = suspended sediment concentration of the river water.

c-Initial and boundary conditions for continuity equation of salt

The continuity equation of salt requires also initial and boundary conditions which are as follows ,

$S=S_o$ (for t=0 , and for t>0 at x=y=∞ and x=0 , y> B/2

$S= S_r$ (for x=0 and 0≤y≤B/2)

$\frac{\partial s}{\partial y} = 0$, at y=0

Where,

S_o= salinity of the sea water

S_r = salinity of the river water

5- Results and Discussions

The suspended sediment content in Shatt Al-Arab River near to the mouth was taken as 120 mg/l as an average (See table 1) [4, 2], and at the same season at which the satellite image was taken (satellite image was taken in 5/3/2001 @ 7:35 AM by NASA, Fig(2)) . In this map a turbidity plume is visible as isoline and is limited by the very low suspended sediment content towards the sea (in this study assumed 10 mg/l). The observed river effluent is shown to be reach a distance of approximately 20 Km off the coastline and it has a maximum width of approximately 14 km . The study under consideration deals with two cases which might be possible , either a spring or a neap tide, which are different in tidal range (TR) , tidal period (Tp) and River velocity . The tidal range in spring tide is always greater than the neap tide case , and from a previous study the tidal period in ebb case in spring tide = 7hr :30 min but in Neap tide = 6 hr :12 min in Ra's Al-Bishah.

In this study, the following data were taken:-

TR = 3.2 m, max velocity = 1.2 m/s and Tp= 7 hr :30 min in a spring tide (ebb case).

And ,

TR = 1.1 m , max velocity = 0.9 m/s and Tp= 6 h : 12 min in a neap tide (ebb case).

The depth of water was calculated as $H=h+\eta$

With ,

η= (TR/2) sin π ($\frac{2t}{Tp}$ +0.5) …… 7

Where ,

η= The surface elevation above MWL

h=The depth from bottom to MWL

t= the time from high water

MWL: mean water level

And this depth assumed to be constant in the domain in every time step.

This model was solved numerically by using the explicit finite difference method, with the aid of computer program .The equations of momentum and conservation of mass for salt were solved by using iteration. Also, a courant condition was applied in the program to insure the stability of results in the explicit method. The isolines which represent the equi - suspended sediment content can be seen in (Fig. 3) for the spring tide case and Fig(4) for the neap tide case at the end of the ebb period. Also, three dimensional suspended sediment concentrations (mg/l) represented in (fig. 5) for a spring tide case and (fig. 6) for a neap tide case , to show the reduction of effluent concentration at the end of ebb period where the velocity approach to zero , and the level of water at the least value . And a comparison of the two cases with the satellite image (Fig. 2) was applied in (fig. 7)

6- Conclusions and recommendations

The conclusions drawn from this study are as follows:-

1- A good simulation has been obtained from this study (Fig. 7).

2- The spring tide case was more verified than the neap tide case . Thus, we can conclude that it might have occurred at that time.

3- There is no effect of eddy viscosity and dispersion coefficients on the shape of the river effluent.

4- The shape of effluent is especially affected by velocity in the river mouth, which is taken as a shape of harmonic sine wave as mentioned previously . But the velocity in the model was build on some records in the same month of satellite photo which was taken but in a different year . Therefore, we can get a very good agreement if the data were taken in that month of the same year.

5- The tidal period was also affected by the shape of the effluent ,i.e. if the ebb period increases that will leads to expanding the effluent and vice versa . But this study depends on common records in this region for the two tides cases.

6- The appearance of the flats around navigational channel (for a distance equal approximately 12 km downstream of Ra's Al - Bishah) (see fig.1), especially in a spring tide case (the high tidal range compared with the neap tide case) and due to the arrival of big quantities of sediment which settled due to reducing the water level with the time of the ebb tide might lead to the appearance of new lands.

7- The model can be modified by taking the effect of wind , coriolis forces .

8- The model can be modified into three dimensions and by taking the effect of settling velocity in consideration.

9- The model can be modified to simulated pollution distribution in the estuary .

10- The model can be modified to simulate heat transfer in the estuary.

Table(1): concentration of suspended sediment(mg/l) in Ra's Al Bishah section at the ebb period [2].

(A: Water surface , B:middle of water column, C: 1 m above the bed)

Section	Position of sample	January 1995	April 1995
West side	A	84	10
	B	112	17
	C	143	38
Middle side	A	138	12
	B	149	20
	C	252	38
East side	A	143	16
	B	-	-
	C	-	-

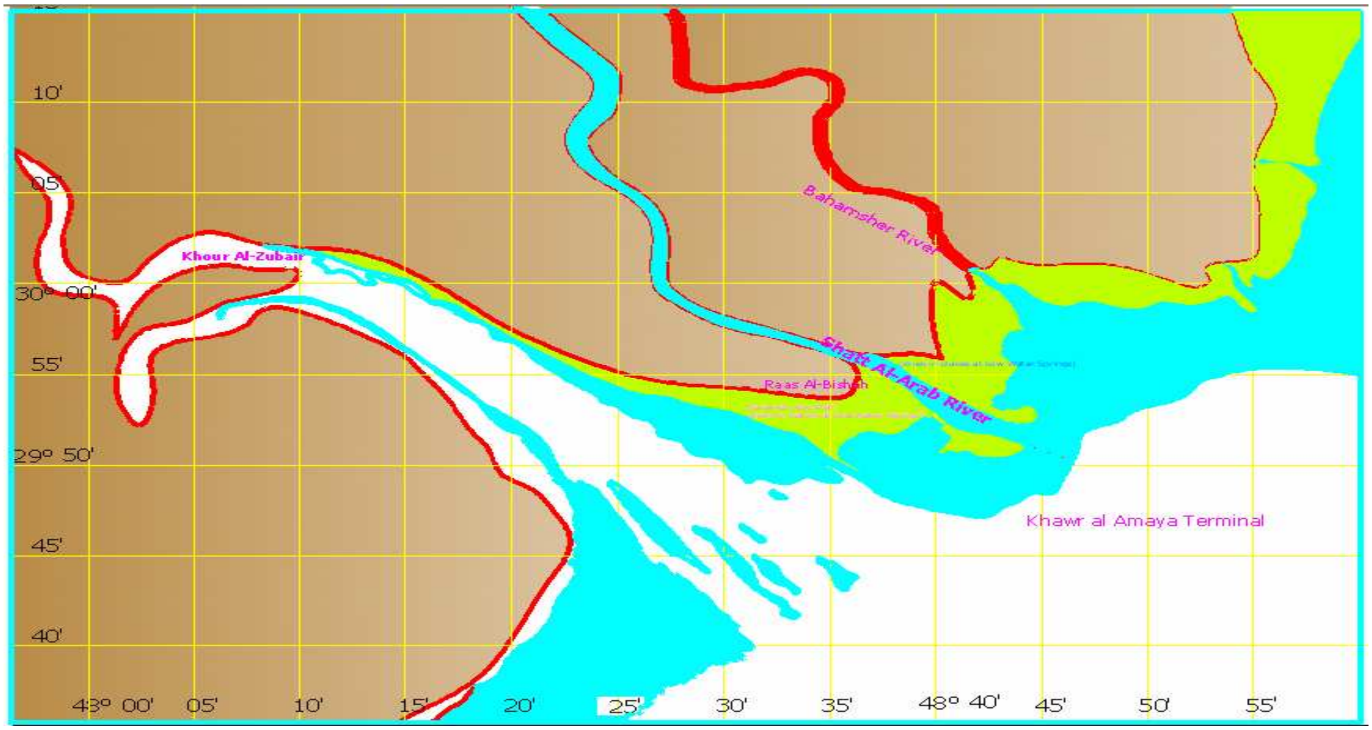
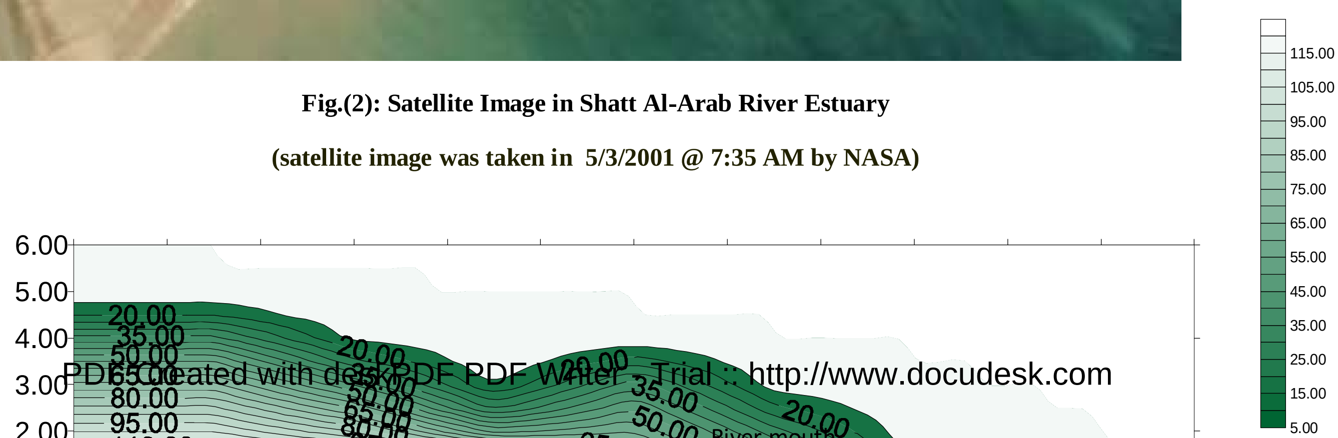


Fig (1) : Shatt Al Arab River Estuary

Fig.(2): Satellite Image in Shatt Al-Arab River Estuary

(satellite image was taken in 5/3/2001 @ 7:35 AM by NASA)



Y-axis

Sediment concentration (mg/l)

Fig.(3):Equi-Sediment concentration contour (for spring tide case).

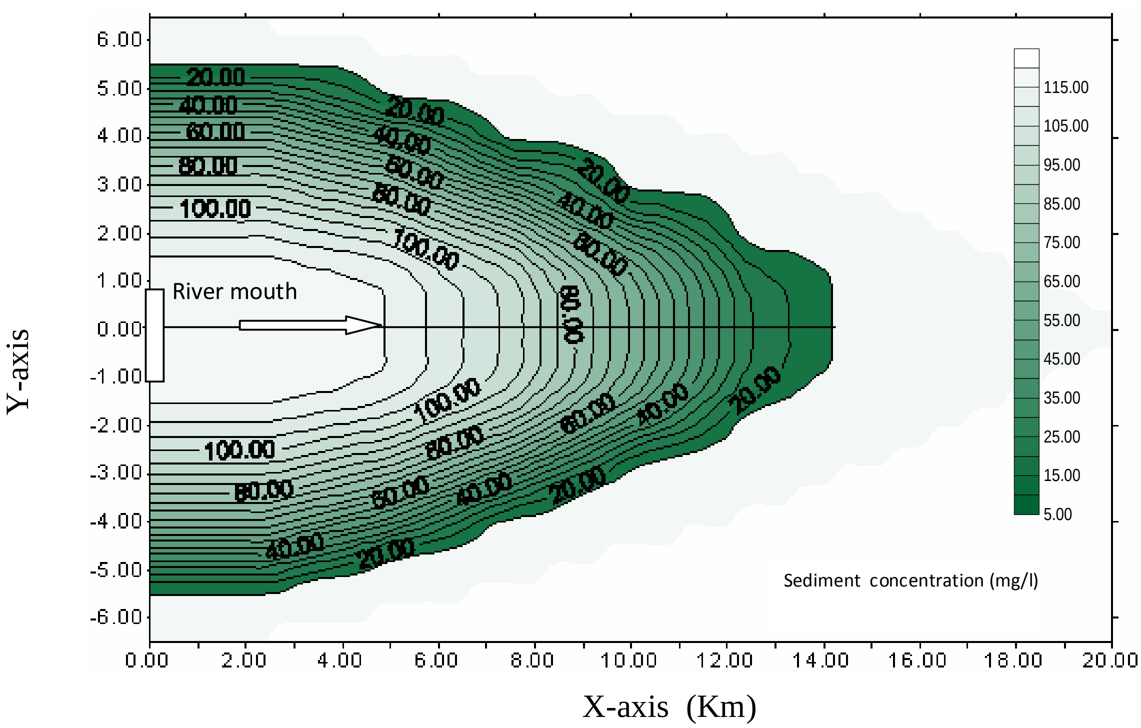


Fig. (4):Equi-Sediment concentration contour (for neap tide case).

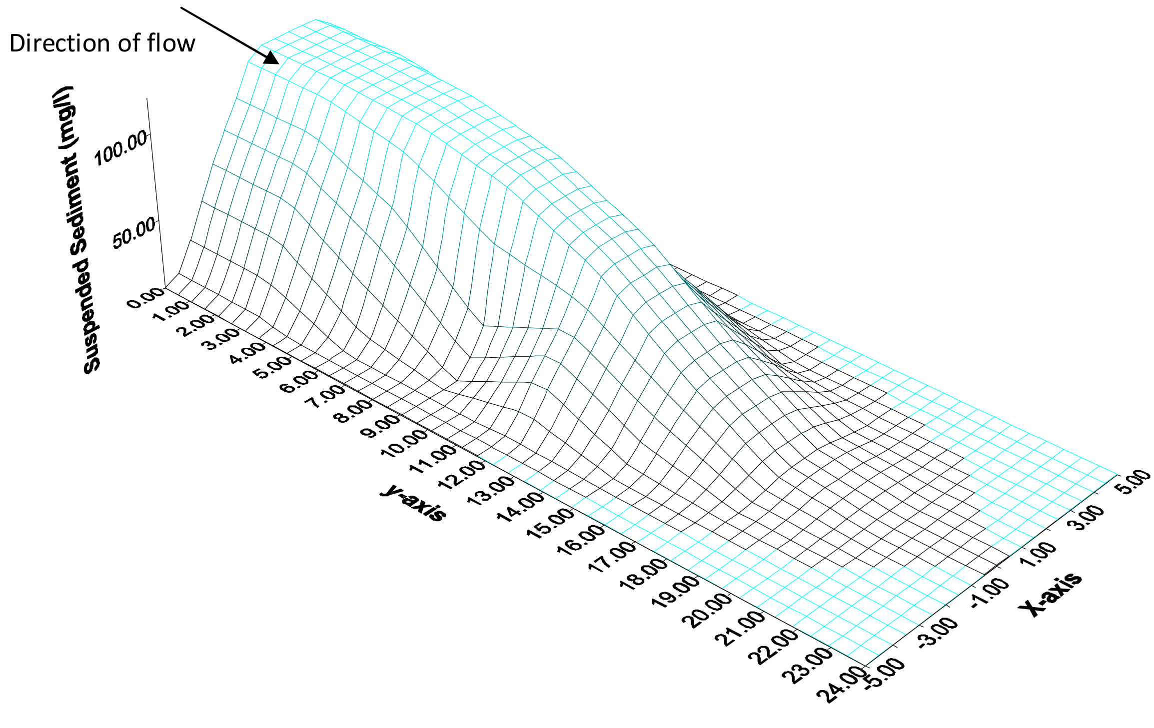


Fig. (5) :3 Dimensional suspended sediment concentration in the estuary at the Spring tide

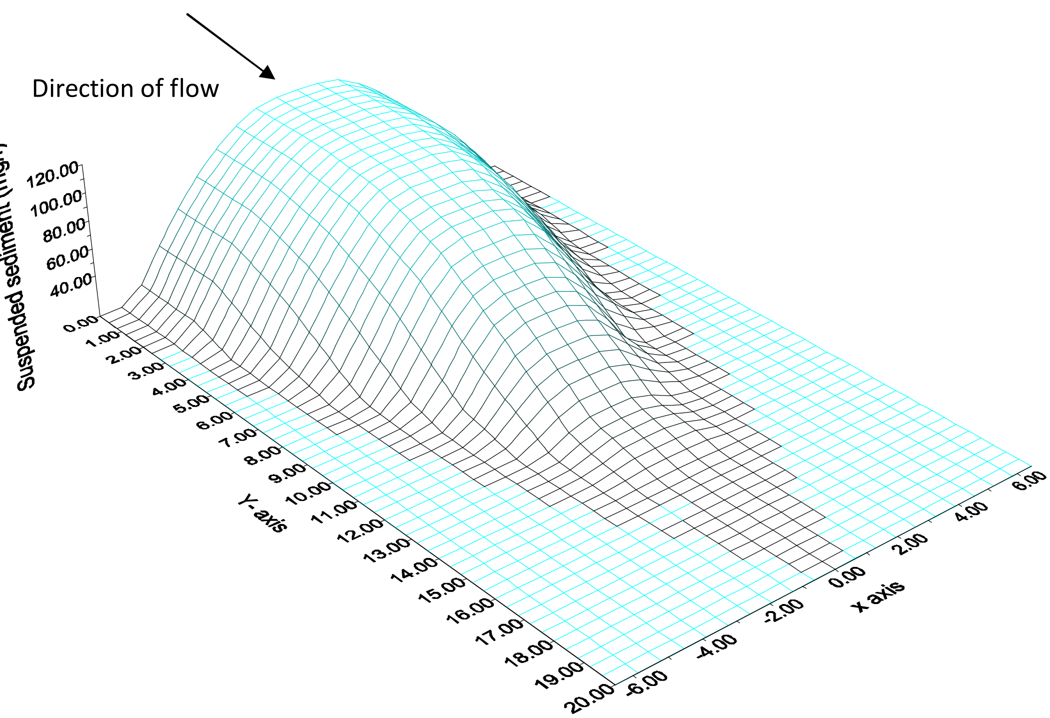


Fig. (6) :3 Dimensional suspended sediment concentration in the estuary at the neap tide case

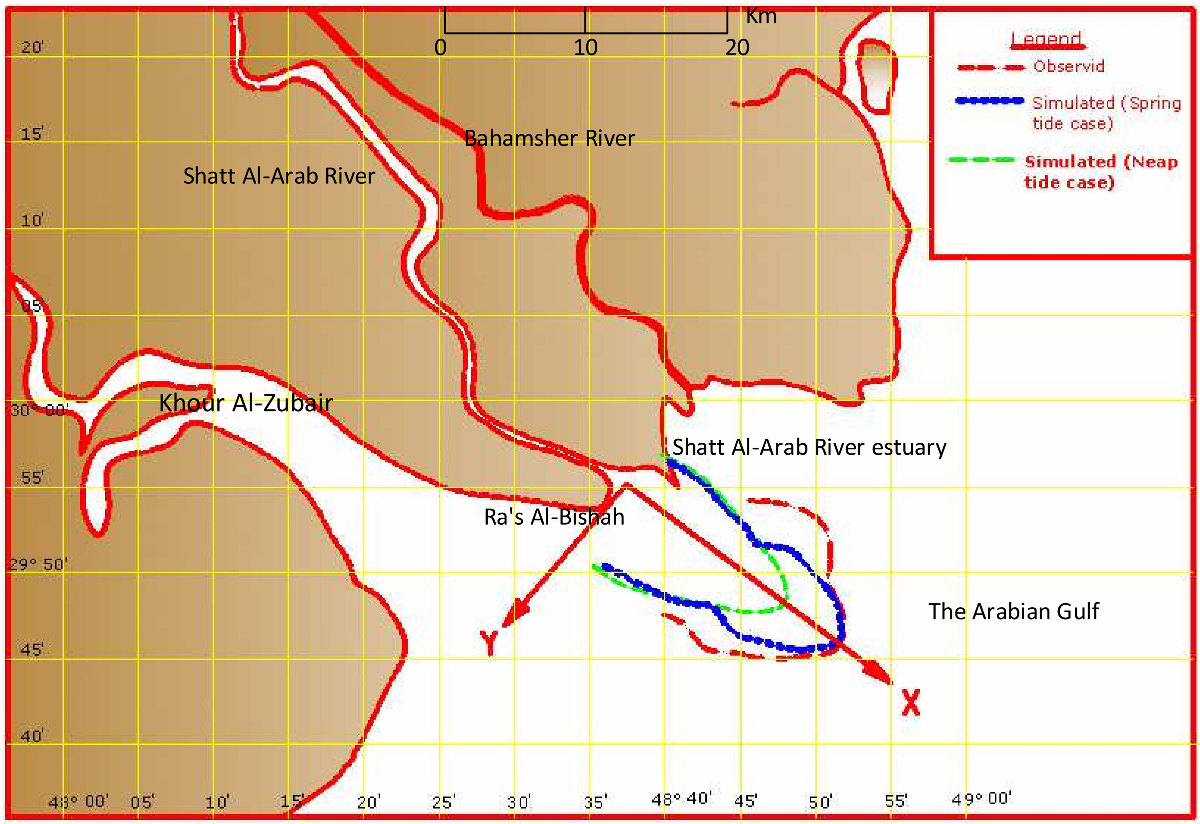


Fig.(7): comparison between observed and simulated sediment transport in Shatt Al- Arab River estuary.

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ألخلاصه:

هذه الدراسة هي محاوله لتعيين انتقال الرواسب العالقة في مصب شط العرب (شمال غرب الخليج العربي) .لقد طبق نموذج هيدروليكي ثنائي البعد متغير مع الوقت واقترن مع نموذج انتقال الرواسب وحل عدديا" باستخدام طريقه الفروقات المحددة الصريحة. اعد برنامج باستخدام الحاسوب لتمثيل الجريان وانتقال الرواسب العالقة . وقد لوحظ تطابق جيد مع ألصوره الفضائية .وقد طبقت حالتا المد الفيضي والمحاقي على المصب .وأظهرت الدراسة إن حالة المد الفيضي قد حققت تطابقا" أكثر من حالة المد المحاقي في الوقت الذي أخذت فيه ألصوره الفضائية .