Simulation of Salinity Intrusion from Arabian Gulf to Shatt Al-Arab River

AHMED NASEH AHMED HAMDAN
Dept. of Civil Eng., College of Eng.
Univ. of Basrah
ahmed.n.ahmed2015 @email

Abstract: **This study is an attempt to determine the salinity intrusion from Arabian Gulf to Shatt Al-Arab River. One dimensional time dependent hydrodynamics model coupled with salinity model were applied and solved numerically by using the explicit finite difference method, a computer program was used to simulate the flow and the salinity concentration. "Total tide" software has been used to get an information about tide level in the day of field measurement, field measurement of salinity and tide velocity in Al-Fao Station was taken for a full tidal cycle and compared with the program results shows a good agreement between field measurement and numerical model results. Three sections were taken along the Shatt Al-Arab River to study the effect of salinity intrusion from the sea. It were found that the effect of salinity intrusion from the sea, reach a distance of a few kilometers upstream of Shatt Al-Arab mouth, but not farther than Abadan region. It is found that the salinity increased rapidly in the last of tidal period to a distance approximately equal 50 km downstream of Karun river or 10 km upstream of Al-Fao, and reach gradually to the salinity of the sea.**

Keywords: Numerical model , salinity intrusion, Shatt Al-Arab River

I. 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. Its flows along a wide channel in a south-easterly direction and downstream of Al-Fao discharges into the Arabian Gulf, at a latitude equals nearly 29º 58' N and longitude nearly 48º 29' E (see fig. 1). The length of Shatt Al-Arab river is about 180 km and its width ranges between 400-1200 m. Two tributaries join the Shatt Al Arab river during its course, most importantly Karoon and Karkha which were flowing from Iran. Due to the impact of climate change and drought on the region as a whole, Iran diverted both tributaries inside its territory and because of that, Shatt Al-Arab river water became highly saline due to the backflow from the Gulf. [1].

Salinity intrusion is an entrance of saline water from the sea towards the river, which always causes a problem in the estuary. This phenomena is affected by many parameters such as river flow, tidal range, and the difference in the densities between the river and the sea.

The salinity of the Shatt Al-Arab River water is of great importance in designing the future usage of this water for irrigation, municipal and industrial purposes.

The main reason of salinity in the Shatt Al-Arab river near to the estuary is due to the intrusion of salt water from the Arabian Gulf in the flood tide case. The intrusion of the sea water actually may reach the distance of a few kilometers upstream of the mouth, but not farther than Abadan [2]. Therefore, in this research, the area of study was taken from Shatt Al-Arab river estuary to Karun river estuary.

In the Al-Fao region the salinity increases due to the Arabian Gulf effect, where the salinity decreases in the ebb period and increases in the flood period. The type of circulation at Al-Fao, changing from a salt wedge in the wet season to partially mixed in the dry season [3].

The salinity of the River calculated as total dissolved solids (TDS) expressed in PPT.

The aim of this study is to give a detailed view on the characteristics of salinity intrusion from Arabian Gulf during ebb and flood cases. Total Tide software (by UK Hydrographic Office (UKHO) of Admiralty Way, Taunton, TA1 2DN, United Kingdom). and field measurement of salinity and tide velocity in Al-Fao section was compared with numerical model. Also the width and area of the cross section in the Shatt Al -Arab river were calculated at each 1000 m and taken as an input data to computer program.

II. THE MODELS

A. Governing Equation

One dimensional tidal motion will be considered in the Shatt Al-Arab River. The vertical velocities and vertical accelerations of the water particles were negligible.

The flow pattern in the estuary is unsteady because of the tidal rise and fall at the mouth. The flow is one-dimensional, i.e. the velocity is uniform over the cross section .
The governing equation of the model are:- [4].

I. Continuity equation

$$\frac{\partial Q}{\partial x} + B\ \frac{\partial z}{\partial t} = 0 \qquad (1)$$

Where,
Q : Flow discharge
x : distance along Shatt Al-Arab River
B : Surface width
z : Water surface elevation
t : time

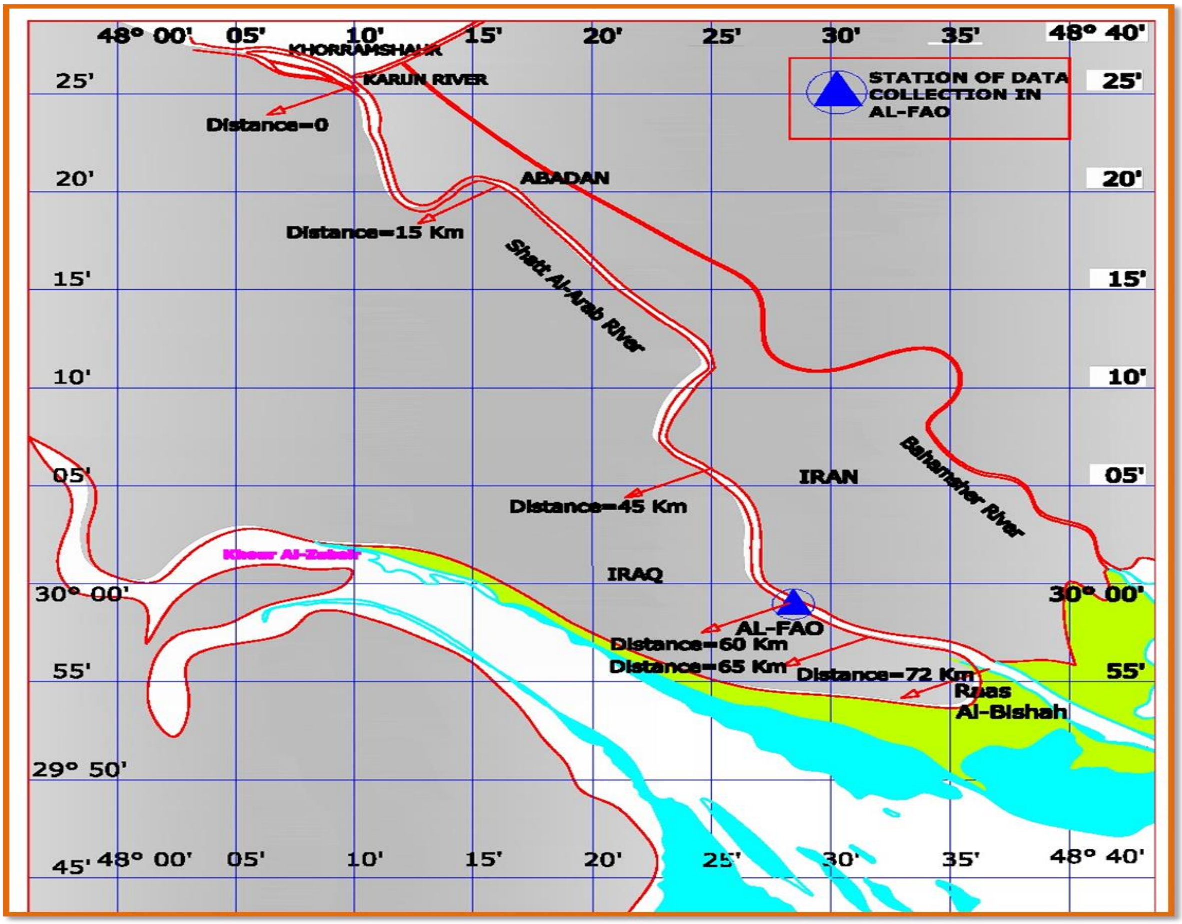


Fig. (1) : Shatt Al Arab River

II. Momentum equation

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial z}{\partial x} + g\frac{u\,|u|}{R\,C^2} = 0 \qquad (2)$$

Where ,
u :velocity component in the x-direction
g: acceleration due to gravity
R: Hydraulic radius
C: chezy's friction coefficient

III. Dispersion equation

$$\frac{\partial s}{\partial t} + u\frac{\partial s}{\partial x} = 0 \qquad (3)$$

Where, [5]

S: Salinity
u :velocity component in the x-direction
t: time

B. The General Method of Schematization

In a one dimensional finite difference formulation it is necessary, for the schematization of an estuary, to divide the estuary into a discrete number of longitudinal segment and to assign particular geometric characteristics to these segments. In this research the main parameters required to perform the computations are: surface width, the cross sectional area, mean depth, wetted parameters and the longitudinal bottom slope.

The surface width and the cross sectional area at each section, i.e. each 1000 m in the study area were measured in the field.

The reference water level at each section is taken as the mean water level at that section, and equals to (H_o+Z_o). The instantaneous fluctuation of the water surface is defined by "η" . which could be a positive or a negative quantity.

The hydraulic mean depth will be the depth of this section and can be found from the relation,

H=A/B (4)

And the hypothetical mean water surface elevation can be approximated to:

$$Z=Z_o+H+\eta \qquad (5)$$

The bed elevation, Z_o , and the depth, H_o, are functions of x, but not of time. Hence.

$$\frac{\partial Z}{\partial t} = \frac{\partial \eta}{\partial t} \qquad (6)$$

And ,

$$\frac{\partial Z}{\partial x} = \frac{\partial Zo}{\partial x} + \frac{\partial Ho}{\partial x} + \frac{\partial \eta}{\partial x} \qquad (7)$$

Where,

Zo : channel bed elevation
H : hydraulic mean water depth
η : Instantaneous water surface elevation

The depths H_o and Z_o will be measured from the reference water level downwards.

The reference datum was taken as the mean sea level. The depth and bed slope at each section will be measured below this reference datum. So that $\frac{\partial Z}{\partial x}$ could be expressed as,

$$\frac{\partial Z}{\partial x} = \frac{\partial Ho}{\partial x} + \frac{\partial \eta}{\partial x} \tag{8}$$

Where $\frac{\partial Ho}{\partial x}$ represents the slope at different sections.
The hydraulic radius calculated from the equation is :

$$R=A/P \tag{9}$$

Where,

P: wetted parameter

The chezy's friction coefficient "C" was calculated from the equation :

$$C=60- Q_r /60 \tag{10}$$

Where,
Q_r : river discharge [4].

C- Numerical Scheme

Numerical model was used to simulate the tidal flow. The domain of the study is discritized into grids with a size of Δx= 1000 m.

The origin was taken at the Karun River estuary which is a distance far equal approximately 72 Km from Shatt Al-Arab River estuary in Raa's Al Bishah. (see Fig.1). Simulation were done from starting an ebb tide case to finish the flood tide case .(i.e. for a one tidal cycle). An explicit finite difference scheme was used to represent the model.

The system of equations transformed to numerical formulas and a computer program was used to solve it, also a courant condition was applied in the program to insure the stability of results in the explicit method.

a-Initial condition and boundary conditions for hydrodynamic model.

The numerical solution of the one-dimensional momentum equations requires boundary as well as initial conditions to indicate, and then to advance the solution in time and space.

The boundary conditions for the computation give water velocity at the upstream boundary points and downstream boundary points .

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

$$u = u_{max} \sin \frac{2\pi\, t}{Tp} \quad \text{(for x = 0 and x =xe)} \tag{11}$$

where ,[4]

u_{max} maximum velocity .
t= the time from starting the tidal period
Tp: tidal period
Xe = the distance from Karun River estuary to the Shatt Al-Arab River estuary (Xe=72 Km).

The initial condition for the velocities will be :-
u = 0 , (for t = 0) (Slack water)

And the boundary conditions for the computation tidal elevation are given tidal elevation at the upstream boundary points and downstream boundary points.

The tidal wave that will enter the estuary could be calculated from the formula :-

$$\eta = \text{Amp} \,.\, \sin \frac{2\pi\, t}{Tp} \quad \text{(for x=0 and x =xe)} \tag{12}$$

Where,[4]
Amp: the amplitude of the entering tidal wave.

Amplitude can be taken from "Total Tide" software, this program is able to give a full information about the tide at any time at different locations in the world, nine locations were found along Shatt Al- Arab river in this software such as Al Fao region, and Abadan region.

b-Initial and boundary conditions for Salinity dispersion equation .

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

$S=S_o$ (for x= xe , and t $\geq$ 0)
$S= S_r$ (for x=0 , and t $\geq$ 0)
S=Sr (for $0 < x < xe$, and at t=0)

Where,
S_o= salinity of the sea water
S_r = salinity of the river water

III. Results and Discussions

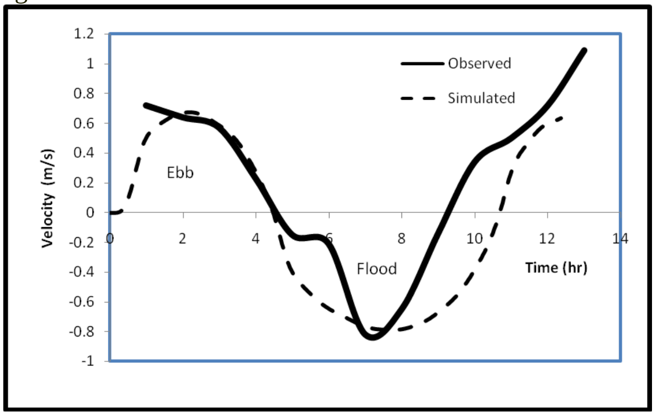
The numerical model is used to simulate salinity intrusion into the Shatt Al-Arab River in September,11 and 12, 2014 at the same time of data which are collected from the field. The recorded data of the velocity and salinity at Al-Fao station inside the river system was used to verify the model.(See Fig.1).

The width and area at each 1000 m was measured in the area of study and input as data to the computer program.

In this study, the following data were taken depending on field measurement:-

1) The salinity content in the Arabian Gulf was taken equal to 36.5 PPT and in the Karun River estuary was taken equal to 1 PPT .
2) The tidal period TP was taken equal to 12^o 21' .
3) Tidal range (TR) in the Shatt Al-Arab River estuary = 3.2 m, by using Total Tide software, and in the Karun River estuary=2.5 m.
4) Maximum velocity in the Shatt Al- Arab River estuary = 1.0 m/s ,and maximum velocity in the Karun River estuary = 0.9 m/s.

Fig. 2 and 3 depict examples of the comparison between the computed and observed velocity and salinity concentration at Al-Fao station. As seen the model can simulate the real salinity intrusion picture with satisfactory agreement.



Fig(2):A comparison between simulated and observed velocity profile at Al-Fao.

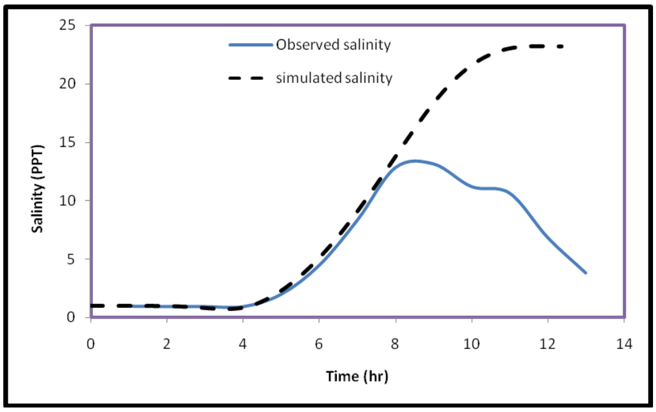


Fig.(3): A comparison between simulated and observed salinity profile at Al-Fao

Fig.4, Fig.5 and Fig. 6 represent salinity profile at a distance in Km from the Karun river.

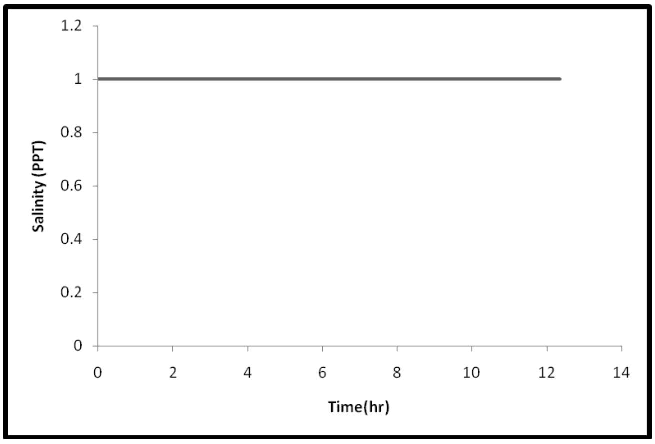


Fig.(4) : A salinity profile at a distance 15 Km from the Karun river

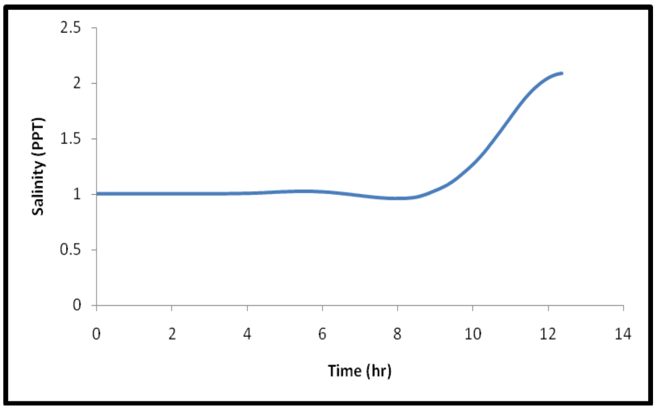


Fig.(5) : A salinity profile at a distance 45 Km from the Karun river.

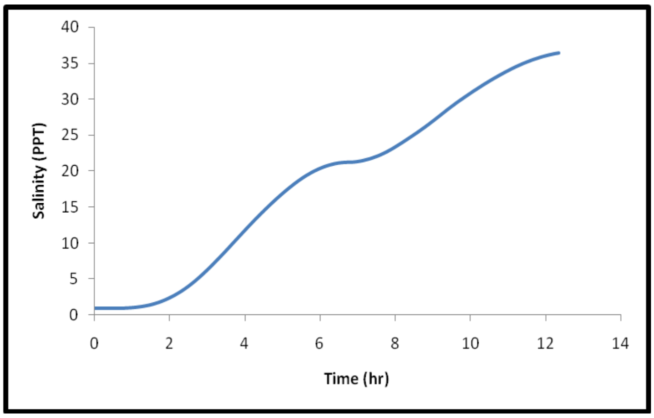


Fig.(6): A salinity profile at a distance 65 Km from the Karun river.

Fig. 7 represent a salinity profile with distance from the Karun river at the end of flood period.

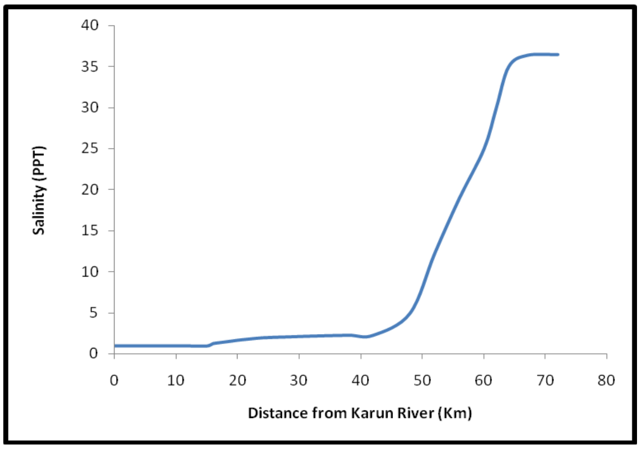


Fig.(7): A salinity profile with Distance from the Karun river at the end of flood period.

IV. Conclusions and recommendations

The conclusions drawn from this study are as follows:-

1) A good simulation has been obtained from this study (Fig.2 and 3).
2) It is found that during the time of ebb tide, the salinity is approximately equal to the salinity of the river (i.e. 1 PPT), that is due to the River flow discharged into the Arabian Gulf . But in the flood tide case the sea water inter to the Shatt Al- Arab River, and that lead to increasing the salinity of the River .
3) The comparison between observed and simulated salinity shows that the observed salinity curve (Fig.3) follows the velocity curve(Fig.2), i.e. the salinity approximately equals the river salinity from the starting tidal cycle in the ebb period to the end of the ebb tide period. But in case of flood, the salinity increases rapidly until the end of flood. However, it returns to decrease when the ebb case starts again.

   Also in simulated salinity curve (Fig.3) it can be seen that the same, i.e. the salinity curve follows the velocity curve (Fig.2), i.e. in the ebb period, the salinity approximately equals the river salinity, and when the flood case starts, that leads to the rapid increase of salinity. Yet, it returns to decrease when the ebb case start again.
4) The salinity in the flood tide case effected especially in the regions near to the estuary and decreasing when become far from the estuary.

   The study get that in a distance till 15 km downstream of Karun river, there is no effect of sea water intrusion (Fig.4), and this result assures the result of a previous field measurements studies that a salinity intrusion has no effect farther than Abadan [2], (Fig. 5) show that there is a little effect of salinity intrusion from the sea in a distance equals 45 Km downstream of Karun River, but (Fig.6) shows that in a distance equal 65 Km downstream of Karun River, there is a big effect of sea water salinity intrusion, there is approach the Sea water salinity in the end of flood period.
5) The salinity regime varies greatly along the axis of the estuary of the Shatt Al-Arab River (Fig.7). The generally well-defined decrease in salinity with distance from the sea is highly variable at a fixed point in time and is related to fresh water discharge and tidal phase.
6) The model could be study the salinity intrusion in different day along the year and in spring and neap tide cases, wet and dry seasons which the effected parameters which changed as fresh water velocity, tidal range and tidal period, and to verify that a fixed station must be doing to measure the velocity and salinity at each tidal cycle.
7) The model can be modified into two dimensions and taking the effect of velocity and salinity variance with river width. or a two dimensional and taking the effect of velocity and salinity variance with depth.
8) The model can be modified to study transport of sediment, pollution and heat transfer.

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