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Empirical prediction model of salt intrusion along Shatt Al-Arab River, southern Iraq

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Abstract - In this paper the prediction of salt intrusion model along the Shatt Al-Arab River was applied. The analyses showed the result of salinity intrusion in Shatt Al-Arab River which is a confluence of Tigris and Euphrates Rivers, is essential to present a holistic picture. The analyses were based on data of seven years (2005-2011) as well as full day tide during 2009 when the salinity rose to its highest level. Due to the decrease in the quantity of water releases reaching the River from it's sources, the salinity of the saline water is increased with the flow decrease of fresh water. During the study period, the amount of flow was between 5-50 cubic meters per second. The salinity value fluctuated according to the flow reaching it's highest level in 2009, when the discharge was 5 m^3/Sec. The field salinity at the studied stations: Al-Fao, Al-Seba, Al-Ashar and Bin Ummer were 32.2, 26, 11.7 and 1.4 ppt., respectively. However, salinity prediction model gives values of 32.44, 24.1, 13.4 and 2.9 ppt. for the four stations, respectively. But when the discharge was 50 m^3/Sec., the field salinity at these stations were 27.5, 2.2, 1.92 and 0.8 ppt., respectively, the salinity prediction model gives values of: 27, 2.28, 1.73 and 0.5 ppt. at the four stations, respectively. These results represent a good salinity prediction model in the Shatt Al-Arab River.

Key words: Salinity Intrusion, Empirical Model, Estuary, Shatt Al-Arab River.

Introduction

An estuary is a transitional watery body at which a fresh and salt water meets. It is one of the important commercial and economic areas in many countries because of its important advantages.

The salinity and estuary position are predisposed to either of the two conditions which have a driving force to overcome the other. If the flow of freshwater is greater than the flow of saline water, it will make the estuary farther away from the mouth of the river into the sea(Fischer *et al.*, 1979). There are several factors affecting the saline dispersion of the river, the most important of which are tides, flow of fresh water and the geometric shape of the river (Geyer and Signell, 1992). Water contaminated by salt from the sea is no longer useable (Aerts *at al.*, 2000).There are more than one reason for the salinity increase in the rivers of which the lack of withdrawal of excess groundwater and the construction of dams on the rivers, which restrict the flow of water to the downstream. Therefore, the geometric shape of the river and the amount of water flow and tide are essential to assess the salt intrusion (Shaha and Cho, 2009) as well as many other factors such as distance, rain, sewage and temperature (Ralston *et al.*, 2008). In the mixed estuaries, the salinity penetrates through the process of mixing. There are several mixing mechanisms drive longitudinal dispersion of salinity. Dispersion is the distance that particles travels between the beginning and the end of the distance (Mahmood, 2016). There are three methods to study the salinity in the estuary and rivers: (Shaha and Cho, 2009).

1- The empirical correlation method, which needs a large number of data and is using an empirical formula to the river and the estuary in terms of salinity, discharge and flow for long periods of time.

2- The material analysis method, describes the distribution of salt water and the mixing characteristics of salt water and fresh water.

3- Numerical simulation technology, uses the different boundary conditions, to determine the different influences on salt water intrusion.

   There are two models which assess the salt intrusion, those based on natural environment and the laboratory experiments in channels of constant cross-section. Empirical models unlike the others, are a fast and easy to use simple tools and do not need extensive field data, therefor, can be considered as an optimal alternative to assess the impact of human on the salinity intrusion length in estuaries, for example the (Savenije, 1993) model which has more capabilities for predicting the salinity intrusion length in alluvial estuaries, and the other models as the Van Der (1972); Fischer *et al.* (1974) and Shaha and Cho (2009).

Study Area:

The Tigris, Euphrates and Karkheh Rivers are meet near Qurna southern Iraq to from Shatt Al-Arab River (Fig. 1), it is a 193 km long, passing along many districts as Bin Ummer, Al-Ashar and Al-Seba ends at Al-Fao. From Al-Qurna to Basra the river had different widths ranging from 400m to 240 m with a distance of 65 km long and an elevation of about 0.7 meters. The Shatt Al-Arab River receives water from Al-Hammar marshs near Garmat Ali and Sweeb. The width of the is River 240 m downstream of the confluence to 800 m near Al-Fao town. The water column varies from 6 to 13 m (Marine Science Center Report 1991). It's high sedimentation rate occurred Al-Fao town and carries large amounts of silts. The River is considered as a vital artery of the city of Basra and its environment, where many people rely on for irrigation and watering plantations and also used in river navigation as it connects Iraq with the world.

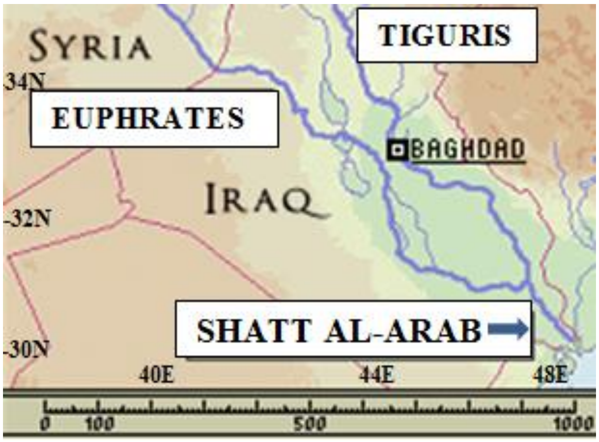

Figure 1. Area of the study.

Description of the Model

The data for the present study were collected from 2005 to 2011, the parameters measured were salinity, current speed and direction, tide, conductivity and pH with the depths in the middle and at both banks of the River. Five stations were selected along Shatt Al-Arab River (Fig. 2). Samples were collected in same time for daily tide. There are five stations along the river were these are Al-Fao near the estuary with a cross section area of 4680 m^2, AL-Seba; 50km from the estuary with across section of 1600 m^2, Al-Ashar 100 km from the estuary with the cross section 3007 m^2,Garmat Ali with a distance 110km from the estuary and a cross section of 2964 m^2 and Bin Aummer with a distance of 135 km from the estuary and a cross section of 2450 m^2. It is important to the main factors affecting salinity intrusion: (a) the distance from the salinity source, (b) tide, (c) the flow of fresh water discharge through the river (d) the nature of water as a sweat water, artificial water or wastewater, (e) geometric shape of the River (Savenije, 1986 and 1989). In general, the main prediction of salinity depends on the distance from estuary, tide, drainage and geometric shape of River (Savenije, 1993 and 2005). The data collected through seven years revealed gradient of salinity along the River and the maximum was during 2009, at Al-Fao station it was 35 ppt., at Al-Seba 22 ppt., Al-Ashar 12 ppt., Garmmat Ali 10 ppt. and 1.4ppt at Bin Ummer station. The surface salinity curves distribution at a tidal period at two stations: Al-Fao and Al-Seba are shown in Figures (3 and 4), respectively.

In the present study a time interval of four months, was found appropriate to describe the behavior of salinity dispersion, and a simulation over a long time. The boundary conditions of salinity at the upstream and downstream were 1.5 to 38 ppt., respectively. Several other substations were developed when testing the model.

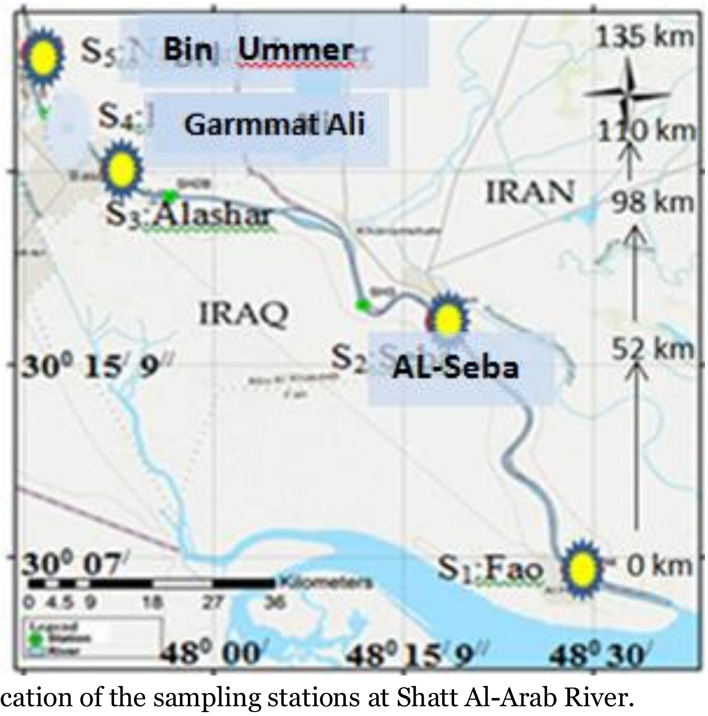

Figure 2. Location of the sampling stations at Shatt Al-Arab River.

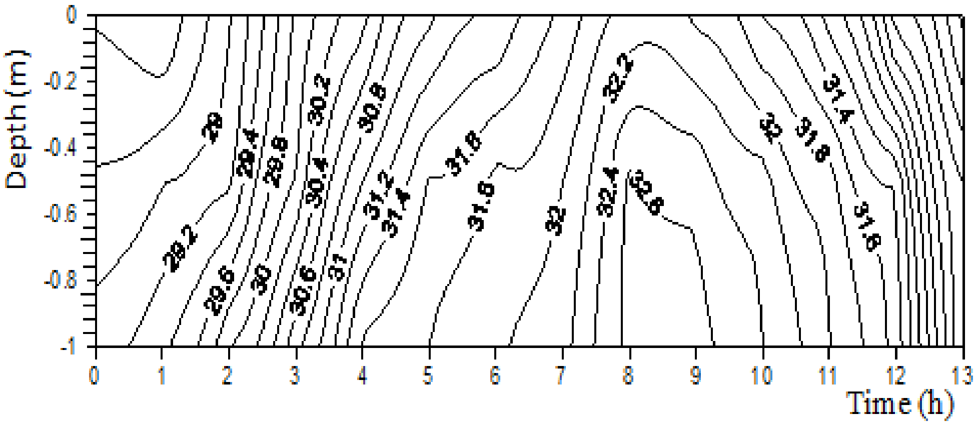

Figure 3. Salinity curve distribution at Al-Fao town with the tidal period.

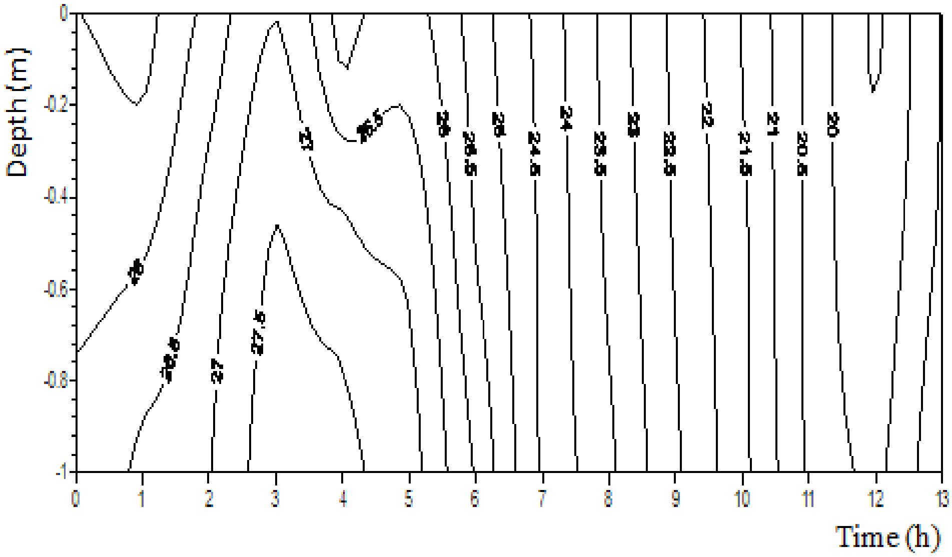

Figure 4. Salinity curve distribution at the Al-Seba town with the tidal period.

The geometry of an estuary can be presented by exponential functions describing the convergence of the cross-sectional area and the width along the estuary (Graas and Savenije, 2008):

$$\left.\begin{aligned} A &= A_0 \exp(-\frac{x}{a_0}) \\ B &= B_0\, exp(-\frac{x}{b_0}) \end{aligned}\right\} \qquad (1)$$

Where A, B are the cross-sectional area and the width of the estuary, respectively, at a distance x from the mouth. A_0 is the cross-sectional area at the mouth, B_0 is the width at the mouth, a_o is the cross-sectional area convergence length and b_o is the width convergence length. The relation between the distance and each of the width, depth and cross-sectional area are demonstrated in Figure (5).The boundary condition: (Parsa and Shahidi, 2009).

$$h_{ave} = h_0 + \frac{D}{2}\sin(\frac{2\pi t}{T}) \qquad at \quad x = 0 \tag{2}$$

Where h_{ave} is the tidal average depth, h_0 the tidal average depth at the mouth of the estuary, D is the tidal range, T is the tidal period, t is the time. Although there are a number of sources of salinity, but the main source is the sea water which decrease when far from the estuary.

There are two situations when the current velocity is zero with the change of direction. The first, when the current velocity of the tide is stopped with high water level known as high water slack (HWS) and the second when the low water level slack known as (LWS).

The seawater intrusion length (L) is a function of distance and cross section at high water slack (HWS) which is given as: (Shaha and Cho, 2009).

$$L^{HWS} \propto (m - \frac{x}{x_0}) \tag{3}$$

$$L^{HWS} = k(m - \frac{x}{x_0}) \tag{4}$$

Where the L^{HWS} is the salinity at any distance x from the estuary, m is the estuary salinity measured, k constant and x_0 is the measured salinity at a constant factor. Normalization of equation (4) for a number of stations along the River leads to the expression of:

$$L^{HWS} = (S_0 - m) - \frac{x}{(5 + 0.846m)} \tag{5}$$

Where s_0 is a constant.

The River discharge and cross-sectional area with the required information on the River are given by field measurements. In the estuary it is not easy to measure the discharge accurately because of the tidal fluctuations. Therefor, the discharge data measured from an area further of Al-Fao town were used in the analysis. In addition there were no data on the discharge at Al-Qurna.

The geometry of the River such as the cross section area, depth and width were calculated by the River cross section, which were taken along the River at each 500 m intervals by the Acoustic Doppler Current Profiler (ADCP), these parameters may be expressed as:

$$z = \frac{y}{A} = \frac{y}{y \times h_{ave}} \tag{6}$$

Where (y) is the River width in meters, (A) is the cross section area and h_{ave} is the water column at HWS. When the geometric of the River is a function of salinity (Shaha and Cho, 2009), the normalization equation (5) is represented as:

$$L^{HWS} = (S_0 - m) - \frac{x}{(5 + 0.846m)} + \exp(z) \qquad (7)$$

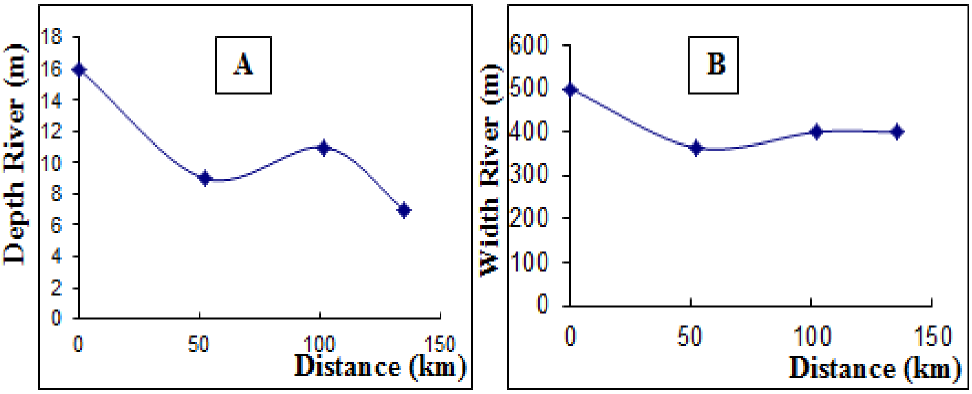

Figure 5. Relation of the depth and width (m) with the distance (km) at Shatt Al-Arab River.

The main effective factor reducing the salinity in the Shatt Al-Arab River is the fresh water. The reduce salinity dispersion is due to the difference in concentrations between the up and down stream.

When the amount of the flow of fresh water Q coming to the River between 50 m3/sec to 5m3/sec, will change the salinity level through the River (Fig. 6), a proximate relation between salinity and distance in each fresh water situation are given as follows:

$$y = 19.031\, E(-0.027X) \quad at \quad Q = 50 \ m^3/\sec \qquad (8)$$

$$y = 41.061\, E(-0.015X) \quad at \quad Q = 5m^3/sec \qquad (9)$$

In order to understand the distance relation with two parameters Q and the mixing factor Q_f which was consisted of a types of waste water as sewage (G), pond water (P), washing water (W) and rain water (R) $(GPWR)$ respectively, each was measured by a special tool, has a logarithm function, the behavior are different from one to the other (Fig. 7).

$$n = \ln \frac{Q_f}{Q} = \frac{GPWR}{Q} \qquad (10)$$

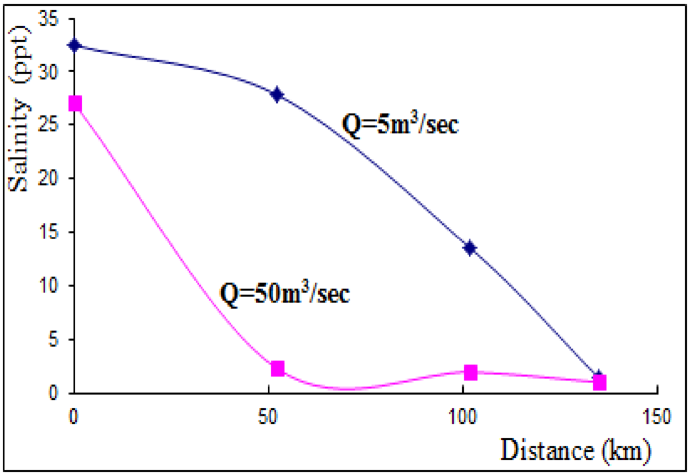

Figure 6. Behavior of salinity with distance (km) at $Q=5m^3/sec$ and $Q=50m^3/sec$, at the Shatt Al-Arab River.

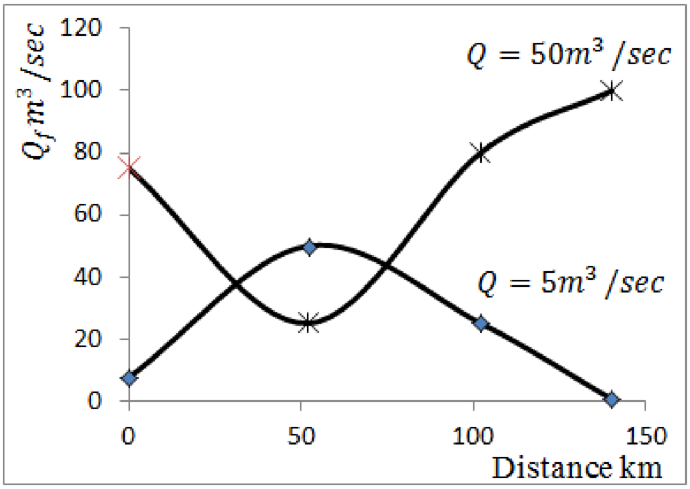

Figure 7. Relation between the distance (km) and Q_f in the River Shatt Al-Arab, at Q: (5, 50)m^3/sec.

However, the salinity prediction at any distance from the estuary equation (7) may be written as:

$$L^{HWS} = \left| \ (S_0 - m) - \frac{x}{(5 + 0.846m)} + \exp(z) \cdot \ln \frac{Q_f}{Q} \ \right|$$

$$L^{HWS} = \left| \ a + \ln(n) \cdot \exp(z) \ \right| \qquad (11)$$

Where:

$$\left.\begin{aligned} a &= (S_o - m) - \frac{x}{(5 + 0.846\ m)} \\ n &= \ln(\frac{Q_f}{Q}) = \ln(\frac{GPWR}{Q}). \end{aligned}\right\} \qquad (12)$$

Results

The monitoring of salinity changes in the Shatt Al-Arab River and the data analyses indicate that, the average salinity dispersion was mainly related to the flow and distance from the sources and the salinity rose to 5 or 7 times the known rates at some times. The amount of fresh water discharge comes to the River determines the limits of the estuary as a result of pushing the salinity ahead. When the discharge was 5 m^3/sec and 50 m^3/sec., respectively, the salinity dispersion increased through the River's water at 5 m^3/sec and decreased at 50 m^3/sec. (Figs. 6-7).

The fresh water River discharge is changing seasonally, it might be 50 m^3/sec. or 5 m^3/sec. depending on the discharge flow to the River. Considering the design capacity of the supplying canal (5 m^3/s), the fresh water Rivers' discharge could be less than the water consumption along the River. The dispersion of salt intrusion length may reach up to Garmmat-Ali station when the River average discharge was was5 m^3/sec., but seawater intrusion length is approximately 50 km, which is reached when the average discharge water is 25 m^3/s. If the River discharge was 50m^3/ sec the sea water intrusion was less in the two cases above. The combined effect behavior of mixing between the River discharge changed Q and Q_f c at any point, and this simulation scenarios is expressed in Figure (8).

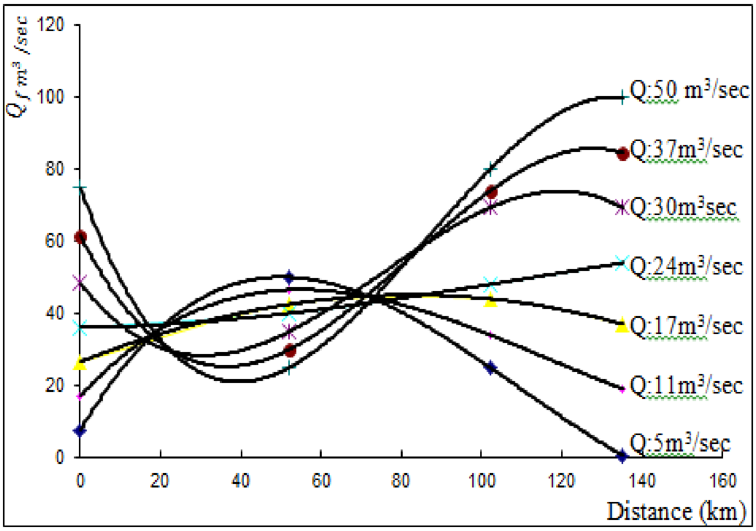

Figure 8. Change of discharge (Q) with (Q_f) along the Shatt Al-Arab River's distance.

The distance is a main factor causing the dispersion of salinity intrusion through the River's water, as there is a distance of 135 km from the mouth of the River to the last station, the salinity intrusion was needs a several time to salinity dispersion intrusion reach to upstream (Fig. 2).

The second factor to rise the salinity intrusion was tide come's from sea. The prediction of salinity with distance suggested a good correlation between field and model application (Table 1), in both discharge cases (5, 50 m^3/sec), R^2 =96% and R^2 =71%, respectively. The correlation is well expressed in Figures (9 and 10).

However, the distance has different effect according to the cross-sectional area, width, and depth (Fig. 5). The relation between the computed cross-sectional areas A, width B, and depth h based on equation (6). According to expression (6), the depth is slightly changed and the average depth h is almost constant.

Table 1. Comparison between the field and model data of salinity in both discharge cases (5 and 50 m^3/sec), of the Shatt Al-Arab River.

Stations	Distance (Km)	Discharge Q=5m^3/sec		Discharge Q = 50m^3/sec	
		Field	Model	Field	Model
Al-Fao	1	32.2	32.44	27.5	27
Al-Seba	52.2	26	24.1	2.2	2.28
Al-Ashar	102	11.7	13.4	1.92	1.73
Bin Ummer	135	1.4	2.9	0.8	0.5

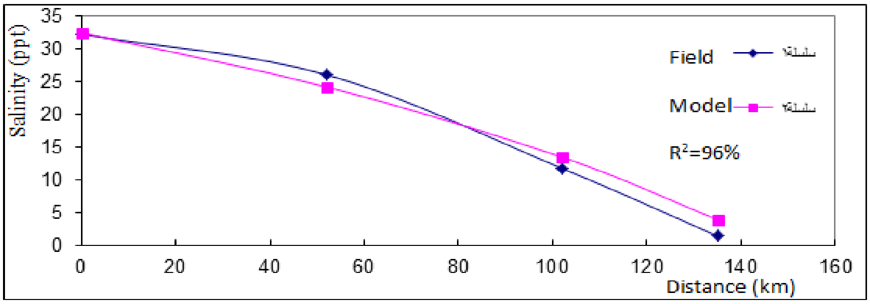

Figure 9. Correlation between field and model salinity at a discharge of 5 m^3/sec, at the Shatt Al-Arab River.

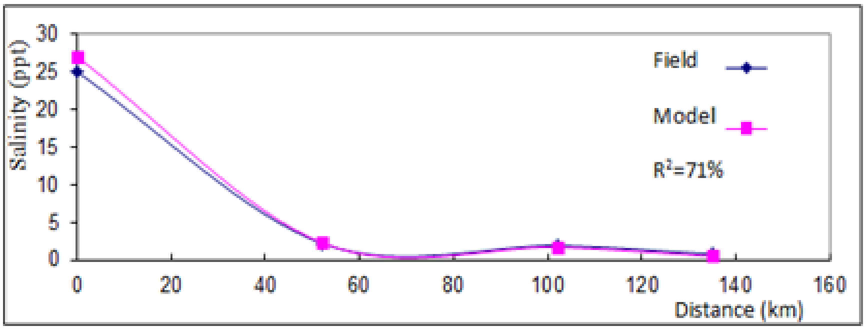

Figure 10. Correlation between field and model salinity at discharge 50 m^3/sec, at the Shatt Al-Arab River.

Empirical Predictive Models:

The empirical models were applied very well in different estuaries, one of these is at HWS situations (Savenije, 2005) ant it is apparent that the predictive model can precisely predicts the salt water intrusion length. The application of the present model to the Shatt Al-Arab River was very good, except beyond the 110 km distance from estuary, due to the interaction between several factors such as artic canal of Kteban village and Garmmat-Ali River.

Conclusions

The main objective of the present modeling is to compute the salinity and seawater intrusion at any time and location so that to assess the influence of the downstream and upstream movements of water in the Shatt Al-Arab River. The application of the predictive model in the Shatt Al-Arab River agreed very well with the field data. The salinity distribution along the River is closely linked with many parameters such as flow regulation and water withdrawals.

For the prediction of salinity along the River, fast and costless model may be built experimentally and mathematically and may be used to estimate the seawater intrusion length. The dispersion of salts in the River was associated with many factors, the salinity corresponds to water released from the Tigris and Euphrates into the Shatt Al-Arab River. The salinity intrusion lengths are plotted against a range of freshwater discharges from 5 m^3/sec to 50 m^3/s, indicating that, the salinity intrusion changed in a non-linear manner with the River discharge. The experimental data, indicate that the seawater intrusion could reached up to 112 km when the discharge was 5 m^3/sec.

Recommendations

The present results suggested that more information about the River's discharge, withdrawals and wastewater lead to improve the performance of the predictive equations in order to apply water management actions to control levels of salinity. Moreover, the wastewater must be treated before returning to the River. Meanwhile, monitoring underground water and water discharge coming from the marshes should be carried out because they provided the River with water, also monitoring of the water sources of salinity along the Shatt Al-Arab river should be done.

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موديل تجريبي للتنبؤ بتوغل الجبهة المالحة في شط العرب, جنوب العراق

مناف قاسم جابر البطاط

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المستخلص - في الدراسة الحالية تم تطبيق نموذج رياضي تجريبي للتنبؤ بتوغل اللسان الملحي على طول شط العرب. أظهرت التحاليل على ضرورة تقديم صورة شاملة لتوغل الملوحة في شط العرب الذي هو ملتقى نهري دجلة والفرات. استندت التحليلات إلى بيانات حقليه من سبع سنوات وامتدت الفترة الزمنية ما بين 2005-2011, بالإضافة إلى دورة مدية كاملة خلال سنة 2009 عندما ارتفعت الملوحة إلى أعلى مستوى لها بسبب انخفاض كمية المياه التي تصل إلى شط العرب من مصادرها حيث لوحظ زيادة الملوحة مع انخفاض تدفق المياه العذبة. خلال فترة الدراسة، كان مقدار التدفق ما بين 5 الى 50 متر مكعب في الثانية, تذبذبت نسبة الملوحة وفقا للتدفق حتى وصلت إلى أعلى ارتفاع لها في عام 2009 عندما كان التدفق 5 متر مكعب بالثانية حيث بلغت الملوحة الحقلية في محطات الفاو والسيبة والعشار وبن عمر 32.2 و 26 و 11.7 و 1.4 جزء بالألف على التوالي, ومن خلال تطبيق النموذج الرياضي التجريبي للتنبؤ بالملوحة على طول منطقة الدراسة كانت 32.44 و 24.1 و

13.4 و 2.9 جزء بالألف. في حين عندما كان التصريف 50 متر مكعب بالثانية، كانت الملوحة الحقلية في هذه المحطات 27.5 و 2.2 و 1.92 و 0.8 جزء بالألف وعلى التوالي، وعند تطبيق الموديل الرياضي على التنبؤ بالملوحة كانت النتائج التي تم الحصول عليها هي 27 و 2.28 و 1.73 و 0.5 على التوالي. ان النتائج التي توصلنا لها من خلال تطبيق الموديل الرياضي التجريبي للتنبؤ بالملوحة على طول منطقة الدراسة في شط العرب انه يوجد تطابق ممتاز ما بين النتائج الحقلية والنتائج النظرية, وهذا الاستنتاج يعزز امكانية استخدام النموذج الرياضي التجريبي للتنبؤ بالملوحة.