Climate Change and Sea Level Rise Impacts on Seawater Intrusion at Jefara Plain, Libya

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Abstract: Almost of population in Libya are concentrated in north part at coastal areas, Jefara Plain located at north western of Libya. Jefara Plain influenced by Mediterranean Sea to the north in coastal areas and arid desert areas to the south near Jabal Nafusa. The main source of water in Libya is groundwater especially in Jefara Plain where 60% out of 6 million are living in the Plain. Current discharge is bigger than the recharge sources so the groundwater resources are not covering the rapid development in the plain. In this study the Numerical modeling was used as an effective tool for managing and predicting groundwater resources, MODFLOW and MT3DMS used to simulate groundwater flow and solute transport in Jefara Plain. Three suggested scenarios for years 1993 to 2040 have been applied in the model, the mentioned numerical model is based on the finite difference (FD), model (MODFLOW 2000) was used to simulate the flow system, and the solute transport model (MT3DMS) used to predict the transport of total dissolved solids. These scenarios include: first, pumping of agriculture assumed constant in this scenario, and the pumping of municipal are varied depending on population demand; second, this scenario studies the impact of sea level rise to seawater intrusion due to climate change without change in the recharge rates; and finally dealing with the extreme impacts of climate change by combining both the maximum rates of sea level rise (59 cm/100 yr.) and the minimum recharge rate (-10%). Results indicate that the third scenario has biggest effect on the drawdown and seawater intrusion extent. Different parameters including TDS, recharge, model boundary and advection parameters were adjusted to run the model. The third scenario caused a slight increase of TDS values over the values simulated by other scenarios.

[A.M.S. Gejam P. H. S. Riad, M.A. Gad, K. A. Rashed and N. A. Hassan. **Climate Change and Sea Level Rise Impacts on Seawater Intrusion at Jefara Plain, Libya.** *Nat Sci* 2016;14(3):75-81]. ISSN 1545-0740 (print); ISSN 2375-7167 (online). http://www.sciencepub.net/nature. 11. doi:10.7537/marsnsj14031611.

Keywords: Jefara Plain, Groundwater, Modflow, MT3D, TDS, SWI, Abstractions

1. Introduction

In Libya there is no perennial surface water, so the groundwater is the main source of water, population are concentrated in the north near the coast where the climate is affected by Mediterranean Sea and mean temperature is 18c^0. 60% of Libyan population are living in Jefrar Plain. The total discharge from the groundwater in Jefara Plian estimated to reach 767 Mm^3/yr in the year 1993 (NCB, MMD, 1993), which is bigger than the safe yield of the recharge (165 Mm^3/yr.). Absence of control from Government in pumping rates in both private and authority wells resulted in huge drawdown and deterioration of groundwater quality in coastal area especially in Tripoli.

There are two aquifers in Jefara Plain, unconfined and confined, the unconfined aquifer constitutes the main source of agriculture productions and municipiality. Many studies carried out to evaluate seawater intusion in Jefara Plain, (Cederstrom & Bertiola, 1960; Ogilbee, Vorhis and Dghies, 1962; GEFLI, 1972; Navarro, 1975; Pencol, 1978; Floegel, 1979; Krummenacher, 1982; NCB & MMD, 1993; Office of Researches and Engineering Consultants, 2002), these studies indicated that the groundwater flow before 1975 was from south to north, after that extraction of huge quantities of water from unconfined aquifer due to the rapid increasing of agriculture and municipality requirements resulted changing of the hydraulic gradient direction causing seawater intrusion.

Seawater intrusion observed in the last fifties (1957) in east of Tripoli.

2. Description of study area

Jefara Plain located in north western of Libya, the Plain is nearly flat area near the coast, and the elevation increase gradually from north to south, the Plian bounded from north by Mediterranean Sea and from south by Jabel Nafusa and stretched from Tunisian board in west to Alkhums in east as shown in (Fig.1). Jefara Plain divided into three different parts: the coastal strip in the north, the central parts and the foot of Jebal Naffusah (mountain) in the south. The elevations near the coast varied between -3 m and 100 m, in the south reach about 400 m above mean sea level and 700 m at some parts at Jebal Naffusah.

The land use in the study area is dominated by agriculture. More details are clarified in (Fig.2).

2.1 Geology & Hydrogeology

The aquifers include significant amounts of water in Jefara Plain have been classified by Krummenacher (1982) as shown in table (1).

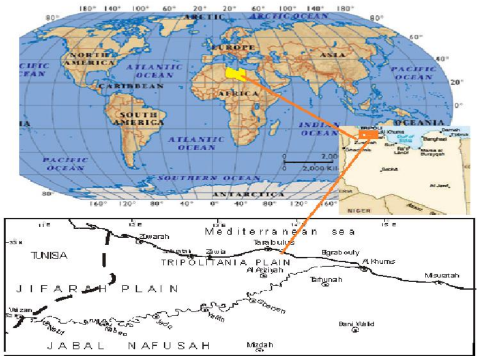

Fig.1: Location of Jefara Plain

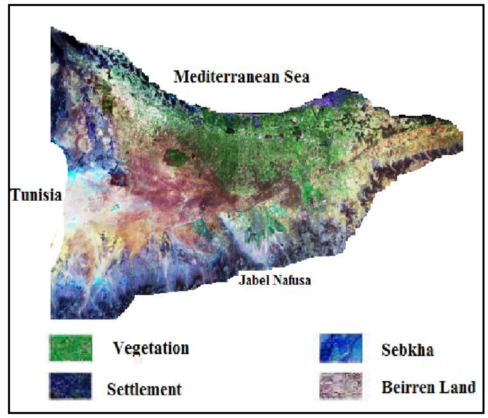

Fig.2: Landuse Patterns in Jefara Plain (Trriki, 2006)

Tab.1: Classification of aquifers in Jefara Plain (Krummenacher, 1982)

Group	**Predominate**	**Comment**
Miocene-Quaternary	Sands, sanstone and sandy limestone	The main aquifer of Jefara Plain; unconfined
Oligo-Miocene	Calcareous sandstones	Significant confined aquifer in the north of Jefara Plain
Group	**Predomintal**	**Comment**
Cretaceous	sandstone and limestone	the main aquifers of this group are the Sidi As Sid limestone which is unconfined aquifer
Jurassic	Detrital limestones and sandstones	Significant source of water at the foot of Jabel Nafusa
Triassic	Limestone and sandstones	The main aquifers of this group are the Aziziyah limestone and the Abu Shaybah sandstone and clay; important source of water in Central Jefara

Many studies were carried out to determine the groundwater resources in Jefara Plain, these studies mentioned that groundwater in northern Jefara Plain is tabbed from the Quaternary as well as from the Miocene rocks. A Miocene deposit consists of several important aquifers; depth to water table ranges from 141-450 m. fig.3 represents the hydrogeological section of Tripoli.

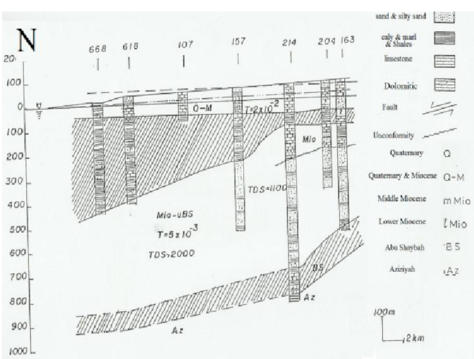

Fig.3: Tripoli hydrogeological section (Kruseman and Floegel, 1978)

The Miocene-Quaternary unconfined aquifer is the main and important source of groundwater in Jefara Plain which is located to the north of Al Aziziyah fault, thus constitute the main source of irrigation and domestic supplies in Jefara Plain, Miocene Aquifer located north of Al Aziziyah fault, this aquifer consists of limestone, sandy limestone, dolomitic limestone, and clay. Thickness of this aquifer varies from few tens of meters in the east (near Garabulli) to several hundred meters in the west (near Sabratah). Transmissivity varies from 7 to 337 m2/d (GEFLI, 1972). Clay layers separate this aquifer from the quaternary and lower Miocene aquifers, Abu Shaybah Aquifer located at depth ranges between 300-700 m and consists of thick layer (125-450 m) of sandstone, which intruded with clay and shell. This aquifer has good yield (sometimes more than 100 m3/h). The depth to water table is not fixed and affected by extensive abstraction, and Al Aziziyah Aquifer is confined except in the south central part between the southern limits of the Miocene transgression and the foothills of the Jebal Neffusah and is rather deep seated; around 1000 m below ground in the Tripoli area and located under Abu Shaybah formation rocks. It is located to the north of Al Aziziyah fault and consists of dolomitic limestone, limestone, and dolomite with intruded by clay and marl.

A typical section taken from north to south by Krummenacher (1982) showing more details for the mentioned aquifers as shown in fig.4

2.2 Hydrochemistry

The data used in hydrochemical analysis collected from more than 198 wells over the basin (NCB & MMD, 1993). The values of TDS (mg/l) imputed to GIS and extracted as shown in figure 5.

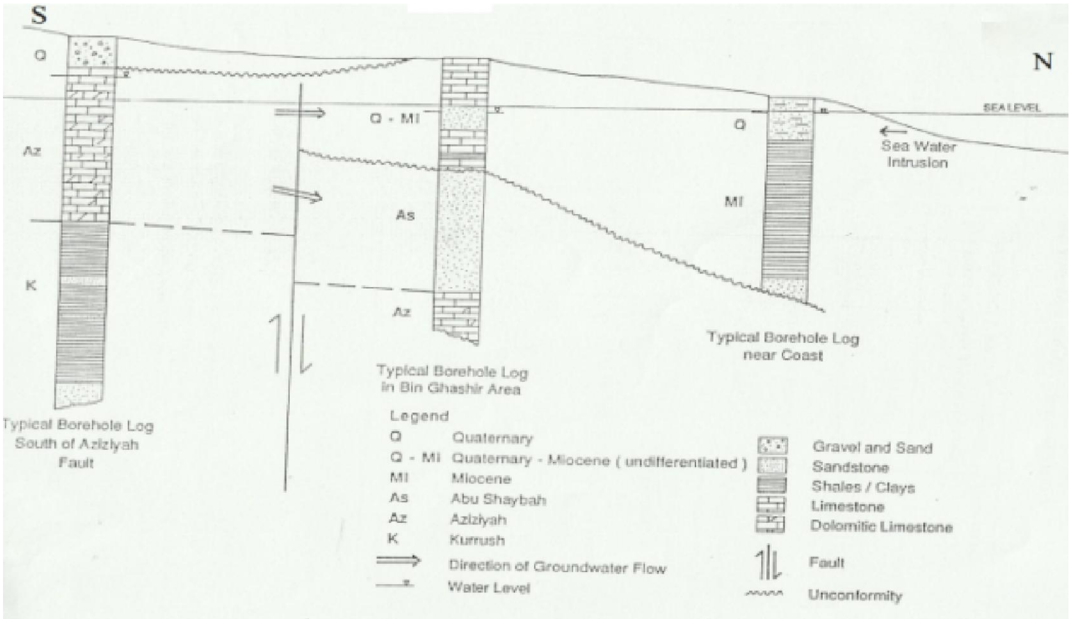

Fig.4 typical cross section from north to south of Al Aziziyah fault (Kruseman and Floegel, 1978)

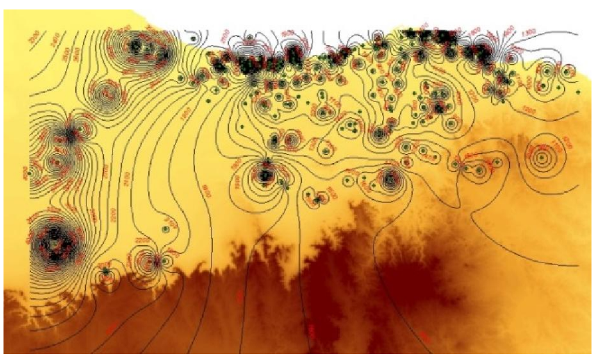

Fig. 5 Distribution of TDS contours over Jefara Plain

2.3 Recharge & Discharge

The main source of recharge to Jefara plain aquifer system comes from direct rainfall, (Pencol, 1978 & Krummenacher, 1982), the estimated recharge is between 5-15% of the rainfall, other sources of recharge are irrigation losses, water supply networks losses, and surface water recharge.

Table (2) estimated of the recharge value in Jefra Plain aquifer system by NCB & MMD (1993)

Recharge source	Volume Mm^3/yr.
Rainfall	83.9
Surface runoff infiltration	9.7
Irrigation and municipal losses	76.9
Total	165

NCB & MMD (1993) estimated the total recharge to Jefara Plain aquifer system as clarified in table (2) per year.

Historical annual estimation of groundwater abstraction from Jefara Plain presented in table (3).

Data from table (3) have been interpolated as shown in figures (6) & (7) and the abstraction rate from Jefara Plain groundwater determined.

Table (3) (Elgzeli, 2010)

Date of estimation	Author	Agriculture use Mm^3	municipal use Mm3	Total Mm3
1959-1962	USGS	195	15	210
1972	GEFLI	313	65	378
1975	GEFLI	475	92	567
1978	SDWR	461	94	555
1980	GEFLI	483	91	532
1993	FAO	802	200	574

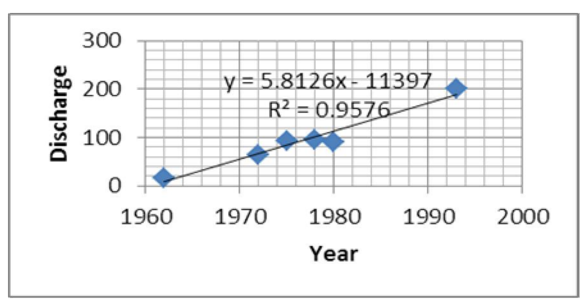

Figure (6): interpolation of abstraction rate from 1962 to 1993 (municipal).

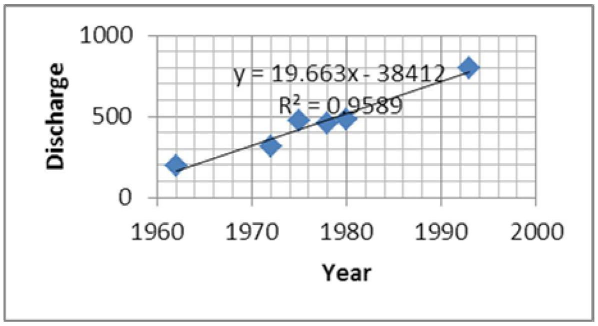

Figure (7): interpolation of abstraction from 1962 to 1993 (agriculture).

3. Model description, calibration and application

3.1 Model Description

The conceptual model for Jefara Plain Basin adapted by this study consists of three hydrogeological layers, two aquifers and a confining layer. The unconfined aquifer is taken as the first layer, followed by the confining layer as the second layer. The third is the confined aquifer. Interaction between the various aquifer systems is represented by leakage terms. These layers in addition to the surrounding boundaries are distinguished from each other by the hydraulic conductivity for each element in its field. First layer forming the unconfined aquifer, which consists of Quaternary, and Miocene deposits, hydraulic conductivity of this aquifer varying between 5-15 m/d, and specific yield varying between 4-10%. Third layer forming the Triassic deposits of the Abu Shaybah and Aziziyah aquifers.

The model domain consists of 111 rows, 195 columns and three layers, grids used in this study are the same for both the flow and transport model. Model covered an area of 21,462 km^2 for whole Jefara Plain.

Constant head boundary is only specified in cells representing the sea in all layers. Constant head boundary is in the north (sea), and south of the domain. The topographic elevation of Jabel Nafusa in the south defined the constant head where flow comes from this side. No flow boundary conditions are in the east, and west.

3.1.1 Governing Equations

The partial-differential equation of ground-water flow used in MODFLOW is (McDonald and Harbaugh, 1988)

$$\frac{\partial}{\partial x}\left(k_x\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left[\left(k_z\frac{\partial h}{\partial z}\right) + W = s_s\frac{\partial h}{\partial t}\right.$$

Where

kx, ky, and kz are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T), h is the potentiometric head (L), W is a volumetric flux per unit volume representing sources and/or sinks of water, with W<0.0 for flow out of the ground-water system, and W>0.0 for flow in (T^{-1}), Ss is the specific storage of the porous material (L^{-1}); and t is time (T).

In steady state calibration the first part of previous equation was used as following:

$$\frac{\partial}{\partial x}\left(k_x\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left[\left(k_z\frac{\partial h}{\partial z}\right) + W=0\right.$$

In addition to the flow equation, a second partial differential equation is required to describe solute transport in the aquifer. Ground-water flow causes the redistribution of solute concentration, and the redistribution of solute concentration alters the density field, thus, affecting groundwater movement. Therefore, the movement of ground water and the transport of solutes in the aquifer are coupled processes, and the two equations must be solved jointly (Guo and Langevin, 2002).

$$\frac{\partial C}{\partial t} = \nabla.(D.\nabla C) - \nabla.(VC) - \frac{q_s}{\theta} C_s + \sum_{k=1}^{N}(Rk)$$

The above partial differential equation describes the transport of solute mass in ground water

Where:

D: is the hydrodynamic dispersion coefficient [L^2 T^{-1}],

V: is the fluid velocity [L T^{-1}],

Cs: is the solute concentration of water entering from sources or sinks [ML^{-3}], and

Rk: (k=1, …, N) is the rate of solute production or decay in reaction k of N different reactions [ML^{-3} T^{-1}].

3.2 Steady State Calibration

Numerical modeling has emerged as an effective tool for managing groundwater resources and predicting future responses, especially when dealing with complex aquifers systems and heterogeneous formations. Among these models, MODFLOW and MT3D are the most commonly used simulators for groundwater flow and solute transport in subsurface systems, respectively (W. Y. Abu-El-Sha'r & R. I. Hatamleh 2007).

MODFLOW and MT3D models used herein as a management tool for the Jefara Plain basin, one of the most important groundwater resources for domestic and agricultural sectors in Libya.

3.2.1 Steady State Calibration using MODFLOW2000 of 1993 year

Steady state calibration for the flow model was achieved by comparing the hydraulic heads obtained from available groundwater levels of the upper and lower model layers and the calculated hydraulic heads of the MODFLOW, data for 1993 from GWA used to calibrate the head in observation wells. Simulation time for steady state was 365 days. During calibration, horizontal and vertical hydraulic conductivities values were adjusted in sequential model runs to match the simulated heads and measured head. Figure (8) compares the simulated results with the observed water level values. The modeled values show a correlation coefficient of 0.99 with the observed values. The calibration results for the groundwater heads for the steady state models are regarded as satisfactory with a RMS value of 2.37 m.

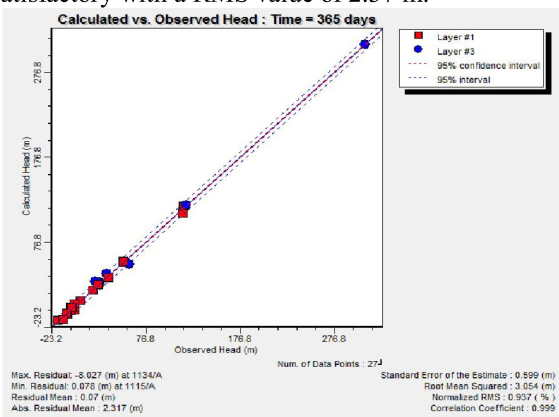

Figure (8): Steady state calibration results (head)

3.2.2 Solute Transport Mdel

Constant concentration cells were assigned along the sea line to the north as 35000 mg/l, and to the south varied from 2500-1500 mg/l depending on distribution of contour lines from data introduces to GIS.

Recharge concentration specified as 1750 mg/l where the area effected by irrigated & municipal recharge water, and specified as 640 mg/l in the area affected by rainfall & surface runoff recharge (NCB &MM 1993),, and Specific concentrations assigned to each domestic well location to reflect the actual conditions. Figure (9) compares the simulated results with the observed concntration values. The modeled values show a correlation coefficient of 1.00 with the observed values. The calibration results for the groundwater concntration for the steady state model are regarded as satisfactory with a RMS value of 29.87 mg/l.

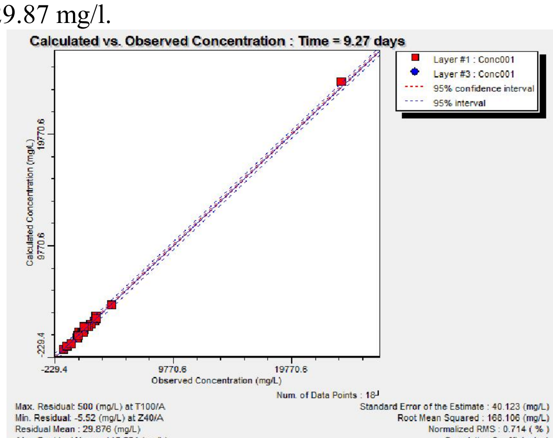

Fig.(9) Steady state calibration results (TDS)

3.3 Model Verification

The data observed by GWA in 2010 and 2002 for head and concentration respectivily compared to the data introduced by model as shown in tables 4&5.

Table 4. verification of head values 2010

Well No	GWA 2010	model 2010
1054	-3	-2.5
1006	-40	-41
1311	-10.67	-10
1057	-18	-11
1134	15	22
1115	119	122
1194	309	301
1020	7	6
1344	36.6	36.12
1054	-3	0

Table 5. Verification of TDS values 2002

well	x	y	Observed	calculated
T23	323100	3633200	947.2	751
T24	333700	3641000	3110.4	3040
T50	340300	3639350	2880	2500
T60	350200	3638950	3436.8	3281
T100	304200	3632000	34352	32372
T203	315350	3632350	691.2	539
T403	335850	3639050	2771.2	2607
Z20	258900	3632400	3993.6	3762
Z100	257500	3633600	2816	2607
T10	301040	3631000	2291.2	2376
Z40	275600	3629400	3417.6	3508
Z52	289300	3629600	2156.8	2444
Z302	273100	3629300	4288	4942
Z400	282900	3630200	5856	6130
Z501	294100	3630200	2368	2590

3.4 Model Predictions

Model predictions have been conducted in order to evaluate the response of the model for three future scenarios. These scenarios have same pumping rates for the different operating well groups in the basin as follows: the first scenario assumes pumping rate of agriculture requirements constant, and the pumping rate of municipality are varied depending on population demand. This scenario approximately represents the actual situation because the agriculture area did not increase due to increasing commercial activities against agriculture activities; the second scenario, studies the impact of sea level rise to seawater intrusion. According to IPCC (2007), the maximum expected sea level rise for the Mediterranean Sea is 5.9 mm/yr.; in the third scenario, considering the impacts of climate change by combining both the maximum rates of sea level rise (59 cm/100 yr) and the minimum recharge rate (-10%)

(IPCC, 2007).

Figure (10) shows the in-land seawater intrusion due to all scenarios.

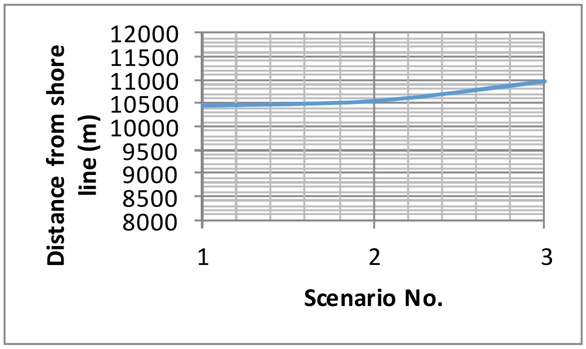

Figure (10): In-land Seawater Intrusion for all scenarios at Ain Zara section.

The maximum drops in GW levels values for all scenarios considered are given in Table (6). These indicate that the third scenario has biggest drops. Also the first and second scenarios have similar effect on GW drops. Among the three scenarios considered, the third scenario has the worst effect on drawdown values.

Table 6: Maximum simulated GW levels for the three scenarios.

Scenario No.	Year	Max Draw Down(m)
Scenario No.1	2020	-117
	2040	-128
Scenario No.2	2020	-117
	2040	-128
Scenario No.3	2020	-120
	2040	-145

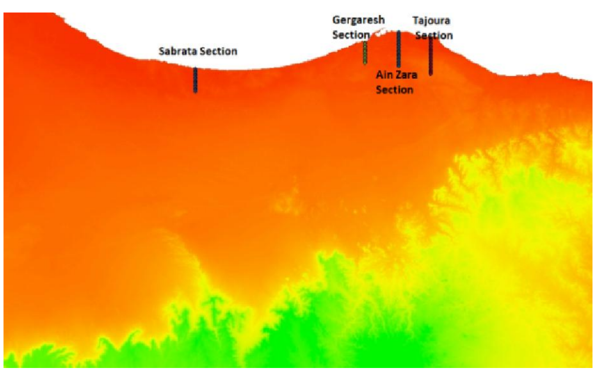

Figure (11): Distribution of sections over Jefara Plain.

4. Results

The main concern in this study is seawater intrusion affecting the groundwater quality due to excessive pumping, sea level rise and climate change.

Four sections were distributed over the coastal area using DEM in GIS, three of them are applied to Tripoli in Gergaresh (west), Ain Zara (middle), and Tajoura (east) and the last one applied over the western part of Jefara Plain calles Sabrata section as mentioned in figure (11).

The models used in this study, MODFLOW 2000 and MT3D, provided an effective tool managing Jefara Plain aquifers by evaluating the effect of the different alternatives under consideration. Simulation results indicate that:

- The most critical scenario for the extent of seawater intrusion is scenarios No. 3 since this scenario will cause an extent rate about 151 m/yr., while the extent rate of scenario 1 by actual pumping rates was 140 m/yr.
- In Tripoli area the worst scenario for the unconfined aquifer is scenario No.3 where the inland seawater intrusion reached 10961m, and 2600 m in confined aquifer.
- The total dissolved solids due to seawater intrusion decrease by increasing the distance from sea shoreline with the involvement of two factors; the first is the location of the well from the sea shoreline, and the second is the depth of the well from the ground surface.
- Decreasing pumping rates by 50% will decrease concentrations between 10% and 40% as compared to the reference scenario.
- Increasing pumping rates by 100% will cause increasing in the concentrations between 3% and 22%, depending on the well distance from sea shoreline.
- There is small effect of sea level rise in seawater intrusion, the extent in scenario No.1 was 10444 m while in scenario No.2 (sea level rise involved) was 10538 m (+1%), (up to 2040).
- Decreasing recharge rates by 50% will cause an increase in total dissolved solids in the wells with a range between 5% and 30% compared to reference scenario. Increasing recharge rates will decrease the concentrations between 7% and 66%.
- By combining the two climate change elements; maximum sea level rise and the minimum recharge rates as in Scenario 3, we found that the increasing range of concentrations will be about 2.5% and 6% as compared to the reference scenario (scenario No.1).
- In-land intrusion rate was found to be 143 m/yr as recharge decreases by 50% and 141 m/yr as pumping rate increases by 100% (nearly same).
- In all scenarios the area south of Tripoli in Bin Ghashir and Al Swani are dried up for an unconfined aquifer.
- Increasing pumping rate decreases the head in both aquifers, and vice versa.
- The maximum inland seawater intrusion in unconfined aquifer at Tripoli area happened at Ain

Zara section, while the minimum inland seawater intrusion happened at Gergaresh section.

- The maximum inland seawater intrusion in confined aquifer at Tripoli area happened at Tajoura section.
- No seawater intrusion observed at confined aquifer in Gergaresh section (Tripoli area) and in Sabrata section (western of Jefara Plain) for all periods of model running.
- The maximum drops in GW levels values for all the scenarios indicated that the third scenario has the biggest effect on GW lowering.
- For any management plan to be successful for Jefara Plain, pumping from both municipal wells and agricultural well must be addressed. This is due to the fact that they both have high impacts on water table elevation especially in Tripoli area that has negative heads.

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2/28/2016