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Modelling of Groundwater Pumping Scenarios and their Impact on Saline Water Intrusion in a Tripoli Coastal Aquifer, Libya

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ABSTRACT

Tripoli coastal aquifer, Libya, which is located in a densely urbanised area, is the primary source of water supply in Tripoli city. In the last few decades and due to population growth, more than 100 wells have been drilled in Tripoli aquifer for the purpose of increasing pumping to meet demand on groundwater. The urbanisation at the Tripoli upper aquifer system has reduced the recharge rates and affected the groundwater storage. In this study, changes in groundwater dynamics in Tripoli's unconfined aquifers were simulated using MODFLOW-2005 code. The model was calibrated and validated using measured and simulated values. Statistical tests such as coefficient of determination, R^2 mean error, mean absolute error, and the root mean square error were computed and found to be 0.97, 0.31, 1.70 and 2.32 respectively. The simulation will assist in the assessment of the long term saline water intrusion. Calibrated transient groundwater flow models for the years 2020 – 2100 indicated that this case is likely to occur along pumping profiles with high pumping rates. Simulation results show that the groundwater levels will decline and exceed 12 m in the Southern area while in the Northern area near the coastal line, depletion is continuous and more than 70 wells will face saline water intrusion by the year 2100. Doubling the pumping rate from the wells will accelerate the drop in the groundwater levels and about 98% of the wells will be subjected to high salinity level by 2100. The salinity levels in these wells will make the groundwater unfit for human consumption.

Keywords: Groundwater levels, MODFLOW-2005, saline water intrusion, simulation, tripoli aquifer

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INTRODUCTION

Libya is a Mediterranean country with a shoreline of approximately 1,900 km and with its population concentrated in the coastal areas (Sadeg & Karahanoðlu, 2001). Groundwater is a limited resource constraining the economy and agricultureal development. This resource is becoming scarce in Libya in light of the fact that it is the primary source for potable, industrial, and irrigation water. Increasing demand of groundwater coupled with population growth has affected groundwater availability and caused it to be over-pumped since the early 1960s. Data show that deamds on groundwater were 6 M.m^3 in 1930; 25 M.m^3 in 1960; 140 M.m^3 in 1980 and 150 M.m^3 in 1990. Also, the demand was 250 M.m^3/yr in 2002. The data shows continuous increase in demand on groundwater and this increase is covered by increasing the pumping rate from the wells (Bashir, 2018).

This continuous over-pumping causes extensive seawater intrusions far inland which have led to the deterioration of groundwater quality. In the past few decades, there have been many studies done on seawater intrusion in northern Libya. Cedestrom and Bertiola (1960) reported that the drop in water levels was marginally near to the coast in the northern parts of the country, while, it reached about 13 meters in the area of Qasr Ben Ghashir. Nair et al. (2006) recommended that the groundwater in North-East Libya was suitable for drinking while that in Susa area was excessively polluted by mixing with seawater and it became unfit for drinking. Jumma et al. (2012) found that the maximum TDS of the groundwater in Derna (North-East Libya) was 8000 mg/l. The high TDS concentration in the area is mainly due to sea water intrusion. Kumar et al. (2012) assessed the quality of the groundwater at Al-Khums city, Libya and they found that the TDS concentration were ranged between 1851 mg/l and 10852 mg/l. These values are higher than the concentration recommended by Libyan standards for drinking water (acceptable TDS= 500 mg/l while the allowable TDS≤ 1500 mg/l). Gejam et al. (2016) reported that the Jifara plain aquifer was suffering from sea water intrusion and the groundwater pumped from the plain was not suitable for drinking. Based on laboratory study, Al Farrah and Walraevens (2018) showed that the groundwater in Jifara plain was severely polluted by sea water. Continuing increases in water consumption have resulted in significant declines in water levels that can affect the direction of groundwater flow. The region along the shoreline from Az Zawiah to Tajura to a depth of 2 km is documented to be exposed to seawater intrusions (Food and Agricultural Orgnaziation, FAO, 1979). Seawater intrusions can be detected from the shape of the shoreline along the coast where the most severe impact has been recorded (Khmaj et al., 2014). In excess of 2.64 mill.ha of land in Libya are suitable for agriculture, but, only approximately 470,000 ha are cultivated annually (Secretariat of Economy Planning-Tripoli, Libya. 1993). The reason for such a vast area of potential agricultural land being left unused is the acute shortage of reliable water supply and also the deteriorated quality of the groundwater in the aquifers. Groundwater resources in Libya are limited (Shanan, 1992; Sloggette & Dickason, 1986). The sensitive exploitation of a coastal aquifer usually creates issues of quantity and quality (Geological and Mining Institute of Spain, GMIS, 2003). Libyan coastal aquifer water levels swiftly dropped following the introduction of diesel pumps in the late 1950s. In Jifara plain, the average declining rate in groundwater level in 1972 was 0.5 m/year while that in 2005 was 2.3 m/year (General Authority of Environment, 2006). Consequently, they are now badly affected by seawater intrusions. Seawater interface has extended 1-2 km inland with significant salinity increases from 150 ppm to approximately 1000 ppm during the period 1950 to 1990 (El Asswad, 1995).

Meludi and Werynski (1980) investigated the seawater intrusions in a main aquifer supplying Tripoli with water resources since 1970, and reported that seawater intrusions were moving inland and were increasing due to groundwater over pumping. Krummenacher (1982) presented a digital simulation model on the basis of Thyson-Weber finite difference method for the Jifara Plain. His model was employed for the prediction of future groundwater availability and quality in the studied Plain (Sadeg & Karahanoðlu, 2001). The Jifara coastal area has been experiencing significant occurrences of drought for the last 20 years. The subsequent water shortage was compensated for by increased extraction from aquifers. Thus, aquifers in the vicinity of coastal areas are most endangered as they are marked by a very strong bore hole density due to extreme over-exploitation (DGR, 1995). The Jifara Plain has been a traditional agricultural area but in the past, irrigation rarely used groundwater. However, since the 1969 revolution, the total impact of significant population growth, extensive economic development, and the implementation of various agriculture and aquaculture projects in the plain has been significant on the groundwater situation. The salinisation and pollution of groundwater has been studied using many different approaches. This study demonstrates the dynamics and processes that control groundwater quality in the Upper Miocene-Pliocene-Quaternary aquifer of the coastal area of Jifara along with the potential seawater intrusion points. The declining water level has caused a significant level in saline water intrusion which reflects the rise in salinity content of the groundwater along a coastal aquifer. Previous studies have indicated that Na Cl concentration has increased dramatically along well profiles, especially those with high pumping rates.This study aims to model the dynamics of the groundwater system under different scenarios of current pumping, and future increase or decrease of pumping rates by assessing groundwater levels.

All scenarios point to the fact that the increase in pumping rate will lead to a dramatic increase in saline water intrusion and the vulnerable areas affected by the intrusion will be defined and considered as the most affected areas.

DESCRIPTION OF THE STUDY AREA

The study location encompasses sections of the coastal area of the Jifara Plain in northwestern Libya. It is a rectangular-shaped area of approximately 763 km^2, between the Mediterranean Sea and the cities of Swani and Bin Gashir in the South (Figure 1). The Jifara Plain itself is a triangle-shaped flat area of about 20,000 km^2, in which the topographical distribution varies from 0 m asl at the coast to reach 140 m asl in the Southeastern parts (Figure 2).

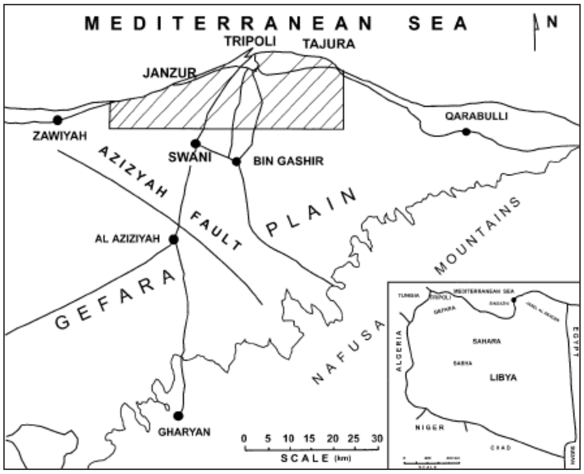

Figure 1. Location of the study area

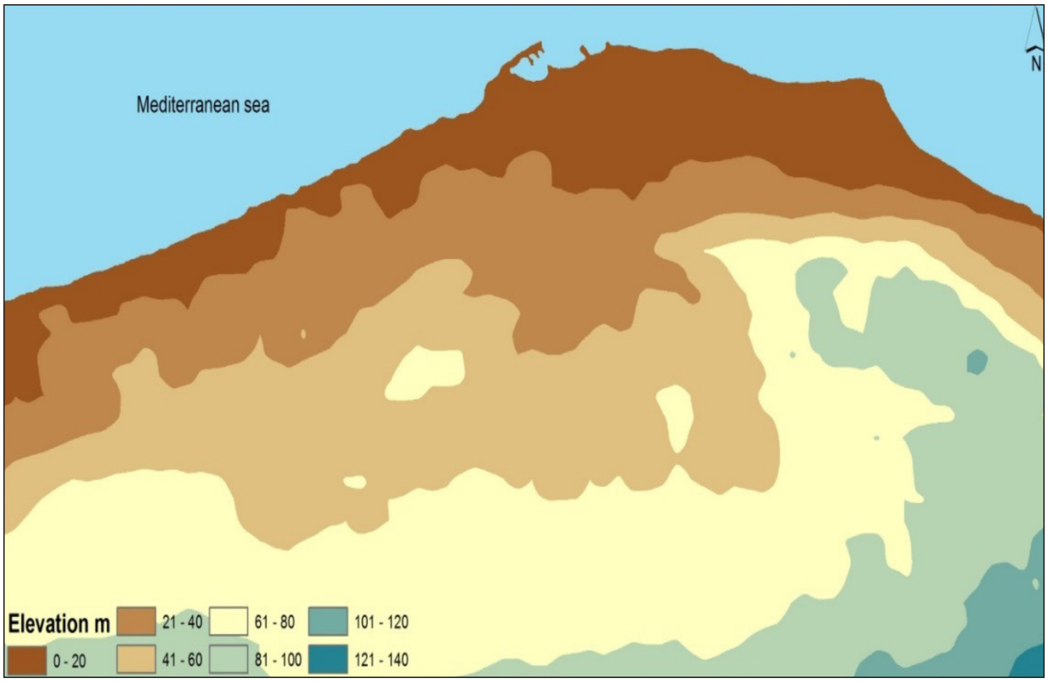

Figure 2. Elevation distribution over the study area

It has the Mediterranean Sea in the North, the Tunisian border in the West and Jebal Naffusah border in the South and East. Climatically the region is semi-arid, Mediterranean, with irregular annual rainfall (Figure 3); the mean annual rainfall is approximately 250 mm. In the study area, the mean annual recorded temperature is about 21.1^{o}C. The Mediterranean climate is most dominant in the coastal areas where this study is focused (with hot, dry summers and moderately warm winters). The rain falls between November and April, with high rainfall recorded in the coastal region in comparison with the Southern elevated region. The estimated recharge rates are illustrated in Figure 4. Corresponding to rainfall; recharge

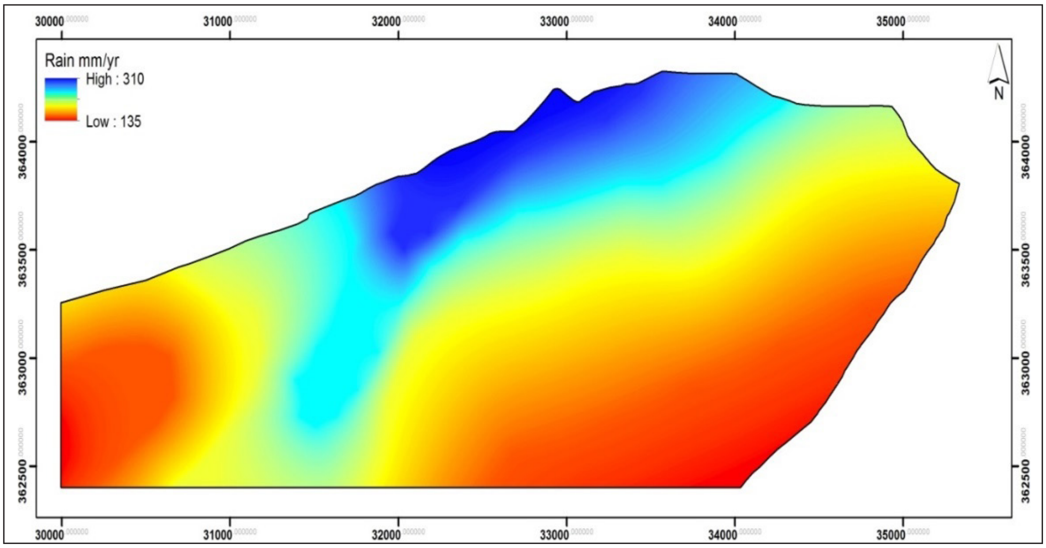

Figure 3. Rainfall rates of study area

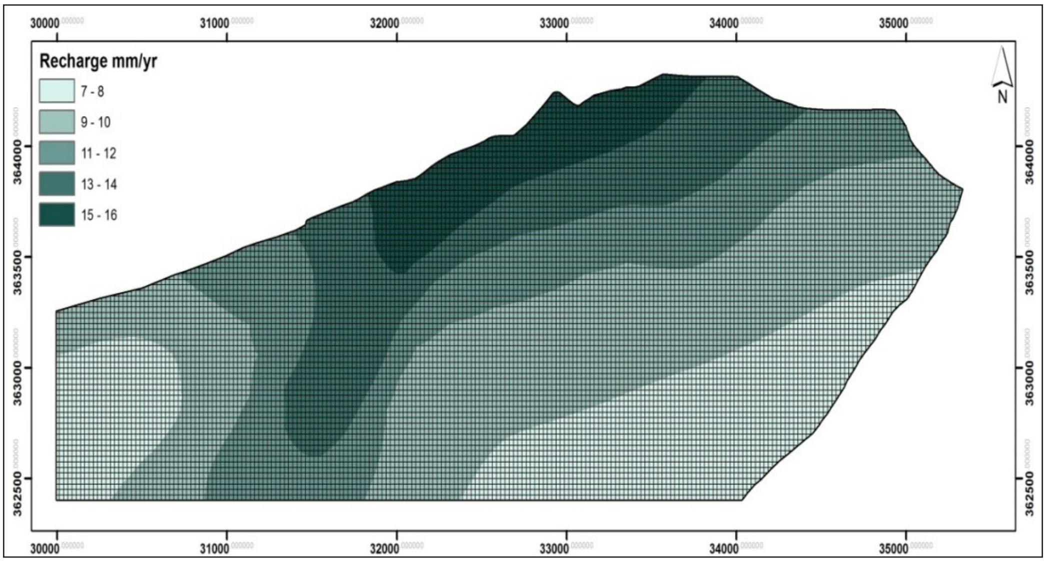

Figure 4. Distributions of recharge rates in the study area

rates are distributed through a range of 7-16 mm/yr. The total abstraction amount from the aquifer wells was 70 M m^3/yr as calculated based on the records of wells obtained from the field with a mean abstraction rate for each well of about 15-20 m^3/hr. The data were used as initial condition and calibration data for the development of a numerical model.

GEOLOGICAL SETTING

Jifara Plain sediments are of early Mesozoic age, deposited in a near shore lagoonal environment. The plain is structurally dominated by EW faults. The main faulting system of the Jifara Plain is significant to the hydrogeology of the area, especially in relation to the Upper Cretaceous and Tertiary water bearing formations and the great Triassic aquifer (General Water Authority, GWA, 2006). Figure 5 shows the geological map for central Jifara.

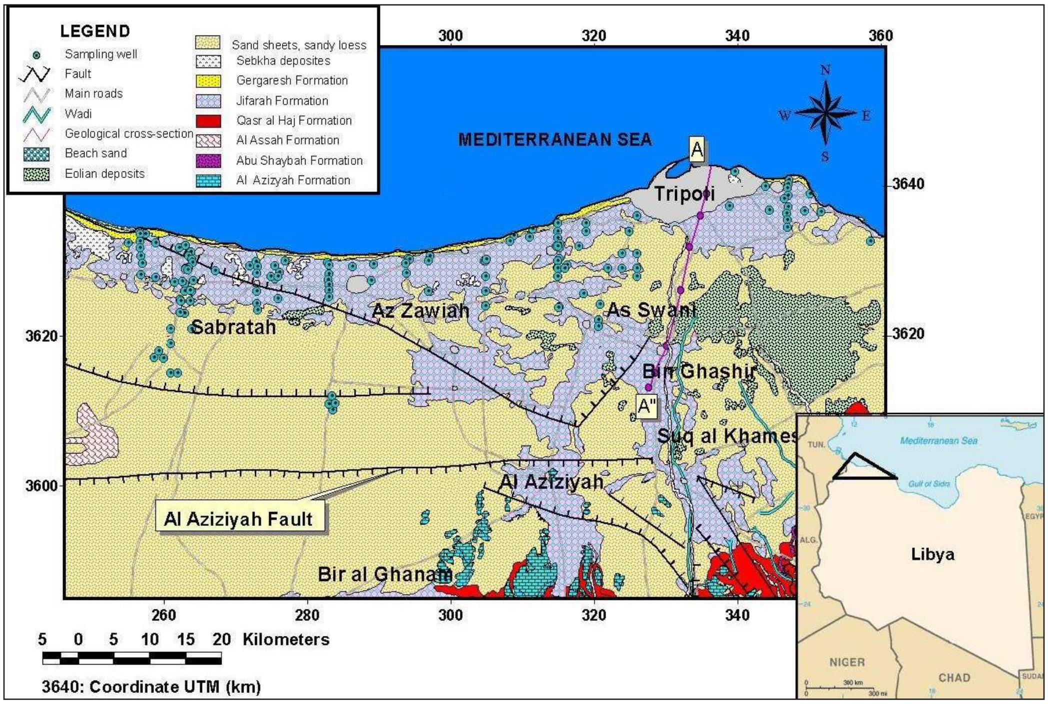

Figure 5. Geological formations in the study area (Al Farrah et al., 2011)

The geological substratum, which has a role in the hydrogeology of the plain, consists of the Middle Triassic (Al Aziziyah Formation, comprising mostly bedded limestone) and the Upper Triassic (Abu Shaybah Formation, comprising continental sandstone). All post-Triassic Formations were subjected before the Miocene sedimentation. Consequently, the Miocene, that covers about two thirds of the coastal plain, overlays the Abu Shaybah deposits directly, except for some minor down-faulted blocks South West of Al Aziziyah area where the Lower Cretaceous Kiklah Sandstone and the Upper Cretaceous Ayn Tobi Limestone are evident in some locations. East and South of Tripoli, the whole series from Miocene to Quaternary are of clayey sandstone with clay lenses intercalated at different depths; the lower clayey unit is lacking and the Lower Miocene aquifer is in hydraulic continuity with the Sandstone formation of Abu Shaybah.

HYDROGEOLOGICAL SETTINGS

Figure 6 illustrates a hydrogeological cross-section through the Jifara Plain. The principal aquifer used by the population in the Jifara Plain is the Upper Miocene-Pliocene-Quaternary aquifer system, called "first aquifer" or "shallow aquifer" or "upper aquifer"; intercalated

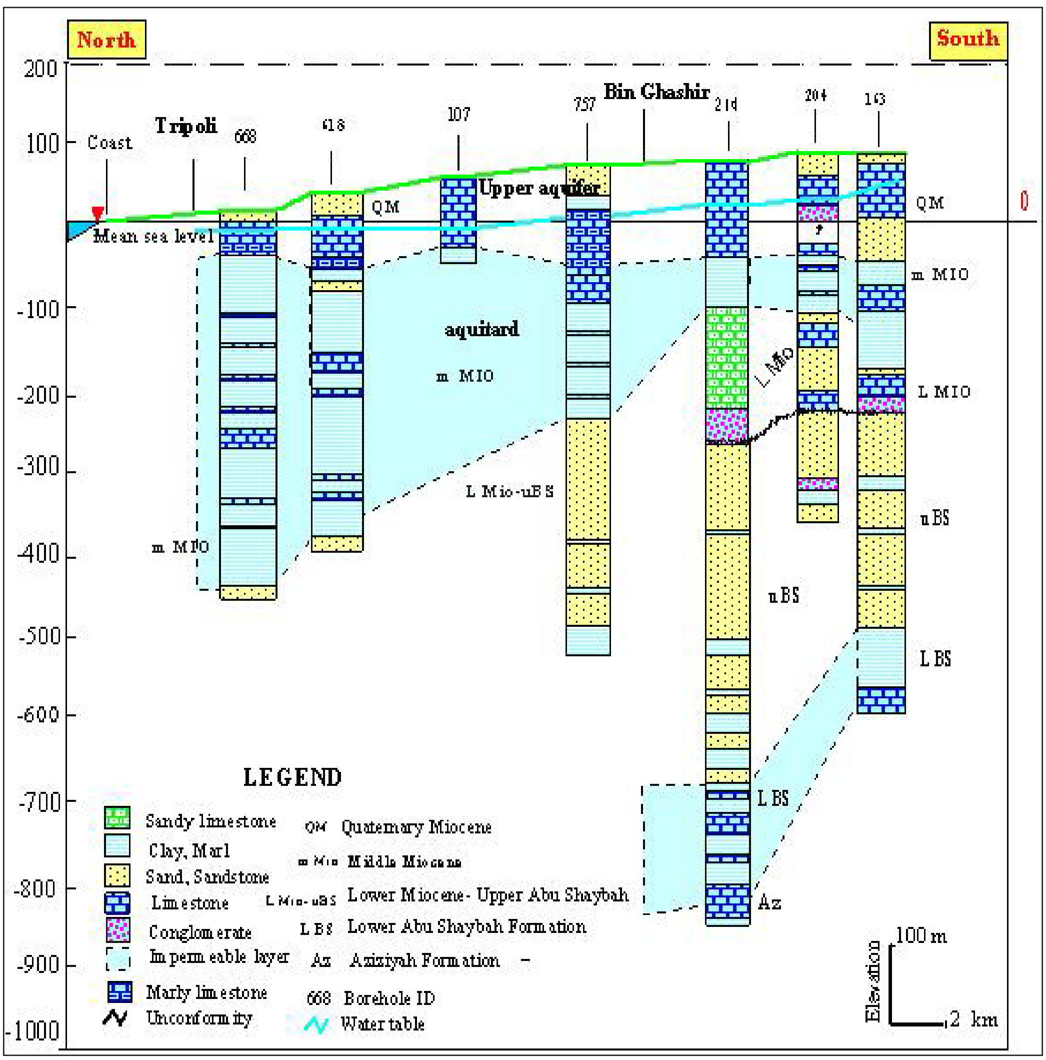

Figure 6. Hydrogeological cross section "A-A" through the Jifara plain (Al Farrah et al., 2011)

with thin clayey sand and marl series partitioning the aquifer into a series of horizons, all of which are regarded as one unconfined entity. Middle Miocene clay separates it from the lower aquifers.

The upper aquifer comprises a number of formations of uncertain age. Al Assah Formation is made up of silt, sand and gravel with local occurrences of crystallised gypsum and associated with the Pliocene-Quaternary deposits. It includes extensive parts of Western Jifara and only a small portion is involved in the studied area of central Jifara. The Pleistocene formations include terraces, of cemented gravel and conglomerate.

Qasr Al Haj Formation is mainly alluvial fans and consists of elastic materials derived from the scarp. Jifara Formation is made up mostly of fine materials, much of which is silt and sand, occasionally with gravel caliche bands and gypsum. It includes vast areas of the Jifara Plain. Gergaresh Formation, which or Gergaresh Sandstone of Tyrrhennian age, sometimes consists of silt lenses and sandy limestone. The Holocene deposits show evidence of recent wadi deposits, which comprise loose gravel and loam of different thickness from 0.5 to 2 m. Beach sands are found in a narrow strip at the coast and are made up of shell fragments with a small ratio of silica sands. Eolian deposits (sand dunes) are in the form of sand dunes and sheets covering large areas in the Jifara Plain (field dunes) and also patches of the coastal strip (coastal dunes). The coastal dunes contain shell fragments with small amounts of silica sands. It should be noted that the eolian material making up both field dunes and coastal dunes contains a high level of gypsum grains. In certain places, it comprises almost pure gypsum (98%) particularly in the area of the sebkhas, with a silty gypsum filling (IRC, 1995). Fluvial-eolian deposits exist on the plateau surface in central Jifara. They are made up of silt, clay, and fine sands with some caliche bands. Sebkha sediments are noted along the coastal area of the plain. They cover the relatively low topographic areas and are separated from the sea by sea cliffs. Some of the sebkhas have occasional incursions of the sea and others may have subsurface connection with the seawater. The majority of them are distinguished by the existence of scattered sand islands. In central Jifara, the lithology of the upper aquifer differs considerably and includes limestone, gravel, marl, clay, sand, and sandstone. Between Sabratah and Bir al Ghanam the lower part of the upper aquifer is of gypsiferous limestone and gypsiferous sandstone. The depth to the bottom of the upper aquifer ranges from 30 to 200 m and depths of the wells that are using this aquifer are between 30 and 180 m. The majority of the wells tapping this aquifer produce about 20-80 m^3/hr (Al Farrah et al., 2011). The thickness of the aquifer varies from 134 m to 169 m (Figure 7), and at the coastal areas the thickness ranges from 141 m to 160 m. On the other hand, the aquifer base (Figure 8) ranges from 0 m in the Southeastern parts to reach -150 m along the coastal areas.

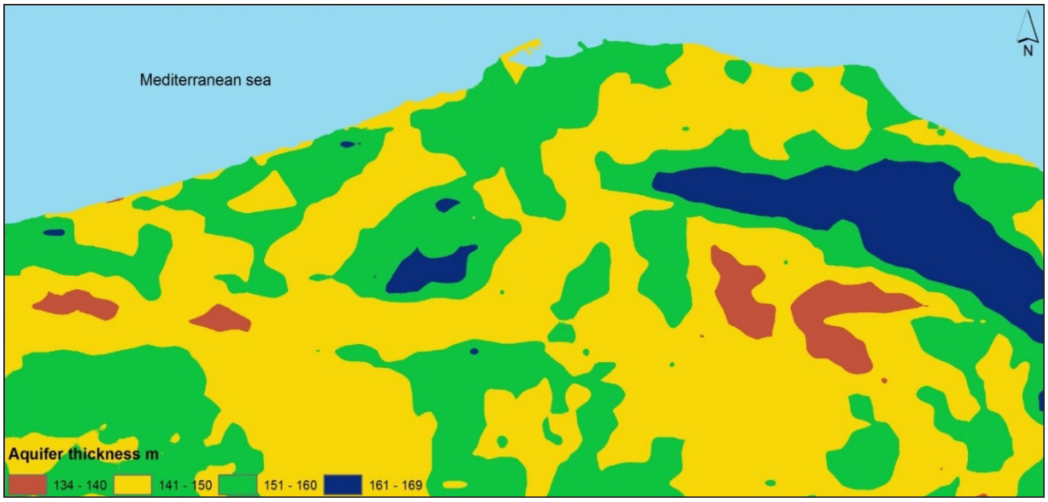

Figure 7. Aquifer thickness

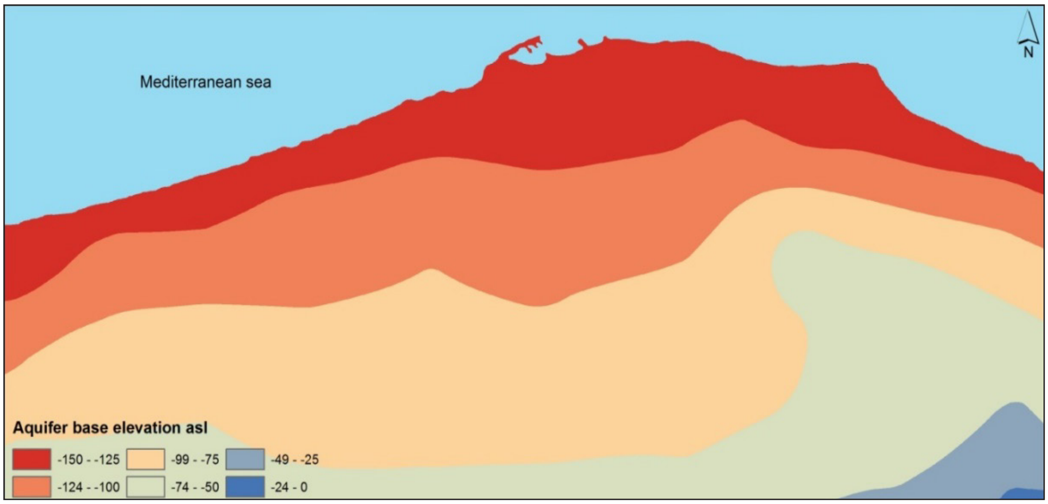

Figure 8. Aquifer base elevation

MODEL DESCRIPTION AND SETUP

In order to evaluate the rate of saline water intrusion, the ModelMuse user interface Version 3, (Winston, 2009) was used as a pre-and post-processing tool for the water level simulation and saline water intrusion. MODFLOW-2005 code (US Geological Survey, USGS, 2005) was used to simulate groundwater flow using ModelMuse (Winston, 2009) as a graphical user interface (GUI). The governing equation of this model is the partial-differential equation of groundwater flow used in MODFLOW (US Geological Survey, USGS, 1988)

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\left(\frac{\partial h}{\partial t}\right) \qquad (1)$$

where: K_{xx}, K_{yy}, and K_{zz} are the values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of the 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 groundwater system, and W>0.0 for flow into the system (T^{-1}); S_S is the specific storage of the porous material (L^{-1}); and t is time (T). The model was discretised in one layer of 250 m by 250 m grid resulting in a total number of 23,862 cells of which 11,809 are active cells. Figure 9 shows the assigned model boundaries based on the hydrodynamic pattern where the constant head boundary is assigned to the coastal line that receives higher amount of the rainfall (250 mm/year) with (head = 0), based on the sea level as fixed datum, and most of the Southern model boundary is with a continuous groundwater flux to the study area and here a constant flow boundary was assigned and as the Eastern and Western boundaries are represented by groundwater flow lines it was assumed as no flow boundary.

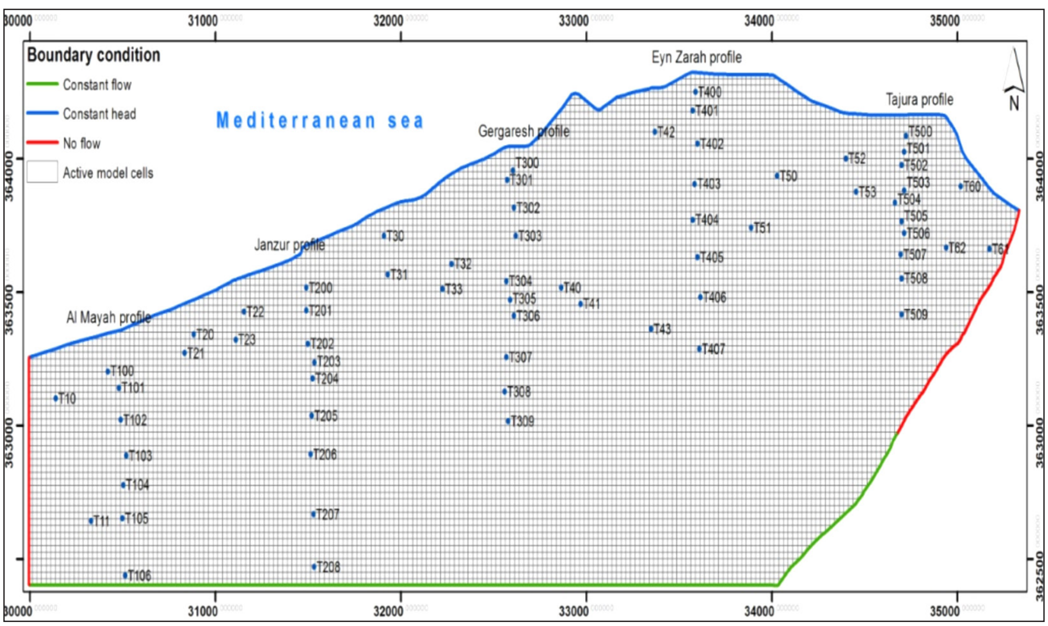

Figure 9. Model boundary conditions

The direct recharge from rainfall at the coast plain was assumed to be 10% (25 mm/year) of the average rainfall.The model was based on lowering the ground water level due to over pumping. After initiating a steady-state model conditions, the model was employed for the simulation of the hypothetical scenarios of increasing pumping rates due to increasing demand for fresh water in the Tripoli area for the years 2010 to 2100. The model input included natural recharge rate, current groundwater level in the year 2010, hydrogeologic parameters and boundary conditions and the pumping rates from private and governmental wells within the area. Hydraulic conductivity was calculated from pumping test data to be in the range of 1.42 m/day for the Eastern and Western model boundary reaching a maximum of 5.79 m/day in the central parts of the model area as shown in Figure 10. The most sensitive parameter in this case was the boundary condition as it controls groundwater flow in and out of the model area. The boundary conditions were assigned based on the groundwater flow map for the year 2010 plotted using field measurements done in the study area (Figure 11).

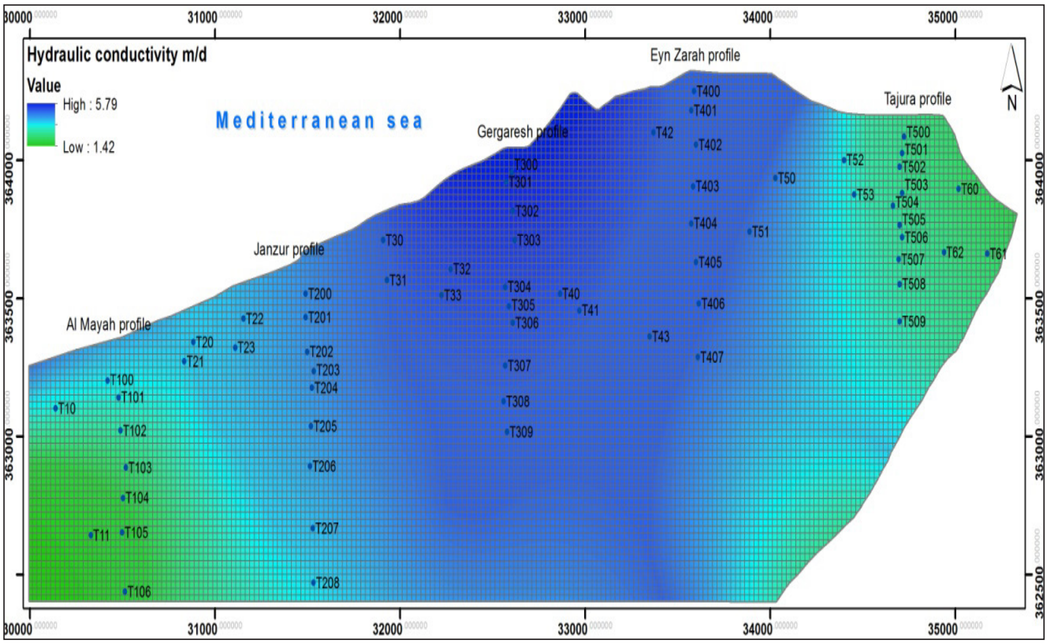

Figure 10. Hydraulic conductivity distribution over the study area

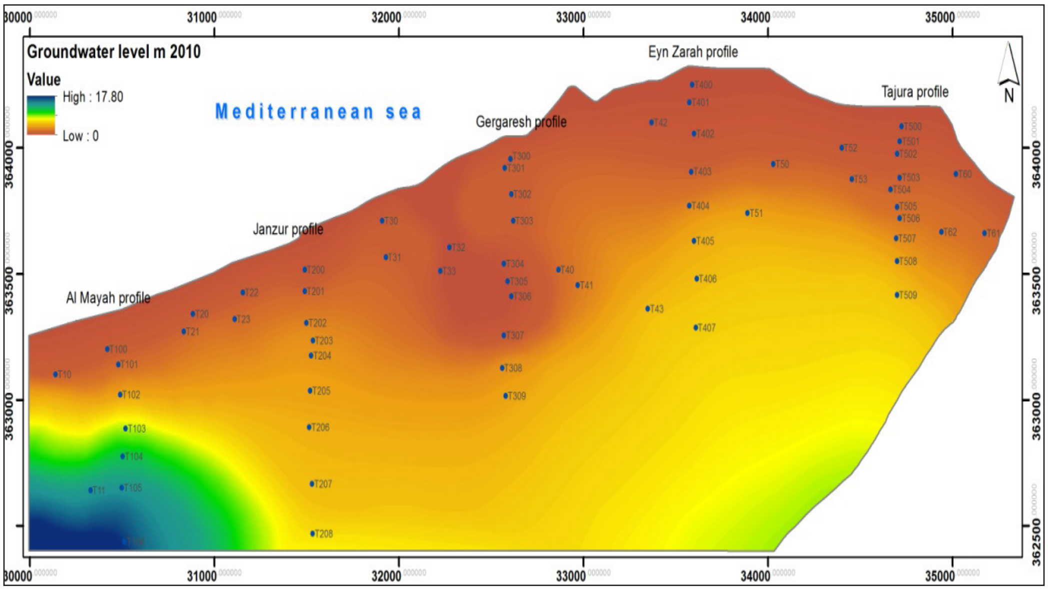

Figure 11. Groundwater levels for initial case

STEADY STATE CALIBRATION

The model calibration was performed for a steady state using a ModelMuse interface based on the match between measures and simulated groundwater heads within the model area using data of year 1995 from 33 wells. Calibration was done based on the groundwater flow map for the year 2010 and direct groundwater level measurements in groundwater wells. Within the calibration stage, most of the parameters were found to be under considerable change, especially hydraulic conductivity and recharge rate. The hydraulic conductivity of the aquifer was modified on a local scale to achieve the best fit between measured and simulated heads. The highest discrepancies in the model results were found in areas with no hydraulic conductivity data due to the absence of wells, mainly in the South Western parts of the model. Figure 12 shows the match between measured and simulated heads obtained after the calibration process.

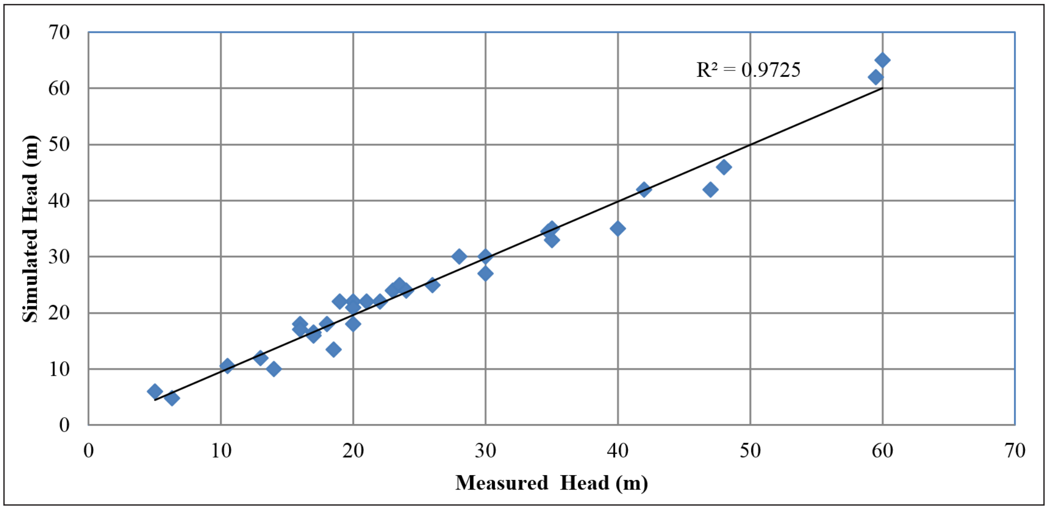

Figure 12. Relationship between measured and simulated groundwater heads in Tripoli aquifer

The results of the calibrated groundwater model show a good match among simulated and measured heads with a correlation factor of 0.97 with the Mean Error between measured and simulated values of 0.31 m. The Mean Absolute Error is 1.70 m and the Root Mean Square Error is 2.32 m which indicates that the model performs well regardless of the limited data availability.

SOLUTE TRANSPORT MODEL

Transient Simulation (Time-Dependent Simulation)

The calibrated hydraulic conductivity and the initial water level map of the year 2010 were used for time-dependent simulation on the long-term run for the years 2010 to 2100. Here, two scenarios were assumed, the first is keeping the current groundwater pumping rate and the second with doubling the pumping rates, which is likely to occur in the coming years to cover increasing demand of fresh water. The transient simulation was carried out to understand the present situation and to predict the hydraulic system behaviour in terms of change in groundwater level which is a key player in the saline water intrusion. The time period of 2010 to 2100 was divided into 20-year segments starting in the year 2020 and here seasonal variation and climate change effects were neglected.

Simulated Scenarios and Model Predictions

Model predictions were conducted for evaluating the response of the model for two future scenarios. These scenarios are different in their pumping rates without any management or climate change effects or population growth, and the first scenario makes the assumption that the model will run through 2020-2100 in five situations with the pumping rate remaining constant from the aquifer during the interval 2020-2100 with about 70 M m^3/year and the second scenario, makes the assumption that the pumping rate will double that of the first scenario to about 140 M m^3/year. These scenarios studied the impact of the pumping on groundwater level in the wells at the Tripoli region. Changes in groundwater level results are considered to analyse the suggested scenarios.

Fixed Pumping Rate for the Time Period 2020 – 2100 (First Scenario)

The resulted groundwater levels based on this scenario are shown in Figures 13 – 17) and they indicate that the system is under a continuous case of depletion and saline water intrusion is likely to occur. The parts most vulnerable to saline water intrusion are found to be along well profiles due to the local decline in water level caused by pumping.

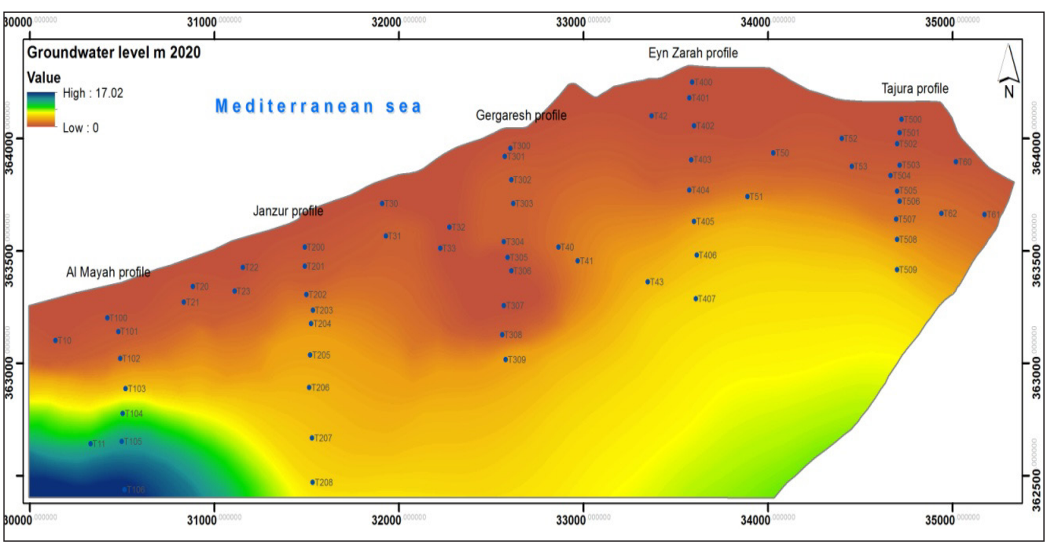

Figure 13. Predicted groundwater levels in 2020

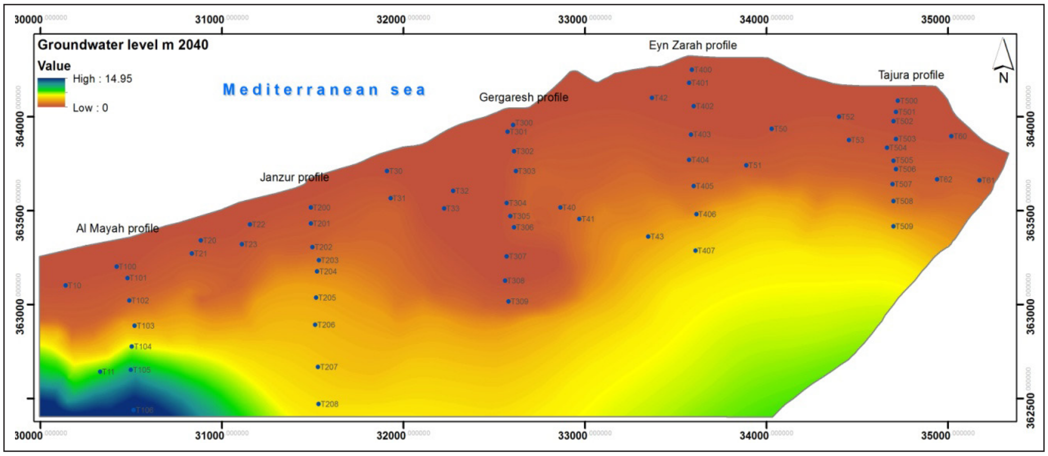

Figure 14. Predicted groundwater levels in 2040

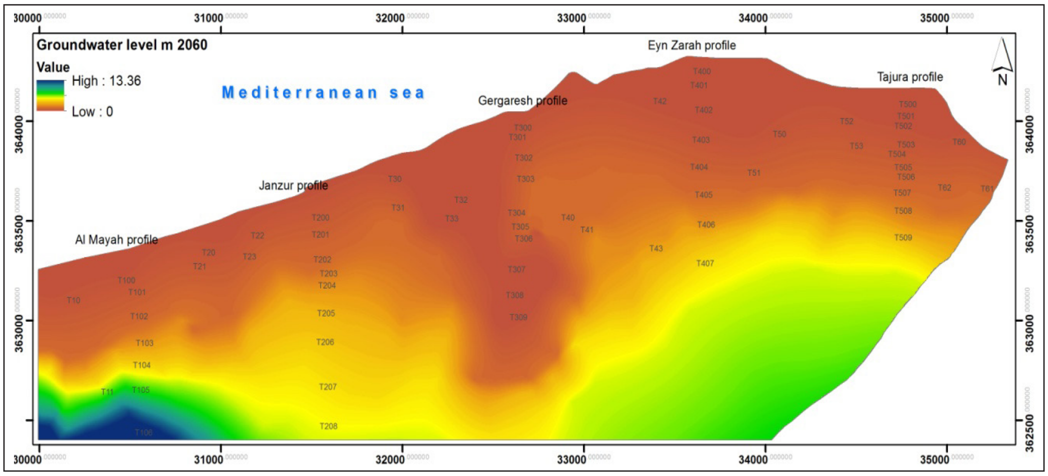

Figure 15. Predicted groundwater levels in 2060

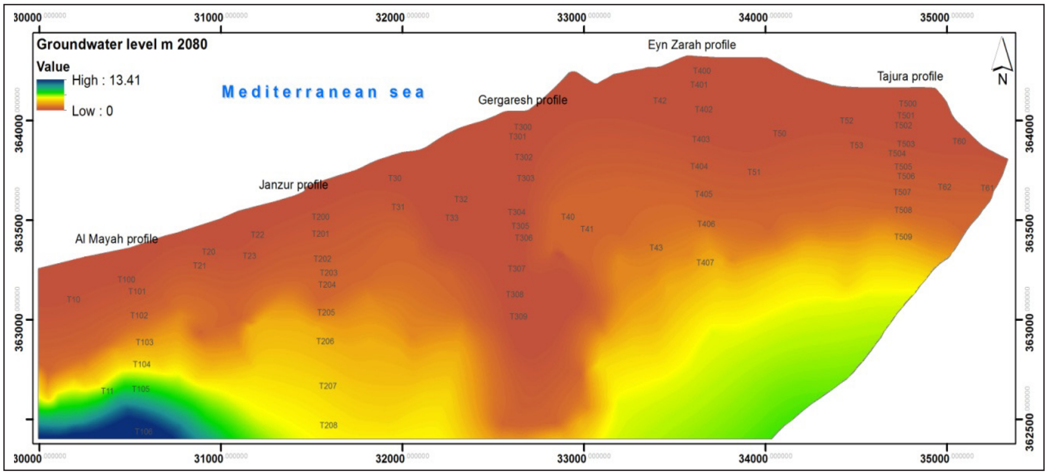

Figure 16. Predicted groundwater levels in 2080

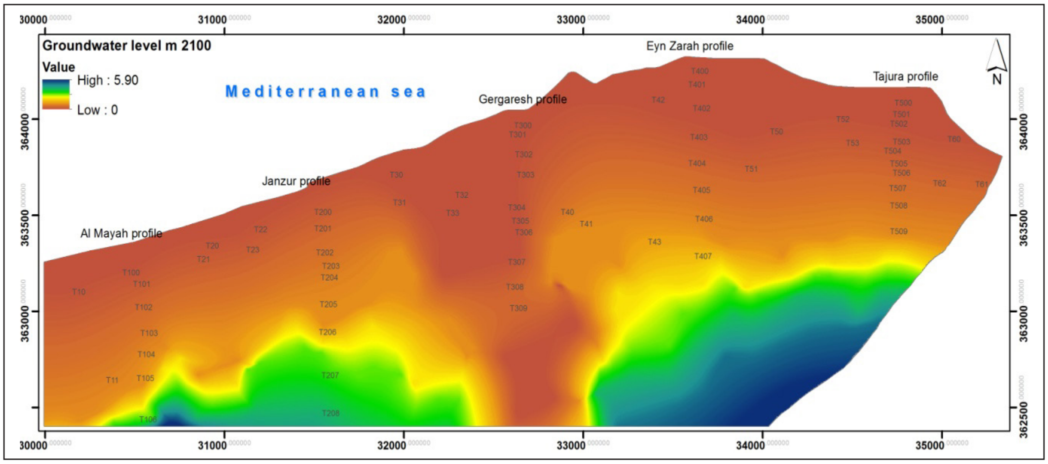

Figure 17. Predicted groundwater levels in 2100

Increasing Pumping Rate for the Time Period 2020 – 2100 (Second Scenario)

Increasing the pumping rate from different wells in the model area was assumed to take place in all wells in the same magnitude as recent data about pumping rates and future plans are missing due to political instabilities in the area. The resulted groundwater levels shown in Figures 18-22 indicate that doubling the pumping rate will have a significant impact on groundwater levels and here depletion in water level is predicted to take place over the whole model area by the year 2100. These results show that increasing the abstraction rate from the wells will double with long-term practice in the Tripoli aquifer and degrade the aquifer. This definitely will increase inflow from sea boundary and hence increase seawater intrusion, therefore will impact the water quality in the aquifer. These results show that after 100 years, this aquifer will be greatly affected.

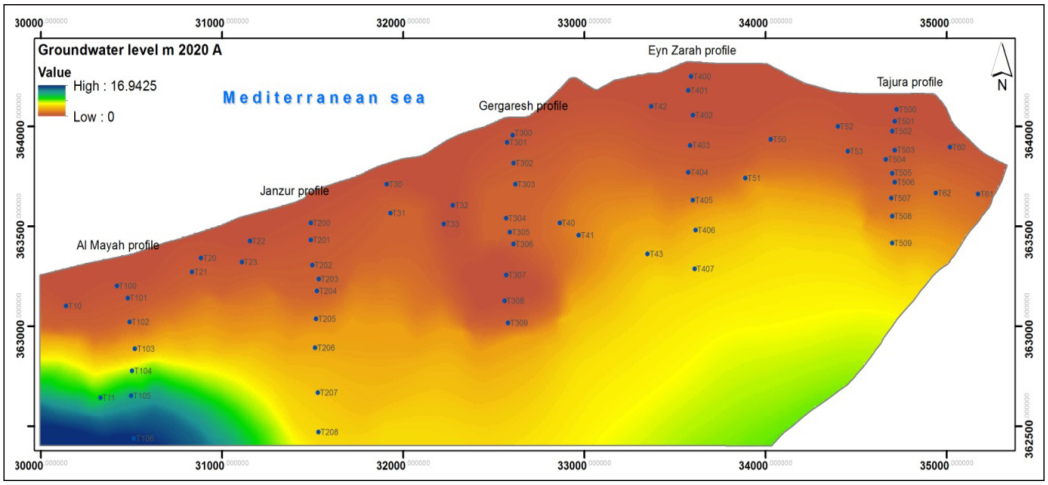

Figure 18. Predicted groundwater levels in 2020 using double pumping rate

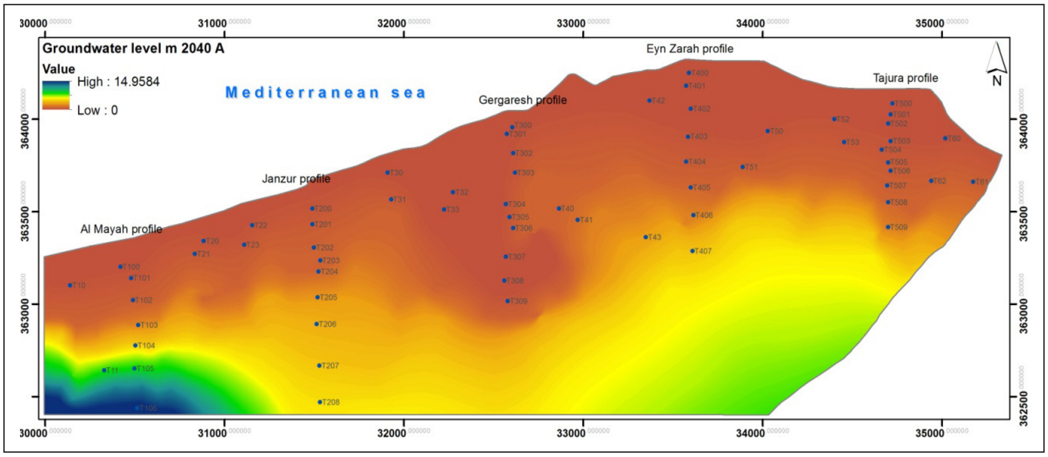

Figure 19. Predicted groundwater levels in 2040 using double pumping rate

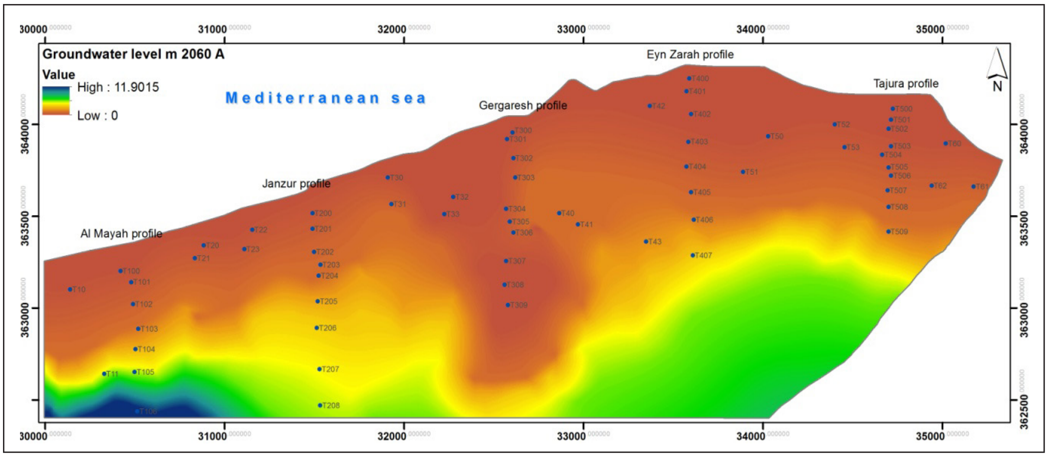

Figure 20. Predicted groundwater levels in 2060 using double pumping rate

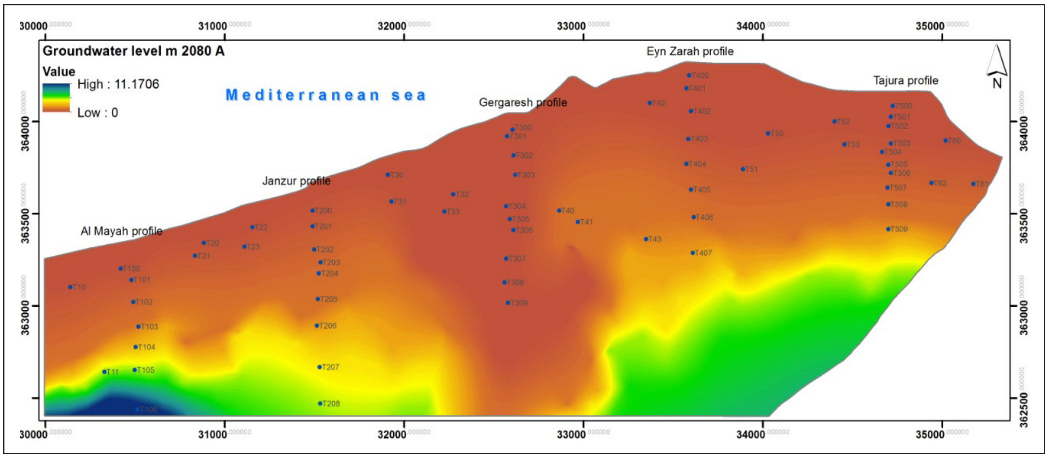

Figure 21. Predicted groundwater levels in 2080 using double pumping rate

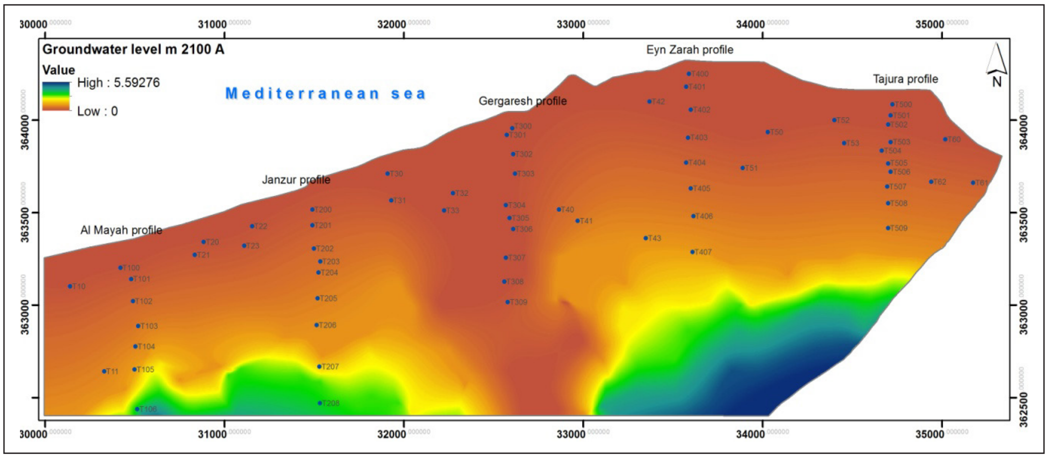

Figure 22. Predicted groundwater levels in 2100 using double pumping rate

RESULTS AND DISCUSSION

In this study, the simulation results highlighted that the current pumping practices in Tripoli aquifer are not sustainable and resulted in severe damage to the aquifer. Due to the aridity of the area, limited groundwater recharge and high pumping rates, the simulation results showed that the groundwater levels in the study area have declined dramatically at the rate of more than 0.5 m/yr. This drastic drop in the groundwater level caused instability in the aquifer system and resulted in sea water intrusion along the studied profiles of the aquifer (Caswell, 1987). The number of the profiles used for this purpose is five and Figure 9 clearly shows the name of profiles and the wells in each one . The names of the profiles are Al Mayah, Janzur, Gergaresh, Eyn Zara and Tajura. MODFLOW2005 model employed in this study offered an effective tool to manage the Tripoli aquifer by calculating the impact of the various pumping scenarios.

Simulation results demonstrate that pumping rate has a huge impact on both groundwater drawdown and seawater intrusion, with the second scenario having the highest pumping rate, therefore, this scenario is the worst scenario in increasing inland seawater intrusion rate and in drawdown. The maximum drops in groundwater level values for both scenarios considered showed that the second scenario has the biggest impact on groundwater lowering. In the first scenario, the maximum decline rate in groundwater level is found to be 0.147 m/yr and it will occur at Al Mayah profile while in the second scenario, the maximum decline rate in groundwater level also occurring at Al Mayah profile and it is found to be 0.053 m/yr. The results of the scenarios are discussed below, but because of limited space for this paper, it will present the Gergaresh profile results which recorded higher deterioration in the central part of this profile in the region after the coastal wells which have seen a substantial deterioration, despite its distance from the coast to the centre of the Gergaresh profile. Figures 23 and 24 shows the analysis of simulation results of groundwater levels at a Gergaresh area in the coming years. These results indicate that continuous pumping in two scenarios; current pumping rate and double pumping rate scenarios will cause the groundwater level to decline several metres over time. Results shown in Figures 23 and 24 confirm that the decline will occur in the middle Gergaresh profile and particularly in wells numbered T305, T306, T308 and T309. Results of using current pumping rate up to 2100 are shown in Figure 23 and the groundwater levels will become equal to the sea level in wells T305 and T306. However, the groundwater levels in wells T308 and T309 are found to be 0.4 m and 0.5 m above sea water level respectively. The results of using double pumping rate up to 2100 are shown in Figure 24 and the groundwater levels will become equal to the sea level in wells T305 and T306 while the groundwater levels in wells T308 and T309 are found to be 0.1 m and 0.2 m above sea level respectively. But in 2010, data show the groundwater levels in wells T305, T306, T308 and T309, were 0.4 m, 0.4 m, 3.1 and 3.7 m above sea level respectively. For current pumping rate, the groundwater levels in well number T309 in 2020 and 2030 are away higher compare with the scenario of double puming rate. This can be attributed to fact that when the pumping rate from a well increases the drawdown in the well increases too and since the current pumping rate is less than the double pumping rate, then this make the groundwater levels in well T309 to be away higher compared with that in the double pumping scenario in 2020 and 2030. This decline is considered the greatest additional groundwater level decline in the Tripoli region after the decline which occurs in the wells close to the coast, due to the intensive pumping of the wells and transferring the water to the city of Tripoli to meet the people's needs for water.

On the other hand, the figures show a clear decline from the coastal to the Southern boundary except for the Southern part where hydraulic conductivity is low and the annual

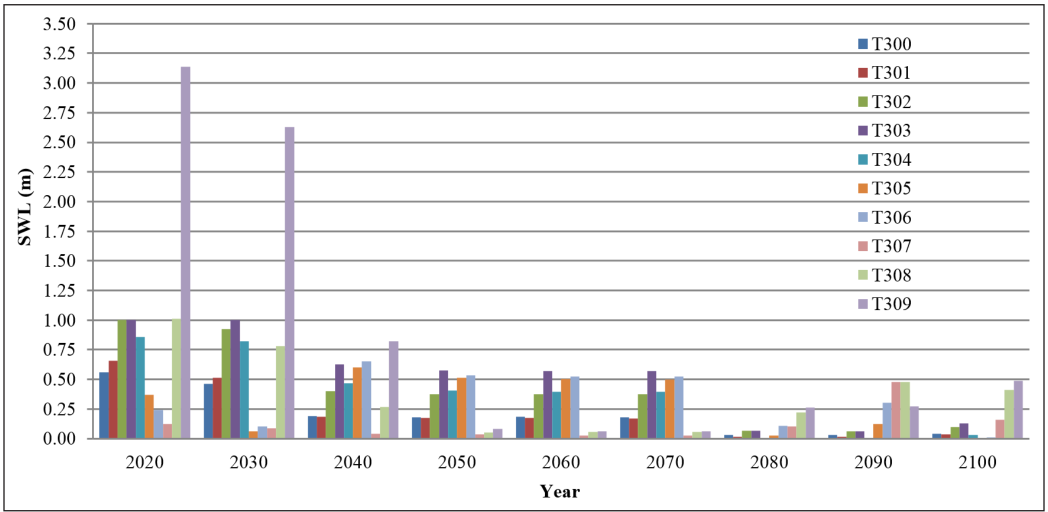

Figure 23. Predication of SWL in the period 2020 - 2100 for current pumping rate

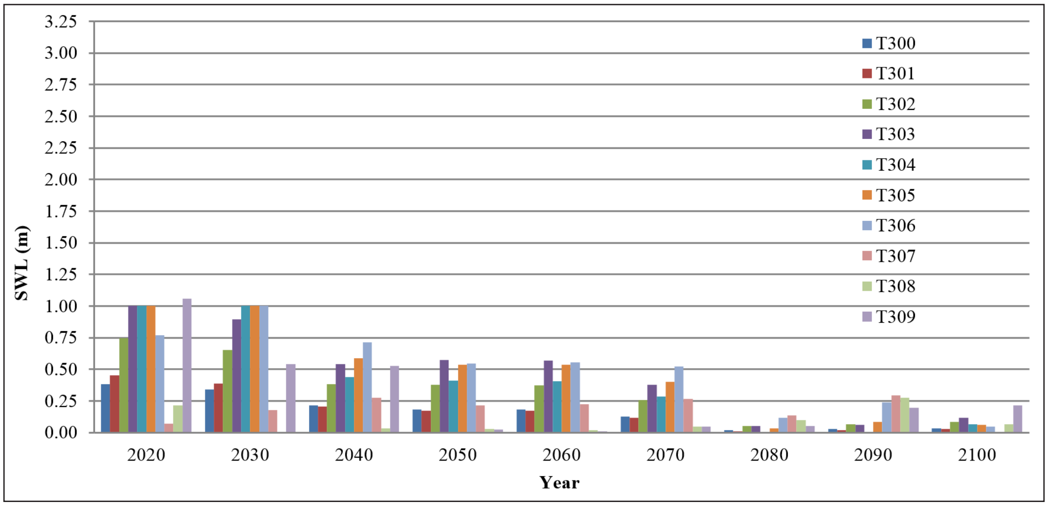

Figure 24. Predication of SWL in the period 2020 - 2100 for double pumping rate

recharge in the Southern part is less than that in the North. By studying spaced intervals in the study area, the figures indicate that the greatest danger in the study area is the prospect of groundwater level decline extending over the Southern region.

CONCLUSIONS

The hydrogeologic system in Tripoli area is under a severe case of over pumping which cannot be controlled due to the political instabilities and the growing demand for fresh water and urbanisation in the area. The system is highly vulnerable to over pumping and drop in groundwater level to the sea level, which causes a notable saline water intrusion in the coastal area extending along the pumping profiles in the area. The Gergaresh profile located in the central parts of the model recorded the highest drop in water level due to the high pumping rate. From this profile, which is located in the most urbanised parts of the model, it can be observed that the high urbanisation rate has caused a depletion in the water level due to high pumping rate, urbanisation and pavements, which reduced the natural replenishment of groundwater by preventing recharge to the system. The groundwater levels under the current pumping rates showed a fixed declining pattern over the modelled period, with greater severity in the last 40 years. This accelerated trend in the last 40 years can be explained by the depletion of saturated thickness and hence the declining rate will be faster. When pumping rates increase to 200%, the system comes under more stress and the decline of water levels is 72% accelerated and here the saline water intrusion is likely to extend to the whole model area. The results also prove that the MODFLOW-2005 model is a useful predictive tool to warn of the possible consequences in the aquifer caused by intensive pumping so that the authorities responsible for the management can control the seawater intrusion.

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REFERENCES

Al Farrah, N., Martens, K., & Walraevens, K. (2011). Hydrochemistry of The Upper Miocene–Pliocene Quaternary Aquifer Complex of Jifara Plain, NW-Libya. *Geologica Belgica, 14*(3-4), 159-174.

Al Farrah, N., & Walraevens, K. (2018). Groundwater Overexploitation and Seawater Intrusion in Coastal Areas of Arid and Semi-Arid Regions. *Water, 10*(2), 143-166.

Bashir, B. (2018). Water resources and desalination in libya: a review. *Proceedings, 2*(586), 1-7. Doi:10.3390/proceedings2110586

Caswell, W. B. (1987). *Groundwater Handbook for The State of Maine* (Vol. 39). Maine: Maine Geological Survey Bulletin.

Cedestrom, D., & Bertiola, M. (1960). *Groundwater Resources of the Tripoli Area, Libya*. Tripoli: U.S.G.S., Joint Services Report.

Directorate General of Water Resources, DGR. (1995). *Directory of Exploitation of Groundwater*. Ministry of Agriculture, Tunisia.

El Asswad R. M. (1995). Agricultural Prospects and Water Resources in Libya. *Ambio, 24*(6), 324-327.

Food and Agricultural Orgnaziation (FAO). (1979). *Seawater Intrusion Study*. SARLD/ FAO Project LIB/005, 4-62., Rome, Italy. Floegel, H.

General Water Authority (GWA). (2006). *Mathematical Modeling of The Tunisian-Libyan Jifara Aquifers*. Tripoli, Libya.

Geological and Mining Institute of Spain (GMIS). (2003). *Highlighting and Study of the Phenomenon of Upconing in the Coastal Water Table of Rharb (NW of Morocco)*. Madrid, Spain.

Gejam, A. M. S., Riad, P. H., Gad, M. A., Rashed, K. A., & Hasan, N. A. (2016). Impact of Pumping Rate on Seawater Intrusion in Jefara Plain, Libya. *American Science, 12*(3), 81-88.

Industrial Research Centre, IRC. (1995). *Geological Card of Jifara Plain* (2nd Ed.). Industrial Research Centre, Tajura, Libya: Great Socialist People's Libyan Arab Jamahiriyah.

Jumma, A. J., Toriman, M. E., & Hashim N. M., (2012). Groundwater Pollution and Wastewater Management in Derna City, Libya. *Environmental Research, 6*(1), 50-54.

Khmaj, A., Ezlit, Y., & Elaalem, M. (2014, June 14-15). The Situation of Seawater Intrusion in Tripoli, Libya. In *Proceedings of International Conference on Biological, Chemical and Environmental Sciences (BCES-2014)* (pp. 1-6). Penang, Malaysia.

Krummenacher, R. (1982). *Groundwater Resources in Jifara Plain, Libya*. Tripoli, Libya.

Kumar, A., Zaiad, G. M., Awheda, I. M., & Fartas, F. M. (2012), Physico-Chemical Analysis of Groundwater in Different Sites of Al-Khums City, Libya. *International Journal of Science and Research, 3*(7), 2395-2398.

Meludi H., and Werynski K. (1980). *Sea Water Intrusion in Gargaresh Swani Well Field Area*. Tripoli, Libya.

Nair, G. A., Bohjuari, J. A., Al-Mariami, M. A., Attia, F. A., & El-Toumi, F. F. (2006). Groundwater Quality of North-East Libya. *Environmental Biology, 27*(4), 695-700.

Sadeg, S., & Karahanoðlu, N. (2001). Numerical Assessment of Seawater Intrusion in The Tripoli Region, Libya. *Environmental Geology, 40*(9), 1151-1168.

Secretariat of Economy Planning-Tripoli. (1993). *Highlights on Achievements in the National Economy Sector.* Tripoli: Government of Libya.

Shanan, L. (1992). Planning and Management of Irrigation Systems in Developing Countries. *Agricultural Water Management, 22*, 113-145.

Sloggette, G., & Dickason, C. (1986). *Groundwater Mining in The United States*. United States Department of Agriculture Economic Research Service. Report No. 555, Washington DC.

U.S. Geological Survey (USGS). (2005). *MODFLOW-2005: Modular of Ground-water flow*. Colorado, USA.

U.S. Geological Survey (USGS). (1988). *A Modular Three-Dimensional Finite Difference Groundwater Flow*. Colorado, USA.

Winston, R. B. (2009). *ModelMuse: A graphical user interface for MODFLOW–2005 and PHAST*. Reston, VA: US Geological Survey.