IMPACT OF GROUNDWATER EXPLOITATION ON SALTWATER INTRUSION IN COASTAL AQUIFER CASE STUDY:DERNA-LIBYA

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ABSTRACT

Coastal zones represent a huge area in the most Arab countries. In these zones the groundwater plays an important role in the sustainable development. Saltwater intrusion is the main problem may threaten the groundwater quality especially when there is an overexploitation of the water. The main objective of this paper is to study the effect of the over-pumping in coastal aquifer, the saltwater intrusion and estimate the up-coning. Derna City in the North Eastern part of Libya was taken as case study to achieve the objective of this work. Based on data of 73 pumping wells, Visual MODFLOW model was used in simulating the groundwater flow in the study area and by using the Ghyben-Herzberg Equation, the up-coning was estimated. The model was calibrated using the available data: water levels, well designs and pumping rates and it gave a significant statistical correlation of value 0.908 when the fractured porous media is simulated in the calibration. The calibrated model was used to predict the water levels and its impact on saltwater/fresh water interface and up-coning due to suggested pumping rates. The drawdown in groundwater levels were found to be 0.142 and 0.4m which led to up-coning of values 5.68 m and 16 m due to pumping rate of 10 and 20 l/s respectively.

Keywords: Groundwater Modeling, Saltwater Intrusion, Coastal Aquifer, Upconning

1 INTRODUCTION

One of the most threaten problem faces the coastal aquifers is the saltwater intrusion due to over-pumping. As a result, the pumping wells that were established in fresh groundwater, may abstract brackish water or saline water due to up-coning.

The city of Derna, Libya is facing the risk of this phenomenon. It is located in the Al Jabal Al Akhdar region, the most important greenery agricultural area in Libya. Abdulmonem Elhassadi, (2008) stated that the main cause of this phenomena is due to the excessive depletion of groundwater more than safe yield without rainfall recharge. He also mentioned that the lack of environmental protection will lead to the severe pollution of these resources. The continuation of this phenomenon will lead to deterioration of agriculture activities area due to:

– Drought as a result of depletion of these resources,
– Desert advancement and loss of green coastal strip.

Actually, there are two simulation approaches for saltwater-freshwater relationship, one of which is sharp interface approximation introduced by Badon-Ghyben (1888) and the other approach is density dependent dispersive model Bear (1999, 2005).

Many researchers studied the phenomena of saltwater intrusion. Part of these studies rely on the modeling of saltwater intrusion and these include Khaled (1999), Lambrakis and Kallergis (2001) and Langevin (2003). Groundwater management options were discussed by Hallaji and Yazicigil (1996), Das and Datta (1999), Mantoglou (2003), and Reichard and Johnson (2005). Other studies field work analysis like that of Sawsan (2012), Jiraporn Sae-Ju etal., (2018) and Nawal Alfarrah and Kristine Walraevens (2018)

The main objective of this work is to study the effect of the over-pumping in coastal aquifer, the saltwater intrusion and estimate the up-coning in Derna City, Libya.

The main objective of this work is to study the influence of pumping scenario on saltwater intrusion and up coning to be taken into consideration for groundwater management in Derna City, Libya.

2 STUDY AREA

Study area located between latitude 32.6° to 33.00° N and longitudes 22.00° to 23.00° E shown in Figure (1). It occupies area about 3500 Km^2. Most of this area are used for agriculture and grazing purposes.

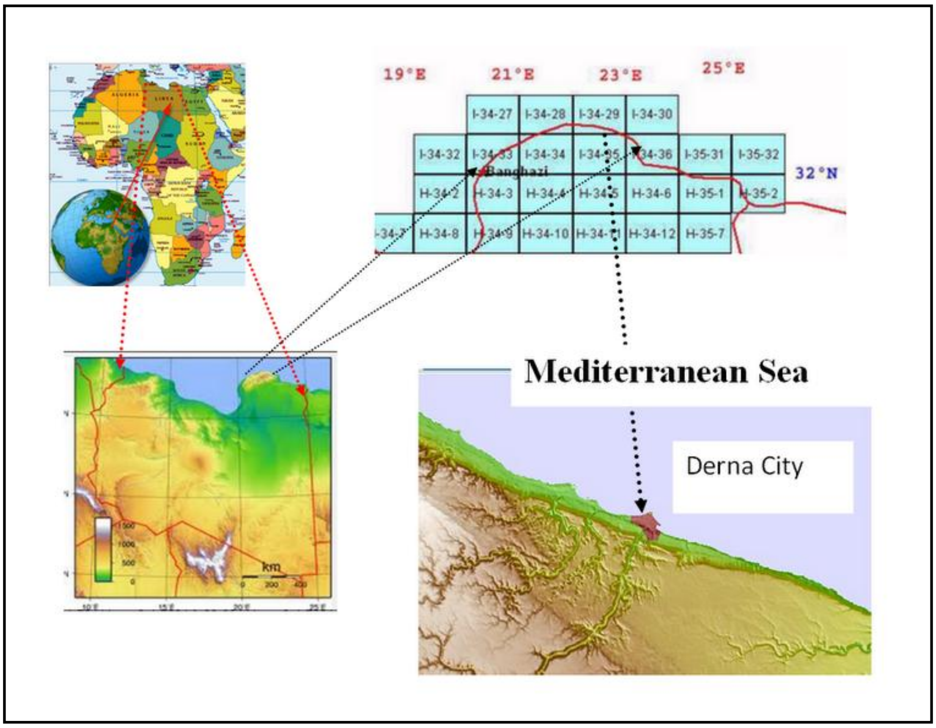

Figure 1. Study Area

2.1 Geomorphology, Geology and Hydrogeology

Derna city is one the main cities in Al Jabal Al Akhdar area, North-East Libya. The main constitutes of the aquifers in Al Jabal Al Akhdar area are Tertiary and upper Cretaceous carbonate rocks, while perched aquifers generally occur locally in Quaternary deposits. The lithological natures of those aquifers are predominately made of chalky and calcarenite limestone, in addition to karst processes playing the main role in the presence of water bodies in whole area, in which they are expressed by development of macro-karstic features. Groundwater flow is mainly related to a system of micro fissures and micro pores. The recharge of aquifers is due to the direct infiltration of rainfall and to the seepage of runoff water along the wadi beds. The natural outlets of the aquifers are either springs or in the case of northern flank, to the sea. The following is a brief summary of the exposed formations in the study area; Figure (2).

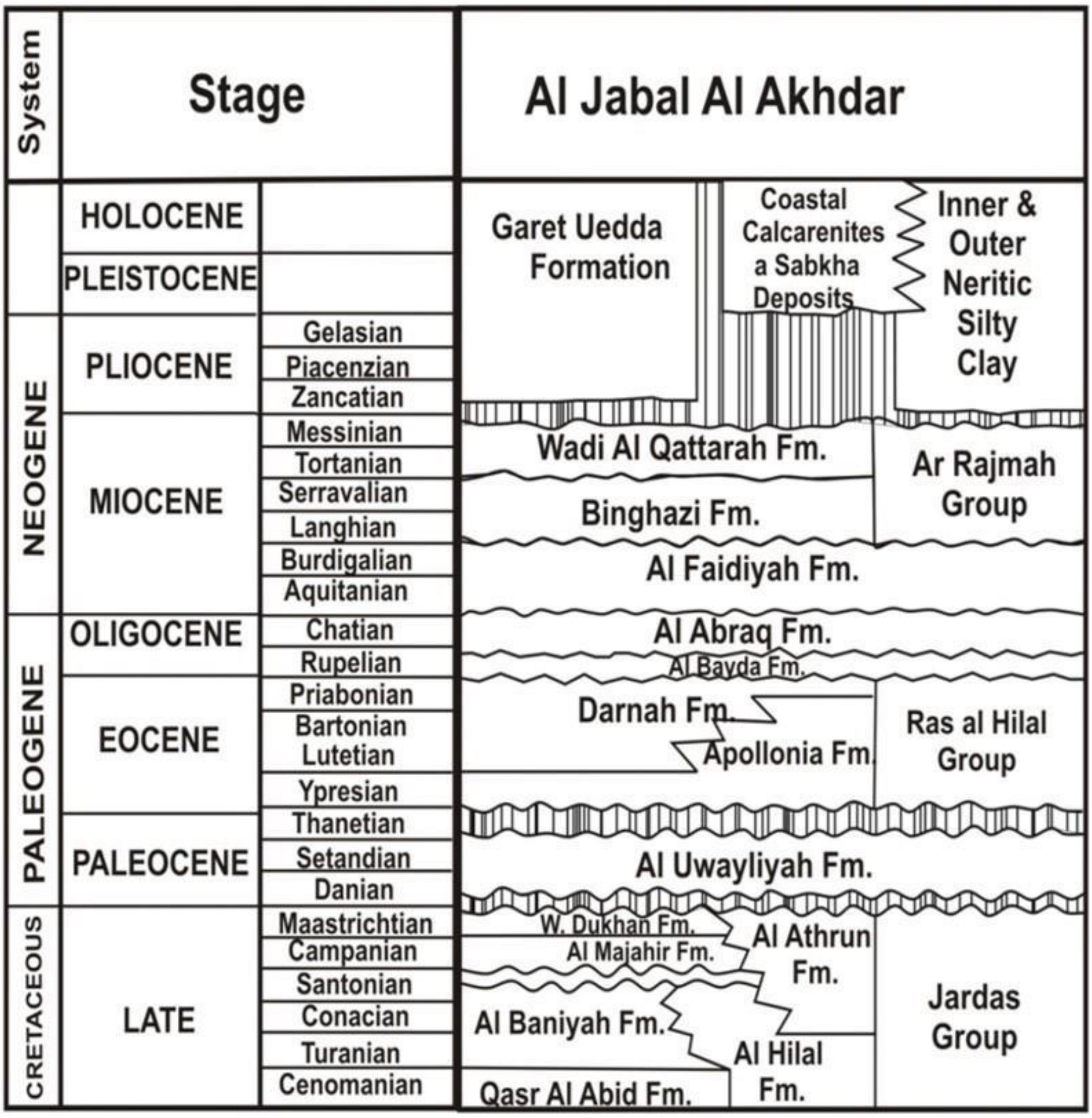

Figure 2. General stratigraphic column of Al Jabal Alakhdar and Coastal region, (after El Hawat and Abdulsamad 2004)

The main feature of the study area is Al Jabal Al Akhdar which runs parallel to the shoreline and reaches its highest level in the most westerly part of the area where it exceeds 650 m a.ms.l, Figure (3). This level diminishes toward the northeast corner of the area where it reaches the sea-level. The maximum high topography which prevails on the northwestern edge of the study area slopes gradually into the southern area also where it descends to lower than 150 a.ms.l. in the central and southern parts of the area as shown in Figure (4).

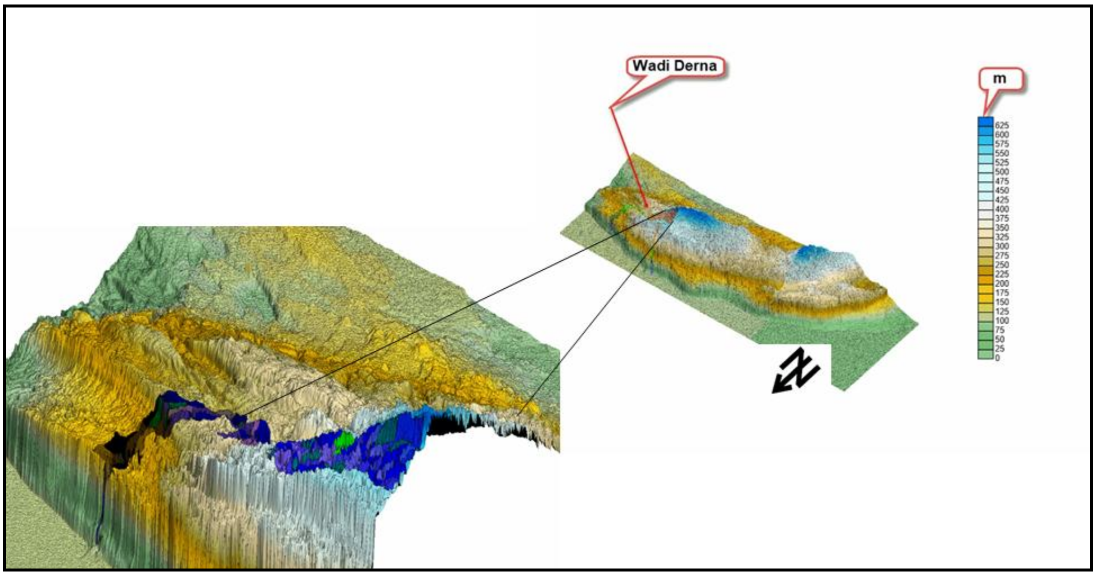

Figure 3. 3-D View of Al Jabal Al Akhdar and Derna Basin

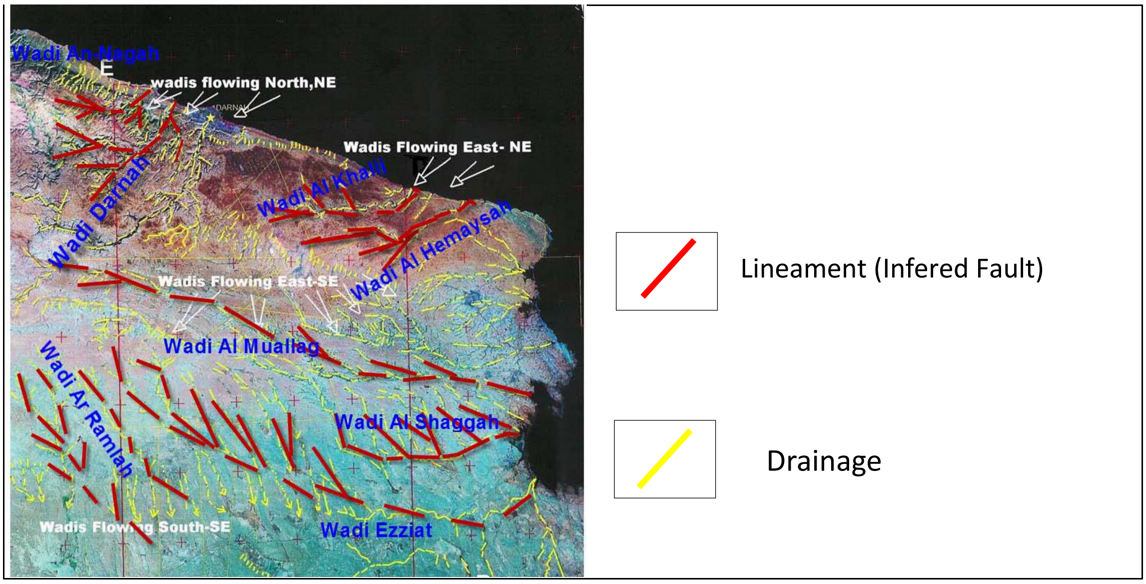

Figure 4. Satellite image of Darnah region shows major drainage pattern (after Salem and Salloum, 2006 and Salloum,2015)

These topographic highs and lows are very much coincident with and controlled by structure influence of anticlinal swells and faulting (Salem, and Salloum 2006), Figure (3).

The Derna area has moderate climatic conditions dominant year-around. As the area is located on the Mediterranean Sea from north and northeast on one side and high topography on the other, while it is open to the semi-desert topography from its southern direction. The mean monthly temperature ranges in the region between 14.9 ^{o}C in winter (January) and 27.3 ^{o}C in summer (August). However, High relative humidity prevails, it ranges between 70% in the winter and 78% in the summer, and the maximum value of the relative humidity was recorded in October.

The rainfall is irregular in Derna area. The annual rainfall increases west of Derna. While it decreases southwards from Derna, where the topography gets lower, away from the coastline, therefore the semi-desert environment prevails. The monthly rainfall ranges were found between 0.1 mm in July and 58.9mm in January; Salloum (2015)

3 METHODOLOGY

3.1 Data Collection

First step in data collection is the site visit to specify the features and boundaries of the study area. The Data was assembled from multiple sources: the digital elevation model (SRTM), non-digital and digital geological and topographical maps of the study area and selected 73 productive wells with their available data: water levels, well designs and pumping rates to cover the study area.

3.2 Simulation Using Numerical Model

3.1.2 Model Description

Visual MODFLOW (3.1.0.84) was used to simulate the study area numerically. The model is worldwide accepted and contributed in several engineering problems and offered reliable results.

3.2.2 Model Input

In order to prepare the model for computation, the following steps were achieved: setting the area to be modeled, defining the boundaries and boundary conditions, establishing network of cells and defining the wells and site features.

As shown in Figure (5) the grid covers an area of 3500 m^2. The mesh has variable cell size, small where the wells are located and coarse elsewhere.

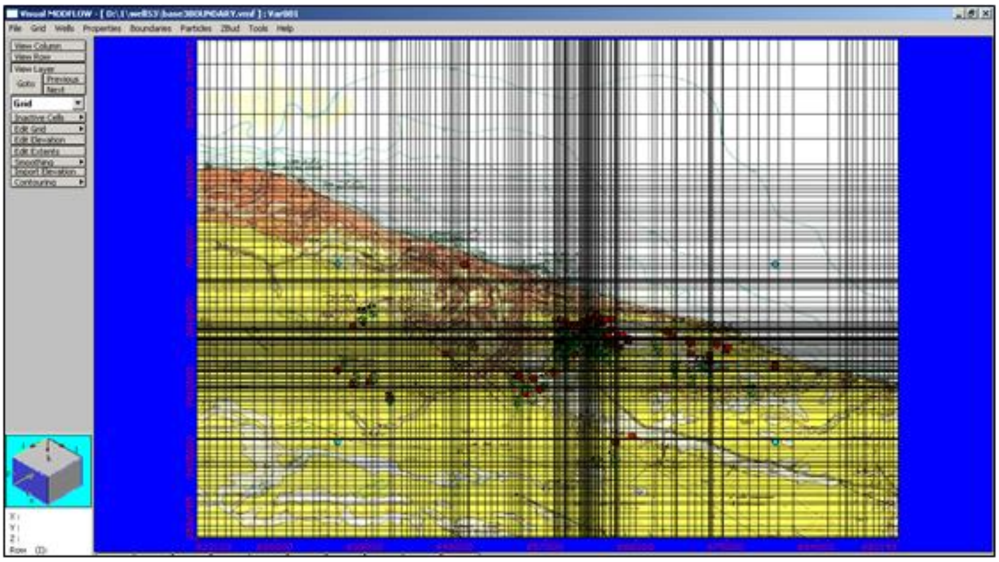

Figure 5. Grid for the study area

The boundary conditions were defined and input to the model as follows: Northern boundary is considered constant piezometric values (prescribed head) and was set to be zero to represent the sea level. The southeastern and western boundaries were considered to be opened “open-boundaries” (no flow condition); Figure (6).

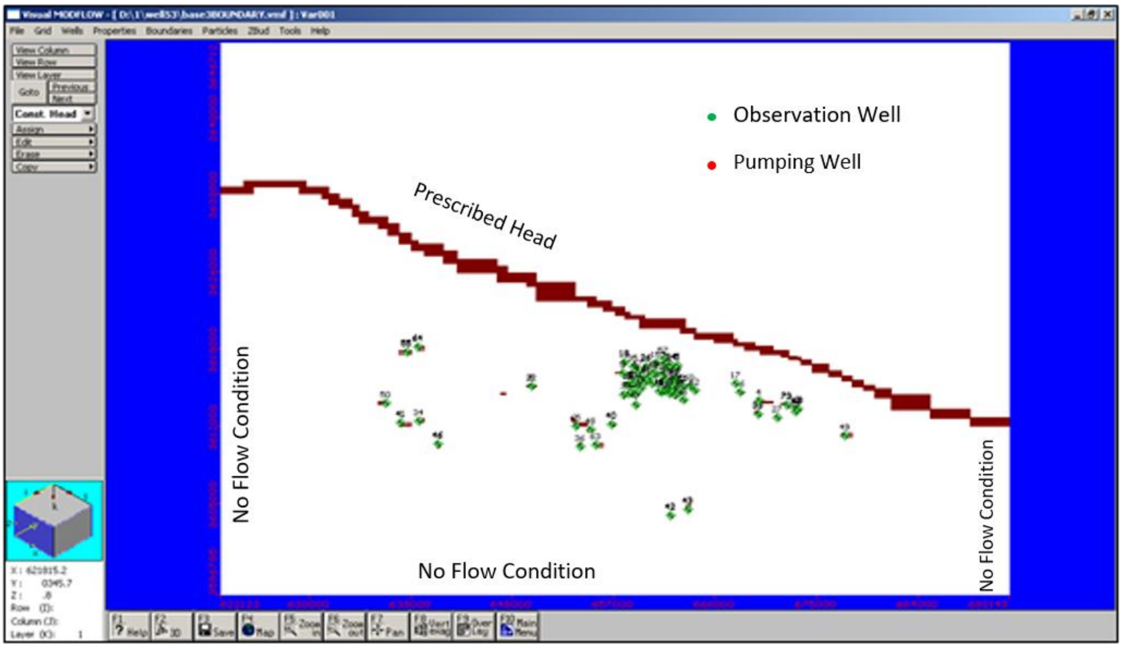

Figure 6. Boundary conditions of Domain and well locations

3.3 Model Calibration

To ensure the ability of the model to simulate the groundwater flow in the study area, the model has been calibrated using actual pumping rates.

The calibration process has been conducted by comparing the observed groundwater levels data with the model results. Many trials have been carried out to meet the observed data. In initial trials, the map of hydraulic conductivity distributions was interpreted using land use, geologic, and geomorphologic maps. Consequently, the model calibration gave low correlation coefficient of value 0.73. These trails didn't take into consideration the geologic fractures in the domain. Due to the model calibration sensitivity to hydraulic conductivity, a new map of hydraulic conductivity distributions was constructed based on geologic structure map to illustrate fractures and cavities positions. Hence by considering fractures of the geologic formations as shown in Figure (7); the calibration had been accelerated and correlation coefficient becomes better with value of 0.89 as shown in Figure (8).

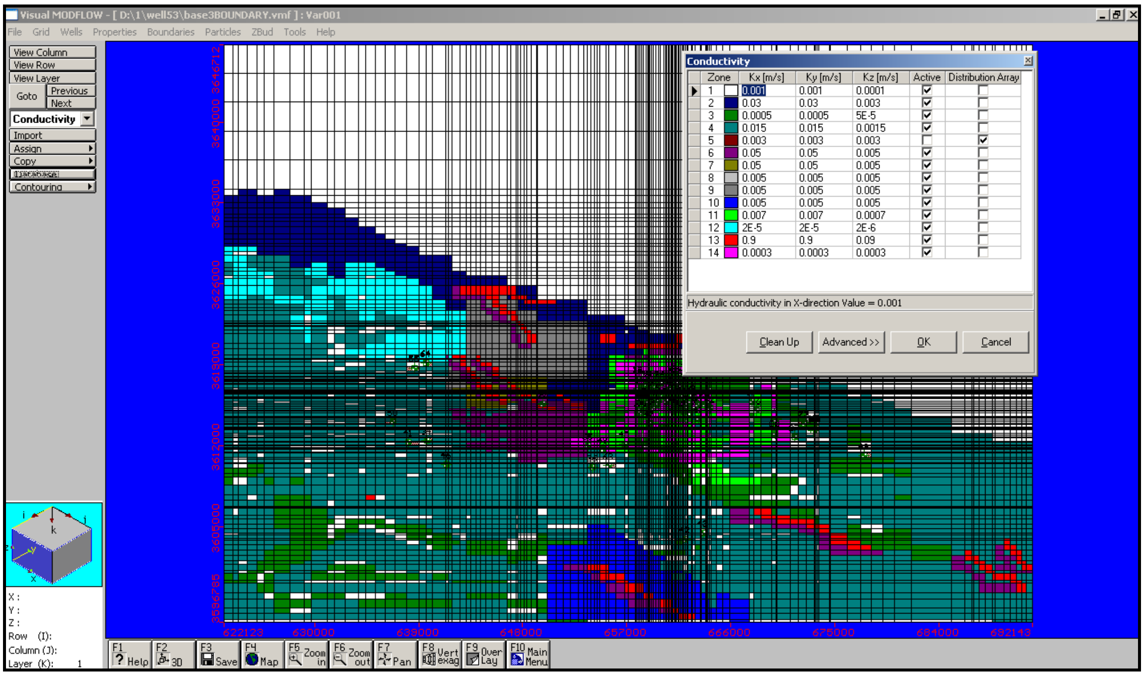

Figure 7. Hydraulic conductivity distribution in study area

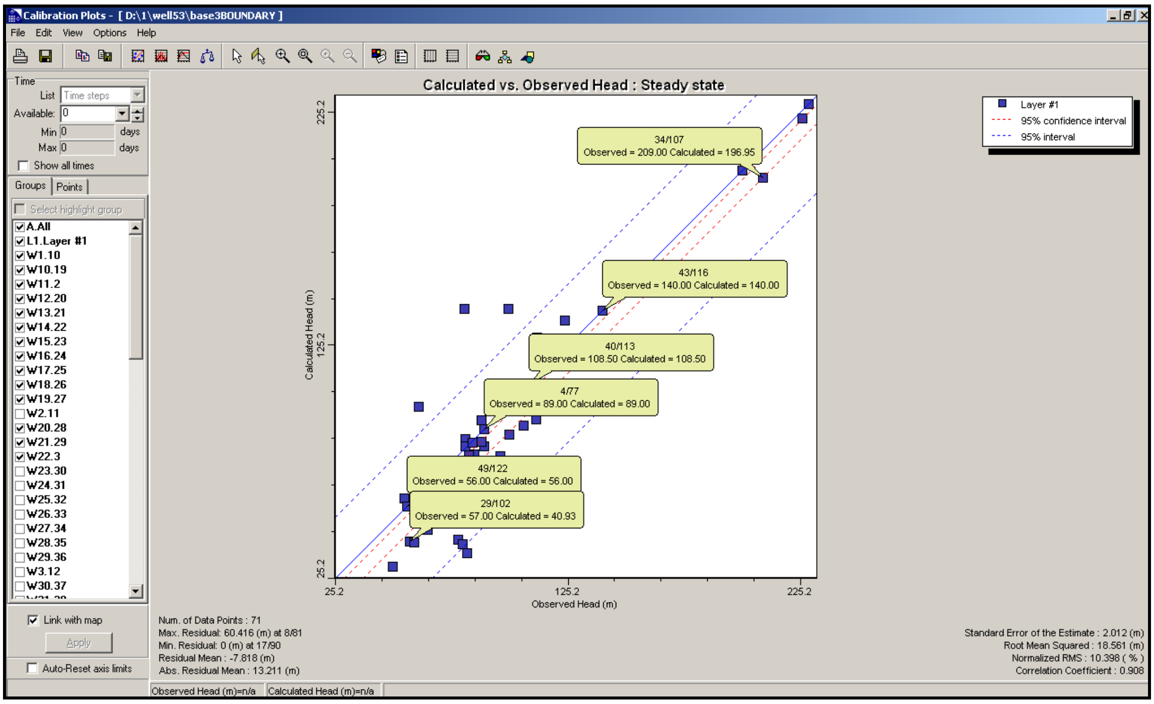

Figure 8. Model calibration results: Observed versus calculated water levels. (Correlation Coefficient; R=0.908)

3.4 Calculation of Initial Interface

Fresh water/saltwater interface was calculated using the Ghyben-Herzberg model which based on the hydrostatic equilibrium between fresh and saline water. It is assumed that seawater and freshwater are immiscible and separated by a sharp interface as shown in Figure (9). This model is represented by Ghyben-Herzberg equation;

$$h_s = \left(\frac{\rho_f}{\rho_s - \rho_f}\right) h_f \quad (1)$$

Where
ρ_f : is the freshwater density
ρ_s: is the saltwater density
h_s : is the depth of interface below the mean sea level
h_f: is the height of potentiometric surface above the mean sea level

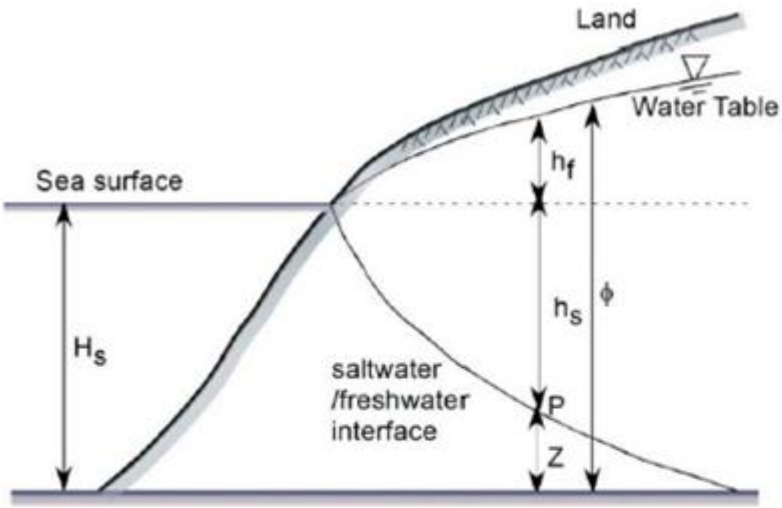

Figure 9. The Ghyben-Herzberg Relation, after Reilly and Goodman (1985)

The calibrated model was run using the actual pumping rate; to generate initial grid represent the fresh/saltwater interface. Figure (10) shows distribution of fresh water thickness and the fresh /saltwater interface. Fresh water thickness found to be maximum in the West while minimum value in the East which comes in harmony with the topography and water levels. This fresh /saltwater interface was taken as a datum for up-coning estimation under the suggested pumping rates.

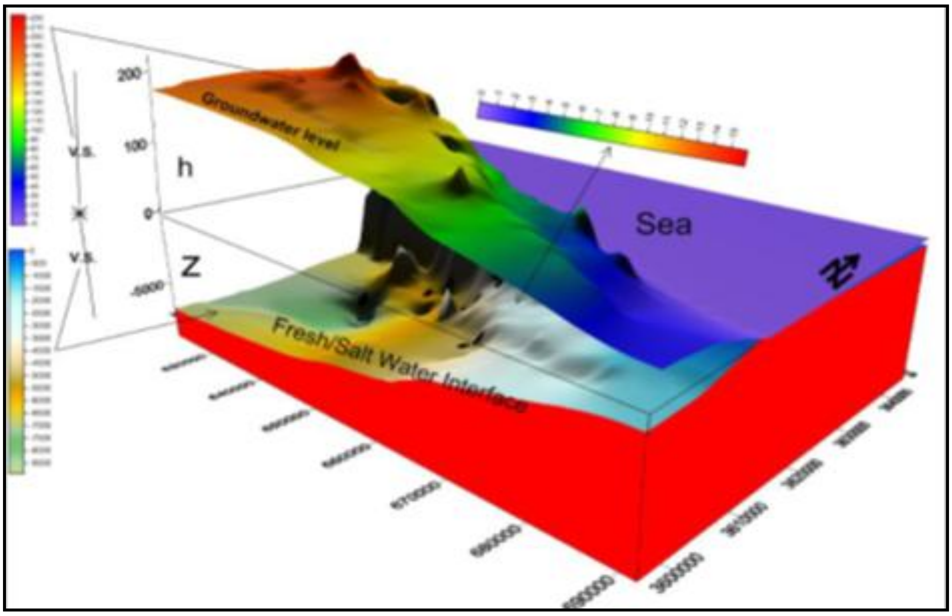

Figure 10. Freshwater-Salt water interface in Study Area

3.5 Model Prediction

In the following section, the calibrated model will be used to illustrate the relationship between the pumping rates and the up-coning based on the initial salt/fresh water interface.

The calibrated model was run again for the two suggested fixed pumping rates 10 and 20 l/s for all wells to study the response of fresh/saltwater interface and up-coning. The groundwater level decreased. Two grids were generated to represent the new water levels and the fresh/saltwater interface for each pumping rate. Each grid of the fresh/saltwater interface was subtracted from the initial grid, resulting in a new grid representing the up-coning.

Figure (11) shows the decrease in water level by 0.142 m due to pumping rate of 10 l/s which led to maximum up-coning of 5.68 m as shown in Figure (12). The drawdown of 0.4 m due to pumping rate 20 l/s is shown in Figure (13) which led to maximum up-coning of 16 m as shown in Figure (14). From these results, it is noticed that Al-Fatayah area is the only place which was affected and faced the appearance of saltwater up-coning. That could be interpreted due to the condensation of water wells in this area.

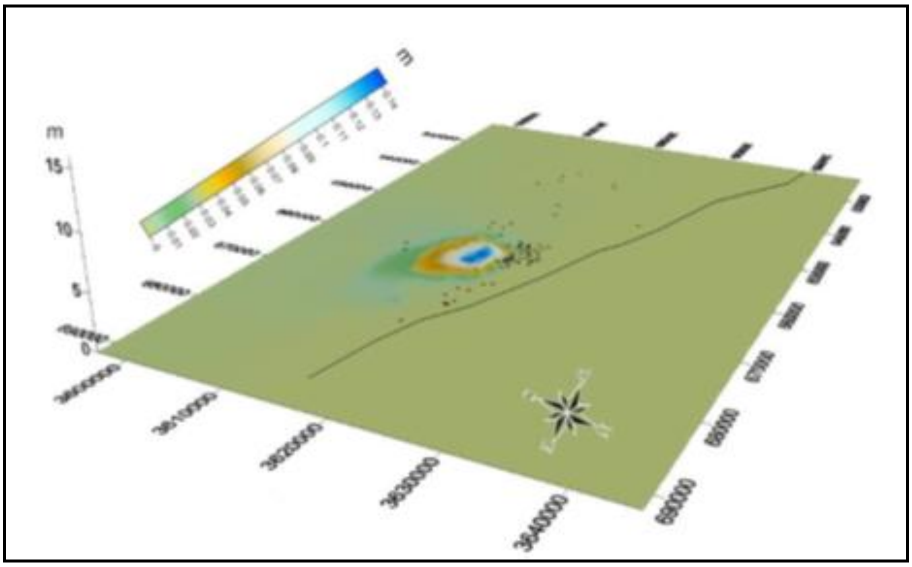

Figure 11. Water level decrease by 0.142 m due to pumping 10 l/s; Al-Fatayah

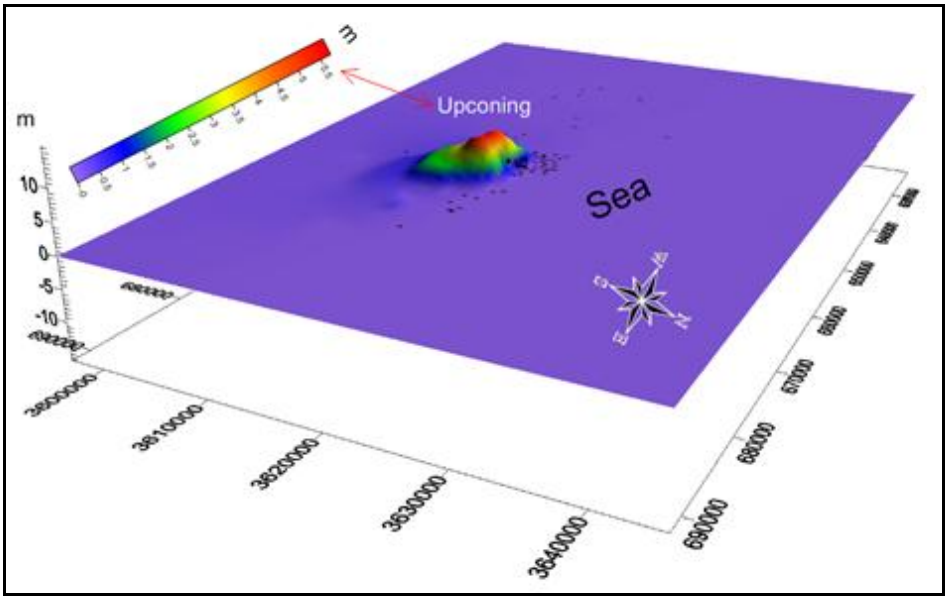

Figure 12. Up-coning of 5.68 m due to pumping rate of 10l/s; Al-Fatayah

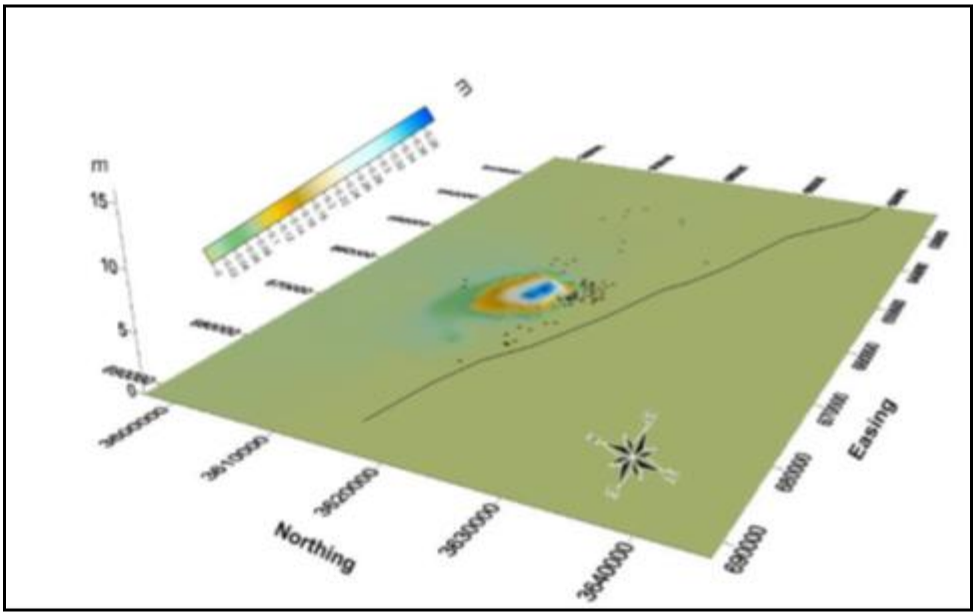

Figure 13. Water level decrease by 0.142 m due to pumping 10 l/s; Al-Fatayah

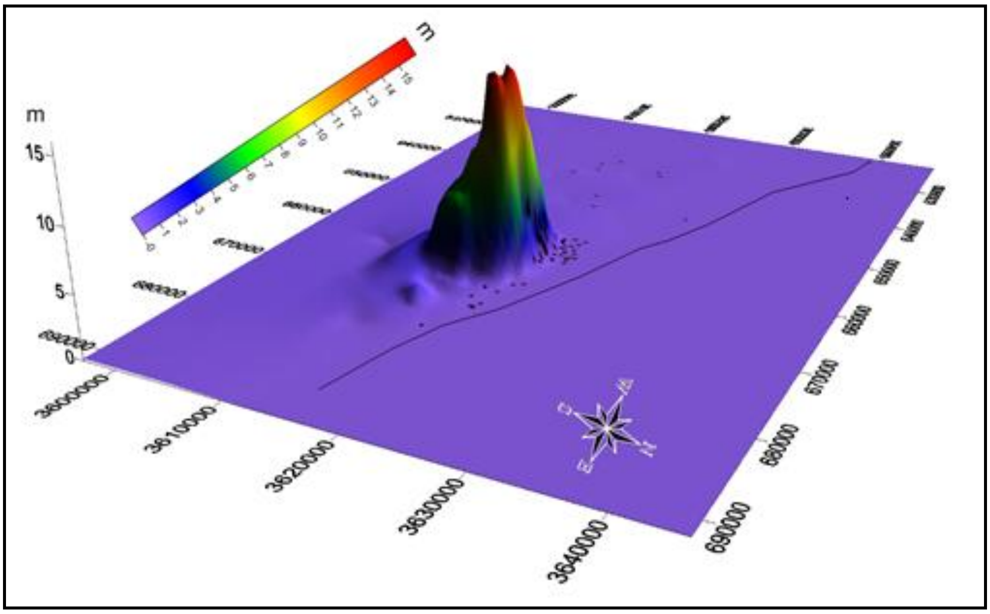

Figure 14. Up-coning of 16 m due to pumping rate of 20l/s; Al-Fatayah

4 CONCLUSIONS AND RECOMMENDATIONS

Studying saltwater intrusion and up-coning phenomenon is mandatory requirements for groundwater management in coastal aquifers. This study concluded that visual MODFLOW can be used in simulation of groundwater flow in fractured media and saltwater intrusion in Derna area. The results are promising to predict the aquifer response against changing the pumping rates.

The results show that the only area which is affected and suffering from up-coning phenomenon is Al-Fatayah area. It is noticed that there is a condensed number of wells in this coastal area which are used in multipurpose; drinking, heavy agriculture and bottled water.

As a results of changing pumping rates, the drawdown in groundwater levels were found to be 0.142 m and 0.4 m which led to up-conning of values 5.68 m and 16 m. due to pumping rate of 10 and 20 l/s respectively.

These results can be used as a guide for new pumping wells location and design. It is recommended to execute a monitoring system to get a complete vision about the groundwater management in Derna area. In addition, more investigations are required to determine the maximum critical up-coning and the allowed distance between the location of new pumping wells and shore line. Moreover, it is required to carry out a comprehensive geologic structural study to identify the geometry of fractures.

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