UNIVERSITI PUTRA MALAYSIA

SIMULATION OF SEAWATER INTRUSION IN JIFARA PLAIN, LIBYA

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SIMULATION OF SEAWATER INTRUSION IN JIFARA PLAIN, LIBYA

By

NADIA AHMED ELASWED

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

March 2018

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DEDICATION

I dedicate my dissertation to my family and many friends. Also, to my beloved parents I owe a debt of gratitude. Firstly, to my father: Haj Ahmed M. El-Aswed, may God have mercy on his soul. Secondly, to my mother: Haja Hanona E. Al Geriani who has been my limitless source of encouragement and steadfastness since the beginning of my education till I obtained my bachelor's degree, I will always be thankful.

The thesis is also dedicated to my husband, Professor Dr. Adel M. Al Geriani for his understanding, sacrifice, support and for being there for me on this challenging academic journey. I also also dedicate this work to my beloved children: Mohamed, Taha, and Saja.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

SIMULATION OF SEAWATER INTRUSION IN JIFARA PLAIN, LIBYA

By

NADIA AHMED ELASWED

March 2018

Chairman : Professor Thamer Ahmed Mohamed Ali, PhD
Faculty : Engineering

In Libya, the limited recharge and increasing water demand have resulted in over-exploitation of groundwater storage in the Tripoli aquifer, Jifara plain. The consequences of the aquifer's over-exploitation are serious declines in groundwater levels and deterioration in groundwater quality. The Tripoli aquifer, Jifara plain, is an unconfined aquifer located Northwest of Libya with a total area of 763 km^2. The Tripoli aquifer includes five well profiles, which are: Al Mayah profile (7 wells), Janzur profile (9 wells), Gergaresh profile (10 wells), Eyn Zarah profile (8 wells), and Tajura profile (10 wells) besides 21 wells distributed between them. In total, there are 65 pumping wells in the Tripoli aquifer. The ModelMuse model was calibrated, validated, and applied to predict groundwater levels and TDS concentrations in the Tripoli aquifer, Jifara plain. The simulation results are used to assess the current and future conditions of the aquifer. The geological, hydrogeological, and hydrological data used in the simulation processes were acquired from the Libyan General Water Authority. For the Tripoli aquifer, simulation of future management scenarios under transient state were carried out to study the impact of pumping on groundwater levels and TDS concentrations for a period of 90 years (2010-2100). In this study, three possible pumping scenarios from the Tripoli aquifer were simulated using ModelMuse model. The first scenario was based on using the current pumping rate from the wells of the Tripoli aquifer, which was estimated to be 74.35×10^6 m^3/yr as a fixed pumping rate up to 2100. The second scenario was based on using varying pumping rates (74.35×10^6 m^3/yr in 2010 and 152.65×10^6 m^3/yr in 2100), which took into account the population growth for 90 years (2010-2100). The third scenario was based on using a fixed pumping rate of 19×10^6 m^3/yr, which is equivalent to the annual recharging rate in the Tripoli aquifer. The annual recharging in the Tripoli aquifer was recommended to be taken as 10% from the annual rainfall. Simulation results showed that for fixed pumping rare (first scenario), the maximum drop in groundwater level, TDS concentration and the aquifer affected area by seawater intrusion were 13.2 m (found in Al Mayah profile, well number T106), 25817 mg/l (found at the wells

located in Al Mayah profile), 694 km^2 respectively. For future increased pumping rate (second scenario). The simulation results showed that the maximum drop in groundwater level, TDS concentration and the aquifer areas affected by seawater intrusion were 15.4 m (found in Al Mayah profile, well number T106), 37783 mg/l (found at the wells located in Al Mayah profile) and 727 km^2 respectively. When the pumping rate was equivalent to the recharging rate at the Tripoli aquifer (third scenario), simulation results indicated a considerable increase in groundwater level, which was found to be 3.5 m while the decrease in TDS concentration in the areas affected by seawater intrusion were 13928.8 mg/l and 172 km^2. Among the simulated pumping scenarios, sustainable pumping rate of 19×10^6 m^3/year was recommended since it would result in a considerable rise in groundwater level and a noticeable decrease in TDS concentration. Besides, following this scenario, augmentation of water from other sustainable management practices such as rainwater harvesting should be followed in order to control the problem of seawater intrusion in the Tripoli aquifer.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SIMULASI GANGGUAN AIR LAUT DI PADANG JIFARA, LIBYA

Oleh

NADIA AHMED ELASWED

Mac 2018

Pengerusi : Profesor Thamer Ahmed Mohamed, PhD
Fakulti : Kejuruteraan

Di Libya, caj semula terhad dan peningkatan permintaan air telah menyebabkan eksploitasi berlebihan penyimpanan air bawah tanah di akuifer Tripoli, dataran Jifara. Akibat daripada eksploitasi akuifer adalah penurunan serius paras air bawah tanah dan kemerosotan kualiti air bawah tanah. Akuifer Tripoli, dataran Jifara, adalah akuifer tidak terkurung yang terletak di Barat Laut Libya dengan jumlah kawasan seluas 763 km^2. Aquifer Tripoli terdiri daripada lima profil telaga iaitu profil Al Mayah (7 telaga), profil Janzur (9 telaga), profil Gergaresh (10 telaga), profil Eyn Zarah (8 telaga), dan profil Tajura (10 telaga) selain 21 telaga diedarkan di antara mereka. Secara keseluruhannya, terdapat 65 buah telaga yang mengepam di akuifer Tripoli. Model ModelMuse telah ditentukur, disahkan, dan digunakan untuk meramalkan paras air bawah tanah dan kepekatan TDS di akuifer Tripoli, dataran Jifara. Hasil simulasi digunakan untuk menilai keadaan semasa dan masa depan akuifer. Data geologi, hidrogeologi, dan hidrologi yang digunakan dalam proses simulasi diperolehi daripada Pihak Berkuasa Air Umum Libya. Bagi akuifer Tripoli, simulasi senario pengurusan masa depan di bawah keadaan sementara telah dijalankan untuk mengkaji kesan pam pada paras air bawah tanah dan kepekatan TDS selama 90 tahun (2010-2100). Dalam kajian ini, tiga senario pengepaman dari akuifer Tripoli disimulasikan menggunakan model ModelMuse. Senario pertama adalah berdasarkan penggunaan kadar pam semasa dari telaga akuifer Tripoli, yang dianggarkan 74.35×10^6 m^3/tahun sebagai kadar pam tetap sehingga 2100. Senario kedua adalah berdasarkan penggunaan kadar pemanasan yang berbeza-beza 74.35×10^6 m^3/tahun pada tahun 2010 dan 152.65×10^6 m^3/tahun pada 2100), yang mengambil kira pertumbuhan penduduk selama 90 tahun (2010-2100). Senario ketiga adalah berdasarkan penggunaan kadar pengepaman tetap 19×10^6 m^3/tahun, yang bersamaan dengan kadar pengisian tahunan di akuifer Tripoli. Pengisian tahunan di akuifer Tripoli disyorkan untuk diterima sebagai 10% daripada jumlah hujan tahunan. Hasil simulasi menunjukkan bahawa untuk kadar pengepaman tetap (senario pertama), penurunan maksimum dalam paras air bawah tanah, kepekatan TDS dan kawasan terjejas akuifer oleh pencerobohan air laut adalah 13.2

m (didapati dalam profil Al Mayah, nombor T106), 25817 mg/l (ditemui di telaga yang terletak di profil Al Mayah) masing-masing 694 km^2. Untuk peningkatan kadar pam pada masa depan (senario kedua). Keputusan simulasi menunjukkan bahawa penurunan maksimum paras air bawah tanah, kepekatan TDS dan kawasan akuifer yang terjejas oleh kemasukan air laut adalah 15.4 m (didapati dalam profil Al Mayah, telaga bernombor T106), 37783 mg/l (ditemui di telaga yang terletak di Al Profil Mayah) dan 727 km^2 masing-masing. Apabila kadar pengepaman bersamaan dengan kadar pengisian di akuifer Tripoli (senario ketiga), hasil simulasi menunjukkan peningkatan yang tinggi dalam paras air bawah tanah, yang didapati 3.5 m manakala penurunan kepekatan TDS di kawasan-kawasan yang terjejas oleh kemasukan air laut adalah 13928.8 mg/l dan 172 km^2. Di antara semua senario pam simulasi, kadar pemantauan yang berterusan sebanyak 19×10^6 m^3/tahun disyorkan kerana ia akan menyebabkan kenaikan paras air bawah tanah dan penurunan kepekatan TDS yang ketara. Selain itu, menurut senario ini, penambahan air daripada amalan pengurusan mampan lain seperti pengumpulan air hujan harus diikuti untuk mengawal masalah kemasukan air laut di akuifer Tripoli.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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CHAPTER 1

INTRODUCTION

1.1 Background

Groundwater is the water found in the voids between the subsurface soil particles and in the cracks. Large quantities of groundwater are present in geological formations called aquifers which are the primary sources of water for human activities such as industry, agriculture, and domestic drinking water, especially in regions with limited annual precipitation (Todd, 1980).

The groundwater located in a deep reservoir is less vulnerable to pollution. However, anthropogenic activities such as fertilisation and other pollution sources as well as the over exploitation of the aquifers create serious problems in groundwater quality. These problems limit the use of groundwater and create additional restrictions to meet the increasing water demand. The main pollutants found in groundwater are nitrate, heavy metals, and seawater. However, seawater intrusion is the most common contamination problem occurring in the coastal aquifers (Charbeneau, 2000).

Seawater intrusion degrades groundwater quality by raising the salinity to levels that make it unacceptable for drinking, irrigating crops and restricts the future exploitation from coastal aquifers.

When the hydraulic gradient in coastal aquifer is towards the inland, intrusion of seawater occurs and seawater displaces fresh water. There are many sources of saline water that cause groundwater contamination, some of which are, geology of the area, waste discharge, and excess irrigation. In deep coastal aquifers, excessive pumping to meet the increasing water demand is the main cause of seawater intrusion. So, over-pumping of groundwater wells near the shoreline is a major cause of encroachment of seawater into the aquifers. This causes the reduction or reversal of groundwater gradients, which permits denser saline water to displace fresh water (Todd, 1980).

Globally, the population is growing and the rise in living standards has also increased water demands. Coastal zones are among the most densely populated areas in the world with over 70% of the world’s population. This leaves the coastal aquifers in these zones exposed to serious hydrological problems such as scarcity of fresh water, contamination of groundwater, and seawater intrusion.

Over-pumping has led to a dramatic increase in seawater intrusion problems. Normally and in coastal aquifers, the existing hydraulic gradient is towards the sea. In this case, the flow of excess fresh water is towards the sea. Owing to the presence of seawater in the formation of coastal aquifers under the sea bottom, a zone of contact is formed between lighter fresh water, which is flowing to the sea and heavier underlying seawater. The fresh water and seawater are actually miscible fluids and therefore, the zone of contact between them takes the form of a transition zone caused by hydrodynamic dispersion. Across this zone, the density of the mixed water varies between that of fresh water and that of seawater. Under certain conditions, the width of this zone is relatively small when compared with the thickness of the aquifer, so that the boundary can be considered as a sharp interface that separates the two regions occupied by the two fluids, in this case, the two fluids are assumed to be immiscible. But, if the transition zone is wide, this assumption becomes invalid (Bear, 1979). Figure 1.1 shows the interface between seawater and fresh water.

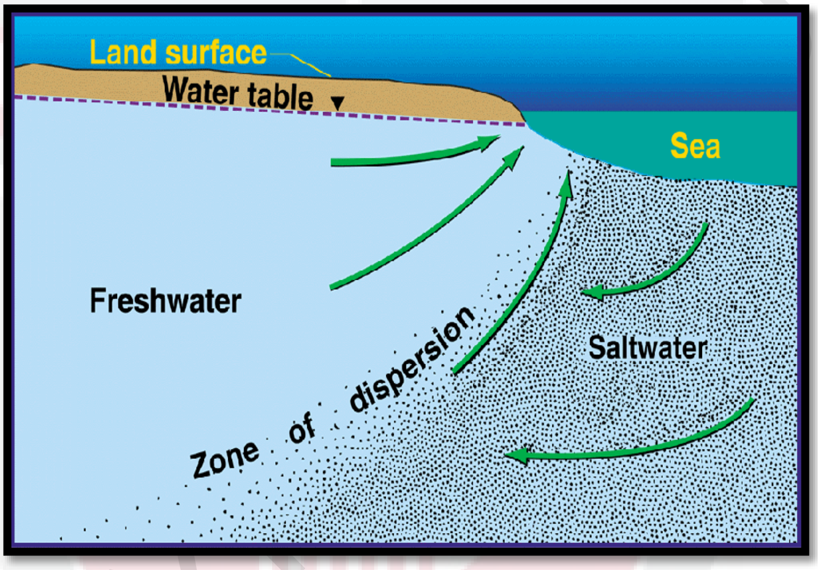

Figure 1.1 : Hydrostatic equilibrium at the fresh/seawater interface and the zone of dispersion in a coastal aquifer (Larabi, 2007)

The Mediterranean coast is a good example of seawater intrusion where the coastal aquifers are facing a severe contamination problem. Coastal aquifers located in arid and semi-arid zones are subjected to a severe seawater intrusion problem. This is because the area of the aquifers is characterised by a dense population, urban development, limited surface water resources making it necessary for intense exploitation of groundwater (Elina, 2006).

Most of Libya's population are living in the Jifara plain and water demand for the plain is met using groundwater exploited from the Tripoli aquifer. The water is used for agriculture, which plays an important role in the Libyan economy. The groundwater exploitation from the Tripoli aquifer is rapidly increasing due to population growth and expansion in agricultural and industrial production. As a result of excessive groundwater pumping from the Tripoli aquifer, groundwater levels are declining and there is a landward migration of seawater towards the aquifer (Sadeg, 1996).

1.2 Problem Statement

In Tripoli aquifer, Jifara plain, Libya, the gradual population growth, land use changes, and heavy urbanization have increased the pressure on groundwater, the traditional source of water in Libya since there are no surface water sources at all. According to the hydrologic cycle, all groundwater in Libya originates from precipitation and mainly the percolation of rainwater. In the Tripoli Aquifer, the recharge of groundwater forms about 10% of the annual rainfall (Kruseman and Floegel, 1978). In the Tripoli coastal aquifer, which is subjected to intensive pumping, the groundwater storage is exposed to salinisation due to lateral intrusion of seawater into the aquifer. So, the fresh water storage is continuously threatened by salt water intrusion. Salt water intrusion is a common contamination problem in developed and urbanised coastal areas especially in arid and semi-arid regions worldwide, including the Tripoli aquifer. The human activities in the area of the Tripoli aquifer continue to increase the threat of seawater intrusion in the Tripoli aquifer. The overexploitation of the Tripoli aquifer is mainly to meet the increasing domestic and other demands resulting from population growth and development. This has led to a considerable drop in groundwater level and TDS concentration as well as seawater intrusion as confirmed by field observations. According to the Libyan General Water Authority, the groundwater level in 1995 dropped to 5 m above sea level in well number T401 of Eyn Zarah profile, Tripoli aquifer. Data in 1995 showed that the TDS concentration in well number T200 in Janzur profile was found to be 3036 mg/l and this confirmed that the quality of groundwater in the above well was within brackish water quality (between 3000 and 4000 mg/l). Long term solutions are required to control the seawater intrusion in the Tripoli aquifer, Jifara plain. There were many studies conducted on the Tripoli aquifer and these studies used different methodologies and outputs. Studies can be divided into either water resources management and quality control (Al Farrah and Walraevens, 2018; Salem, 2015; Ekhmaj et al., 2014; Ghazali and Sadeg, 2012; El Trriki et al., 2011; Hafi, 1998) or studies that use the mathematical models to simulate aquifer behaviour, indices for geological contents and impact of climate change on seawater intrusion (Gejam et al., 2016; Al Farrah and Walraevens, 2014; Elgzeli et al., 2009; El Fleet, 2008; El Fleet, 2006; El Fleet and Baird, 2001; Sadeg and Karahanoglu, 2001; Ghazali et al., 2001). Up to now, the models used to simulate the impact of pumping on seawater intrusion in the Tripoli coastal aquifers were SUTRA and MODFLOW 2000 but the performances of the models were not subjected to proper assessment when applied to the Jifara plain.

The present study focuses on simulation of various possible pumping scenarios in order to recommend a sustainable solution for the Tripoli aquifer. The latest version of ModelMuse model will be used to simulate the over-exploitation and sustainable pumping from the Tripoli aquifer and the aquifer response to these pumping scenarios. Simulation of suitable solutions will also be included.

1.3 Objectives of the Study

The main objective of this study is to simulate the impacts of fixed pumping, future increasing pumping, sustainable abstraction and the proposed solutions to address the issues of groundwater level and seawater intrusion in the Tripoli aquifer, Jifara plain, Libya by using ModelMuse. The specific objectives of the study are:

1. To calibrate, validate and statistically test the ModelMuse model by using the available recorded data for the Tripoli aquifer, Jifara plain.
2. To simulate the impact of fixed pumping rate, future increasing pumping rate and sustainable abstraction on groundwater level and TDS concentration in the aquifer by using ModelMuse Model.
3. To investigate the impact of the suggested practices that will increase the aquifer recharge and reduce pumping rate on groundwater level in the aquifer.

1.4 Scope and Limitation of the Study

The scope and limitations of the study are as follows:

1. This study focused mainly on the Tripoli aquifer, Jifara plain, Libya. The aquifer is located in the Northern part of Libya bordered by the Mediterranean Sea. The Tripoli aquifer forms a rectangle shape with an area of 763 km^2.
2. The Tripoli aquifer extends from Al Maya in the West to Tajura in the East. The total number of wells is 65. Among them, 44 wells are distributed in five profiles, namely, Al Mayah (7 wells), Janzur (9 wells), Gergaresh (10 wells), Eyn Zarah (8 wells) and Tajura profile (10 wells) while 21 wells distributed between the above profiles. The depths of these wells ranged from 7 m to 120 m.
3. The part of the Tripoli aquifer included in this study is a shallow, unconfined, homogeneous, and isotropic aquifer.
4. The geology of the Tripoli aquifer consists mainly of sandstone and sandy limestone with thickness is variable, but is typically 150 m thick.
5. The groundwater level of the aquifer is generally found between 0.26 and 16.34 m above sea level (taken as 0 m). These data were used in the simulation model.
6. Data on population from 1973 to 2006 were used in the future population projection and also for estimation of water consumption.
7. ModelMuse (Version 3.9) was used in the simulation of seawater intrusion in the Tripoli aquifer.
8. ModelMuse model was calibrated and validated based on the data of year 1995.
9. The characteristics of the Tripoli aquifer that were used in the simulation model included hydraulic conductivity (1.42 - 5.79 m/day), thickness of the Tripoli aquifer (134 - 169 m), effective porosity (0.20) and porosity (0. 30).
10. The total pumping rate from groundwater wells in the Tripoli aquifer, Jifara plain in the year 2010 was approximately equal to 74.35×10^6 m^3/yr. In the fixed pumping rate scenario, this value was taken as constant without any increment up to 2100.

11. The pumping increase was based on population increase in Jifara plain from 2010 up to 2100. The rate of increase in pumping was computed based on the method proposed by Gupta (1989).
12. The simulation excluded the impact of climate change, rise in seawater level and recharging of the Jifara plain.
13. The values of the maximum and minimum TDS concentrations in the groundwater wells of Tripoli aquifer in the year 2010 were 28,364 mg/l and 454 mg/l respectively.
14. The annual rainfall in the Tripoli area ranged from 310 to 135 mm while the average annual recharge of groundwater ranged from 15.5 to 7.5 mm.
15. For the Tripoli aquifer, the assigned model boundaries were based on hydrodynamic pattern. A constant head boundary assumed equal 0 and this was based on sea level as a fixed datum. Most of the Southern boundary was assumed with a continuous constant groundwater flux in the model. The Eastern and Western boundaries of the aquifer were assumed as no flow boundary.
16. According to the published literature on the Tripoli aquifer, the average amount of recharging rate was recommended to be 10% from the mean annual rainfall which was found to be 250 mm.
17. There is no ground check was made for Jifara plain.
18. The projection of future water demand was based on population forecasting computed based on the equation of the arithmetic method (Gupta, 1989).
19. The statistical tests to be used to check the accuracy of ModelMuse model were mean error (ME), mean absolute error (MAE) and the root mean square error (RMSE).

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LIST OF PUBLICATIONS

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