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NUMERICAL MODELLING OF SEAWATER INTRUSION AND POSSIBLE SOLUTION IN COASTAL AREAS

Theses of PhD dissertation

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I. INTRODUCTION AND OBJECTIVES

In my research I have studied the saltwater intrusion phenomenon in Syrian coastal aquifer area (Damsarkho plain), by the numerical simulation of possible solutions for this problem. Coastal aquifers serve as major sources for freshwater supply in many countries around the world, especially in arid and semi-arid zones. Many coastal areas are also heavily urbanized, a fact that makes the need for freshwater even more acute. Coastal aquifers are highly sensitive to disturbances. Inappropriate management of a coastal aquifer may lead to its destruction as a source for freshwater much earlier than other aquifers which are not connected to the sea. The reason is the threat of seawater intrusion.

The choice of this topic is justified because it has been observed all over the world, and also in Syria, since a very large population living in coastal area needs very large amount of fresh water from coastal wells, changing their water to saline.

This phenomenon has also been observed on Syrian coast north of Latakia (the Damsarkho plain). The Damsarkho coastal plain is currently experiencing seawater intrusion thanks to the irrational exploitation of the aquifer via wells of different types, depths and pumping rates. The first in-depth investigation of this problem was undertaken in 2000 by Abed Rabo R., who specified the location and extent of the intrusion by chemical analysis and measurement of groundwater levels. The next study was carried out in 2003 by Abou Zakhem and Hafez, who used the analysis of electrical conductivity and isotopic elements to investigate the phenomenon. The results obtained in these two studies have confirmed the existence of intrusion.

A number of different measures are used to control seawater intrusion and to protect the groundwater resources. The main principle of protection is to increase the volume of fresh groundwater and reduce the volume of saltwater. There are various means for preventing saltwater from contaminating groundwater sources, such as subsurface barriers, artificial recharge, and relocation of abstractions wells.

The modern use of models (such as Visual MODFLOW) for the simulation of the best abstraction plans or for simulation of the application of possible solutions was not applied in this area.

The main aims of my research - based on the above – are the followings:

1- Comparison of the results and the interpretation of the unjustified studied phenomenon of seawater intrusion in the Syrian area in the Syrian and international literature.

2- Collection of needed data for simulation of the occurrence of Syrian seawater intrusion, using the best programs for this purpose.

3- Building of hydrodynamic model that can be used to describe the current situation and forecasts of the seawater intrusion in studied area.

4- Simulation of the known solutions in international literature for this problem on the basis of the data in the studied Syrian area, and investigating their effects on the intrusion of seawater.

Depending on the above mentioned objectives I will search the answer for the next question:

Can the observed seawater intrusion problem in Syrian territory be solved, and if so, which solution is most effective?

According to this, my sub-questions are:

1- In the running of the model which are the most important hydrogeological parameters, and how their changes can affect the movement of seawater intrusion, and the efficiency of solution methods.

2- Depending on the chemical interpretation of data how does the amount of chloride change, what is the relationship between its concentration and groundwater level, and depending on groundwater quality where are the best places of abstraction wells.

3- In order to reduce the amount of invaded seawater and the effective salinity, among the following solutions (subsurface barrier, re-location of wells, injection wells) which solution is recommended and can be used.

II. BRIEF DESCRIPTION OF MATERIALS AND METHODS

In my work I have used the results of a hydrogeological survey of the studied Syrian area to create the hydrodynamic model. The purpose of this model is to examine how to reduce the area of saltwater intrusion, and to predict what will happen to the coastal aquifer after using and without using solutions.

I have made the simulation of the seawater intrusion by VISUAL MODFLOW (SEAWAT) package. The SEAWAT-2000 software package enables modelling of groundwater, coupling flow and transport, using the flow and transport equations of two widely accepted codes; MODFLOW and MT3DS. Some modifications are also employed to include density effects based on the extended Boussinesq assumptions.

MODFLOW was modified to solve the variable-density flow equation by reformulating the matrix equations in terms of fluid mass rather than fluid volume and by including the appropriate density terms. Fluid density is assumed to be solely a function of the concentration of dissolved constituents. Temporally and spatially varying salt concentrations are simulated in SEAWAT using routines from the MT3DMS program. SEAWAT uses either an explicit or implicit procedure to couple the ground-water flow equation with the solute-transport equation. With the explicit procedure, the flow equation is solved first for each time step, and the resulting advective velocity field is then used in the solution to the solute-transport equation. With the implicit procedure for coupling, the flow and transport equations are solved multiple times for the same time step until the maximum difference in fluid density between consecutive iterations is less than a user-specified tolerance.

The first step is to specify which the most important parameters are that influence the seawater intrusion and how their different values affect this intrusion. This was done using of hydro geological properties of the most known rocks as aquifers as reasonably possible values, and I recorded and investigated the effect of their changes.

After the completion of the area model for the period between 1997 and 2010, I calibrated it to measured water levels. Then I examined the potential water management strategies to stop or significantly reduce the seawater intrusion between 2010 and 2020.

In the first solution method I have simulated the effects of subsurface barrier placed between the beach and the extraction wells. The subsurface barrier was (one meter thick, with 10^{-5} m/day hydraulic conductivity, starting from the second layer to down).

In second method as possible defence, I have installed re-injection wells in the model, between the extraction wells and the coast with 250 m^3/nap yield. The injection is done at the same time of extracting in -5 and- 20 m depth section.

As a third examined possibility, I have moved the wells near the sea, to internal areas with the same pumping yield, the new place of wells was depended on chemistry evaluation of tested data.

III. THESIS POINTS HIGHLIGHTING THE MOST IMPORTANT RESULTS

1- The varies of access time firstly and importantly depends on the variants in the values of hydraulic conductivity and porosity, this change in the access time is straightly with the porosity while the hydraulic conductivity is inversely. The value of anisotropy at low hydraulic conductivity and porosity exceeding 30% has clear role, in such case the access time increases with the increasing of anisotropy.

According to the values of hydraulic conductivity, three intervals can be distinguished in the detection of saltwater intrusion.

1. –K < 0.1 m/d, the seawater intrusion can be considered as negligible.
2. 0.1 < K > 1 m/d, at this interval the seawater intrusion can be detected especially at large-scale and long-term water extraction.
3. –K > 1 m/d, at this interval the seawater intrusion definitely exist.

The value of hydraulic conductivity of the main aquifer (limestone) in the study area, according to the previous studies, was estimated at 10-15 m / day, while in accordance to the international literature it has been evaluated to the value of 0.8 - 800 m / day, therefore, these parameters should be measured and adjusted with high precision for applying them in the proposed model. The access times depending on the combination variation of different values of hydraulic conductivity and porosity was calculated as follows:

1. (K > 1 m/d) in proportion to minimum and maximum values of porosity the access time is 200 and 500 days.
2. (K <1 m/d) in proportion to minimum and maximum values of porosity the access time is 800 to 3600 days.

2 - In areas where recharge of fresh water and production of water is seasonal, I found that in the calculation of the access time the specific storage and specific yield have a role if the hydraulic conductivity is less than 0.1 m/day.

High hydraulic conductivity, and the confined layer of the value of specific storage is not so important, with the decreasing of hydraulic conductivity the difference in access times becomes clear when hydraulic conductivity is less than 0.01 1/m, and this time begins to grow exponentially.

After running the model, I found that the influence of specific yield is so small on the velocity of intrusion that it does not matter what the value of specific yield is provided the hydraulic conductivity is greater than 1 m / day, but when the hydraulic conductivity is less than this value, then the access time increases exponentially.

3 - I found that the distribution of chloride in the studied area depends on two parameters, the distance from the sea and the direction of the prevailing wind. This distribution can be changed by seawater intrusion due to fresh water production. The largest amount of chloride in the southern and western parts can be observed where the groundwater level is the lowest, while it is the smallest in the northeastern part where the water table is at highest levels.

The variation of Cl^- ion in the time was followed by two types in the tested wells. On the one hand, in some wells, the chloride concentration varied to a great extent, on the other hand, in some wells the value of Cl^- ion stayed at almost constant values. Wells closest to the coastline had the largest change, and in the case of the most distant wells from the shoreline the chloride concentration remained almost constant.

The formation of the largest changes in the concentrations is influenced by prevailing winds. When examining the relationship between chloride concentration and the groundwater level, I found that in the southern part of the area where the water table is low the chloride concentration was higher, while in the northern part, where the water table is higher, lower concentrations of chloride existed.

4 – From the chemical analysis of chemical composition of groundwater, I have distinguished provinces. Furthermore, I have calculated values of SAR criteria. By using these parameters I have determined the ideal places for extraction of groundwater, which are located in the central part of the plain, and in the eastern and north-eastern parts.

For prevention of saltwater intrusion the relocation of extraction wells is one of the popular solutions. According to the chemical data, the best place is in the middle, eastern and north-eastern parts of the plain, where the SAR criteria is between 1-4, which refers to very good quality of water for irrigation purposes, $Ca(HCO3)^{+}$ type of water.

5 – At the same volume of water abstraction, I have performed various technical interventions in the model to do a comparative evaluation of changes in salinity of groundwater. They are based on the following conclusions:

a. After using a subsurface barrier the incoming salt water would be reduced by 95% in contrast to the untreated situation. (The thickness of subsurface barrier was 1 m, with 10^{-5} m / s hydraulic conductivity was set in the model. It was observed in all wells that the reduction of incoming saline water was 95%).

b. After using the re-injection wells, the incoming salt water into the main aquifer (limestone) would be reduced by 80%, but the disadvantage of this solution is the difficulty of obtaining fresh water for reinjection. (The re-injection wells have to be located between production wells and the sea, with 500 m between each other, the reinjection well was activated at the same time with production wells. Incoming saltwater decreased rapidly and clearly in the extraction wells. After putting off the re-injection wells, the salt content increased again, but did not reach the situation prior to reinjection).

c. After the relocation of the extraction wells the amount of incoming saline water in the monitoring points decreased significantly in the first few years, then began to rise, but the final state is still 76% lower than that in the baseline period. (This solution is especially effective in the southern part, where the water quality is not good for irrigation. Many wells here should be abandoned and new ones drilled, but anyway, by this solution we would get a better quality of ground water because of the reduction of incoming saline water).

d. After using the combined solution, the incoming salt water into the main aquifer (limestone) would be reduced by 96%, at the combined solution, more fresh water came through the eastern boundary of the studied area than the recharge from the sea. This solution is the most expensive but the most effective method of all.

6 – According to efficiency and economic considerations, I suggest using the subsurface barrier.

The reduction of the incoming saline water after the installation of the subsurface barrier is the largest among the tested solutions. Another advantage is that after the installation of the barrier, it does not require either constant supervision, or extra energy. Maintaining the subsurface barrier is the cheapest among the studied solutions, and there is no need to build any new channels or pipes.

IV. PUBLICATIONS IN THE TOPIC OF THE DISSERTATION

Allow K – Szanyi J. – Kovács B.: Potential solutions in prevention of saltwater intrusion: a modelling approach, Advances in the Research of aquatic Environmental Earth Sciences, 2011, Part 4, 251-257, DOI: 10.1007/978-3-642-19902-8_29

Allow K.: Seawater intrusion in Syrian coastal aquifers, past, present and future, case study, Arabian Journal of Geosciences, 2011, Volume 4, Numbers 3-4, pages 645-653.

Allow K.: The use of injection wells and a subsurface barrier in the prevention of seawater intrusion, a modeling approach, Arabian Journal of Geosciences, 2011, Volume 5, Number 5, Pages 1151-1161

Allow K.: Hypothetical thermohaline transportation study of pumping-reinjection wells in the geothermal field, Arabian Journal of Geosciences, Online First™, 30 May 2011