Original Research Article

Validating Visual Modflow Numerical Model To Predict Future Impact Of Brine Disposal On Groundwater

ABSTRACT

The aim of this research is to simulate the groundwater extraction and brine disposal fate. The Visual MODFLOW numerical model was used to predict the salt concentration emigration over time in an aquifer. The main objective of this study is to check the validity of using a numerical model in predicting the impact of brine disposal on the groundwater salinity. A numerical modelling study was carried to simulate the groundwater extraction and brine disposal using Visual MODFLOW and it was calibrated using a laboratory experiment results. The model results revealed that there was a great agreement between the results obtained from the model and the laboratory experiment where the correlation coefficient obtained from the model for the COB3 was 0.991, while for HOB1 was 0.901.

Keywords: Desalination; Injection well; discharge well; salt concentration; aquifer

INTRODUCTION

Water desalination is one of the non-conventional water resources where fresh water is produced from treatment of salt water. However, the negative impact of desalination process is the brine disposal which is a real environmental problem that should be considered and studied before constructing a desalination plant. The brine resulted from the desalination process is usually injected into aquifer or discharged into the sea. The practice of disposing the rejected brine into the sea is common for plants located in coastal areas [3]. The problem of disposing the rejected brine into the sea may increase seawater salinity leading to injuring plants and animals in the marine sanctuary [7,9,11]. In the case of disposing the rejected brine into the ground, it is necessary to design a disposal system in a way that respects the environment.

Numerical groundwater models have been used in developed countries since 1970's. Afterwards, there has been an increase in the usage of groundwater models, especially MODFLOW to address a wide range of water-related problems. [8] assessed the behaviour of production and injection well of desalination plants through an experimental setup and computational simulation. Their results showed that the injection well will affect the salinity of the production well on the long run. [1] used MODFLOW to simulate groundwater extraction for managing groundwater level in Jordan Valley. [5] developed a mathematical groundwater model for the Mahesh River basin in the Akola and Buldhana districts using a MODFLOW model to predict the groundwater levels variation under different hypothesis conditions to manage the groundwater. [10] used MODFLOW to develop a model for the study area to determine the interaction between the surface water and groundwater. [2] developed a mathematical model for the Upper Awash river basin using the MODFLOW then calibrated it in order to manage the sustainable groundwater resource of the country.

Calibration/validation has become a practice to ensure a model represents the observed groundwater conditions of a studied area. Model calibration is the process where values of model inputs are adjusted so that the model matches the observed data [6]. In this research, the laboratory experiment of [8] is used to calibrate the Visual MODFLOW (VMOD) model. The main objective of this study is to check the validity of using a numerical model in predicting the impact of brine disposal on the groundwater salinity.

VISUAL MODFLOW MODEL

Visual MODFLOW is a software developed by Waterloo Hydro geologic. The software is used to simulate three-dimensional groundwater movement and solute transport. Visual MODFLOW provides many numeric engines that perform the numeric calculations required to solve the finite difference scheme of groundwater flow and mass transport. SEAWAT is the numerical engine implemented in this study as it simulates three-dimensional, variable-density, unsteady groundwater flow in porous media. The density-dependent groundwater flow model is governed by the equation developed by [2] as shown in Eq. (1)

$$\frac{\partial}{\partial x}\left(\rho K_{fx}\left[\frac{\partial h_f}{\partial x}\right]\right)+\frac{\partial}{\partial y}\left(\rho K_{fy}\left[\frac{\partial h_f}{\partial y}\right]\right)+\frac{\partial}{\partial z}\left(\rho K_{fz}\left[\frac{\partial h_f}{\partial z}+\left(\frac{\rho-\rho_f}{\rho_f}\right)\right]\right)=\rho s_f\frac{\partial h_f}{\partial t}+\theta\frac{\partial \rho}{\partial C}\frac{\partial C}{\partial t}-\underline{\rho} q_s \quad (1)$$

Where ρ is the fluid density, K_{fx}, K_{fy} and K_{fz} are freshwater hydraulic conductivity in the x, y and z direction, h_f is the equivalent fresh water head, ρ_f is the density of freshwater, S_f is the fresh water specific storage, θ is the porosity, C is the concentration of solute mass per unit volume of fluid, q_s is the volumetric flow rate of sources or sinks per unit volume of aquifer and t is time. The governing equation for solute-transport is given by Eq. (2):

$$\frac{\partial(\theta C)}{\partial t} = \nabla(\theta D.\nabla C) - \nabla(qC) \pm q_s C_s \qquad (2)$$

Where:

D is the hydrodynamic dispersion coefficient tensor, q is specific discharge and

C_s is the solute concentration of water entering from sources or sinks.

NUMERICAL MODEL

Brine disposal by injection well in a coarse sand soil has been studied by [8] at Hydraulic Laboratory of Cairo University, Giza, Egypt using a rectangular seepage tank with dimension of 1.42 m long, 0.1 m wide and 0.6 m high. An injection well of 10 cm width was inserted on the left side of the seepage tank with a screen of 10 cm width that located at 0.15 m from the base of the tank. While, a constant head boundary of 24.5 cm was maintained on the right side of the tank. A constant head reservoir containing brine water of 39,400 ppm concentration was used to feed the injection well at a rate of 0.144 m^3/day. Several observation points were constructed within the seepage tank to get the observed values of head and salt concentration as shown in Table 1. The head observed value and the salt concentration observed value at the specified location and time has been recorded by a sounder and a digital conductivity meter respectively. A numerical model was built to simulate the laboratory experiment using Visual MODFLOW as shown in the following section.

Models domain

As shown in Fig.1 the model domain consists of one row, 29 columns and five layers. Each cell, with the exception of the cells in column 1 and cells in layer 1, is 0.05 * 0.05 m in size. Cells in column 1 are 0.02m * 0.05m and cells in layer 1 are 0.05m * 0.2m.

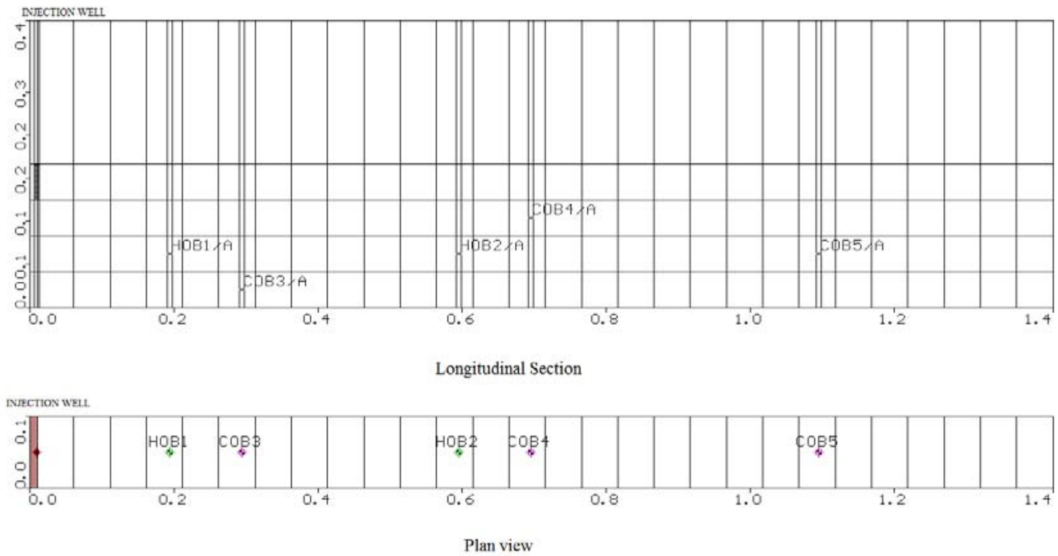

Fig.1. Model grids layout

Initial and boundary conditions

Initial water concentrations of model domain are set to be 800 mg/l and initial fresh water heads are all set to be 0.245 m. Brine is applied in column one and layer two through a well with injection rate 0.144 m^3/day and of concentration equal to 39400 mg/l. A constant fresh water head boundary of 0.245 m and a constant concentration equal to 800 mg/l are specified at column 29 and layer one.

Model parameters

The parameters used in this model are hydraulic conductivity which is generally uniform and isotropic, specific yield, porosity and coefficient of effective molecular diffusion. The assigned values for these parameters were set to be 83 m/day, 0.27, 0.3 and $8.53*10^{-8}$ m^2/min respectively.

Observation Points

Several observation points were constructed within the model domain as shown in Fig.1 and Table 1.

Table 1. Observation points locations

Observation Point No.	Observation point type	X (cm)	Y (cm)	Z (cm)
HOB1	Head	19.5	5	7.5
HOB2	Head	59.5	5	7.5
COB3	Salt conc.	29.5	5	2.5

COB4	Salt conc.	69.5	5	12.5
COB5	Salt conc.	109.5	5	7.5

MATHEMATICAL MODEL CALIBRATION

In order to calibrate the numerical model, the initial and boundary conditions of the laboratory experiment were assigned. Injection well (injection rate 0.144 m3/day and of concentration equal to 39400 mg/l) and different observation points were represented in the model as specified by [8]. The records obtained from the head and concentration observation points are required during the calibration process of the Visual MODFLOW model.

Time steps were set to be 24 steps to represent both head and concentration values for six hours model run.

Results of calibration

The outputs of the model are illustrated in Fig. 2 and Fig. 3. A comparison between the results obtained from the VMOD and the laboratory experiment of [8] for the concentration observation points COB3, COB4 and COB5 is shown in Fig. 2.

The correlation coefficient obtained from the model for these observation points were equal to 0.991, 0.995 and 0.981 respectively. While, Fig. 3 shows a comparison between the results obtained from the VMOD and the laboratory experiment of [8] for the head observation points HOB1 and HOB2.The correlation coefficient obtained from the model for HOB1 equal to 0.901and for HOB2 equal to 0.835.

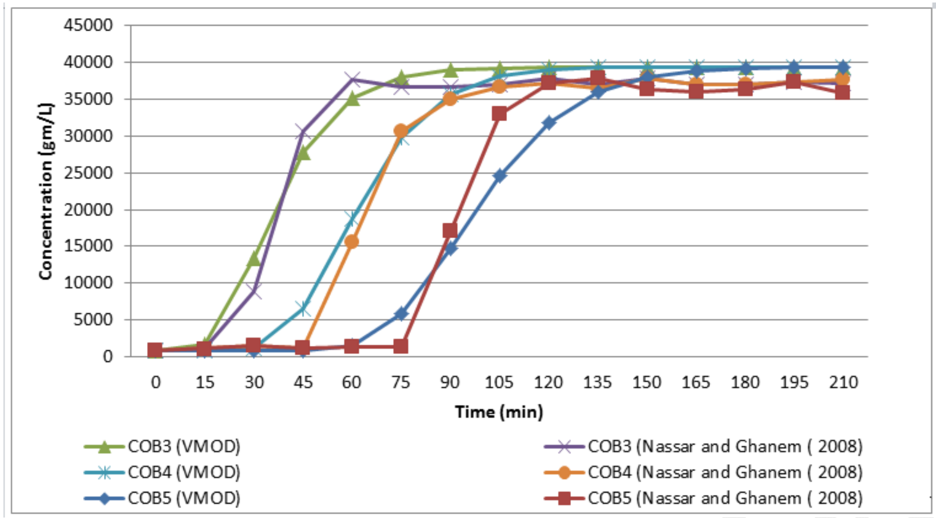

Fig.2. Comparison between results of Visual MODFLOW and laboratory experiment of [8] for COB3, COB4 and COB5

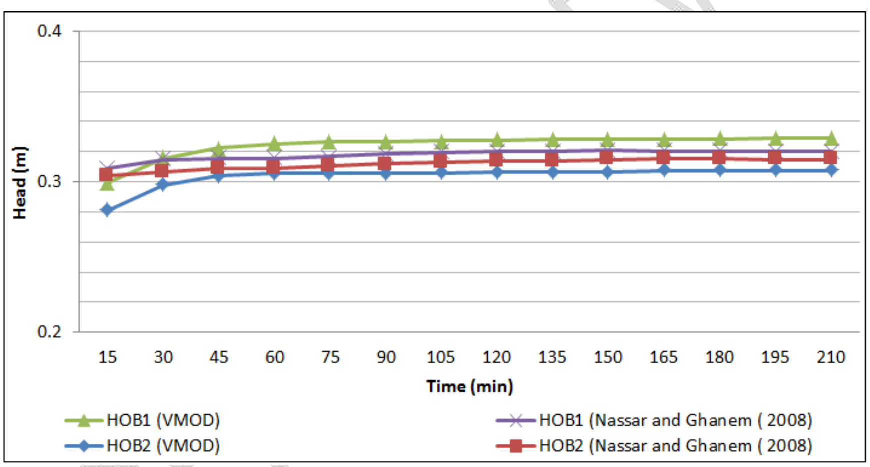

Fig. 3. Comparison between results of Visual MODFLOW and laboratory experiment of [8] for HOB1 and HOB2

CONCLUSIONS

From this study we can conclude that:

1. There was a great agreement between the results of the Visual MODFLOW and that of the laboratory experiment, where the correlation coefficient obtained from the model for the COB3, COB4 and COB5 were 0.991, 0.995 and 0.981 respectively. While for HOB1 and HOB2 were 0.901 and 0.835 respectively.

2. The Visual MODFLOW can assist engineers and researchers in simulating and predicting the future impact of brine disposal on the groundwater salinity.

Competing interests: no competing interests exist

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