Groundwater modeling of Khash aquifer and predicting effect of artificial-recharge project on the groundwater level

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Abstract

Surface water deficiency redounded to using the groundwater resources in the arid and semiarid regions of the state in order to providing ever-increasing requirements because of social-economic development programs have led to overuse and negative budget of groundwater resources. Therefore, the only way to regulate it is to use managerial methods for proper use of water resources while taking into account permanent development. Intelligent management of these resources requires exact identification of groundwater fluctuations and determination of its behavior as result of changes affected on them in the future. Using novel modeling methods and integrating them led to results that are more exact and consume less time. Continuous level downfall led to negative budget in Gouharkouh plain aquifer (Khash, Sistan & Baluchistan, Iran) and based on conducted researches the aquifer is confront with 12.4 MCM annual shortage and about 57 cm Annual water level downfall in past 5 years. In this study, GMS (Groundwater Modeling System) and integrated data layers in GIS (Geographic Information System) have been used for plain modeling in the steady and unsteady states. Finally using calibrated model, effect of an artificial-recharge project on eastern part of the Gouharkouh aquifer has been surveyed and amount of rise in groundwater level during 1 year has been predicted. According to the modeling results, artificial-recharge project will lead to groundwater level rise about 1.7 m around the areas near the implementation of the project.

Keywords: Groundwater Modeling System, Geographic Information System, Artificial-Recharge, Calibration.

Introduction

Groundwater resources have some advantages to surface water such as higher quality, lower impressibility from yearly and seasonal weather fluctuations, and uniform scattering. In addition, in some countries such as Denmark, Saudi Arabia, and Malt water resources limited to groundwater bodies [Zektser and Everett 2004]. In order to estimating groundwater resources potential and identifying affects of projects implementation on its quality and quantity, preparing a quantitative and qualitative model is necessary. This model should represent all groundwater resource conditions and features and could use it to predict different aspects of aquifer. Groundwater resources are far away from the vision and located beneath the earth surface. Therefore, knowing all features of it is a time consuming activity and require intensive discovery surveys that almost impossible. Even after semi-detailed stages studies, groundwater resources features will not be revealed thoroughly so prepared model should be verified using suitable historical aquifer data. Therefore, these models recommended for regions with adequate information about groundwater discharges and recharges and water level fluctuations [List of services 2001]. Mathematical equations used in these models created based on some simplified assumptions and would be solvable with different techniques. Also in complicated situations, numerical models that using finite element and finite difference estimations to solving groundwater flow differential equations can be used. In this case, study area replaced with grids, modeling time should be divided to several smaller time intervals, and finally acquired equations would be solving by computer.

Unlike analytical techniques, numerical ones could simulate groundwater flow in different layers [Chiang and Kinzelbach 2001]. Groundwater mathematical models have been used from 1800 AC. in recent years whereas computer software and hardware progresses, groundwater models diverted to quantitative hydrogeology studies. Among these models, predictive ones are very attractive for operational sectors, because they can predict feedbacks of the aquifer in respect of different activities such as recharges, discharges, and groundwater pollution in addition to proper simulation of natural and physical condition of the aquifer. Significant portion of Sistan & Baluchistan province aquifers confront with several difficulties such as aqueducts(qanats) and springs parching, and decrease in wells discharge and have high costs for pumping water because of continues downfall of groundwater level.

In this study in order to assessing natural and artificial discharges and recharges of the Gouharkouh plain aquifer, a mathematical model was produced for groundwater simulation using basic stage studies results and then considering aquifer features, GMS model used for groundwater simulation. Since this model has nice compatibility with GIS software, data layers production were implemented in the GIS software environment. After using grid approach modeling, defining initial and boundary conditions and applying input data and information such as aquifer hydrodynamic coefficients, model was run in the steady state. Then, model calibration was implemented by comparing observation wells data and model results. Finally, this calibrated model was run in the unsteady state and groundwater level rise was predicted by exerting artificial-recharge project. Model results showed a rise about 1.7 m in the groundwater level nearby project exertion site.

Study area

Study region is coinciding to the Gouharkouh plain with about 303.5 km^2 areas and located between 60 deg 22 minutes to 60 deg 34 minutes of eastern longitude and 28 deg 16 minutes to 28 deg 34 minutes of northern latitude. Fig 1 showed location and altitude range of the study region.

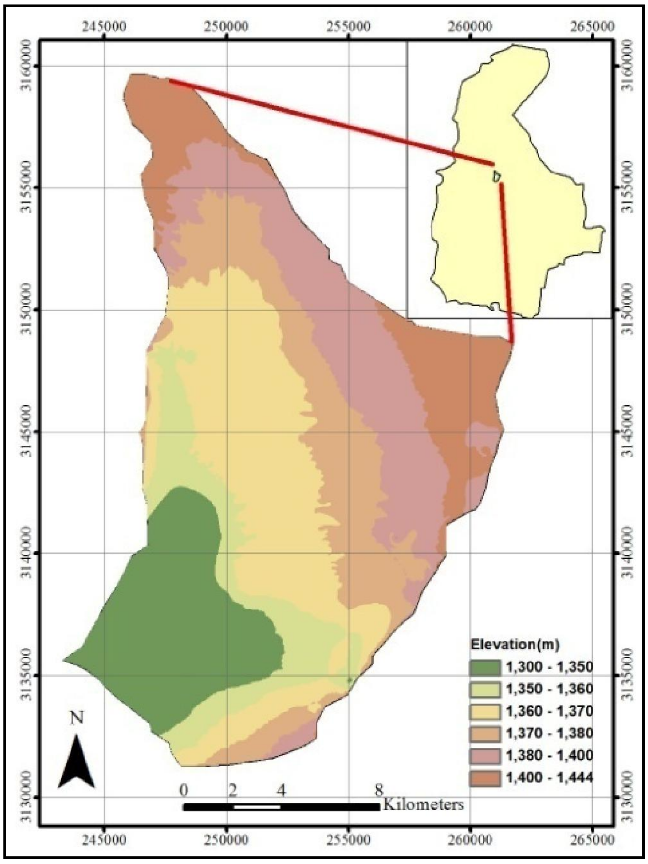

Fig 1. Gouharkouh aquifer and elevation range in the Sistan & Baluchistan province.

Groundwater modeling steps

Groundwater modeling steps may outline as followed [Katibeh and Hafezi 2004]:

At first aquifer data and information such as hydrogeological, hydrological, hydraulical, geological, and geometrical features should be acquired and verified. In order to taking in account the stresses and tensions to the system, type, time, and location of any artificial and natural discharge and recharge should applying in the modeling process. Conceptual model should implement to simplifying the physical system. Selected boundary layer conditions should properly justify groundwater flow. In the next step, the modeling software should be select considering some limitations such as model running time, software accessibility and complementary supports, required data, model adaptability to aquifer conditions and features simulation, meshes dimensions, and required accuracy. Aquifer grid plan, choosing time intervals, adjusting initial conditions, and importing input data and information should implement using selected model. Then, model calibration and verification should implement by altering different input parameters in several steps in order to coinciding physical and natural conditions to model results. Automatic calibration is a special option in novel models that can significantly increase the groundwater modeling in respect of traditional trial and error models. In addition, sensitivity analysis can use to defining groundwater impressibility rate from input parameters [Mirabbasi and Rahnama 2007].

Data sources and model selection

Hydrological and climatological data were obtained from region weather stations in order to estimating rainfall and runoff rates in the plain. Topographic conditions were prepared in the GIS software using 1:50000 topographic maps and transferred to the groundwater model (Fig 1). In addition, bedrock topographical layer was prepared using geophysical studies and observation wells data information and inserted in the model. Results of pumping tests of observation wells (consist of 18 observation wells) were used for defining aquifer hydrodynamic coefficients. Deep and semi-deep wells data and information obtained from last Sistan & Baluchistan Regional Water Authority surveys. Required geological information and type of the alluvial materials that play an important rule to defining groundwater inflow and outflow boundaries were obtained from Iran Geological Union (IGU). In order to producing unit hydrograph and groundwater level fluctuations graph, Gouharkouh aquifer piezometric wells information (consist 20 piezometric wells) were used and according to unit hydrograph (Fig 2), groundwater level showed about 2.86 m drop between Oct2004 to Sep2008. Also, Fig 3 showed bedrock topography and wells and piezometric wells position in the Gouharkouh aquifer.

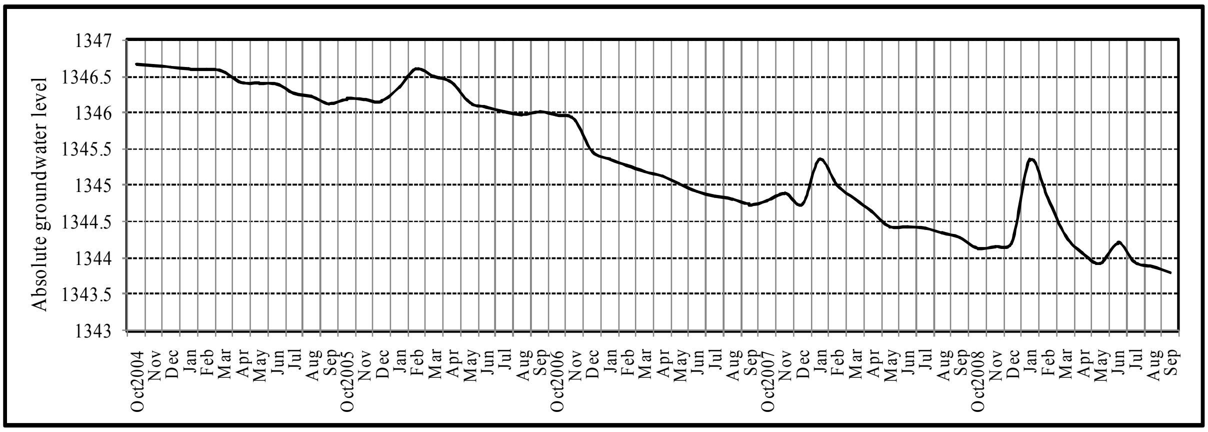

Fig 2. Unit hydrograph (Oct 2004 to Sep 2008).

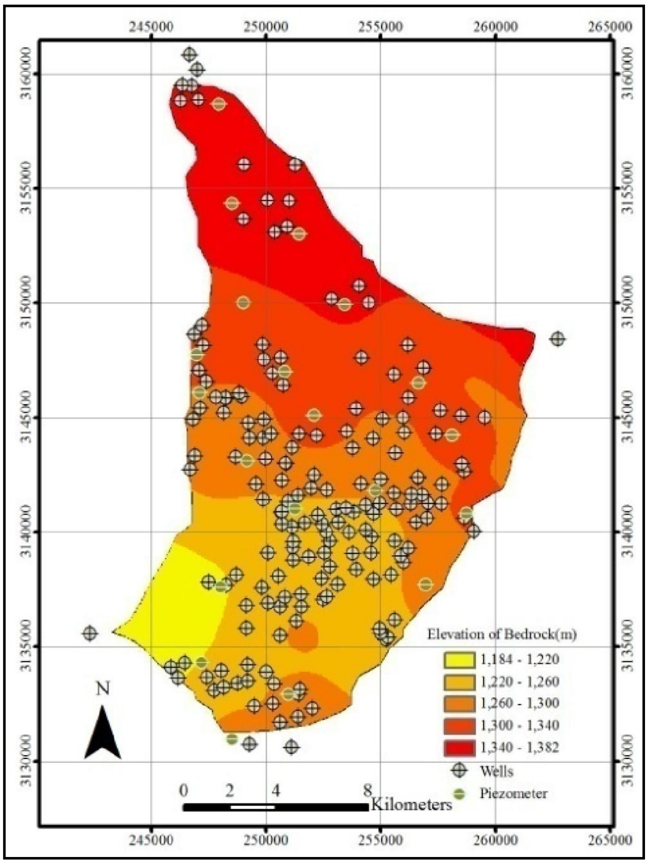

Fig 3. Bedrock elevation range, piezometric and exploitation wells position in the Gouharkouh aquifer.

Groundwaters modeling system (GMS) is novel and comprehensive groundwater modeling software and has been used in over 90 countries intensively. This model provides conceptual simulation method in GMS Map module using GIS software tools (point, line, and polygon). Conceptual model preparing some options for defining boundary conditions, type of the alluvial materials, and discharge and recharge areas. After completion, this model can convert to grid model and simulate wide areas in a simple environment. In addition, GIS module that provided in the GMS software can simplify conceptual modeling [AQUAVEO website 2009].

Conceptual model and basic schema

The flow direction in the gouharkouh-unconfined aquifer is almost from north, east, and south to southwest and while it is a part of the Gouharkouh basin, its boundaries (except west boundary) consider as principle inflows and outflows of the groundwater and assumed boundaries with general head. In addition, west boundary and some parts of the north and east of the plain assumed boundaries with zero discharge, considering topography and flow direction. In order to running mathematical model of aquifer, precise data of groundwater level fluctuation (observation wells network), plain and bedrock topography, study area meshing, initial and boundary conditions, unsteady state time steps, aquifer hydrodynamic coefficients such as hydraulic conductivity and storage coefficient and aquifer recharge and discharge quantities should import in to the model. These parameters will verify in steady and unsteady modeling and simulation process.

Effective factors on aquifer discharge and recharge

Basically, in Gouharkouh aquifer both natural and artificial-recharges may be occurred as mentioned below.

-Groundwater inflow and outflow

Groundwater flow direction is an important factor for aquifer boundaries identification. Gouharkouh unit hydrograph was showed a smooth variation between May to October2006. Also, mean Groundwater level in this period was showed minimum difference with Augost2006, therefore this month was used for modeling in steady state. In addition, Oct2005-2006 period was used for modeling in unsteady state and storage coefficient values were calibrated in this step. Fig 4 showed groundwater level in Sep 2006. Surface and bedrock topography, available water sources in the aquifer such as wells, springs, aqueducts, surface water channels, geological features, and relation with Ghaleabid aquifer located in the north of the Gouharkouh aquifer are other important factors for aquifer boundaries identification. Finally, aquifer inflow and outflow boundaries that assumed with general hydraulic head in the model were showed in fig 4 considering all above criteria.

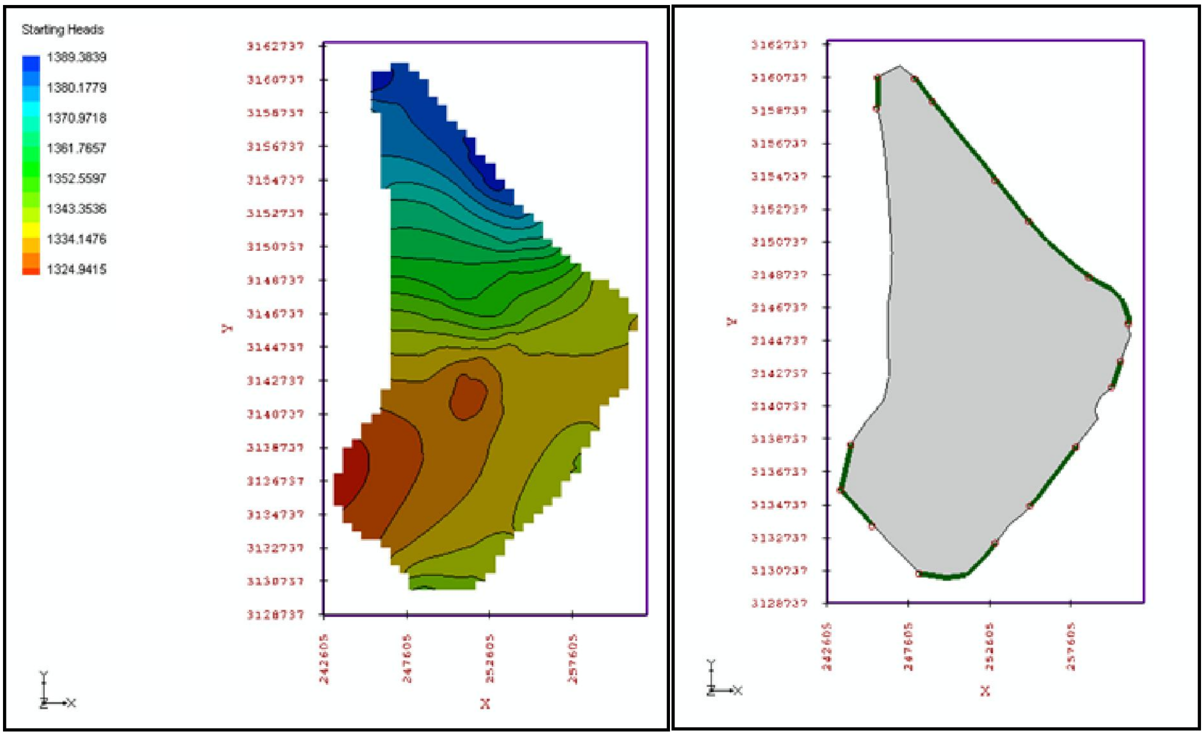

Fig 4. Groundwater level in Sep 2006 (left) and boundaries with general head (green bold lines) (right).

-Recharge from rainfall

According to hydrological and hydrogeological studies, rainfall seepage to the aquifer is very low and negligible. Surface water inflow to the Gouharkouh plain was about 18.3 MCM for year 2005-2006. Therefore, recharge from surface flows was assumed to be 15 percent or about 2.74 MCM (this amount will differ after model calibration) considering aquifer thickness, grains size and flow lines length.

-Recharge and discharge from wells

All of the Gouharkouh basin demand provide from groundwater resources. There are 174 active wells in the basin with 59 MCM yearly discharges. Considering seepage coefficient about 10 percent, yearly agricultural water seepage to the aquifer would be about 5.84 MCM. Therefore, total yearly recharge of the aquifer from surface flows and agricultural water seepages would be about 8.58 MCM. In order to assigning these recharges, the aquifer was apportioned according to fig 5.

Aquifer grids

The dimensions of Gouharkouh aquifer grids were selected to be 50×50, considering basic information of the groundwater and while there is no active river or drain in the region. Fig 5 showed Gouharkouh aquifer apportioning contains 68 rows, 39 columns, 4830 nodes, and 2312 cells.

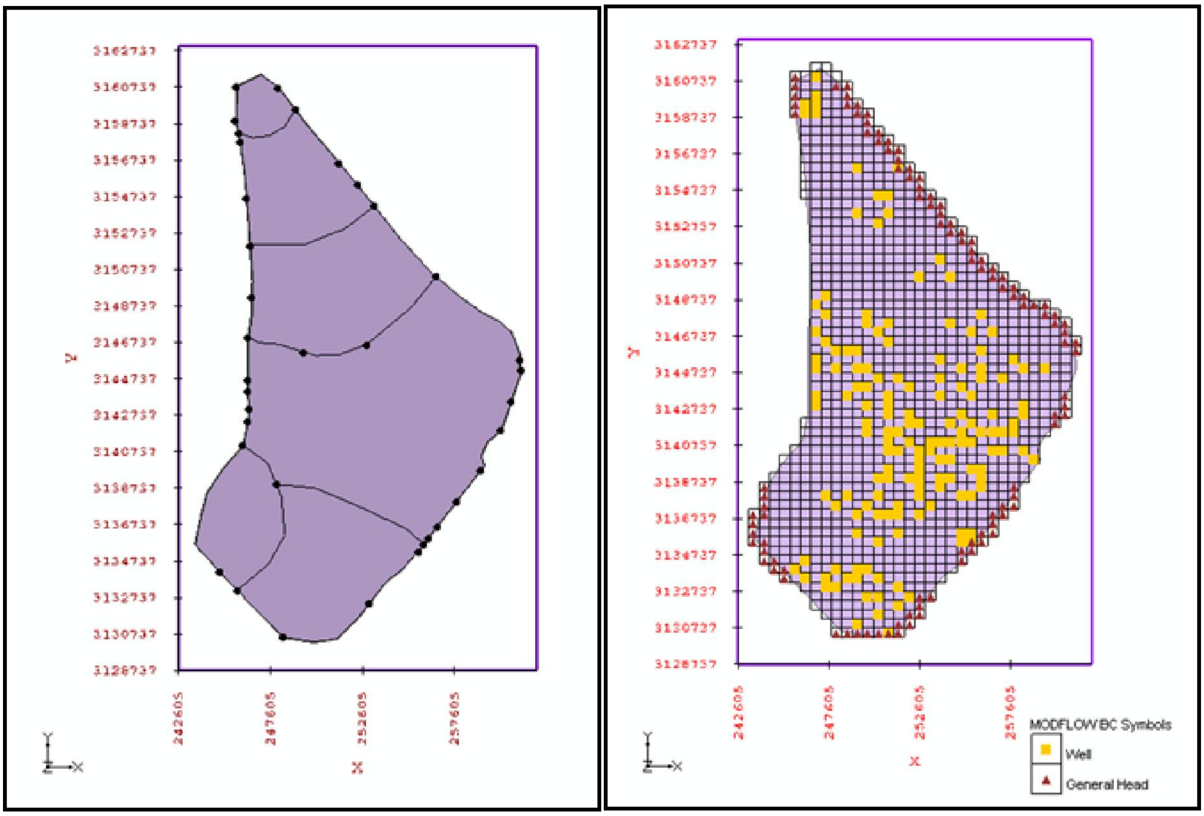

Fig 5. Gouharkouh aquifer apportioning in order to assign surface recharges (left) and Gouharkouh aquifer mesh (right).

Steady state modeling

In this step, all of the model requirements such as permeability (K), Initial head, local spreading of the aquifer discharges and recharges (runoff, discharge, and recharge from wells), and also general head boundary were introduced to model and after several running, these information were verified and adjusted.

Model calibration in steady state

After introducing all input parameters to model, first running was revealed about one to several meters difference between observed and estimated groundwater levels at the control points (pizeometric wells located in the modeling area). In order to calibrating Gouharkouh aquifer model, we have used PEST module (a package in GMS software) and simultaneity calculated values of hydraulic conductivity(in pilot points) and seepage quantities(in zonal approach) of the aquifer were calibrated using apportioning approach. Finally, the difference between observed and estimated groundwater levels was minimized by altering boundary conditions (general head boundary). According to estimated values of hydraulic conductivity that showed in fig 6, this parameter varies between 45 and 65 meters per day for wide parts of central regions of the aquifer. Also, estimated quantities of seepage (recharge) to the aquifer using PEST module showed in fig 6. By multiplying these quantities to relevant polygon area and summing all of them, the yearly recharges from runoff and seepages from agricultural wells would be about 12.1 MCM; about 29 percent further than before model calibration.

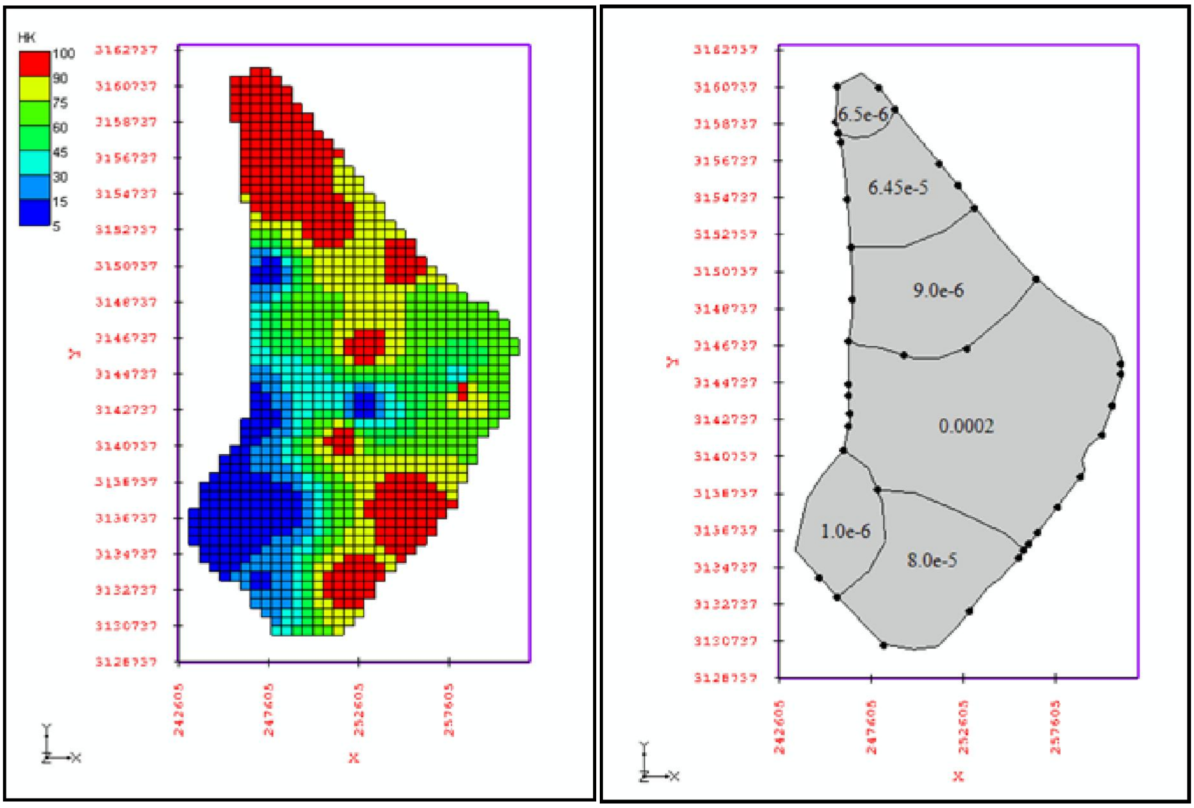

Fig 6. Estimated values of hydraulic conductivity for Gouharkouh aquifer (left) and estimated quantities of aquifer recharge (m/day) using PEST module (right).

Fig 7 showed the results of model running with final and calibrated values of hydraulic conductivity and recharge quantities and final estimated groundwater levels for the calibrated model using PEST module. According to this figure, almost for all of the pizeometric wells (except two of them) difference between observed and estimated groundwater levels is acceptable and can use them for run model in the unsteady state.

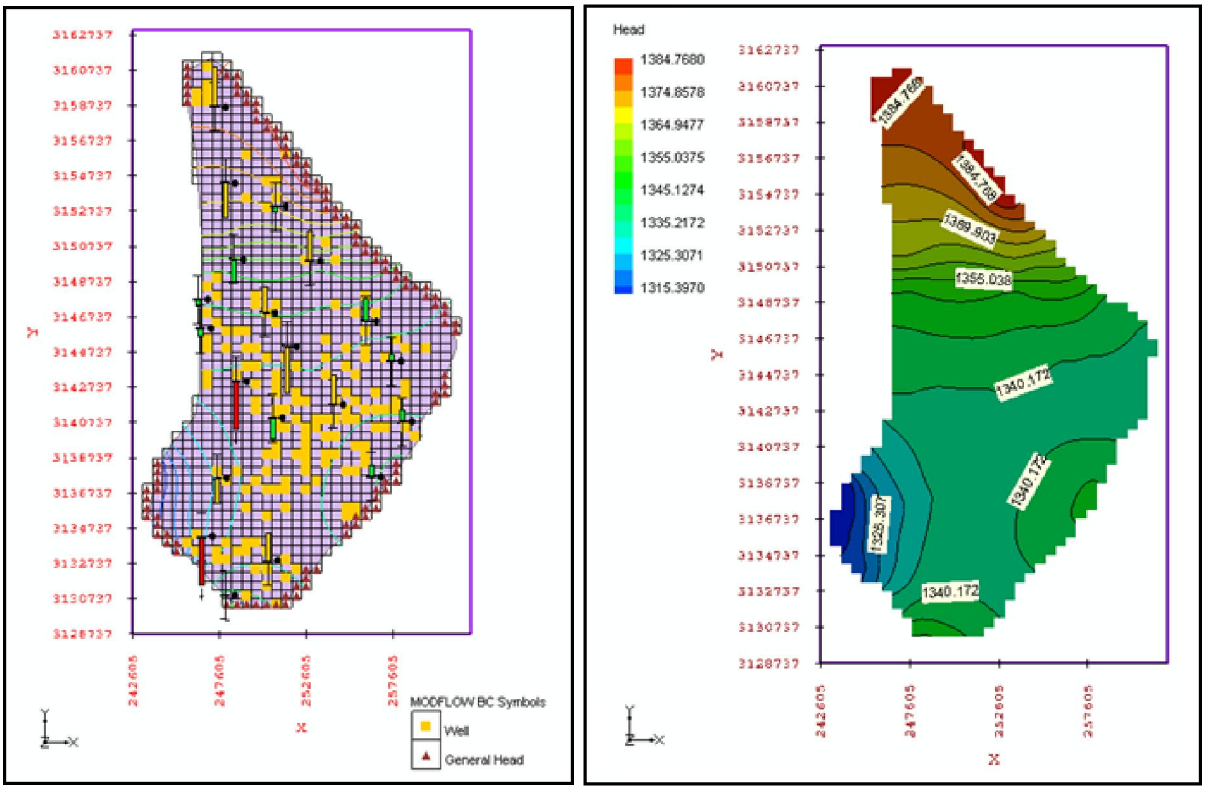

Fig 7. Model results after calibration using PEST module (left) and final estimated levels for the calibrated model in the steady state (right).

Fig 8 showed difference between observed and estimated groundwater levels for calibrated model using PEST module. The difference of mean, absolute mean, and mean square errors between observed and estimated groundwater levels are -0.231, 1.065, and 1.34 respectively (these errors are located in the acceptable range).

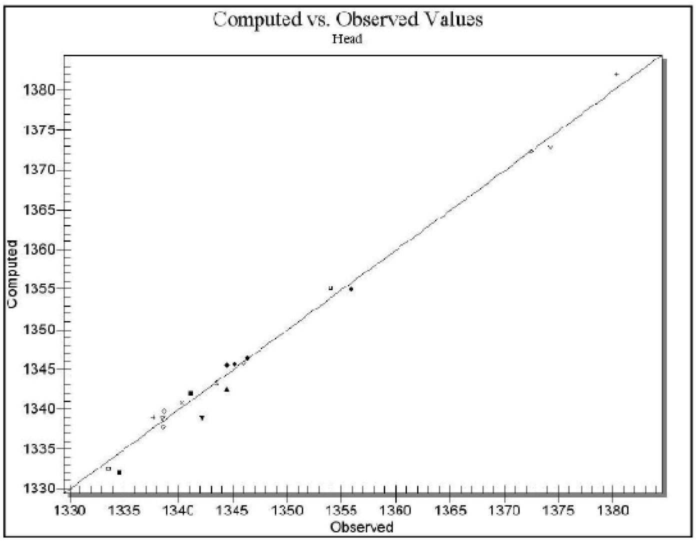

Fig 8. Difference of estimated and observed pizeometric water levels for calibrated model using PEST module.

Sensitivity analysis

After running calibrated model in the steady state using hydraulic conductivity values and recharge quantities, sensitivity analysis of the model in respect of different parameters was accomplished and results were showed in the fig 9. According to this figure, the model is more sensitive to the hydraulic conductivity values in compare of recharge quantities and this sensitivity is higher for variation coefficients less than unit.

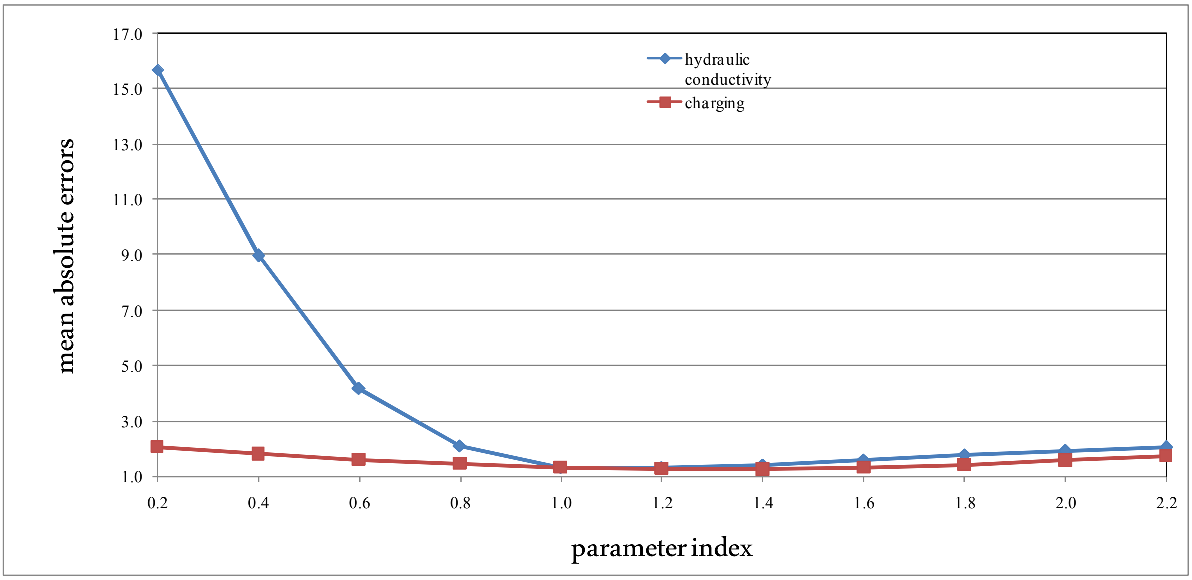

Fig 9. Mean absolute errors variability for estimated water level in respect of parameter coefficients.

Unsteady state modeling and verification

In addition of required information for modeling in the steady state, some data such as storage coefficient (S) and time spreading of aquifer recharges and discharges are require for adjusting unsteady state model. According to the Hydrogeological studies and pizeometric and observation wells log, storage coefficient was estimated about 8 percent for entire of the aquifer. This value was changed after model calibration in unsteady state considering seven polygons and using PEST module. Also, after defining monthly local spreading of aquifer discharges and recharges, these parameters were inserted in the unsteady state model. Monthly runoff quantities were estimated by considering the percent of rainfall for each month while the year 2005-2006 (consist 12 months) was selected simulation period zone for unsteady state modeling. Also, this procedure was used for estimating monthly aquifer recharges and discharges from agricultural wells. Using these information and require adjustments in GMS software, the aquifer system was simulated for 12 months (between Oct 2005 and Oct 2006) in unsteady state. Fig 10 showed differences between observed and estimated groundwater levels for Jan 2005 in order to verifying Gouharkouh aquifer model in unsteady state.

Model calibration in unsteady state

After dividing aquifer area to seven zones, storage coefficient values were estimated for each zone using PEST module and zonal approach showed in fig 10. Adjusted model of Gouharkouh aquifer was ran several times and finally results were showed nice accordance for observed and estimated groundwater levels. Fig 11 showed difference of mean, absolute mean, and mean square errors between observed and estimated groundwater levels for modeling period.

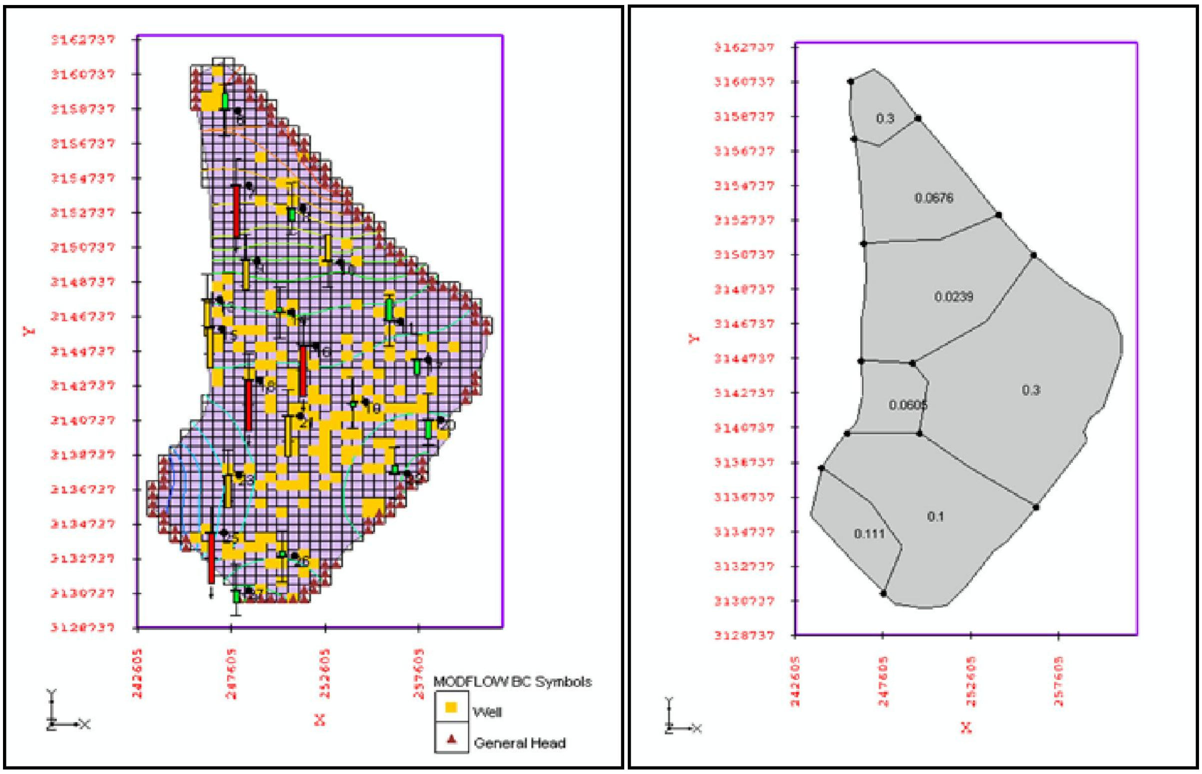

Fig 10. Verification of Gouharkouh aquifer in Jan 2005 (left) and storage coefficient for calibrated model in unsteady state (right).

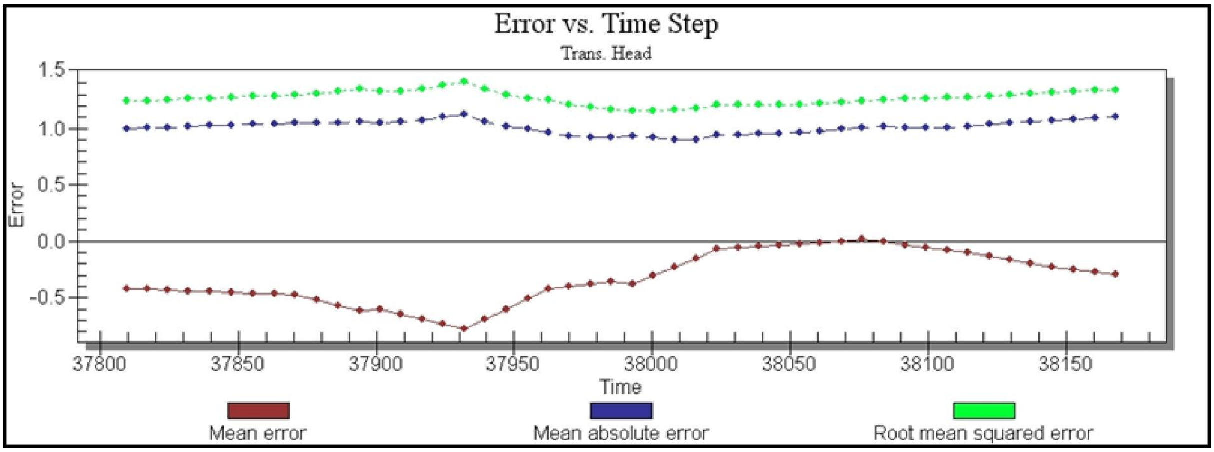

Fig 11. Difference of mean, mean absolute, and mean square errors for estimated and observed level in modeling period.

Predicting the impact of artificial-recharge on groundwater level

Artificial-recharge projects are effective factors for equilibrium of groundwater budget. After determining potential areas for artificial-recharge, five places were proposed for this project [Aidi and Helalbeiki 2010] and groundwater fluctuations related to third place as premier alternative were analyzed. Generally, artificial-recharge projects improve groundwater level and quality [Moghaddas et al. 2006]. Although, rising groundwater level is expectable after implementing artificial-recharge, groundwater quality improvement is not a rule and there are several exclusive cases [Kalantari and Rahmani 1999].

In order to predicting aquifer conditions, all of probable alternatives should define as information layers for model. By exerting these information layers to the model, the user can predict the aquifer system feedback in the future [Katibeh and Hafezi 2004]. In this study, for analyzing the artificial-recharge of Gouharkouh aquifer from runoff, areas of 80 hectares with 0.02 m/day recharge (this amount is equal to yearly mean runoff from Gouharkouh basin minus 15 percent direct seepage to the groundwater) was considered in the surface recharge layer (runoff quantities from rainfall and seepage from agricultural wells) in third place. Fig 12 showed new zoning of the aquifer surface recharge and results of final groundwater level in steady state for selected scenario (third place). Also, fig 13 showed the rise of groundwater level varied from 0- 1.71 m after one year of implementing artificial-recharge operation. While unsteady state model require some trial and error guesses and have uncertainties foe each time periods (one month), to simplifying comparison between groundwater level before and after recharge project implementation, steady state model was used instead of unsteady state model.

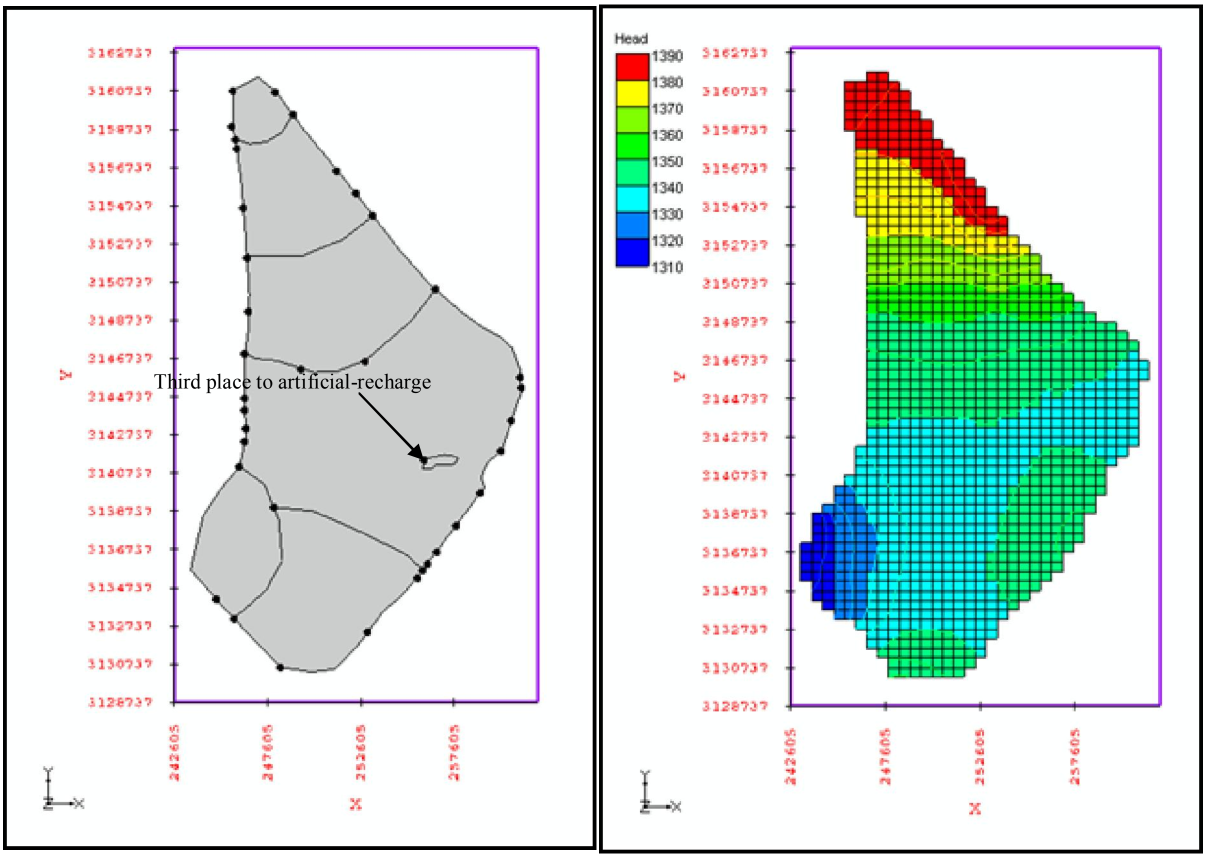

Fig 12. New zoning of the aquifer surface recharge (left) and results of groundwater level after modeling (right).

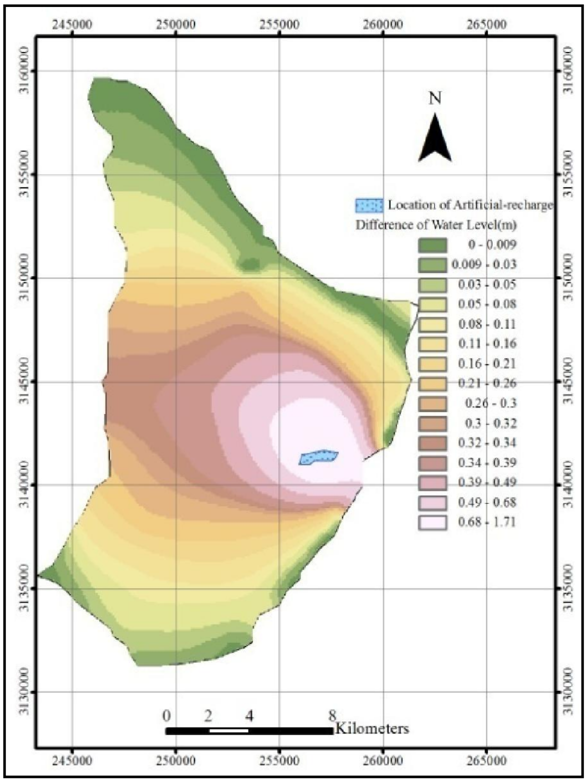

Fig 13. Rise of groundwater level after one year by implementing artificial-recharge project.

Conclusion

Integrating GIS information layers in GMS software can significantly decrease the costs and time of the groundwater modeling process. This advantage together with automatic calibration option, make it different from other groundwater simulation models. The results of this model were predicted a rise of about zero to 1.71 meter for groundwater level after artificial-recharge implementation. Expectedly, maximum groundwater rise was occurred near the project implementation that considers as principle agricultural regions of the Gouharkouh basin. Therefore, increasing of wells discharge located in this area will thrive agricultural activities.

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