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Long Term Simulation of Shazand Plain Aquifer under Changing Resources and Applications

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ABSTRACT

Iran is among the world's arid and semi-arid regions and its demand for water has been increased due to population growth, urbanization and the development the economic sectors (industrial and agricultural). In many of these regions, the lack of planning and the unauthorized use of resources have led to excessive exploitation and a lower level of groundwater. The usable groundwater for the country water supply is about 55 percent. Research has been carried out for modeling the Shazand groundwater, which is located in Markazi Province. Modeling has been carrying out using Visual Modflow software. In recent years Shazand aquifer groundwater levels have dropped significantly. Groundwater level during 8 years (1998-2006) was 0.84 m and the annual average 0.105 m has also fallen. Population, urbanization and increasing migration in this region have resulted in higher demand for water which its only solution is inevitably limited consumption in the agriculture sector through efficiency improvement. The model execution results for these two options reveal that efficiency improvement will increase the basin hydrograph about 3.4m during an 8 year period with 0.42 m annual average. Increasing population trends during a 10 year period have resulted in 2.5m reduction in the water table level with annual average of 0.23 m. According to planning horizon and drinking water supply, final results indicate that the stability of aquifer resources without other complementary resources depends on more limited agricultural usage through the improvement of efficiency and irrigation methods.

Keywords: Aquifer; Ground Water Model; Shazand Plain

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INTRODUCTION

Nowadays, the management of ground water resources is among the basic requirements in every country. Rapid population growth during the recent years along with increasing development of social and economical activities in Iran have resulted in over-exploitation of underground resources which in some areas are the only available resources. Unfortunately such practices have led to reduction of groundwater level in most of the regions and plains. In this respect, water resources management and exploitation system necessitate quantitative and qualitative evaluations of such resources, current exploitation trends inspection and negative/positive factors recognition as well as delineation of present and future requirements for social activities and economic development (Heidarbeigi *et al*., 2007). The Shazand plain is not an exceptional case. The plain is situated in a semi-arid area in which agriculture lands irrigation requirements will probably take about 8 months. Due to the potential for agricultural development along with industrial activities, recent years have experienced a huge development in agricultural activities and this development have exclusively relied on more water extraction (production) from underground resources. For this reason, there are no equilibriums between recharge and discharging of water tables. The present condition in Shazand aquifer indicates that its reservoirs are significantly losing a high volume of water on annual basis. In addition, population increase, welfare development and potentially high drought periods have presented warning signals in Shazand plain. Due to above mentioned factors; the aquifer needs precise planning for appropriate exploitation of resources.

All countries must protect their underground resources in order to support national economic and social activities. So they need precise planning and specific management methods (San & Al-Somajian, 1991). Ngatchan *et al*. (2008) showed that the management of water resources in arid and semi-arid regions is not limited to discovering and recognizing reservoirs, but it needs the evaluation of water table recharge for permanent and stable water production as the most important part of the above mentioned problems. The results reveal that the most suitable recharge regions are situated in high land topography and sandy land.

It is also difficult to increase groundwater level in the arid area because the water table recharge variables depend on spatial and temporal which are characteristic features of arid areas (Verma, 1979; Yair & Lavee, 1985; Simmers, 1988).

In their study on a basin located at north east of Ahwaz, Tavalaee Nejad *et al*. (2001) found out that regarding water table fluctuations and the established procedures for well excavation (stability in number and amount of well discharge volume), the aquifer would be faced with losing reservoir water volume at dry year, it would reach to equilibrium at years with average water supply and ultimately it would be faced with increase of reservoir volume at wet year. In a research about water resources in India and Mexico, Scot *et al*. (2004) found that both countries are among the largest consumers of the world's water tables and also are faced with over-exploitation. To solve the problem, these two countries tried to relate pricing and power supply in the groundwater exploitation programs in order to prevent unadjusted applications.

Al-Salamab *et al*. (2011) carried a study on Al-Ghasem aquifer at Burayday, Saudi Arabia. In the aquifer, water table modeling was undertaken using Mod Flow model. The aquifer parameters measurement was carried out through pumping and then, the model was executed for various pumping rates. It was determined that continuation of this pumping method during the next 25 years would result in 28m decrease in the depression cone. The management scheme has been recommended to be adopted for the future protection of groundwater resources in the Kingdom of Saudi Arabia.

In a study on Ogallala aquifer at the west part of Kansas State, Pfeiffer *et al*. (2010) showed that the aquifer is among the region's largest aquifers and currently it supplies 99 percent of water for agriculture sector that in fact has resulted in an outstanding decline in the aquifer water level. The government thus has assigned a specified subside for installation and set up of more effective irrigation systems (higher efficiency) to decrease the aquifer exploitation rate.

In the present research, Shazand aquifer model is developed using Visual ModFlow software. Then the effects of fluctuations in the ground water exploitation are examined precisely which are due to population increase, irrigation efficiency improvement in agriculture sector along with drought and wet season impacts.

One of the preconditions for improving management of groundwater resources in arid and semi-arid regions is evaluation of water table recharge (Vries & Simmers, 2002). With regard to the importance of Shazand plain's groundwater resources, it is necessary to recognize effective parameters on such systems. So the present research follows a multi dimensional objective. At first, a computer simulation for Shazand's aquifer is undertaken which its results are employed in the prediction and presentation of responses to exploitation changes and impacts of various hydrologic periods on fluctuations of water table level. The model is then developed for prediction and evaluation of various scenarios and options for resource management and water consumption at Shazand Basin. With regard to population growth and consumption increase trends, the parameters impacts on the proposed model will be examined. Finally, the irrigation method improvement as one of the consuming for groundwater will be evaluated regarding water resources management in the basin.

MATERIALS AND METHODS

Shazand alluvial aquifer is situated in 35Km of Arak city, Markazi province. The basin area is 1710 km^2 which is categorized as a part of Ghar-e Chai basin. The aquifer is placed at 43′ and 33° to 10′ and 34° latitude and 17′ and 49° to 51′ and 49° longitude. Figures 1 and 2 show the studied area position. The plain exit part is situated at a place named as Doaab. Shazand region is classified among semi-arid regions. Its minimum temperature is -7.7° at January and its maximum reaches to 33.8° on July. From its total area, 50.15 percent includes highlands and hard formations and 44.85 percent contains alluvial sediments and/or sub-mountain screes. So, Shazand region is known as a mountainous region. Shazand aquifer area is 213.73 km^2. The aquifer thickest part is situated at eastern-south section with 110m and its narrowest part is situated at the marginal and central regions with 10 to 20 meters.

Fig.1: Situation of Markazi Province

Fig.2: Situation of Shazand city

Long term changes of water table level in Shazand plain show that in spite of its high recharge potential and physical features, it has been experiencing outstanding changes during the past years such that vast regions of the plain have observed some tangible losses proportional to recharge rate, discharge rate and hydrodynamic condition. The region water table level has shown 0.84m decrease from October of 1998 to October of 2006 and on average, its annual falling rate is 0.105m.But the ground water level also has experienced a relative increase due to successive wet years. The water budget period usually includes a water year.

In the present research, the water budget contains eight water years from October of 1998 to October of 2006. For the purpose of number adjustment and calculation precision, it is divided into wet and dry periods and for each period, every factor in the budget period is averaged annually. The time and duration of wet and dry periods are evaluated using some indexes such as hydro climatology factors and the plain's recharge basins as well as time distribution and interval for surface and groundwater resources exploitation and absolute height fluctuations of water table level. As it can be seen from the plain hydrograph (Figure 3), overall trend of water table height changes is strongly corresponded with dry and wet periods.

In the studied area, the origin of all recharge factors is precipitation in the form of snow and rain and the groundwater resources are utilized through wells, qanats and springs. With respect to various applications, the produced water is used for agriculture, drinking, urban and rural areas hygienic purposes as well as industrial usages. For this reason, it is necessary to evaluate the impact of higher exploitation rate due to population, drinking and irrigation efficiency improvement to achieve better management of Shazand aquifer.

The examination of irrigation efficiency in Shazand plain show that regarding common irrigation practices through water table resources, the overall irrigation efficiency is approximately 30 percent considering irrigation efficiency for lands supplied with surface and groundwater resources. In this respect, it is estimated that the irrigation efficiency for wells is equal to 35percent and for other resources (qanats, springs and surface resources) it reaches to 35 percent. Population-based estimates reveal that the most important center in the region is Shazand city. Based on a survey undertaken at 2006, the city population stands at 31262. Forty nine villages have been identified in the studied area with population of 88691 persons.

According to population predictions for the studied region with regard to urban and rural estimates by Iran Statistics Center and also based on calculations of population growth in urban and rural areas assuming steady growth rate, the estimated values for urban and rural areas are 0.77 and 5 percent respectively. The main reason for the population changes in urban and rural areas is migration from rural to urban areas due to industrial and urbanization growth in the region.

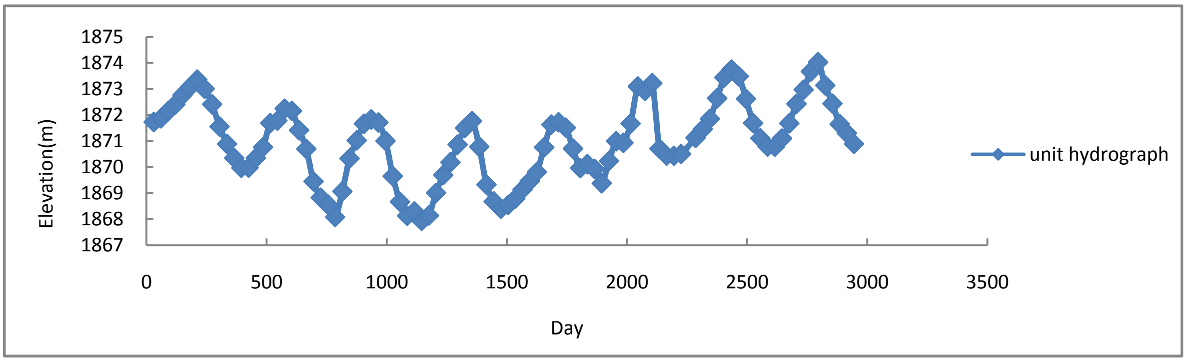

Fig.3: Shazand aquifer hydrograph from october1998 to October 2006

Groundwater model

The groundwater models are numerical or scale-based models among which computer numerical models are more common than other types (Mojtaba *et al*., 2008; Banoeng-Yakubo *et al*., 2008). Many groundwater models have been proposed including ModFlow, PLASM and AQUIFEN-1 to AQUIFEN-N (Gray *et al*., 2005).

The limited component method is used for AQUIFEN-1 to AQUIFEN-N while the limited difference method is applied for ModFlow and PLASM models. At present, the last mentioned models are more common than others. The model development is based upon the well-known three-dimensional flow equation. (Bossinesq equation (1)).

$$\frac{\partial}{\partial_x}\left(K_{xx}\frac{\partial h}{\partial_x}\right)+\frac{\partial}{\partial_y}\left(K_{yy}\frac{\partial h}{\partial_y}\right)+\frac{\partial}{\partial_z}\left(K_{zz}\frac{\partial h}{\partial_z}\right)=S_S\frac{\partial h}{\partial t}-W \quad (1)$$

Where:

h=height

S_S =reservoir coefficient of unconfined aquifer

k_{xx}, k_{yy} and k_{zz}= hydraulic conductivity coefficients in x, y and z directions

w= reservoir

t= time

The equation is nonlinear and its solution is obtained through limited difference method using ModFlow software (Anderson & Woessner, 1992; Wen-Hsing & Wolfgang, 1999). Solving the equation needs the determination of boundary and initial conditions. For groundwater flow, the equation is solved analytically or numerically. In the analytic approach, a homogenous and isotropic condition is required; it means that the condition should not be changed in relation to space and time. In the numerical model, time and space are variable and the equations are solved using components difference method. Of course, there are many other methods to solve the groundwater equation including limited difference method, limited component method and component analysis. Some software have also been introduced to solve the equations each of them has its own advantages and disadvantages. MODFLOW model has been used in this study. ModFlow is a computer code for 3D mathematic model of groundwater. By 1994, it was developed by Harbaugh W.A. and McDonald G.M. Its programming language was Fortran. Afterward, its commercialization was undertaken by the United States Geology Organization. The program designing was based on limited difference method and its model's mesh was in Block-centered format. The program is divided into three main modules i.e. input, execution and output modules.

Ground water modeling of Shazand plain under the present condition

Shazand water table is one of the reservoirs supplying agriculture, drinking and industry demands in the region. Based on geology studies, the water table has only one aquifer. According to Shazand plain's Thissen polygons maps prepared in groundwater surveys at 2004 and based on isopies at 2003-2004, the modeling limit was determined. Then 60 columns and 65 rows were defined in Shazand plain modeling limit considering 500*500m meshes with regard to the plain geometric shape. DAT and ASCII formats were chosen for data input. Piezometric features (water level, height, geographic position and screen length) were recalled with 23 piezometric wells in the region (Figure 5).

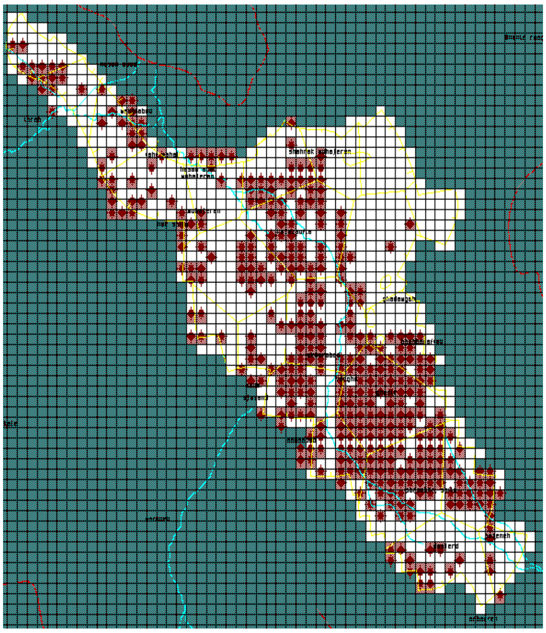

Fig. 4: Production wells position in Shazand aquifer

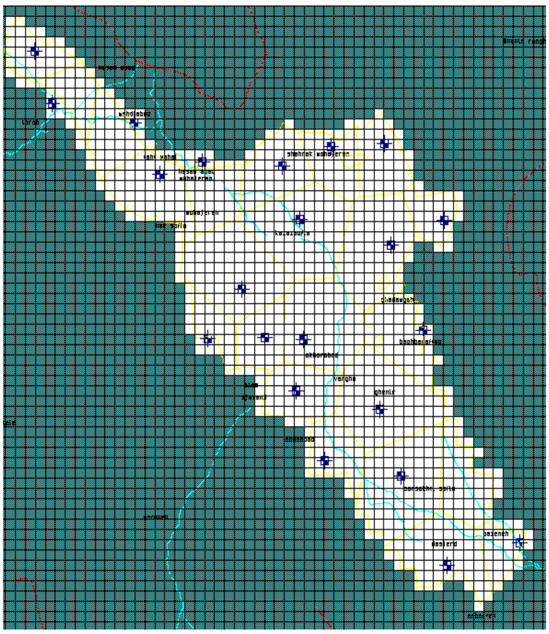

Fig.5:Observation wells position in Shazand aquifer

Then the production wells information (pumping rate, geographic position and screen length) including drinking, agriculture and industry application was recalled. There are 1350 wells in the region which the sum of present wells in a cell unit is considered as a well at the cell center (Figure 4). Therefore, the well numbers were reduced to 360. At the next step, the basin hydrodynamic features are entered into the model including hydraulic conductivity and reservoir coefficient. The hydraulic conductivity value is calculated from dividing transmissibility on basin thickness. The value for Shazand aquifer was 35-70 m/day according to transmissibility map (prepared through pumping tests) and basin thickness in various aquifer parts. The reservoir coefficient value for the basin was on average of 5% (using pumping method). Then the boundary condition, streams specifications, drainage, recharge rate for each cell as well as evaporation and transpiration rates were entered into the model based on available information. The model was executed under stable and unstable condition based on data obtained at 2004.

Model calibration

The basis of model adjustment is water level statistics for piezometric wells. In this respect, the model function validity in each period is confirmed according to agreement between the model-based calculations and observation results for groundwater level. If there is an unacceptable difference between the two values, other statistics and information including hydraulic conductivity, discharge parameters, recharge and boundary condition will be corrected accordingly. The task is based on try and error method. The model is firstly calibrated for stable condition and then for unstable one. In the present research, the calibration for unstable condition was undertaken with a one-month stress period (Oct. 2004). Information was entered into the model and then the model execution was carried out. The calibration was performed using groundwater level isometric curve maps as well as try and error method based on the model hydraulic conductance changes during October (Figure 6). At the next step, information limited to one year was entered into the model in monthly basis.

As it was mentioned, the water table level at the equilibrium month (october) was defined as the initial condition. Using it, the model determined the water table height at the end of initial stress period. In this way, the calculated water table level at the end of each stress period was considered as initial condition for the next stress period and calculations were continued for

12 periods (2004). Again, the groundwater level isometric curve maps, try and error method and changes of the model hydraulic conductance value were used for one year calibration under unstable condition (Figure 7). After the model calibration under stable and unstable conditions, it would be ready for prediction and evaluation of various scenarios and options of resource management and water consumption in Shazand basin. With regard to population growth and consumption increase, the parameter impact on model will be examined. The effect of irrigation method improvement is another option in the basin exploitation management which its influence on aquifer condition will be examined.

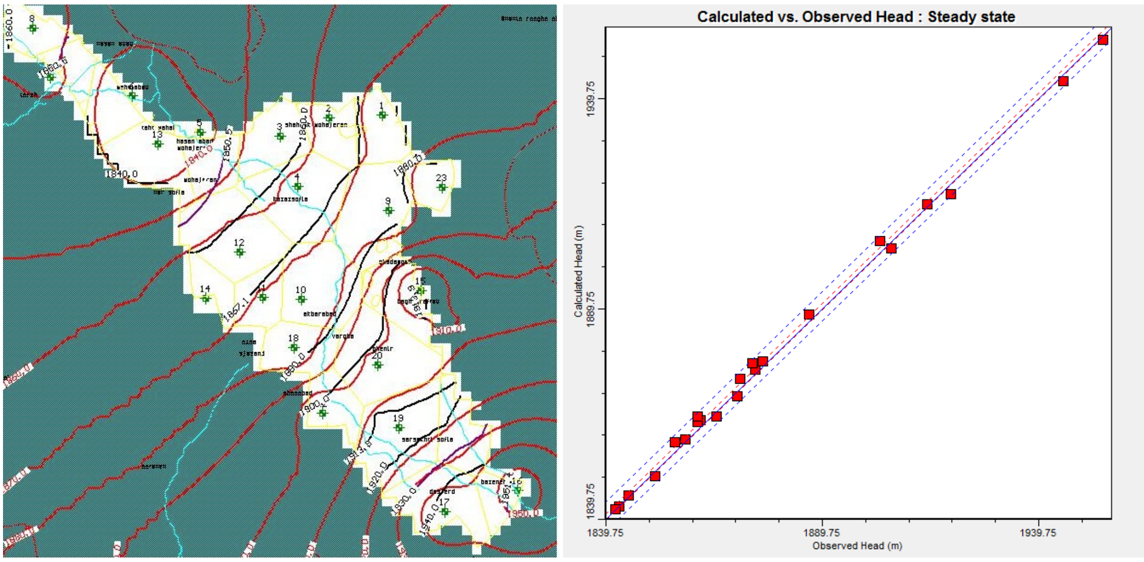

Fig.6: Model calibration under stable condition

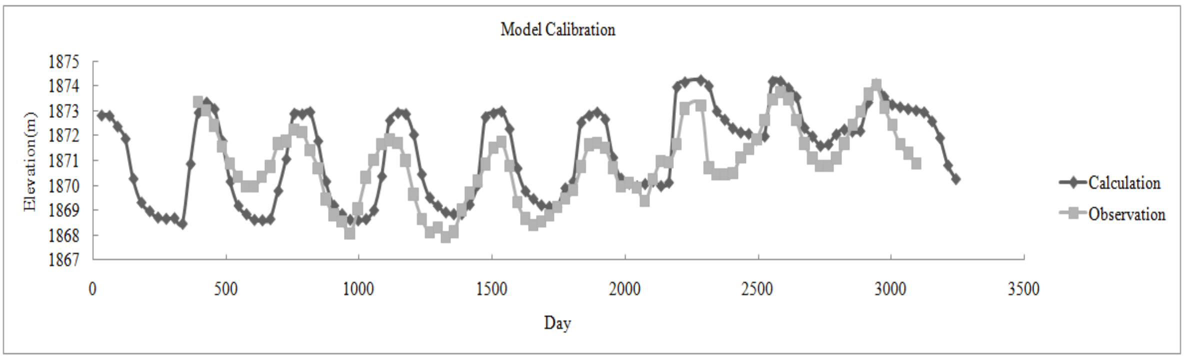

Fig.7: Shazand aquifer calculation and observation unit hydrograph from 1998 to 2006 (under unstable condition)

RESULTS AND DISCUSSION

Following the development of Shazand plain's groundwater model, the impacts of resource and consumption changes are simulated and analyzed using the model various scenarios.

First scenario: Population growth impact on groundwater resources

In the studied region of Shazand plain, rural areas experience population decline due to high urban migration such that by 2004, the city population was 31262 and its related rural areas population stood at 88691. Iran Statistic Center has assumed a steady population growth for rural and urban areas for the purpose of population prediction. It reported 0.77 percent and 5 percent growth rates for the rural and urban areas, respectively. Based on available information, the annual drinking water volume by 2004 was 9.247 million m^3 and the sum of urban and rural population at the same year was equal to 120102.

Accordingly, drinking and hygienic consumptions in rural and urban areas is 50 m^3/year per capita. Because of yearly population increase, it is possible to calculate the volume of consumed water during one year. Water consumed volume per year should be equal to drinking wells discharge rate. Thus, an average coefficient is obtained for all drinking wells. The model is executed for 10 years and its results are drawn as a hydrograph for groundwater unit against the model findings for 1998-2006 (Figure 8).

The experimentation showed that the region population growth is due to urbanization development and migration and causes higher demand for water production. With respect to Figure 8, the water table level shows no or little changes during the early years but the level decrease is about 2.5 m at the last 10 years with annual average of 0.25 m. The diagram steep gradient may be due to the increase of urban welfare in compared to rural areas.

Second scenario: Efficiency improvement in agriculture sector

The exploitation of ground water resources lasts 8 months from April to November. In Shazand region, 30 percent of land is under irrigation system, 23 percent is dry lands and the rest i.e. 47 percent is arid and pasture land. Sixty seven percent of irrigated lands are used for field crops, 6 percent for orchards and 26 percent for left fallow purposes. Irrigation methods carried out in Shazand plain includes flow irrigation (tape, plot and furrow irrigation) and under pressure methods are rarely applicable. According to the undertaken surveys with regard to the most popular irrigation method i.e. groundwater resources, the efficiency is estimated as 35 percent. In addition, with regard to soil-based and uncovered stream beds in Shazand plain, this feature has an important role in water losing and the resulted lower efficiency. So, one of the approaches for water production reduction is improvement of irrigation efficiency. The aim is achieved through using pressure irrigation instead of gravity methods. In the research, 5 percent efficiency increase was evaluated using the proposed model. Assuming efficiency increase from 35 percent to 40 percent, which changes would be happened in Shazand aquifer's water table level over time? In this way, it is estimated that agriculture sector water requirements are met with 40 percent efficiency. The model discharge rate was defined and the model was executed for an 8 year period. Figure 9 shows a comparison of Shazand aquifer hydrograph changes assuming efficiency improvement. The results indicate that the increase of irrigation efficiency during a long term period will be associated with 0.42 m increase in water table level.

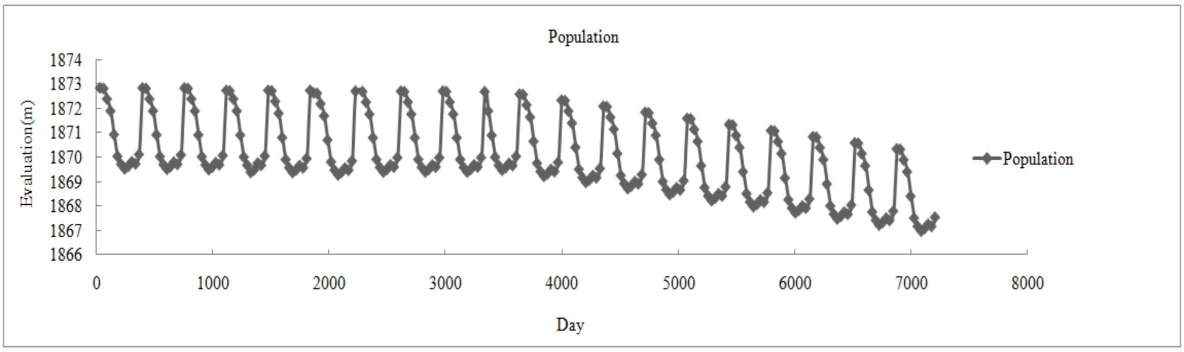

Fig.8: Hydrograph for Shazand aquifer unit with population increase from Oct. 1998 to Oct. 2016

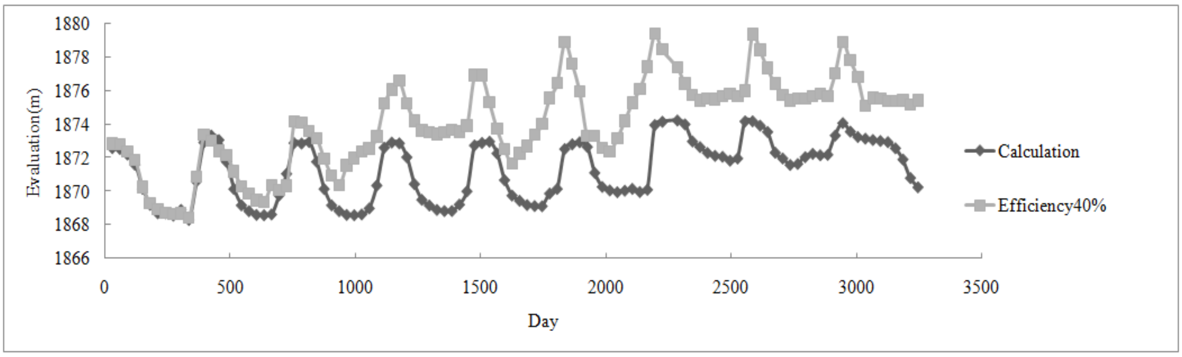

Fig.9: Hydrograph for Shazand aquifer unit with 40% efficiency and population growth from Oct. 1998 to Oct. 2006

CONCLUSION

A Shazand plain's groundwater model was developed using Visual ModFlow software and the model calibration was undertaken under stable and unstable conditions considering a comparison between the observational hydrographs. Here, the quantitative features of Shazand aquifer under the extant condition and its changing trend during an 8 year period were examined. The results reveal that the region groundwater level has been decreased up to 0.84 m with annual average reduction of .105 m during the 8 year period and also the production wells play a main role in groundwater discharge in the Shazand plain. The present condition in the region is such that reservoirs loss a huge amount of water per year. According to the calculated values in the present report, reservoir volume reduction is not important quantitatively but due to potential future draught years, the same value is alarming and needs appropriate management practices to prevent serious damages to the aquifer and environment. Various practices have been studied including irrigation efficiency improvement in agriculture sector along with higher consumption due to population increase and draught. Executing the model through the proposed scenarios shows that with efficiency improvement the basin hydrograph will reveal 3.4 m increase of water table level with annual average of .42m. Population growth in the region during the 10 year period has caused 2.5 m decrease in the water table level with annual average of 0.25 m.

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