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Groundwater modeling for estimation of the recharge rate and identification of appropriate recharge sites in Damghan Plain, Iran

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ABSTRACT

Water is the main option of any development, so having an accurate management of groundwater is necessary. This study has been done in Damghan sedimentary plain in Iran, which is located in northwest of Semnan Province. The main objective of this research was to estimate the rate and right site of recharge in Damghan plain to prevent the aquifer from decreasing the water table. For this purpose, the monthly data of observation wells in a water year from September 2009 to August 2010 were prepared. Next, the type of aquifer, horizontal hydraulic conductivity (K), and the height of top and bottom layers were provided. Finally, the aquifer has been simulated by MODFLOW in two states: steady and transient. After simulation by application of different recharge rates, such as 11, 21 and 31 million cubic meter (MCM), it became clear that the fluctuation of water table on the southwest of the plain is less than the other areas, so it is considered as the right site of recharge. Meanwhile, the water table showed no significant change as a matter of recharge 11 and 31 MCM rates, but it displayed a considerable enhancement by adding 21 MCM recharge rate. Therefore, the study revealed that the appropriate rate of recharge is 21 MCM.

Key words: Damghan Plain, Water table, Simulation, Recharge

INTRODUCTION

Groundwater has many advantages in agricultural and industrial utilization, such as being relatively free of pollution, having relatively constant temperature and chemical compound, and being far from evaporation. It can also be used for supplying water in arid and semi-arid regions. Winter *et al.* (2000) Studied the groundwater at various sites in the US. Their studies revealed that because of a deep water table in some parts, fluctuations in the groundwater are relatively small, and they reflect more seasonal and longer-term recharge conditions. Nimmer *et al*. (2010) Studied the Oconomowoc Wisconsin basin in the US, using the HYDRUS, MODFLOW, and MT3D models. Their studies showed an abnormal decline between measured and modeled heads indicating that there might be two sources: one contribution of infiltration from the basin, and the other, contribution from outside the basin. Zhang & Lerner (2000) Studied the effect of adits (horizontal tunnels under the water table) on the water table in an aquifer in the UK with MODBRANCH which showed that the adits caused a strong vertical effect on heads, as expected, and with least drawdown in the layer below the adits. In addition, the difference between aquifer and the head increase with the decreasing leakage coefficient. Rodríguez-Rodríguez *et al.* (2006), conducted a research to estimate the groundwater exchange in semi-arid playa lakes in southern Spain and concluded that the calculated net groundwater discharge is continuous throughout the year and varies greatly. This variation seems to be related to evaporation patterns, rainfall and surface runoff. Muñoz-Carpena *et al.* (2005), studied the groundwater quality in Everglades National Park (ENP) in South Florida, US, to interpret the interactions of surface-groundwater-land use. The results showed that leaching by rainfall is the main mechanism explaining concentration peaks in groundwater. Newman & Groffman (2006) Studied the interaction between surface water-groundwater in the semiarid climate in the southwest of the US.

Their studies revealed that in cases where there is no shallow aquifer, the surface water could potentially recharge deep groundwater systems.

The work of Liu *et al.* (2006) in Kinmen Island, China, using MODFLOW, was able to successfully simulate the groundwater distribution, and determine the annual rate of infiltration and pumping. The results of the study indicated that groundwater is yearly over pumped, and in order to avoid an adverse impact, surface water infiltration should be enhanced to recharge the aquifer. According to Scanlon *et al.* (2002), the range of recharge rates include different techniques such as physical, tracer, or numerical modeling approaches is based on the evaluation of literature and general evaluation of uncertainties, and should be determined only approximate. In accordance with Liling *et al.* (2011) the water balance method and the numerical simulation method are both acceptable in groundwater evaluation. The water balance method is better to use for small regions, however, because of the poor accuracy, and the numerical simulation method is accurate in large areas because it requires more data.

Tang *et al.* (2007), utilized the water balance method on the Akesu alluvial plain in China and revealed that infiltration is the best main groundwater replenishment system. The modeling in unconfined groundwater flow by Sekhar *et al.* (2004), in the Kabini River Basin, India, with the mean annual rainfall of 650 mm determined that the recharge rate vary from 5 to 10% of rainfall in different zones. Gaur *et al.* (2011), used combined GIS and the groundwater flow modeling to determine the potential zones of groundwater for management. The results revealed that the use of the groundwater model is very helpful to justify the location of potential zones, and gives a more realistic approach for the use of these potential zones. Ghayoumian *et al.* (2007) Identified the suitable sites of groundwater recharge in the Gavbandi River Basin, Iran, by using water spreading and artificial basins and determined that the areas that were covered with the alluvial fan and pediment units were appropriate sites for artificial recharge. Hassan *et al.* (2012), used visual MODFLOW in Al-Fustat area, Egypt, to find out the discharge rate in order to provide a solution for increasing the water table. They recommend in order preventing the area from swampy, 20 wells should be discharged about 200 $m^3.day^{-1}$. According to Bouwer (2002), the artificial recharge is expected to become necessary in the future as growing populations. Goe (2011) employed MODFLOW in an artificial model with multiple layers and sharply topographic bedrock in order to show that the effect of vertical discretization may cause problem in calibration. This research has been done to reclaim Damghan plain and improve the aquifer from declination of the water table, and it would be able to determine the right rate and site of recharge on the plain. Numerical models make it possible to estimate recharge rate, and also provide a reliable way to select index wells for long-term monitoring with an overall reduction of cost (Winter *et al.* 2000).

MATERIALS AND METHODS

Site description

Damghan sedimentary plain is located in Semnan province, Iran, on the arid and semi-arid region that is shows in Fig. 1. It is about 1270 km² and sits between 53° 21' E to 54° 43' E longitude and 35° 44' to 36° 31' N latitude. The long-term average of precipitation, the annual precipitation in water year of 2009-2010 and the long term evaporation are about 151.01mm, 101.85 mm and 3000 mm, respectively. As the annual evaporation is more than precipitation, it has a continental dry arid climate (Tang *et al.* 2007).

The long-term average temperature is 9.8 °C in mountainous areas, and the average temperature is 23.5 °C in plain areas. The area of upland watershed is located in the south of Alborz zone and the elevation varies from 1900 m a. s. l. in northwest, to 886 m a. s. l. in southeast. Generally the situation of plain is suitable for agricultural usages, and over pumping and recent excavations of the wells for irrigation have caused that the water table is decreasing rapidly (S.R.W.C. Company, 2008).

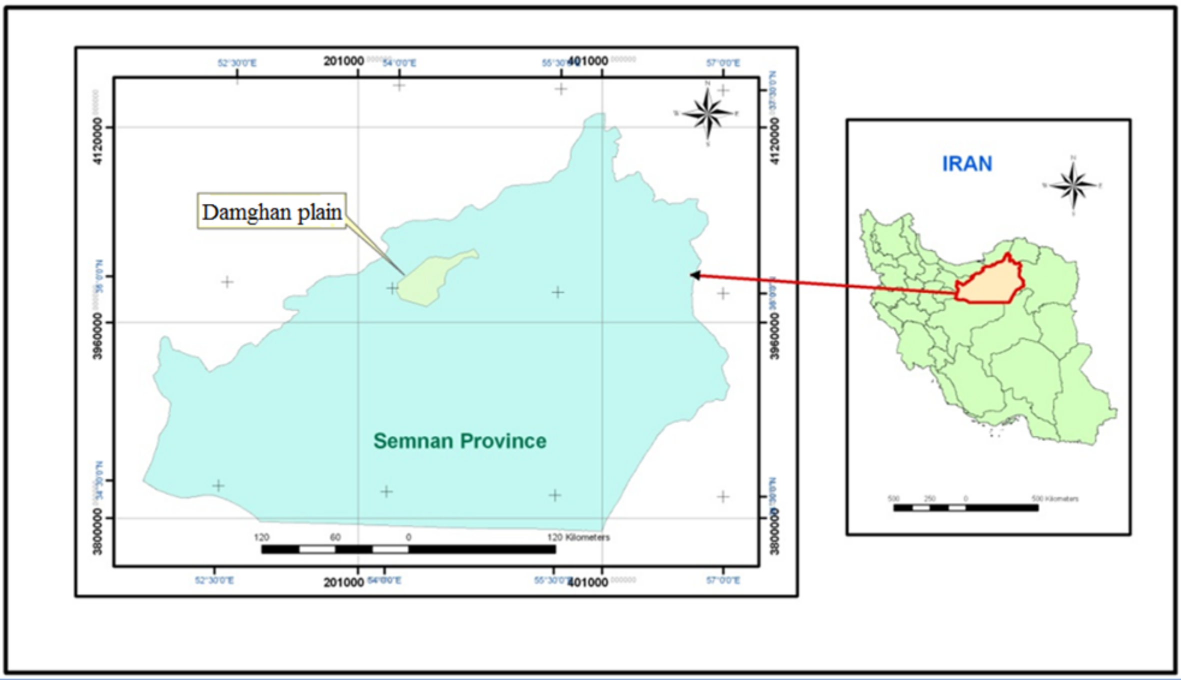

Fig. 1. Location of Damghan plain in Iran.

According to the geological survey, the greater part of the plain is placed in the central zone of Iran, and is covered with Quaternary deposits such as young terraces and alluvial fans, clay flat, old terraces and gravel fan, sand, silt and clay sediment. The rest of the plain is placed in the Alborz zone, and has mountainous characteristics with calcrete layers like Cretaceous formations (Orbitulina, massive and limestone); and conglomerate, sandstone that is related to Paleogene. To put it briefly, most parts of the plain are well in water yield and look good for groundwater recharge. The average thickness of alluvial sediment differs from approximately 150 m on the north, to 240 m on the south. The type of aquifer is unconfined and bedrock is mainly composed of Neogene alluvium, such as marl and conglomerate, and the well logs set out the sediment type. In accordance with the well logs of Mehmandost (P39), Abdia (P22) & Ghosheh (P31), which are shown in Fig. 2. the succession is as follows (T.R.W.C. Company, 2000):

Mehmandost well is placed in the north of the plain, the depth of which is about 125m. Its water table depth is about 75m, and the well log is a succession of sandy clay at about 55m, gravely sand at 20m, sandy gravel at 45m, and about 5m gravel. The thickness of the water layer is about 50 m.

Abdia well is placed in the south of the plaint, the depth of which is about 75m, its water table depth is about 7.5m, and the well log is a succession of sandy clay at about 30m, gravel at 15m, clay and sand at 20m, and clay is found at about 10m. The thickness of the water layer is about 70m. Ghosheh well is placed in the west of the plain, the depth of which is about 215m, its water table depth is about 80m, and the well log is a succession of gravel at about 150m, gravely sand at 35m, sandy gravel at 15m, clay and sand at 5m, and sandy clay at 10m. The thickness of the water layer is about 135m. The data regarding the well logs is presented in Table 1. As a result of the presence of well logs, it is evident that the water table varies in different places of the plain. Factors such as the sediment type and succession in plain show a suitable situation for recharge, but the north of the plain, located in Alborz zone, contains a calcrete layer (S.R.W.C. Company, 2008), proving it to be inappropriate for recharge (UNEP, 2002).

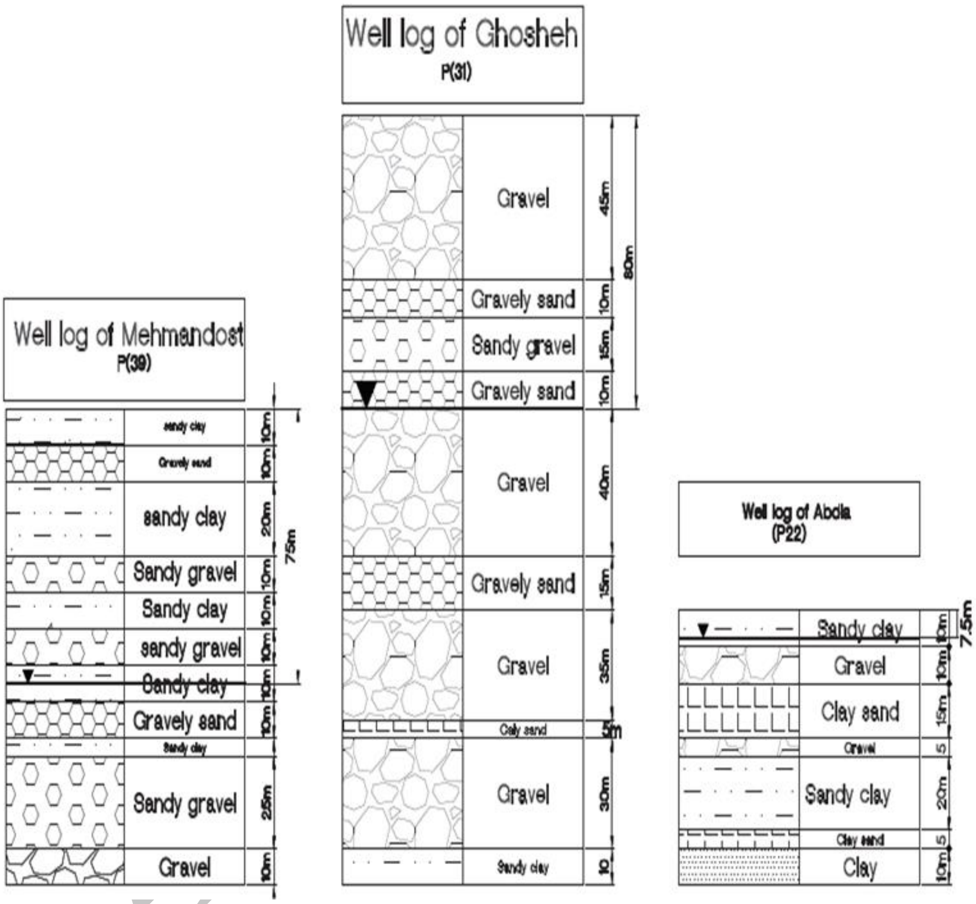

Fig. 2. The well log of Mehmandost (north of the plain) the water table is in depth of 75m, Ghosheh (west of the plain) the water table has a depth of 80m, and Abdia (south of the plain) the water table has a depth of 7.5m from surface.

Table 1. The data of the well logs (T. R. W. C. Company, 2000).

Name of well	X (UTM)	Y (UTM)	Depth (m)	Water Table (m)
Ghosheh (P31)	238090	3993628	215	80
Mehmandost (P39)	280507	4012633	108	75
Abdia (P22)	268393	3996019	75	7.5

While atmospheric pressure is excluded and the other parameters are constant, the water table is the best indicator for water fluctuation (UNEP, 2002), as there is a sudden rise of the water table after irrigation or rainfall (Xu *et al.*, 2012). In this research the water table is selected to find out the appropriate rates for artificial recharge. Since the water table is significantly related to the topography (Ko *et al.* 2012), and slope is an important factor for flood-spreading (Ghayoumian *et al.* 2007), by using slope and water velocity, the suitable place for artificial recharge can be found.

Numerical model

Nowadays, using numerical models in groundwater has gained popularity because the models are more precise than the other methods. In addition, numerical models can generally solve more complex problems in the sophisticated conditions like groundwater. When, for example, there are no other solutions and less idealization is needed, numerical models are used (Randall 2011). According to Barbour & Krahn (2004), a mathematical model is a copy of some natural situation. It is an effort to take our understanding of the process (conceptual model) and translate it into mathematical terms. A numerical aquifer model can consider much more complicated topology and boundary situations, as well as the heterogeneity and any vertical structure (UNEP 2002).

By using a finite-difference method, MODFLOW solves the three-dimensional groundwater flow. MODFLOW made it possible to simulate groundwater flow in two conditions: steady and transient. The equation in three dimensions (3D) that is used for steady state in unconfined aquifer is:

$$\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}+\frac{\partial^2 h}{\partial z^2}=0 \qquad (1)$$

where the potentiometric head is showed by h, (L); and$t$ is time (T) (Mohan & Saikia, 2009). The head of water table was used for the calibration of model in steady state. The equation that is used for transient state in unconfined aquifer is:

$$\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}+\frac{\partial^2 h}{\partial z^2}=\frac{S}{T}\frac{\partial h}{\partial t} \qquad (2)$$

Where the specific storage is showed by S, (L^{-1}); and T is transmissibility (L^2T^{-1}) (Mohan & Saikia 2009).

For simulation by MODFLOW in transient, specific storage, storage coefficient and specific yield are required for each layer of the model (Chiang & Kinzelbach 1998).

The specific storage is defined as the volume fraction of water and a unit column of aquifer releases from storage under a unit decline in hydraulic head; it is used for confined layers only. The value range of specific storage is $3.3\times10^{-6}\,[m^{-1}]$ for rock to $2.0\times10^{-2}[m^{-1}]$ for plastic clay (Chiang & Kinzelbach 1998).

The volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit declines in the water table is defined as specific yield; it is a function of porosity because a certain amount of water is held in the soil and cannot be passed into gravity drainage (Chiang & Kinzelbach 1998).

It is possible to use some parameters such as specific storage, specific yield or effective porosity for calibration the model in transient. In this research as the aquifer is unconfined, specific yield is applied for it. As the thickness of sediments is differ from each parts of the aquifer, so the transmissibility is determined by MODFLOW. Then the results could be checked by head or drawdown.

The approaching model

For the sustainable management of groundwater resources, the rate of recharge that is received by an aquifer is the most important figure required (UNEP 2002). The main problem regarding aquifers, according to S.R.W.C. Company (2008), is overpumping the wells for agricultural activities. In addition, the long-term data from 2000 to 2010 reveal declination of the water table: Fig. 3. Shows the declination of the water table in some observation wells that were established from 2000 to 2010. Thus, the exploitation of wells from 2000 up to now has been prohibited, however the agricultural industry that depends on water faces a grave dilemma: water demand for irrigation and declination of water level.

Despite the special climatic condition (Xu *et al.* 2012), the main land use on the plain is agriculture, and groundwater is the only vulnerable source. The aquifer is faced with insufficient storage of water, and therefore needs to be managed correctly in order for the aquifer to have a future.

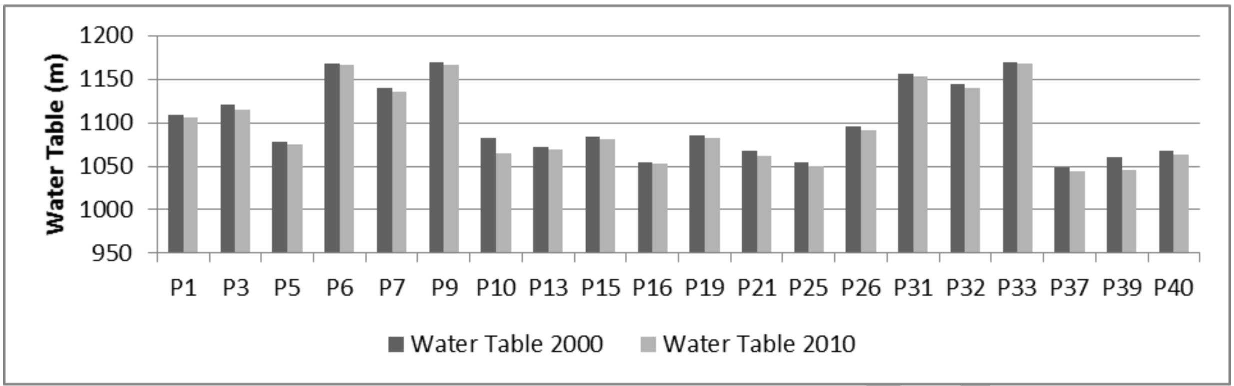

Fig. 3. The fluctuation of water table in some observation wells in 1999 to 2010.

In recent years, drought and water demand have caused over pumping of the wells, and the water table has decreased more than 0.5 m each year. However, according to SRW Company (2008), lack of water storage in 1984 and 2008 were about 21 and 31 MCM respectively.

Damghan plain is located in arid and semi-arid region of Iran and lack of fresh water is a criterion in the plain, so estimating the right site and rate for recharge would be extremely profitable in order to stop the water table from decreasing.

The boundary condition array (IBOUND) has three codes for each model cell, where +1 indicates for the active head, -1 for the constant head, *0* for inactive cell (Chiang & Kinzelbach 1998). In this area from northeast to southwest, the boundary condition is assumed fixed head (-1), because of the geology formations (Cretaceous formations), and the other boundaries are active cells (1) (Fig. 4). As the upland watershed is located in north and west of aquifer so the boundary in these parts are determined as the fixed head while in other parts of the plain, it was considered as active head.

Based on the S.R.W.C. Company (2008) survey, the type of aquifer is unconfined, and the horizontal hydraulic conductivity (K), the specific yield (S_y), and effective porosity (P_e) have been provided and presented in Table 2.

During simulation, the plain is divided into 100 rows and 140 columns, with the grid scale of 500m×500m (average area is 0.25 sq.km) (Eastoe *et al.*, 2010; Liling *et al.* 2011). The effective units are 5080, and the area is about 1270 km^2.

For the steady state time, parameter was assumed as 1 day; for the transient simulation, the period length was 365 days; and the time step was assumed as 12 steps. The data of the model is defined of well logs and S. R. W. C. Company (2008).

Table 2. The data of the model (S. R.W.C. Company 2008).

Parameter	Value	Unit	Type
Aquifer	-	-	Unconfined(1)
Layer	-	-	One Layer
Horizontal Hydraulic Conductivity (*k*)	5×10^{-5}	$m.s^{-1}$	-
Specific Yield (S_y)	0.7	1	-
Effective Porosity (P_e)	0.5	1	-

There are 37 observation wells on the plain, and as it is obvious, they distributed randomly (Fig. 5). According to Winter *et al.* (2000), a selection of index wells for long-term monitoring would considerably reduce the program cost. So after a calibration of the flowing model (see Fig. 6 a comparison between observation and calculated values), in accordance with the water table fluctuations or the depth to water table for vadose zone (Xu *et al.* 2012), and for better analysis (Eastoe *et al.* 2010), the plain is divided into three classes. In each class two observation wells have been selected to reveal the results: the observation of wells P4 and P25 in the low water table class, P1 and P6 in the middle water table class, and P7 and P32 in the high water table class (Table 3). Since the water table differs from 1030 and 1120 meters, the classes are as follows:

1) Low water table (1030m to 1065m) (P4 and P25),
2) Middle water table (1065m to 1090m) (P1 and P6), and
3) High water table (1090m to 1120m) (P7 and P32).

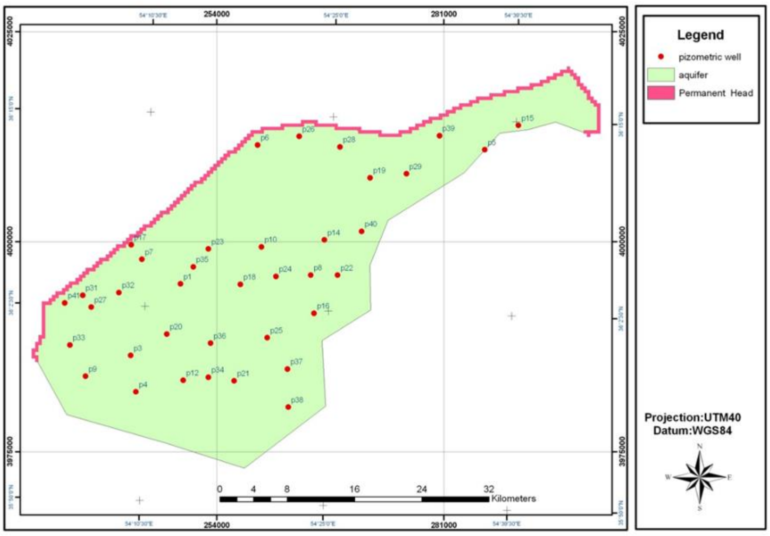

Fig. 5. Location of the observation wells in the plain.

Table 3. The classification of observation wells.

Class	Range of water table fluctuation (m)	Observation wells	Number of wells
Low water table	1030-1065	P4*, P5, P8, P10, P12, P14, P15, P16, P18, P19, P20, P21, P22, P24, P25*, P28, P29, P34, P36, P37, P38, P39, P40	23
Middle water table	1065-1090	P1*, P3, P6*, P9, P17, P23, P26, P31, P35, P41	10
High water table	1090-1120	P7*, P27, P32*, P33	4
Total wells			37
*Selected Wells			

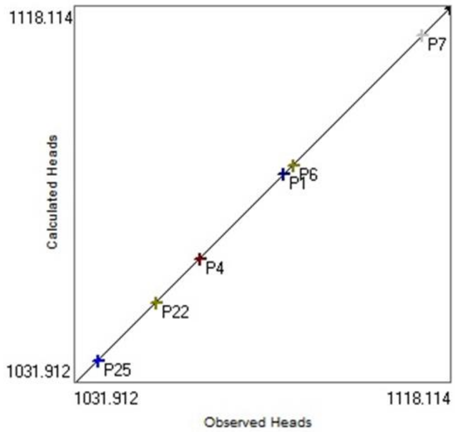

Fig. 6. The comparison of observation and calculated heads on index wells.

RESULTS and Discussion

Estimating Recharge Rate

In arid and semi-arid lands, because of the considerable changeability of hydrological events in any time, it is so extremely difficult to estimate recharge (UNEP 2002). According to Bouwer (2002), natural recharge is typically about 30-50% of precipitation in temperate humid climates, 10-20% of precipitation in Mediterranean type climates, and about 0-2% of precipitation in dry climates. As it is stated in the same study, the annual rainfall of the plain is 101.85 mm, and the well logs are contained of sand and gravel. The natural recharge could be about 12.9 MCM, but according to some studies, in areas with even more arid circumstances (less than 200 mm.year^{-1} average rainfall), local recharge of a few millimeters annually in the area with a coarse-grained soil or fractured-rock outcrops is not uncommon, so in this research the minimum rate of recharge is considered about 9% of rainfall that could be about 11 MCM (Jacobus & Simmers 2002).

After assembling the model, the three values of 11, 21 and 31 MCM have been considered for artificial recharge, and the results are illustrated on the index wells on Figures 7 to 12. As it is revealed on each graph, the results show a decreasing tendency to the water table during one year that is about 3 meters or more, like the aquifers in arid and semi-arid regions (UNEP, 2002). By adding 11, 21 and 31 MCM, the water table comes up to about 0.8, 1.6 and 2.4cm respectively, if the bedrock is fine, but the bedrock has sharply topographic (Gao 2011), and the fluctuation of water table has more relation with surface of bedrock than depth of bedrock (Ko *et al.* 2012), so by adding of 21MCM the water table increasing about 1 meter in a year so the declination of water table compensate by adding this recharge. For artificial recharge, water sources include any water like perennial or intermittent streams that might or might not be regulated with dams, storm runoff (including those in urban areas), aqueducts or other water-conveyance facilities, irrigation districts, drinking-water treatment plants, and sewage-treatment plants (Bouwer 2002).

Additionally, it is said that the natural recharge in this aquifer is 12.9 MCM (10% of annual precipitation), and by adding 11 MCM the water table comes up about 0.8 cm yearly. So by adding 21 MCM as a recharge rate, finally the water table comes up about 2.4 cm (= 0.8 + 1.6) that is equal to adding 31 MCM as a recharge rate, therefore the appropriate rate for artificial recharge would be 21 MCM.

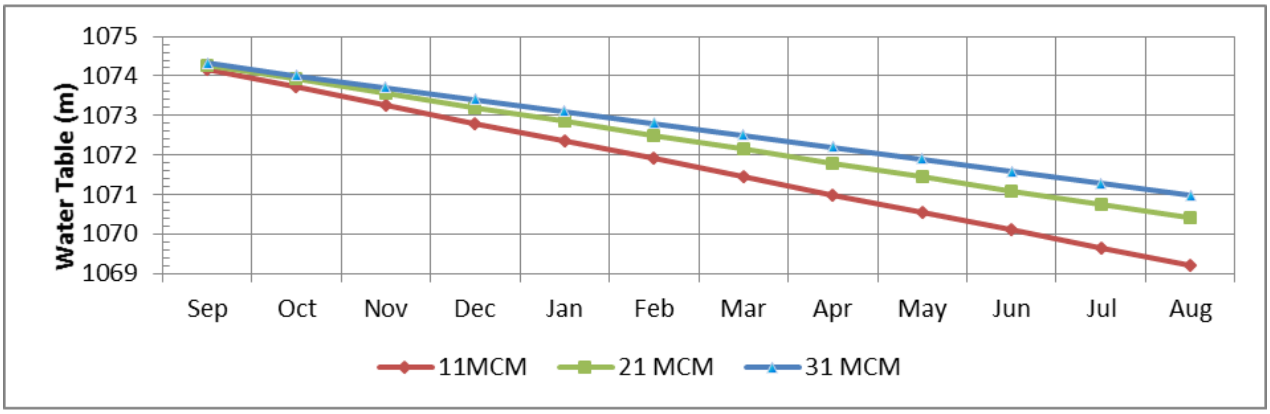

Fig. 7. The comparison of three values for recharge in observation well P1.

The Appropriate Site of Recharge

The site selection for artificial recharge in this research is based on soil types, permeability (Bouwer 2002), lithology and geomorphology in arid and semi-arid areas (Jacobus & Simmers 2002), and slope and water velocity (Ghayoumian *et al.* 2007). According to Bouwer (2002) typical hydraulic conductivity values in various soils (Table 4).

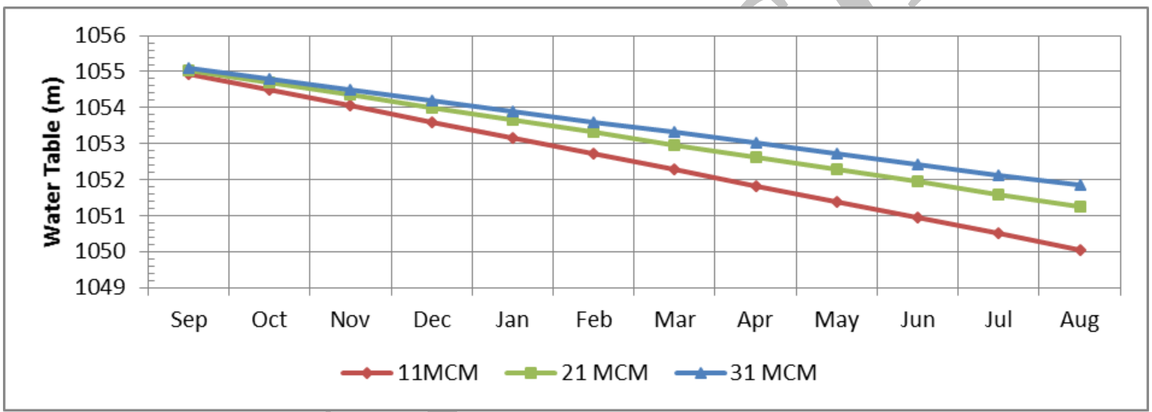

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Fig. 8. The comparison of three values for recharge in observation well P4.

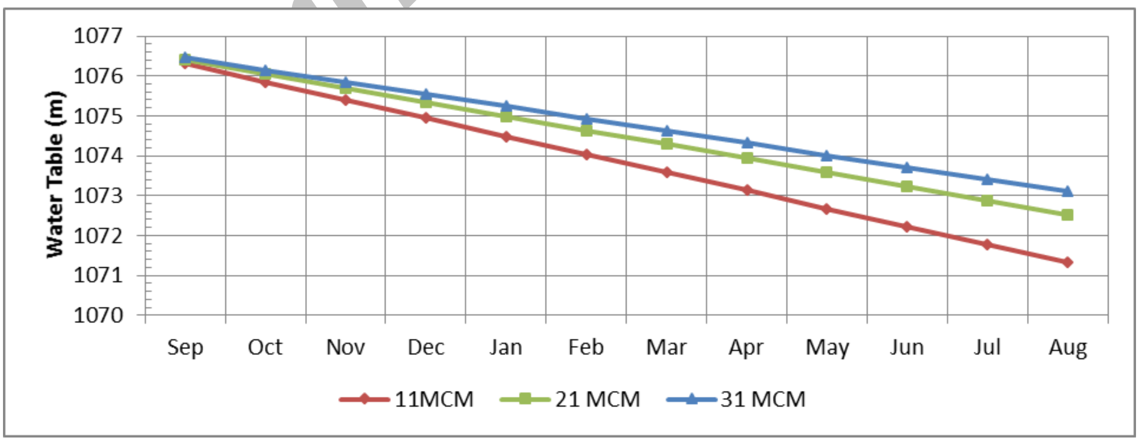

Fig.9. The comparison of three values for recharge in observation well P6.

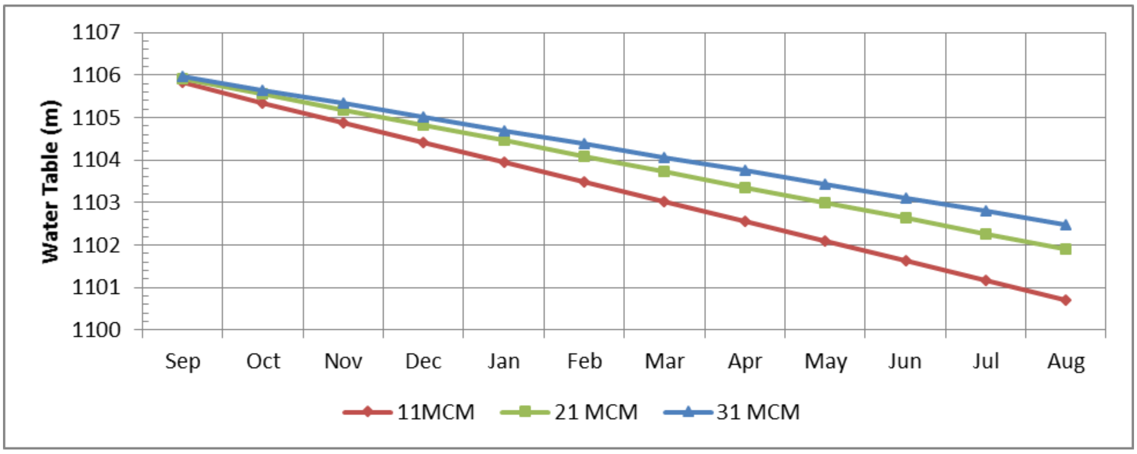

Fig. 10. The comparison of three values for recharge in observation well P7.

Table 4. The classification of soil permeability (Bouwer 2002).

Soil	Hydraulic conductivity (m/day)
Clay soils	<0.1
Loams	0.2
Sandy loams	0.3
Loamy sands	0.5
Fine sands	1
Medium sands	5
Coarse sands	>10

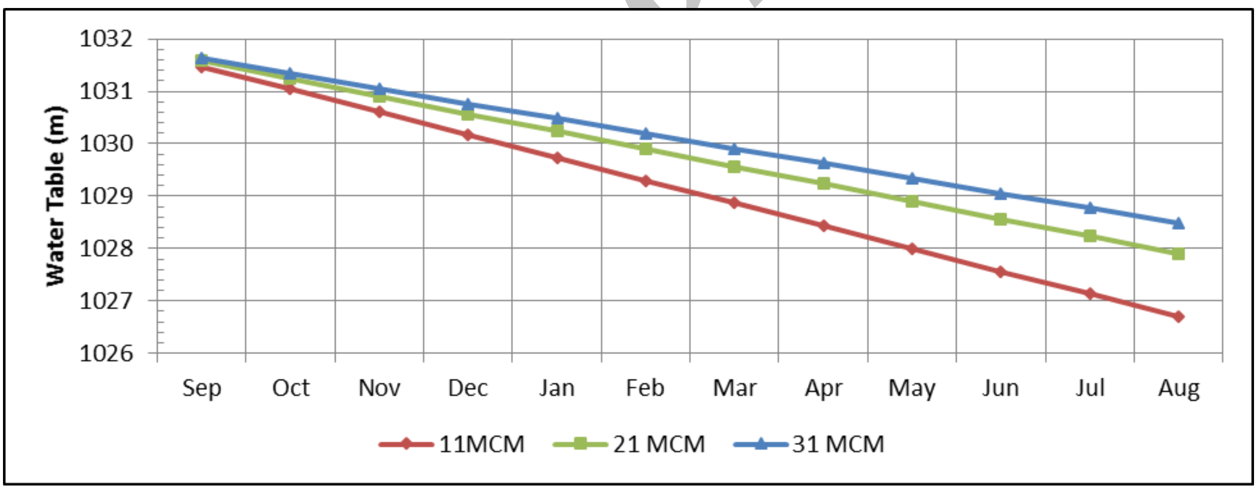

Fig. 11. The comparison of three values for recharge in observation well P25.

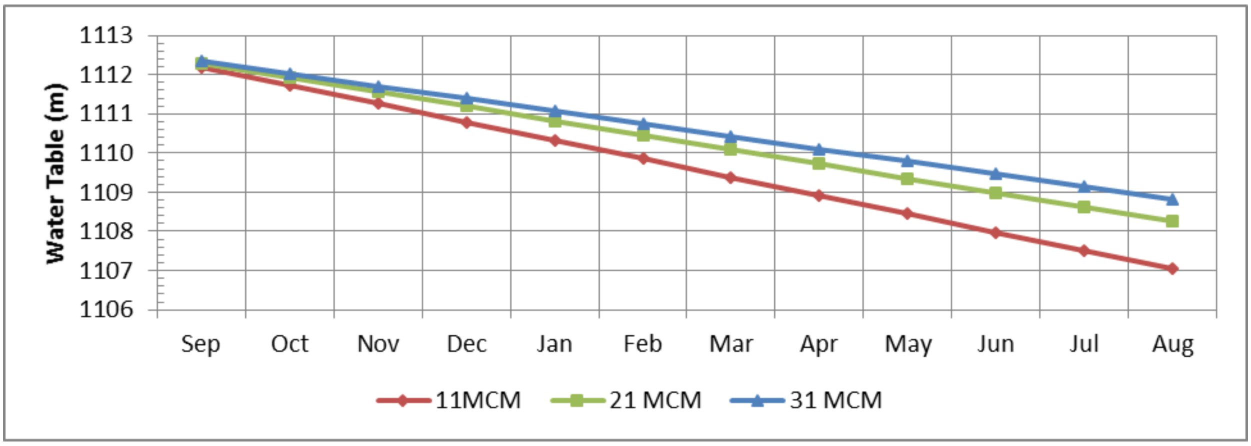

Fig. 12. The comparison of three values for recharge in observation well P32.

According to Kalantari *et al.* (2009), the main aspect of an artificial recharge is the reliability of the retention structure to store water, and due to the well logs it is revealed that sediment successions around Ghosheh is mainly gravel or the combination of gravel and sand, however, the permeability is appropriate for the artificial recharge. In addition, according to the geological survey in (T.R.W.C. Company 2000) the bedrock of this place is a combination of tuff, sandstone that is related to Tertiary, and It is located in Alborz zone. Also, all the events, such as some recharging projects that have done in the north and near Ghosheh region, prove that this place is suitable for the artificial recharge. Finally, after classifying the plain according to the water table fluctuation, the suitable site for the artificial recharge can be defined: this site is around Ghosheh and is located in the high water table class with the area of 97.45km² on the whole plain (Fig. 13) (Table 5).

Table 5. The classification of the Plain for artificial recharge.

Suitability Class	Water table (m)	Area (km²)	Area (%)
Suitable	1090-1120	97.45	7.67
Moderately Suitable	1065-1090	512.35	40.36
Unsuitable	1030-1065	659.57	51.96

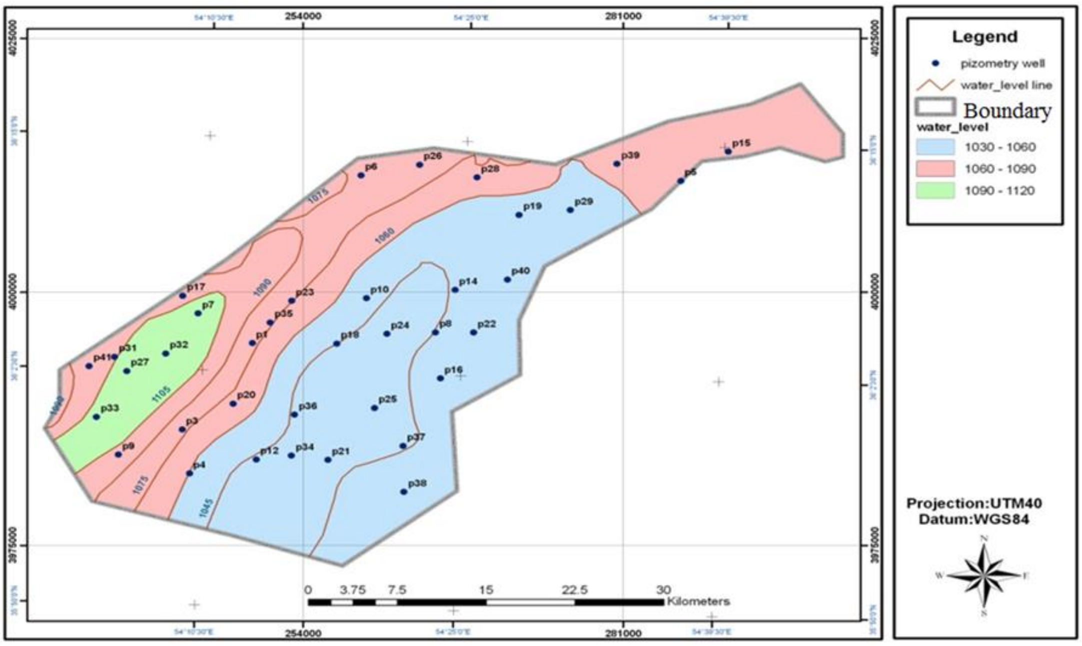

Fig. 13. The classification of water table, as it is illustrated the suitable area is blue: Moderately suitable is green and unsuitable is red.

CONCLUSION

Iran is laid on arid and semi-arid regions, and like the other countries in this area, has always had difficulties in preparing fresh water. Groundwater, as the greatest source, usually undergoes conflicts between over pumping of wells and declination of water table. Moreover, recently decreasing of rainfall and drought may cause the water table to come down more than before. Irrigation demand and industrial developing may cause even more exploitation of the wells as well, leaving the plains to face serious declination of the water table. Therefore, the plains are in need of a comprehensive program for the wells pumping. Having mediation between water discharge and water table is necessary for sustainable management of water resource. The research provided in this essay, by using numerical flow model, makes it possible to find out the appropriate sites for artificial recharge, and estimate the artificial recharge rate.

For the purposes of this study, the simulation of different rates for artificial recharge (such as 11, 21, 31 MCM), were employed to reveal the response of the aquifer, and determine the appropriate rate for the artificial recharge. Despite having 12.9 MCM rate of natural recharge, the aquifer needed more recharge to compensate for the water table declination. By adding 11, 21 and 31 MCM as rates for recharge the water table comes up about 0.8, 1.6 and 2.4 cm respectively in a year. Besides natural recharge, by adding 21 MCM rate for the artificial recharge the water table comes up 1.6m. In order to determine the suitable site for artificial recharge, according to the fluctuation of the water table the plain, the area was divided into the three classes. The suitable class for the artificial recharge is placed around Ghosheh, due to the area's good permeability in soil, the depth of the water table, and the situation of lithology and the area of about 7.67% of the whole plain. It is recommended by the experts and extensive research that there needs to be a better situation for the aquifer. The projects of water spreading and the recharge wells should be placed on the parts of the plain where the depth of the water table is more than 30 meters because of being free from evapotranspiration and having good situation of soil permeability.

By the end of this research it could be suggested, water spreading, artificial recharge and any activities could save water in the ground would reclaim the situation of the plain.

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REFERENCES

Barbour, SL & Krahn, J 2004, *Numerical Modelling Prediction or Process?* GEO SPEC. Geotechnical News, pp. 44-52.

Bouwer, H 2002, Artificial recharge of groundwater: hydrogeology and engineering. *Hydrogeology Journal* 10: 121-142.

Chiang, W & Kinzelbach W 1998, *Processing MODFLOW A simulation system for modeling groundwater flow and pollution.* Hamburg, Zürich, pp. 62-79.

Gao, H 2011, Groundwater modeling for flow systems with complex geological and hydrogeological conditions. *Procedia of Earth and Science*, 3: 23-28.

Gaur, S, Chahar, BR & Didier Graillot 2011, Combined use of groundwater modeling and potential zone analysis for management of groundwater. *International Journal of Applied Earth Observation and Geoinformation,* 13: 127-139.

Ghayoumian, J, Mohseni SM, Feiznia, S, Nouri, B, & Malekian, A 2007, Application of GIS techniques to determine areas suitable for artificial groundwater recharge in a coastal aquifer in southern Iran. *Journal of Asian Earth Sciences,* 30: 364-374.

Harbaugh, AW, Banta, ER, Hill, MC & McDonald, MG 2000, *MODFLOW-2000, The U.S. Geological Survey modular ground-water model- user guide to modularization concepts and the ground-water flow process.* U.S. Geological Survey, Open-File Report 00-92, Reston, Virginia, pp. 1-4.

Jacobus, JdV & Simmers, I 2002, Groundwater recharge: an overview of processes and challenges, *Hydrogeology Journal,* 10: 5-17.

Kalantari, N, Bestland, E & Jalalvand, A, 2009, Alluvial aquifer recharge enhanced by a natural dam: feasibility assessment based on multidisciplinary characterization (Khuzestan, Southwest Iran). *Environmental Earth Sciences*, 59: 51-61.

Ko, N, Ji, S, Koh, Y, Choi, J 2012, Consideration of boreholes in modeling of the regional-scale groundwater flow in a fractured rock. *Engineering Geology*. 149: 13-21.

Liling, Z, Wenjuan, X & Zhihua, H 2011, Groundwater evaluation in KeKeYa groundwater source: Comparision of water balance method and numerical simulation method. *International Journal of Geomatics and Geosciences,* 2: 580-588.

Liu, C, Lin, C, Jang, C, Chen, C, Chang, J, Fan, C & Lou, K, 2006, Sustainable groundwater management in Kinmen Island. Wiley InterScience, *Hydrological Processes.* 20: 4363-4372.

Mohan, DM & Saikia, MD, 2009, Hydrology. Eastern Economy Edition, PHI Learning Private Limited, New Dehli-110001. pp. 283-285.

Muñoz-Carpena, R, Ritter, A & Li, YC 2005, Dynamic factor analysis of groundwater quality trends in an agricultural area adjacent to Everglades National Park. *Journal of Contaminant Hydrology,* 80: 49-70.

Newman, BD, Vivoni ER & Groffman, AR 2006, Surface water-groundwater interactions in semiarid drainages of the American southwest. Wiley Inter Science, *Hydrological Processes,* 20: 3371-3394.

Nimmer, M, Thompson, A & Debasmita M 2010, Modeling Water Table Mounding and Contaminant Transport beneath Storm-water Infiltration Basins. *Journal of Hydrologic Engineering,* 15: 963-973.

Rodríguez-Rodríguez, M, Benavente, J, Julián, JJC & Martos FM 2006, Estimation of ground-water exchange with semi-arid playa lakes (Antequera region, southern

Spain). *Journal of Arid Environments,* 66: 272-289.

Scanlon, BR, Healy RW & Cook PG 2002, Choosing appropriate techniques for quantifying groundwater recharge. *Hydrogeology Journal,* 10: 18-39.

Sekhar, M, Rasmi, SN, Sivapullaiah PV & Ruiz L 2004, Groundwater Flow Modeling of Gundal Sub-basin in Kabini River Basin, India. *Journal of Water, Environment and Pollution.* 1): 65-77.

Semnan Regional Water Cooperative (S.R.W.C.) Company 2008, *Record of Prohibition Water Excavation of Dasht-e-Damghan,* Principal Office of Water Resource.

Tang, Q, Hu, H & Oki T 2007, Groundwater recharge and discharge in a hyperarid alluvial plain (Akesu, Taklimakan Desert, China). Wiley Inter Science, *Hydrological Processes,* 21: 1345-1353.

Tehran Regional Water Cooperative (T.R.W.C.) Company 2000, *Simulation Project for Optimum Excavation of Dasht-e-Damghan,* Principal Office of Water Resources, p. 46.

UNEP 2002, *A Survey of Methods for Groundwater Recharge in Arid and Semi-arid regions.* UNEP/DEWA/RS.02-2, pp. 5-10.

Wang, B, Jin, M, Nimmo, JR, Yang, L & Wang, W 2008, Estimating groundwater recharge in Hebei Plain, China under varying land use practices using tritium and bromide tracers. *Journal of Hydrology*, 356: 209-222.

Winter, TC, Mallory, SE, Allen, TR & Rosenberry, DO 2000, The Use of Principal Component Analysis for Interpreting Ground water Hydrographs. *Journal of Groundwater*, 38: 234-246.

Zhang, B & Lerner DN, 2000, Modeling of ground Water Flow to Adits. *Journal of Groundwater,* 38: 99-105.

مدلسازی آب زیر زمینی به منظور تعیین مقدار و محل تغدیه مناسب در دشت دامغان ایران

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چکیده

از آنجایی که آب از ارکان توسعه محسوب می‌شود، مدیریت صحیح منابع آب زیر زمینی به عنوان مهمترین منبع آب شیرین از اهمیت ویژه‌ای برخوردار است. این تحقیق در دشت رسوبی دامغان واقع در بخش شمال غربی استان سمنان ایران انجام شده است. مهمترین هدف این تحقیق تعیین مقدار و محل تغذیه مصنوعی در دشت دامغان است، به طوری که بتوان از افت سطح ایستابی جلوگیری کرد. به این منظور داده‌های مربوط به سطح ایستابی چاه‌های مشاهده‌ای از سپتامبر ۲۰۰۹ الی آگوست ۲۰۱۰ تهیه شد، سپس نوع آبخوان، هدایت هیدرولیکی (k)، ارتفاع سطح زمین و عمق سنگ کف به مدل معرفی شد. در نهایت آبخوان شبیه‌سازی شده توسط برنامه MODFLOW در دو حالت پایدار و ناپایدار مورد واسنجی قرار گرفت و نوسانات سطح ایستابی در سال آبی مورد نظر بدست آمد، نتایج نشان داد که در بخش جنوب غربی دشت نوسانات سطح ایستابی کمتر از سایر نقاط دشت است، بنابراین این منطقه به عنوان منطقه مناسب تغذیه تعیین شد. برای تعیین مقدار مناسب تغذیه با افزودن مقادیر متفاوت ۱۱، ۲۱ و ۳۱ میلیون متر مکعب تغذیه پاسخ آبخوان مورد بررسی قرار گرفت، به طوری که با افزودن مقدار ۲۱ میلیون متر مکعب سطح ایستابی تغییر قابل ملاحظه‌ای از خود نشان می‌دهد، به این ترتیب مقدار مناسب تغذیه ۲۱ میلیون متر مکعب تعیین شد.

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