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Research Paper

Numerical Simulation of Bijar-Divandere Plain Aquifer Using MODFLOW Code and Investigation in the Effects of Drought on Its Quantitative Changes

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Abstract

In this study, quantitative changes in groundwater in Bijar-Divandere plain with MODFLOW code in GMS software were investigated. Aquifer simulation was performed for a period of six years and a monthly step from October 2010 to June 2016. The SPI annual drought index was calculated for the statistical period of 1987-2015. The results of groundwater simulation showed that during the annual simulation period, there was a decrease of about 0.5 m water level in the aquifer, the intensity of which varied in different areas. Therefore, due to the decrease and taking into account the area and the average amount of storage capacity of the aquifer, the volume of the aquifer has been reduced by about 1.3 MCM per year. The results showed that if the current management process continues, over the next few years we will see a sharp decline in the aquifer and irreparable damage. The results of SPI index also indicated that the drought situation was close to normal, which means that drought has a much lesser effect on the groundwater level of the aquifer in different years.

Introduction

Groundwater aquifers are unignorable and important freshwater resources. In addition, they are very sensitive to contamination caused by the rapid infiltration of contaminated surface waters. Moreover, Groundwater modeling has been proposed in the recent years as a powerful tool in management, optimization of consumption and forecasting of groundwater resources. In drought condition, groundwater resources play the most important role to compensate different water resources needs. Therefore, it is vital to study and pay attention to the issue of drought to prevent the intensification of damage and its negative conditions. In relation to Bijar-Divandere plain located in Kurdistan province, Iran, no studies have been done so far, and on the other hand, literatures and field visits show quantitative and qualitative changes and a decrease in groundwater aquifer level in the mentioned plain. Therefore, the objective of this study was to simulate groundwater level changes and investigate the effect of drought on the groundwater quantity of the plain using MODFLOW code and SPI drought index.

Material and Methods

The present study was conducted in the Bijar-Divandere study area with code 1309 located in Kurdistan province, in northwestern Iran. According to Demarten classification, the area has a semi-arid climate, land and a structure of sedimentary rocks, especially clay, limestone and sandy mixtures, which is related to the changes of the third geological period. To simulate the groundwater flow of the plain aquifer, the MODFLOW code from the codes in the GMS software was used. To investigate the observational and simulated level of groundwater in the study area, different data of 26 observation wells during statistical period of 6 years (October 2010 to June 2016) were used. Nevertheless, for drought investigation by standard rainfall index, meteorological data used were from year 1987 – 2015. In the studied aquifer, the groundwater level was first plotted by observation wells and the inlet and outlet flows were determined by drawing iso-potential lines in the aquifer. The groundwater flow equation in the free aquifer under non-steady flow conditions is as equation (1).

$$\frac{\partial}{\partial x}\left(K_x h \frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y h \frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z h \frac{\partial h}{\partial z}\right)=S_y \frac{\partial h}{\partial t} \quad (1)$$

Where, Sy special watering coefficient, K_x ،K_y and K_z are respectively hydraulic coefficient in the direction of x, y and z axes in terms of (l/T), h is the hydraulic head at any point in the aquifer in terms of (l) and "Δx", Δy and "Δz" are the dimensions of the grid cells (L). The model was calibrated with corrections in the values of hydraulic conductivity and monthly distribution of source and drain parameters of the aquifer. The accepted values at this stage were then taken as the baseline values for further calculations. Drought was assessed using the SPI index in the basin as Eq. (2).

$$SPI=\left(\frac{P_i-P}{SD}\right) \quad (2)$$

Where, Pi is the annual rainfall and P is the average long-term rainfall and SD is the standard deviation of rainfall during the statistical period.

Results

The results showed that the north of the aquifer had hydraulic conductivity with values between 9 to 13 m/day. The lowest value belonged to the eastern part of the aquifer, which varies from 6 to 7.5 m/day. The central area of the aquifer also had values ranging from 7.5 to 9 m/day. In the simulation of groundwater for the steady state conditions (Fig. 1) according to the results obtained for RMSE = 0.8 m, MAE = 0.73 m and R^2 = 0.999, the model was able to simulate the groundwater level values with suitable accuracy. For unstable state condition, based on the results of RMSE = 0.88 m, MAE = 0.85 m and R^2 = 0.99, the model was able to perform simulation operations with appropriate accuracy as well. The results of the evaluation of SPI drought indices on an annual basis at the 1987-2015 are presented in Table (1).

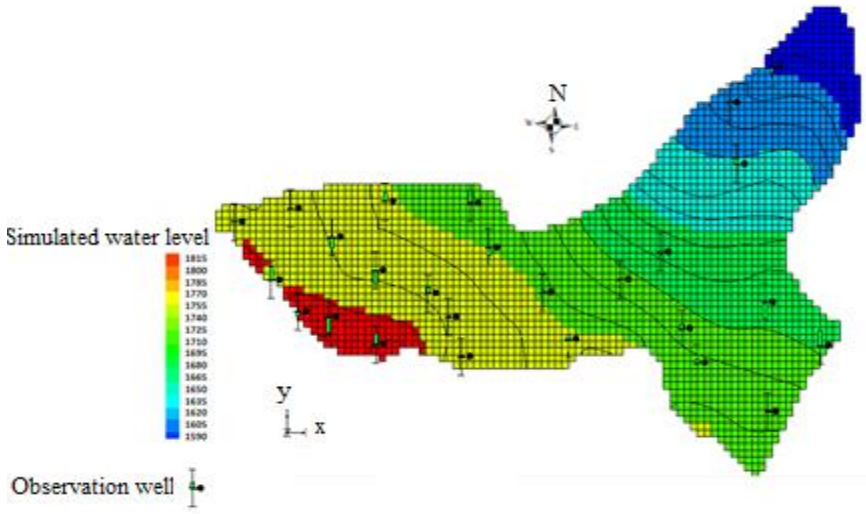

Fig. 1 Simulated groundwater level and calibrated observation wells at steady state condition

Table 1 Status of different years in terms of drought (near to normal) according to SPI drought index

Year	SPI	Year	SPI
1987	0.051	2001	-0.25
1988	0.035	2002	-0.06
1989	-0.009	2003	0
1990	-0.054	2004	-0.015
1991	0.025	2005	-0.044
1992	-0.011	2006	-0.009
1993	0.19	2007	0.31
1994	0.094	2008	0.039
1995	0.024	2009	0.023
1996	0.025	2010	0.03
1997	-0.015	2011	-0.066
1998	-0.017	2012	-0.124
1999	-0.080	2013	-0.010
2000	-0.030	2014	0.008

The SPI index indicates a normal upward statistical period in the aquifer under study. In the period 1997-2002, the highest duration of drought was observed on an annual scale for seven years. In the period 1975-2005, four different drought periods were observed on an annual scale, which are: 1989, 1990, 1997-2002, 2006-2004, 2013-2011. The highest value of SPI index was related to 2007 with a value of 0.31 and the lowest value of SPI index is related to 2001 with a value of -0.25. In general, the results indicated that the model was able to show, well groundwater level changes behavior in aquifer. Therefore, it can be used to implement management scenarios. The results showed that in the study area and during the period of investigation, severe drought did not occur and often the phenomenon of drought with intensity and extent was very low and close to normal. From the results of drought and the decrease of groundwater level in the same period, it can be concluded that in the aquifer under study, the decrease of groundwater level was not effective due to drought.

Conclusion

According to the findings of this study, it can be concluded that: there was no severe drought and most of the drought phenomenon was very low in intensity and limits and close to normal; in Bijar-Divandarreh plain of Kurdistan province, the decrease of groundwater level was not effective due to drought, but also the other factors such as harvesting increase, climate change and the area under cultivation increase could play a role; during of the annual simulation period, a decrease of 0.5 m in the aquifer was occurred; The volume of Bijar-Divandere plain aquifer was reduced by about 1.1 MCM annually; Different management solutions, such as installing volumetric meters on existing and active wells, blocking unauthorized wells, and other management strategies such as artificially feeding in suitable areas and change of cultivation pattern are necessary to be able for preventing of groundwater draw down.

Data Availability

The data used in this research are presented in the paper.

Conflicts of interest

The authors of this paper declared no conflict of interest regarding the authorship or publication of this article.

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مقاله پژوهشی

شبیه‌سازی عددی آبخوان دشت بیجار- دیواندره با استفاده از کد MODFLOW و بررسی تأثیرات خشک‌سالی بر تغییرات کمی آن

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چکیده

در این پژوهش به بررسی تغییرات کمی آب زیرزمینی دشت بیجار- دیواندره با کد MODFLOW موجود در نرم‌افزار GMS پرداخته شد. شبیه‌سازی آبخوان برای یک دوره شش ساله و گام ماهانه از مهر سال ۱۳۸۹ تا خرداد سال ۱۳۹۵ انجام و شاخص خشک‌سالی SPI نیز برای دوره آماری ۱۳۶۶- ۱۳۹۴ محاسبه شد. نتایج شبیه‌سازی آب زیرزمینی نشان‌داد که در طول دوره شبیه‌سازی سالانه در حدود ۰/۵ m افت در آبخوان ایجادشده که شدت آن در ناحیه‌های مختلف متفاوت بود. لذا، با توجه به افت ایجادشده و با در نظر گرفتن مساحت و مقدار متوسط ضریب ذخیره آبخوان موردنظر، سالانه در حدود ۱/۱ MCM از حجم آبخوان کاسته شده است. نتایج به‌دست‌آمده نشانگر آن است که اگر همچنان روند مدیریت کنونی ادامه یابد، در طول چند سال آینده شاهد افت شدید آبخوان و خسارت جبران‌ناپذیری خواهیم بود. نتایج شاخص SPI نیز حاکی از وضعیت خشک‌سالی نزدیک نرمال بوده و این بدان معنی است که خشک‌سالی تأثیر بسیار کم‌تری در تراز آب زیرزمینی آبخوان موردنظر در سال‌های مختلف داشته است.

اطلاعات مقاله

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واژه‌های کلیدی:

آب زیرزمینی

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شاخص SPI

مدل مفهومی

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۱- مقدمه

سفره‌های آب زیرزمینی منابع آب شیرین مهمی هستند که نمی‌توان آن‌ها را نادیده گرفت. علاوه بر این، در برابر آلودگی ناشی از جریان نفوذی سریع آب‌های سطحی آلوده که در سنگ شکسته رخ می‌دهد، بسیار حساس هستند (Karay and Hajnal 2015). با استفاده از مدل‌های عددی می‌توان نحوه واکنش آبخوان نسبت به برداشت و تغذیه با روند موجود یا سناریوهای مختلف مدیریتی را پیش‌بینی کرد (Valivand and Katibeh 2019). مدل‌سازی آب‌های زیرزمینی در سال‌های اخیر به‌عنوان ابزاری قدرتمند در مباحث مدیریتی، بهینه‌سازی مصرف و پیش‌بینی منابع آب زیرزمینی مطرح شده‌است (Taheri Tizro and Kamali 2016). در مواقع خشک‌سالی نیز منابع آب زیرزمینی بیشترین نقش را در تأمین نیازها دارند. ازاین‌رو ضرورت بررسی و توجه به موضوع خشک‌سالی (مطالعه کمی)