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Impacts of Climate Variation and Groundwater Declination on Groundwater Quality in an Arid Environment

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ABSTRACT: In arid and semi-arid region, rainfall occurred in a short time with high intensity and consequently a large amount of rainfall convert to runoff. In these areas, evapotranspiration is high and a significant volumes of surface water lose through evapotranspiration. In such area, groundwater is the main source of fresh water for agricultural, industrial and other human activities. But climate change and over extraction should affect groundwater quality and quantity. The main aim of this study is to investigate the impacts of climate variation and over extraction of groundwater on temporal and spatial variation of groundwater quality in Kashan aquifer located in the center of Iran. For this propose, the meteorological drought index (SPI) and groundwater drought index (GRI) was calculated for 23 years (1991-2015). The relationship between groundwater quality, SPI and GRI was investigated via Pierson correlation method. According to results, for the studied period, groundwater level decreased continuously. Annual groundwater declination was about 13 centimeters. Groundwater quality was decreased with decreasing of groundwater level. A significant relationship was observed between GRI and water quality indexes (P<0.01), while relationship between groundwater quality and SPI was not significant. The results of this study indicate that the impact of groundwater over extraction in groundwater quality is more perceptible than drought impacts. This results indicate the important of groundwater extraction for aquifer management, especially in arid area.

Key words: Climate Change, Over extraction, Groundwater quality, Drought index, Arid environment

INTRODUCTION

Groundwater is the major freshwater sources in the hydrological cycle of arid and semi-arid area (Ghazavi *et al.*, 2010). During droughts, groundwater is the main and in some case is the only source of fresh water for agricultural, industrial and other human activities. In the recent years, the over extraction of groundwater for human consumption and agricultural activity lead to groundwater depressing in most parts of the area located in arid and semi- arid environment (Treidel *et al.*, 2012; Ghazavi *et al*, 2016; Wada *et al.*, 2010).

It is well recognized that climate change is also a regional and world wiled problem that affected groundwater resources (Treidel *et al.*, 2012; Lee *et al.*, 2014; Zhang *et al.*, 2016). The studies about the climate change indicate that water resource management policies need to include the effects of global climate change for correctly predict of water supplies (Woldeamlak *et al.*, 2007; Ying *et al.*, 2015).

The prediction of climate change in many parts of the world indicate a significant decreasing in precipitation and a significant increasing of evapotranspiration (Kumar, 2012), consequently, in such area, groundwater recharge decreased, while groundwater discharge increased (Hiscock *et al.*, 2012). Climate change should decrease precipitation, but also it is accepted that climate variability should affect other components of the hydrologic cycle include surface components such as temporal and spatial distribution of precipitation and evapotranspiration, soil moisture and runoff, soil permeability and soil cover (Liu, 2011; Milly *et al.*, 2005; Bates *et al.*, 2008) and subsurface hydrologic cycle components such as saturated and unsaturated zone. Both of these change souled affect recharge, discharge, and consequently, groundwater quantity and quality.

While the impacts of groundwater over extraction and climate change on groundwater level have been investigated in several studies, modification impacts on groundwater quality have received less consideration (Ghazavi *et al.*, 2012; Mukherjee, 2015).

In the arid and semi- arid area, Groundwater uses rise as the precipitation decreases due to climate change (Sheng, 2013; Hutchison 2006). In such area, aquifers are less sensitive to climate change than surface water bodies, and so, they used for mitigate the effects of droughts. Aquifers located in this area experience large drops in groundwater level due to long-term groundwater over extraction (Mirzavand and Ghazavi, 2016). Groundwater declination lead to land subsidence and intrusion of brackish water, consequently to deterioration of water quality (Hutchison and Hibbs 2008; Sheng and Devere 2005; Zhou, 2009). Depletion of groundwater quality souled continue until groundwater level decline and the pumpage from this aquifer is not limited (Barnett *et al.* 2008; Zektser *et al.* 2004; Ma *et al*. 2005; Mirzavand and Ghazavi, 2016).

Study of the groundwater consumption, climate variability, water storage, and other human activities are important for sustainable water management (Ghazavi *et al.* 2008). During recent decades, pressure on aquifers increased via climate change, increasing water demand and weak irrigation management. These pressures should modify groundwater quality and groundwater level as well as their temporal patterns and threaten vital ecosystem services. Due to lack of fresh water in arid regions, the important of water quality is more critical than water quantity. The main aim of this study is to investigate the impacts of drought and over extraction of groundwater on temporal and spatial variation of groundwater quality in Kashan aquifer located in the center of Iran.

MATERIAL AND METHODS

A. Study area

The study aquifer is located in Kashan plain (longitude: 51°32' to 51°03'E, latitude: 33°27' to 34°13'N), Esfahan province, Iran (Fig. 1). The Kashan plain has an area of 1570.23 km^2. The annual evaporation of the study area ranges from 2100 to 3000 mm. The average of annual humidity is about 42 percent. Maximum and minimum temperatures are 48 °C and 5° degrees below zero respectively. Annual rainfall is varied spatially (75 mm at the east to 300 mm in the southwest mountains). The Kashan aquifer experiences a critical negative budget (about -32 million m^3 annual discharge).

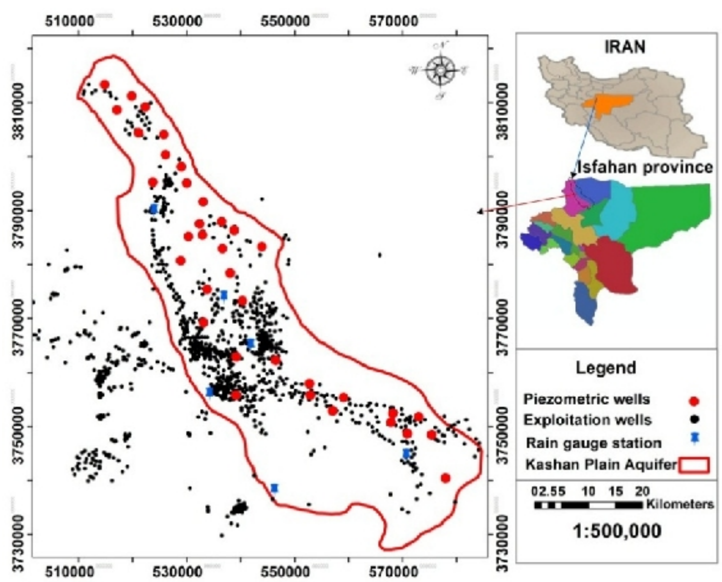

Fig. 1. Location of the study area in Iran.

B. Methodology

Topographical and geological maps, rainfall data, aquifer information, number of extraction wells and volume of annual groundwater discharge were prepared using Kashan regional water authority studies. The result of geophysical studies was used to determine the thickness of the alluvium area in the various parts of the aquifer. The pumping test results was used to determine the hydrodynamic coefficients (effective porosity and hydraulic conductivity).

Amounts of Nitrate, EC and TDS of 36 wells was investigated for evaluate water quality of the studied area.

Monthly water table level during 20 years (1991-2011) and polygon area affected by 22 observation wells were evaluated. Thiessen method was used to determine the area affected via each study wells. In order to evaluate the overall condition of the aquifer and spatial change of groundwater level, the unite hydrograph of the aquifer was drawn.

For meteorological drought analysis, precipitation has been commonly used (Pinkeye, 1966; Santos, 1983; Chang, 1991; Eltahir, 1992). Considering drought as precipitation deficit with respect to average values (Gibbs, 1975), several studies have analyzed droughts using monthly precipitation data. One of the most popular tools in meteorological drought tools, is Standardized Precipitation Index (SPI index). SPI can be expressed as equation.

$$SPI = \frac{X_i - \bar{X}}{S} \quad (1)$$

Where SPI *is* Standardized Precipitation Index, X_i is rainfall in the year the desired, $\bar{X}$ is the Long-term average annual rainfall and S is Standard deviation. The SPI classes Based on McKee *et al* (1993) is presented in Table 1.

In thus study, Meteorological drought was investigated using SPI On a scale of 3, 6, 9, 12, 18, 24, 36 and 48 months.

Mendicino *et al* (2008) indicate that Groundwater Resource Index (GRI) is a useful and reliable indicator for monitoring and predicting hydrological drought situation in the Mediterranean region GRI can be expressed as equation 2.

$$GRI = \frac{D_{y,m} - \mu_{D,m}}{\sigma_{D,m}} \quad (2)$$

Where GRI is Groundwater Resource Index, $D_{y,m}$ is groundwater level in the Piezometer *y* and month *m*, $\mu_{D,m}$ is the monthly average of groundwater and $\sigma_{D,m}$ is the standard deviations of these values in month m. The GRI classes Based on Mendicino *et al* (2008) is presented in Table 1.

In this study, GRI was used to determine the impact of drought on groundwater resources. groundwater drought index was calculated at 7-time Scale (3, 6, 9, 12, 24, 36 and 48 months) using DIP software.

The relationship between groundwater quality, SPI and GRI was investigated via Pierson correlation method.

Table 1: Classification of the severity of SPI and GRI indicators (Mendicino *et al.* 2008).

Drought levels	SPI and GRI values
Without drought	2 ≤
Severe wet	1.5 to 1.99
Moderate wet	1 to 1.49
Normal	+.99 to -0.99
Moderate drought	-1 to -1.49
Severe drought	-1.5 to -1.99
Very severe drought	-2 ≥

RESULTS AND DISCUSSION

A. Hydrological and climatological drought

To determine the spatial groundwater level change in the study area, unit hydrograph of the aquifer was extracted based on monthly groundwater level measured in 22 observation wells (Fig. 1). Based on the results, groundwater decline continuously. During 24 years (1991-2015) annual groundwater declination was about 3 m. Maximum level of groundwater was observed in the winter and autumn and minimum groundwater level was observed in the summer. In the study area, maximum rainfall occurred in the winter (about 51.2%). Based on 22year rainfall of the study area (1991-2011), average of rainfall in the winter, autumn, spring and summer was 51.23, 23.27, 0.77 and 24.62 mm respectively. According to results, also annual rainfall was decreased slowly due to climate variation, but not significant trend was observed in rainfall decreasing (Fig. 3). For investigation the impacts of climate change and over extraction on temporal and spatial variation of groundwater quality, meteorological and groundwater drought indexes were calculated on a scale of 3, 6, 9, 12, 18, 24, 36 and 48 months. The relationship between SPI and GRR was exanimate via regression analysis method (Table 2). A significant correlation was observed between SPI and GRI in different time scale, but the biggest correlation coefficient was observed between SPI calculated for 6-month time scale and GRI calculated for 48-month time scale (R2=0.49; P<0.01).

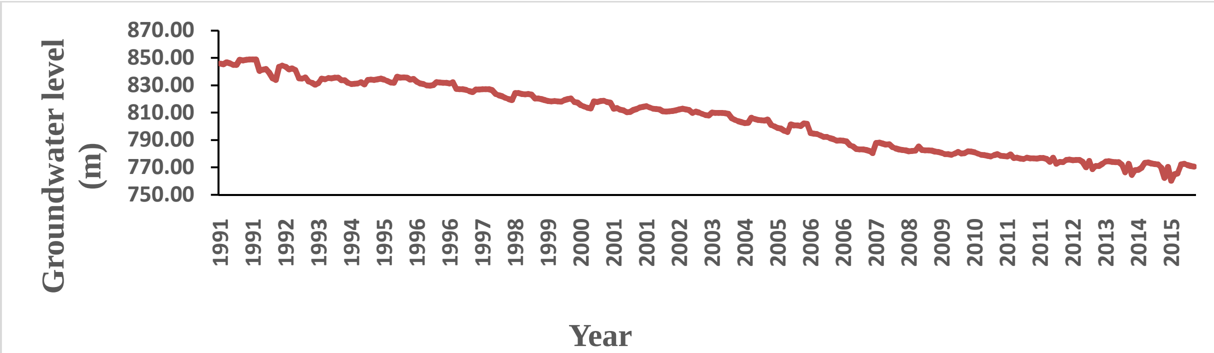

Fig. 1. Unit groundwater hydrograph of the study area.

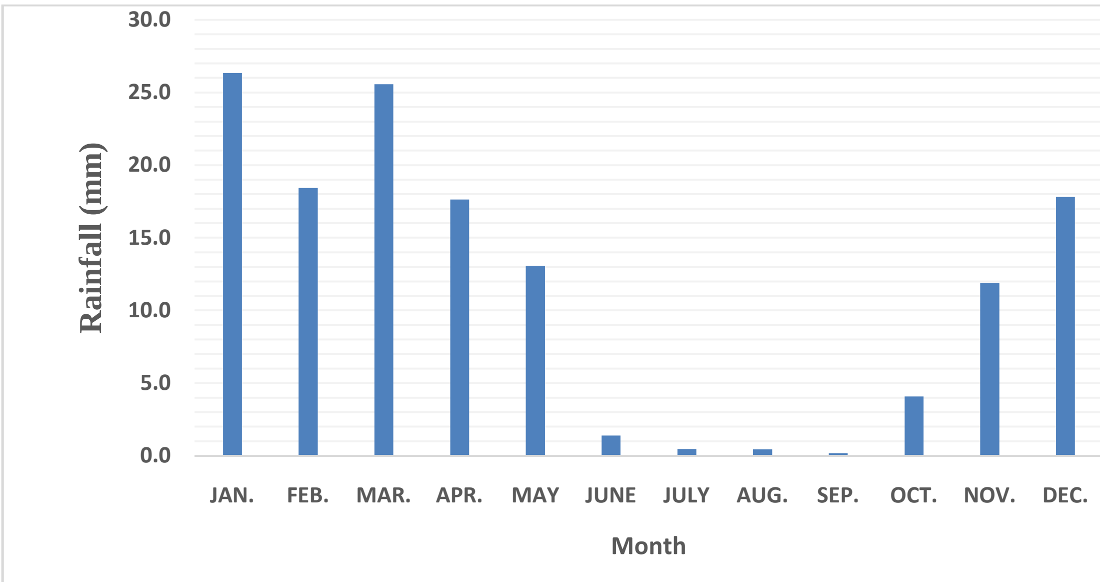

Fig. 2. Monthly rainfall distribution of the study area.

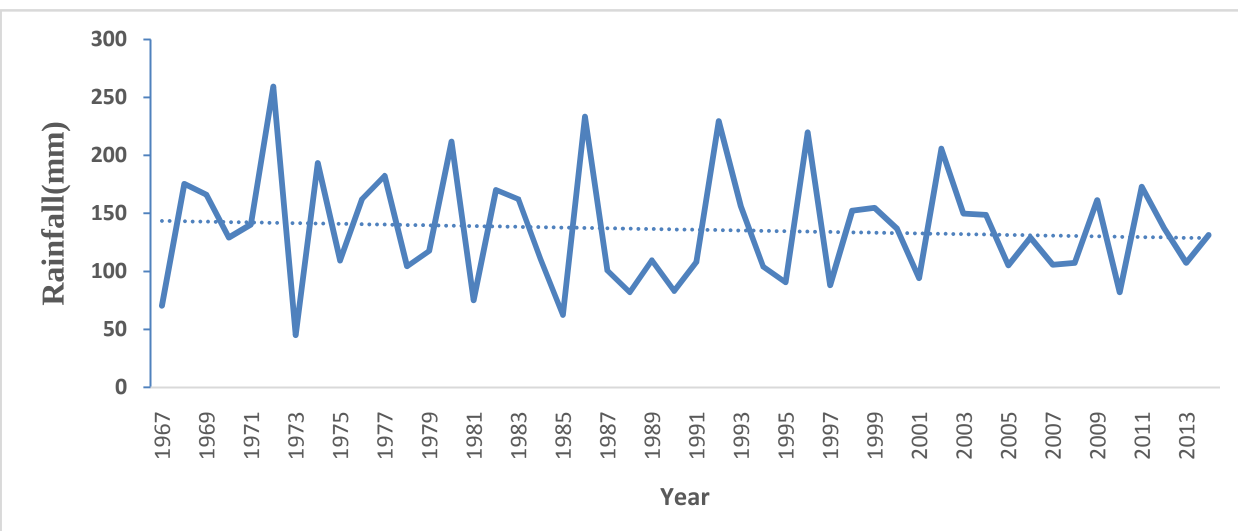

Fig. 3. Annual rainfall variation of the study area.

The correlation coefficient between SPI calculated for 3,18 and 12-month time scale and GRI calculated for 48-month time scale was 0.41, 0.29 and 0.28. This results indicate that for the study aquifer, a delay of 48 months was exited between hydrological and meteorological drought. According to results, delay between hydrological and meteorological drought increase with increasing of groundwater level. In the first year of the studied period, annual GRI was followed SPI, but the delay between two indexes was increased continuously with increasing of groundwater level, as the maximum delay was observed in the end of the study period (Fig. 1 and 4). For example, increase of SPI in 2008 cause an increase of GRI in 2010.

Table 2: Correlation analysis between SPI and GRI for the study aquifer.

	3-month GRI	6-month GRI	9-month GRI	12-month GRI	18-month GRI	24-month GRI	48-month GRI
3-month SPI	0.21*	0.23*	0.24*	0.24*	0.25*	0.27*	0.41**
6-month SPI	0.22*	0.22*	0.24*	0.25*	0.23*	0.28*	**0.49****
9-month SPI	0.22*	0.22*	0.22*	0.24*	0.25*	0.26*	0.21*
12-month SPI	0.21*	0.21*	0.21*	0.21*	0.24*	0.22*	0.28*
18-month SPI	0.2*	0.19*	0.19*	0.2*	0.2*	0.23*	0.29*
24-month SPI	0.12*	0.12*	0.13*	0.13*	0.12*	0.11*	0.18*
48-month SPI	-0.07	-0.05	-0.05	-0.05	-0.06	-0.04	-0.11

**Significant correlation($P<0.01$); * Significant correlation($P<0.05$)

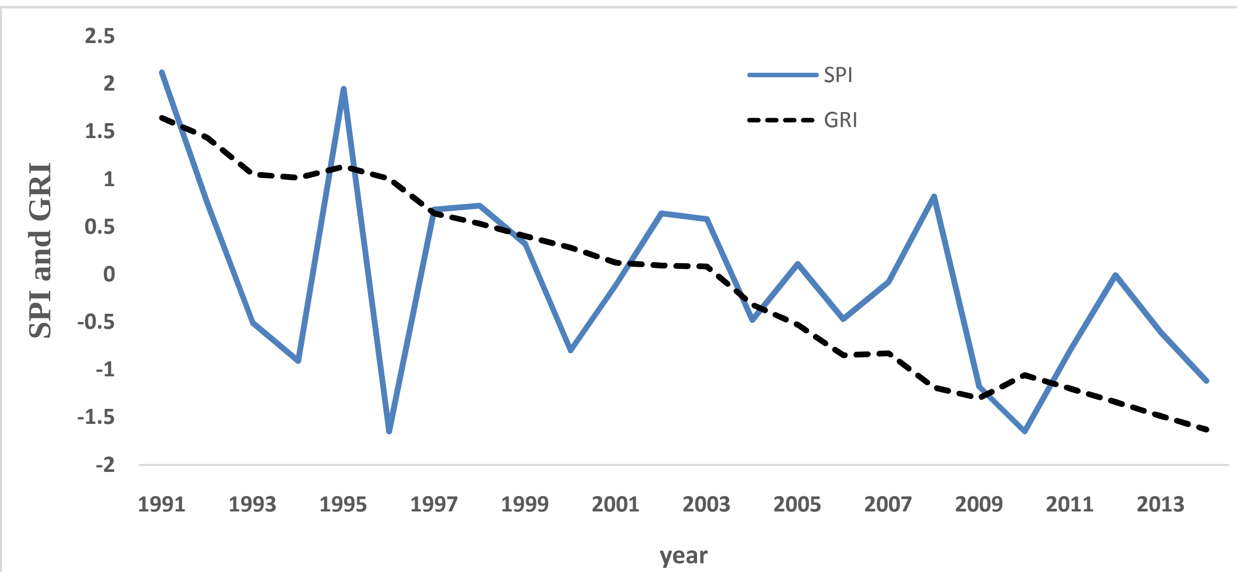

Fig. 4. Annual SPI and GRI for the studied aquifer.

B. Groundwater quality variation

The relationship between several groundwater quality parameters, SPI and GRI was investigated via Pierson correlation method using SPSS software (Table 3). According to results, a significant correlation was observed between EC, TDS, NO_3 and Na ($P<0.01$), but correlation between P and other chemical parameter was not significant($P<0.05$). A significant correlation was observed between GRI and chemical characteristics of groundwater include EC, TDS, NO_3 and Na ($P<0.01$), but relationship between SPI and studied chemical parameters was not significant.

According to results, groundwater level decline continuously in the studied aquifer, consequently GRI decreased. Electrical conductivity (EC) and TDS are the main factors that indicate concentration of the anions and cations. EC is one of the useful measured water quality parameters and also an early indicator that indicate the change in a water system. The results of this study indicate that EC, TDS and No_3 were increased with decreasing of GRI (Fig. 5), so groundwater quality decreased.

Table 3: Pierson correlation between water quality parameters, SPI and GRI.

		Na	NO3	EC	TDS	P	GRI	SPI
Na	Pearson Correlation	1						
	Sig.(2-tailed)							
NO3	Pearson Correlation	0.888**	1					
	Sig.(2-tailed)	0.000						
EC	Pearson Correlation	0.944**	0.791**	1				
	Sig.(2-tailed)	0.000	0.000					
TDS	Pearson Correlation	0.941**	0.815**	0.965**	1			
	Sig.(2-tailed)	0.000	0.000	0.000				
P	Pearson Correlation	0.304 ^{ns}	0.217 ^{ns}	0.273 ^{ns}	0.182 ^{ns}	1		
	Sig.(2-tailed)	0.363	0.521	0.418	0.591			
GRI	**Pearson Correlation**	**-0.925****	**-0.973****	**-0.875****	**--0.879****	**-0.183**	**1**	
	Sig.(2-tailed)	0.000	0.000	0.000	0.000	0.028		
SPI	**Pearson Correlation**	**-0.386** ^{ns}	**-0.238** ^{ns}	**-0.565** ^{ns}	**-0.419** ^{ns}	**0.158** ^{ns}	**0.385***	**1**
	Sig.(2-tailed)	0.363	0.521	0.418	0.591	0.158	0.59	

ns treatment effect not significant, ** Significant correlation (P <0.01)

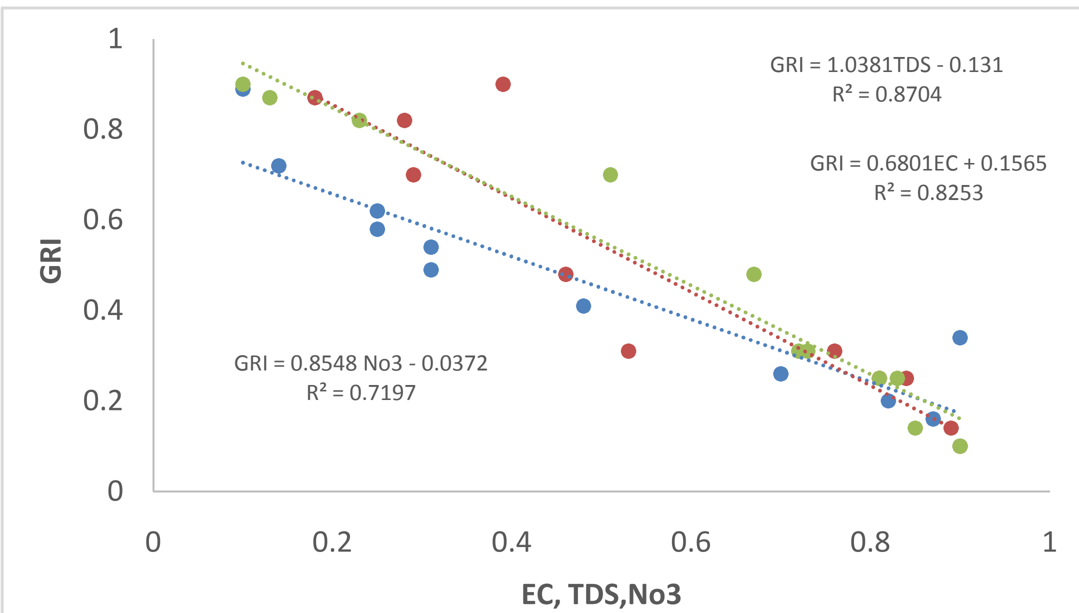

Fig. 5. Liner relationship between GRI and EC, TDS and NO3.

RESULTS AND DISCUSSION

In this study, the impact of climate variation and groundwater declination on groundwater quality was investigated using SPI and GRI. Based on the results, also groundwater decline continuously during 23 study years, but rainfall decreasing was not significant. This results indicate that also climate variability should effect groundwater recharge, but in this study area, groundwater over extraction should be the most important factor that decreased groundwater level. In the year 1980, annual groundwater extraction was 0.17 million cubic meter and the number of extraction wells was 105. In 2013, the number of extraction wells increase to 1130 and the volume of groundwater extraction increased to 2.5million cubic meter.

This over extraction lead to groundwater level declination. Other researchers indicate that in arid area, the effect of groundwater discharge is more important than climate variability (Shahid and Hazarika.,2010; Mishra and Singh., 2010; Pandey *et al.,* 2010).

The results of statistical analysis between drought and groundwater indexes indicate that rainfall variability affected groundwater level. A significant correlation was observed between SPI and GRI, but the best correlation was observed between SPI calculated for 6-month time scale and GRI calculated for 48-month time scale (R2=0.49; P<0.01). This results indicate a delay of 48 months between hydrological and meteorological drought. Chamanpira *et al* (2014) indicate a negative trend between groundwater and meteorological drought. They show a significant correlation between 24-month time scale SPI and 24-month GRI without any delay, while several other researchers indicate a significant correlation between SPI and GRI with different time scale delay (Mendicino *et al.,* 2008; Seif *et al.,* 2012)

Groundwater decreasing companied with decreasing of groundwater quality. A significant correlation was observed between EC, TDS, NO3, Na and GRI (P<0.01), but relationship between SPI and studied chemical parameters was not significant. This results indicate a direct and linear relationship between groundwater level and groundwater quality. The studied aquifer located in an arid area and in the coastal of a saline lake named Maranjab lake. Groundwater level decreasing souled lead to an inverse hydraulic gradient in groundwater, consequently, saline water souled penetrate to the aquifer. Deeper groundwater has also more dissolved solid due to less discharge and the nature of the existing groundwater, which may be thousands of years old.

CONCLUSION

The results of this study indicate that groundwater quality and quantity souled affect via meteorological drought and water extraction for agricultural, industrial and other human activity. According to results, the effect of groundwater extraction is more important than meteorological drought. Annual groundwater extraction in the study area increased from 0.17 million cubic meter in 1980 to 2.5 million cubic meter in 2013. In Iran, more than 92% of re-new able water use in agricultural activity. Therefore, it is important that manage agricultural water utilization.

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