Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env. Pharmacol. Life Sci., Vol 3 [10] September 2014: 48-56

Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD
Global Impact Factor 0.533
Universal Impact Factor 0.9804

ORIGINAL ARTICLE

Effect of Drought on Groundwater Resources; a Study to Optimize Utilization Management (Case Study: Alashtar Plain)

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ABSTRACT
Drought is the most hazardous natural phenomenon. Although not preventable, its negative effects can be reduced through taking some measures. One of the systems severely affected by drought while less considered is the groundwater. In this study, drought status and its impact on groundwater resources was investigated in Alashtar Plain using standardized precipitation index (SPI) at monthly, quarterly, and annual scales and the groundwater resource index (GRI) during the statistical period of 1991-2010. The results indicated that the trend of plain meteorological and groundwater drought is negative. Correlation between SPI at different time scales with and without the time delay with average groundwater level and GRI was analyzed. Statistical analysis showed that SPI was significant at the level of 0.01, in the 24-month time scale without any time delay with mean groundwater level and GRI and had the highest correlation coefficient, suggesting the impact of drought on Alashtar plain groundwater. Regression relationship between the mean level of the water table and SPI_24 showed that 64.4% of the variance at the mean level of water table was affected by SPI_24 and 35.6% was affected by other factors. Drought magnitude (DM) analysis showed that meteorological and groundwater droughts are consistent with winter and autumn, respectively. Undoubtedly, optimized utilization management, especially in spring and summer, may have a critical impact on preventing damages to the groundwater resources of the region.
Key words*: drought magnitude (DM), time delay, Standardized Precipitation Index (SPI), Groundwater Resource Index (GRI), optimized utilization management*

Received 02.05.2014 Revised 16.06.2014 Accepted 21.08. 2014

INTRODUCTION

Droughts are caused mainly due to lack of rainfall, but occurrence of successive droughts can cause serious changes in the intensity, duration, and spatial distribution of rainfall [9]. These changes will be followed by meteorological, agricultural, hydrological, and socioeconomic droughts. Drought occurs when water availability in short term is lower than normal. Droughts exist in all climatic zones and affect various components of hydrological cycle [23]. In the last century, drought has imposed enormous costs on environment, especially in arid and semi arid areas; so that 50% of the world's wetlands have disappeared, 20% of the freshwater fish generation have been extinct or endangered, some rivers do not join to seas, and many of the most important groundwater resources destroyed or are being destroyed quantitatively and qualitatively. Yet over the past century, the world population has tripled and water use has increased six-times [4]. World Water Council (WWC, 2000) predicted that the water use will be increased by about 50% in the next 30 years.

Common to all droughts is a deviation from normal conditions. Meteorological drought is the lack of precipitation which is often associated with more than natural evapotranspiration [20]. Groundwater drought occurs in periods when the rainfall is less than the long term average [16]. When groundwater systems are affected by drought, the flooding is reduced first; then the level, and finally the groundwater discharge rate will be decreased. Such a drought is called groundwater drought [22].

In recent droughts, groundwater was heavily exploited for various agricultural, industrial, and urban uses. This problem has escalated the drought stress on groundwater resources in many parts of Iran.

Although groundwater is an important source of water in the world, but it remains unnoticed in many drought-related studies [18].

Therefore, the long-term data of areas vulnerable to drought need to be monitored and evaluated in order to optimally manage water resources exploitation and reduce the negative effects of drought. Droughts are often analyzed descriptively, while a quantitative analysis of drought requires an accurate index [19]. Various indices are provided so far for drought monitoring, but some have been more considered due to their simplicity and applicability [8]. For example the Standardized Precipitation Index (SPI), developed by Mckee*et al*. (1993) for monitoring meteorological drought, is very important for different calculated time scales and for early warning and help to assess drought severity. The calculation of this index requires fitting of the most suitable probability distribution function which is usually fitted with gamma distribution. Then the cumulative distribution function is calculated and converted to normal distribution [12]. Lack of rainfall in short time scales mainly affects soil moisture, whereas long-term rainfall deficit often affects groundwater, streamflow, and water resources [5].

Groundwater Resources Index (GRI) was tested by Mendicino *et al*. (2008) in Calabria, Italy, for monitoring and prediction of groundwater resources drought. GRI, as the most recent and applicable indicator, has been tested with 40 years simulated data. It was better than the other indices for monitoring of groundwater drought in Mediterranean region [15]. Investigation showed that SPI and GRI are widely used as two reliable and useful indicators for monitoring of meteorological and geohydrological droughts in Iran and other countries. Naserzadeh and Ahmadi in a study entitled "Evaluation of meteorological drought indices in assessment and zonation of drought in Qazvin Province" found that SPI gained the first place in indicating severe droughts [13]. Yassamani*et al*. used GRI to study the influence of meteorological drought on groundwater level in Torbatjam Plain of KhorasanRazavi. Their results showed a significant relationship between meteorological drought and groundwater drought with the 48-month time delay [24]. When meteorological drought occurs, water supply decreases at first and then water table and aquifer discharge falls. Although all droughts arise from rainfall deficit, hydrological droughts usually occur with a time delay after meteorological and agricultural droughts [3]. In a study in Saveh Plain, Mohammadi Ghaleni and Ebrahimi (2011) showed a significant correlation at 0.01 level between SPI (Ahmadabad station) and water table level in 24-month scale, meaning that the meteorological drought in Saveh Plain exerted its highest impact on groundwater resources after two years [10]. Mohammadi and Shamsipour (2003) investigated the impact of recent droughts on groundwater resources in Northern Plains of Hamadan and concluded that drought influenced groundwater after 9-month delay [11].

The present study aimed to define and characterize meteorological and geohydrological droughts and to quantify the precipitation deficit at different time scales and its impact on groundwater resources. The results obtained will be an important step towards optimized utilization planning and management of water resources in the region.

MATERIALS AND METHODS

The study area

Alashtar Basin with a surface area of 795 km^2 is located at 60 km northwest of Khorramabad City. The basin is geomorphologically divided into two units of mountain and plain. With an area of 110 km^2, Alashtar Aquifer accounts for about 14% of this basin. Figure 1 shows the geographical location of Alashtar Basin. The basin altitude range is about 2180 m; *i.e.* from 1450 m at the outlet to 3633 m at its highest point. The plain average height is 1580 m above the sea level and its north and northeast boundaries are formed from calcareous mountains. The plain alluvial sediments are composed of sand, gravel, and rubble with alternately deposited clay layers. Known formations of the plain include cretaceous sediments, Kashkan Formation, Bakhtiari Conglomerate, and alluvial deposits. The average annual rainfall is approximately 554 mm. The precipitation is Mediterranean-type with maximum precipitation in the cold season and minimum precipitation in the warm season. Eighty-six percent of annual rainfall occurs from December to May. Originating from the southern slopes of Grin Mountains as one of the permanent flooding centers in Lorestan, Alashtar River is a permanent river which flows with the name of Kahman firstly toward West and passes through a narrow valley. It supplies water for Karjan, Darreh Tang, and Upper and Lower Kahman villages. The average annual discharge of the river at the outlet is estimated about 261.9 million m^3[25].

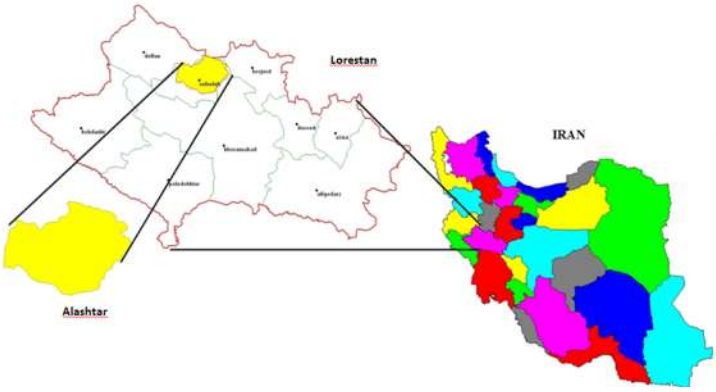


Figure 1: Location of Alashtar Basin

RESEARCH METHOD

After collection of rainfall data, uniform tests were monthly performed on them in selected rain gauge and synoptic stations, and statistical errors were corrected by subtraction and ratios method. Then to determine the status of meteorological drought, SPI was calculated with DIP software on an annual, seasonal, and 3, 6, 9, 12, 18, 24, and 48-month time scales for Alashtar Plain during the period of 1991-2010. Then, according to SPI value, the moisture status was determined for each period using Table 1. Simplicity of calculations and availability of required data has resulted in global acceptance of this index in quantitative analysis of drought [14, 17].

Table 1: Status of moisture, based on SPI (Mckee*et al*., 1993)

Class	Status of moisture	(SPI) Values
1	Very wet	>2
2	Wet	From 1 to 1.92
3	Normal	From -0.99 to 0.99
4	Dry	From -1.99 to -1
5	Very Dry	<1

Drought magnitude (DM) is defined by Equation (1) based on SPI (Mckee*et al*., 1993)

$$DM = \sum_{j=1}^{n} SPI_{ij} \qquad (1)$$

Where *DM* is drought magnitude, *j* drought month, *n* number of drought months, and SPI_{ij} drought index of months less than -1 based on *i* time scale in month *j*.

The data from 15 piezometric wells were used to evaluate the impact of drought on groundwater resources of Alashtar Plain during the statistical period. To calculate the monthly average groundwater level of the plain, the effect level of piezometric wells was determined using ArcGIS10 analytical tools by Thiessen method. The monthly observations of water table over the period were then arranged as a 234 × 15 matrix in which rows indicated the months of year repeating throughout the period and columns indicated the signs of piezometric wells. Then the average weight of monthly water table level was calculated during the period using Equation (2). Figure 2 shows the locations of piezometric wells and their effect levels.

$$Wt_{Ave} = \frac{\sum A_i Wt_i}{\sum A} \qquad (2)$$

Where A_i is the effect level of the i^{th} piezometer and W_i the level of water table in the i^{th} polygon.

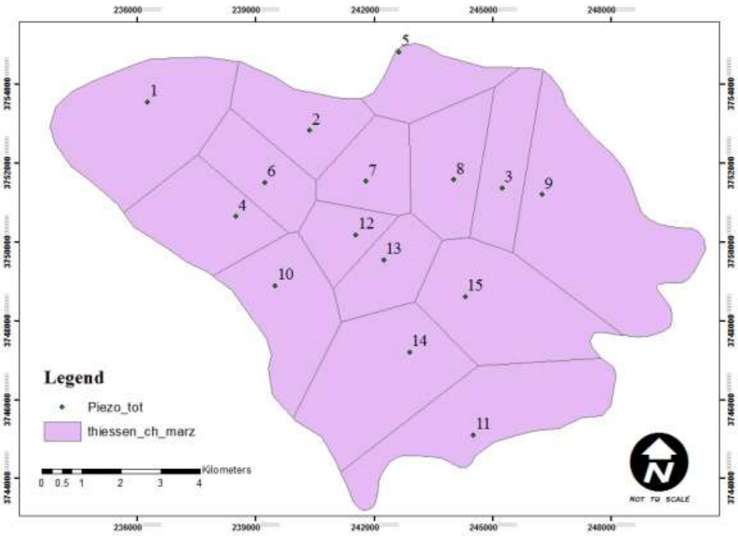


Figure 2: Location of Alashtar Plain piezometric wells and their effect levels

The plain aquifer GRI for 20-year statistical period was calculated by Equation (3) [8].

$$GRI = \frac{D_{y,m} - \mu_{D,m}}{\sigma_{D,m}} \quad (3)$$

Where *GRI* is groundwater resources index, $D_{y,m}$ the amount of groundwater level in year *y* and month *m*, $\mu_{D,m}$, the average ground water level in monthm and $\sigma_{D,m}$,Standard deviation ofgroundwater levelinmonthm.
Classification and determination of soil moisture status by GRI is similar to SPI, because both methods use normal distribution [15].
To study the effect of rainfall intensity on the quantitative changes of groundwater resources, the correlation coefficient between SPI, the average groundwater level and GRI was calculated at different time scales with and without any time delay [24, 17]. The correlation coefficient of the mean water level indicator and SPI was calculated through Equation (4) [6].

$$P_{x,y} = \frac{cov\ (x,y)}{\sigma_x \sigma_y} \quad (4)$$

Where $P_{x,y}$ is the correlation between standardized index and mean of groundwater level, *x* standardized precipitation index, *y* average groundwater level, σ_x standard deviation of standardized precipitation index, and σ_y standard deviation of mean groundwater level.
The correlation coefficients between variables were calculated by MINITAB-14 after an initial processing with Excel 2010. Then SPI was analyzed using quantitative parameters of Alashtar Plain groundwater with monthly, quarterly, and annual delays.

RESULTS AND DISCUSSION

The plain moisture status was calculated and classified by DIP-2 on an annual and monthly basis, according to SPI and GRI, using monthly rainfall and groundwater levels in selected stations and piezometric wells during a 20-year period (1991-2010) (Tables 2, 3, and 4) (Figure 3).

Table 2: Annual moisture status of Alashtar Plain according to SPI and GRI

Year	Precipitation Yearly(mm)	(SPI) Values	Class	Status of moisture	(GRI) Values	Class	Status of moisture
1991-92	784.5	1.38	2	Wet	0.8	3	Normal
1992-93	803.5	1.47	2	Wet	1.54	2	Wet
1993-94	583.4	0.31	3	Normal	1.25	2	Wet
1994-95	852.5	1.7	2	Wet	1.27	2	Wet
1995-96	707	0.99	3	Normal	1.22	2	Wet
1996-97	536.6	0.02	3	Normal	0.74	3	Normal
1997-98	584.2	0.31	3	Normal	0.82	3	Normal

1998-99	261.5	-1.12	5	Very Dry	0.22	3	Normal
1999-2000	332.3	-1.46	4	Dry	-0.58	3	Normal
2000-01	538.6	0.04	3	Normal	-1	4	Dry
2001-02	451.6	-0.54	3	Normal	-0.6	3	Normal
2002-03	487.9	-0.35	3	Normal	-0.61	3	Normal
2003-04	544.3	-0.07	3	Normal	-0.5	3	Normal
2004-05	502.3	-0.19	3	Normal	-0.34	3	Normal
2005-06	549.2	0.1	3	Normal	0.13	3	Normal
2006-07	620.9	0.52	3	Normal	0.14	3	Normal
2007-08	333.9	-1.44	4	Dry	-0.83	3	Normal
2008-09	368.8	-1.16	4	Dry	-2.13	5	Very Dry
2009-10	595.5	0.38	4	Normal	-1.59	4	Dry

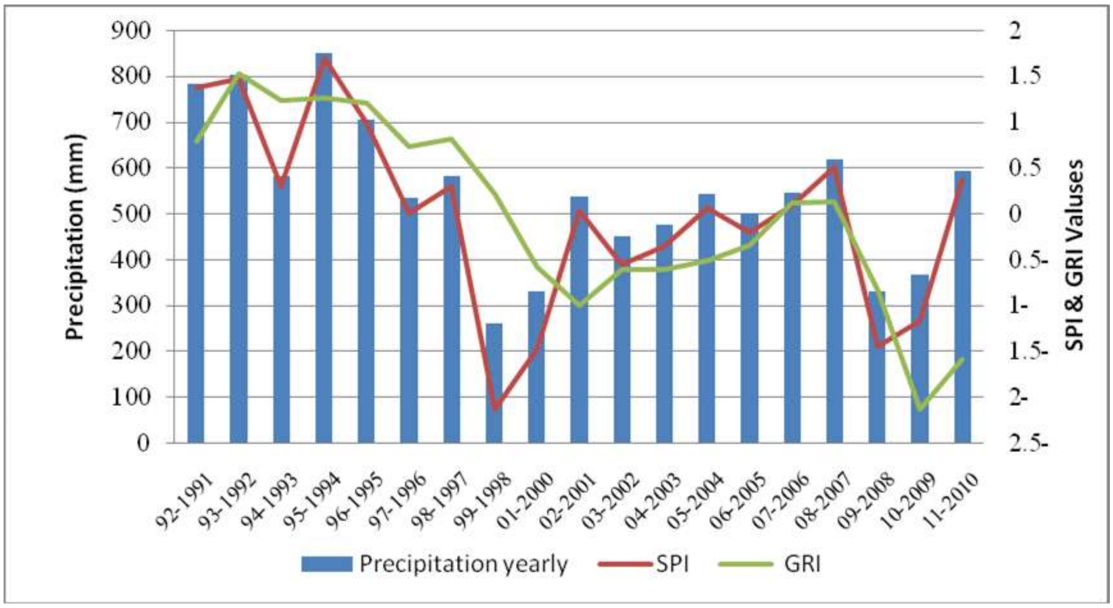
Table 3: Frequency of relative occurrence of Alashtar Plain monthly moisture status based on SPI in percent

Status of moisture	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
Very wet	0	0	5.9	5.9	5.9	5.9	0	0	0	0	0	0
Wet	23.5	11.8	11.8	11.8	11.8	11.8	23.5	23.5	23.5	23.5	23.5	23.5
Normal	64.7	76.5	64.7	64.7	64.7	64.7	64.7	64.7	64.7	64.7	64.7	64.7
Dry	11.8	5.9	17.6	17.6	17.6	17.6	5.9	5.9	5.9	5.9	5.9	5.9
Very Dry	0	5.9	0	0	0	0	5.9	5.9	5.9	5.9	5.9	5.9

Table 4: Frequency of relative occurrence of Alashtar Plain monthly moisture status based on GRI in percent

Status of moisture	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Very wet	0	0	0	0	0	0	0	0	0	0	0	0
Wet	21	21.1	21.1	21.1	15.8	21.1	25	30	25	25	25	25
Normal	57.9	57.9	63.2	63.2	68.4	57.9	60	50	55	60	60	60
Dry	15.8	10.5	5.3	5.3	10.5	10.5	5	15	15	10	10	10
Very Dry	5.3	10.5	10.5	10.5	5.3	10.5	10	5	5	5	5	5

Figure 3: Comparison of annual precipitation and annual moisture status of Alashtar Plain based on SPI and GRI



Values of correlation coefficients between SPI at different monthly time scales with the average water level and monthly GRI was calculated for the statistical period. The results showed that the correlation coefficient of SPI with the average level of groundwater index and GRI increased by increasing SPI time scale. The results obtained in this part are consistent with the results of Mendicino*et al*. (2008) and Seif*et al*. (2012). The highest correlation coefficient between monthly SPI and quantitative variables of Alashtar

Plain groundwater in a 24-month time scale was significant at the 0.01 level and 99% probability (Table 5).

Table 5: Correlation coefficients between monthly SPI and average groundwater table and GRI during the period of 1991-2010

	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_18	SPI_24	SPI_48
average groundwater table	–	0.187	0.429	0.637	0.718	0.716	0.803	0.713
) GRI (	–	0.256	0.454	0.633	0.704	0.755	0.799	0.685

The impact of monthly delay of meteorological drought on average groundwater table and GRI was studied at the time delays of 1, 2, 3, 4, 5, 6, 9, 12, 18, 24, and 48 months. The results showed that the highest correlation with an R value of 0.84 was between SPI at 24-month scale and GRI with 12-month delay. The correlation coefficient between SPI_24 and average water table without any time delay was 0.808 which was significant at the 0.01 level (Table 6).

Table 6: Correlation coefficients of SPI in 24-month scale with average water table and GRI of Alashtar Plain with time delay during the period 1991-2010

month	1	2	3	4	5	6	9	12	18	24	48
water table	0.808	0.798	0.773	0.747	0.711	0.678	0.648	0.672	0.546	0.481	0.250
GRI	0.726	0.741	0.754	0.764	0.771	0.775	0.776	0.841	0.770	0.791	0.590

According to the results, a simple linear regression was established during the period 1991-2010 between the average water table as a dependent variable and SPI_24 as an independent variable, such that the relationship was significant at 0.0001 level (Table 7).
The linear regression between these two variables in Alashtar Aquifer is as Equation (5).

$$D_{y,m} = 1578 + 1.64\ SPI\_24 \qquad (5)$$

Where $D_{y,m}$ is the values of groundwater level in year y and month m and SPI_24 standardized precipitation index in a 24- month scale without any time delay.

Table 7: Results of the linear regression between average water table and SPI_24 during the period 1991-2010

Coefficients	P Value	R (adj)	R^2	dependent variable	Independent variable
Constant=1578	0.000	64.4	64.3	$D_{y,m}$	SPI_24
SPI_24=1.64					

According to the calculated coefficient of determination (R^2), 64.4% of the average water table variance was influenced by SPI_24 and 35.6% was affected by other factors. The highest correlation between SPI in different seasons of the year and the average water table and GRI during the period of 1991-2010 was observed in spring. The correlation between SPI in summer and autumn were not significant (Table 8).

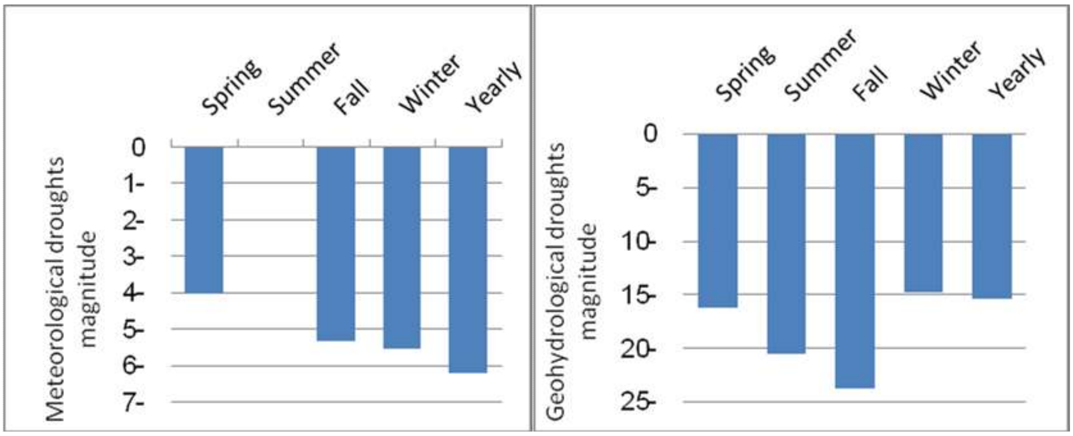
Table 8: Correlation coefficients between seasonal SPI and average water table and GRI in Alashtar Plain during the period 1991-2010

Seasons (SPI)	Spring	Summer	Fall	Winter	Yearly
average water table	0.677	0.147*	-0.254*	0.532	0623
GRI	0.658	0.435*	-0.239*	0.591	0.599

* Not significant

The magnitude of meteorological and geohydrological (groundwater) seasonal droughts were calculated using Equation (1). The results showed that during the period 1991-2010 the magnitude of meteorological and geohydrological droughts corresponded with winter and autumn, respectively. Investigation revealed that the cause of geohydrological drought magnitude in autumn is due to the decreased winter rainfall and utilization of groundwater resources in spring and summer for irrigation (Figure 4).

Figure 8: Comparison of meteorological and geohydrological droughts magnitude in Alashtar Plain based on SPI and GRI



In order to determine the effect of rainfall on groundwater quantitative parameters in annual scale, the relationship was established between annual SPI and average groundwater table and GRI with and without any time delay. It was found in this study that the highest correlation between annual SPI and average water table and GRI was seen in the two-year time delay which was significant at the 0.01 level (Table 9).

Table 9: Correlation coefficients between annual SPI and average water table and GRI in Alashtar Plain during the period 1991-2010

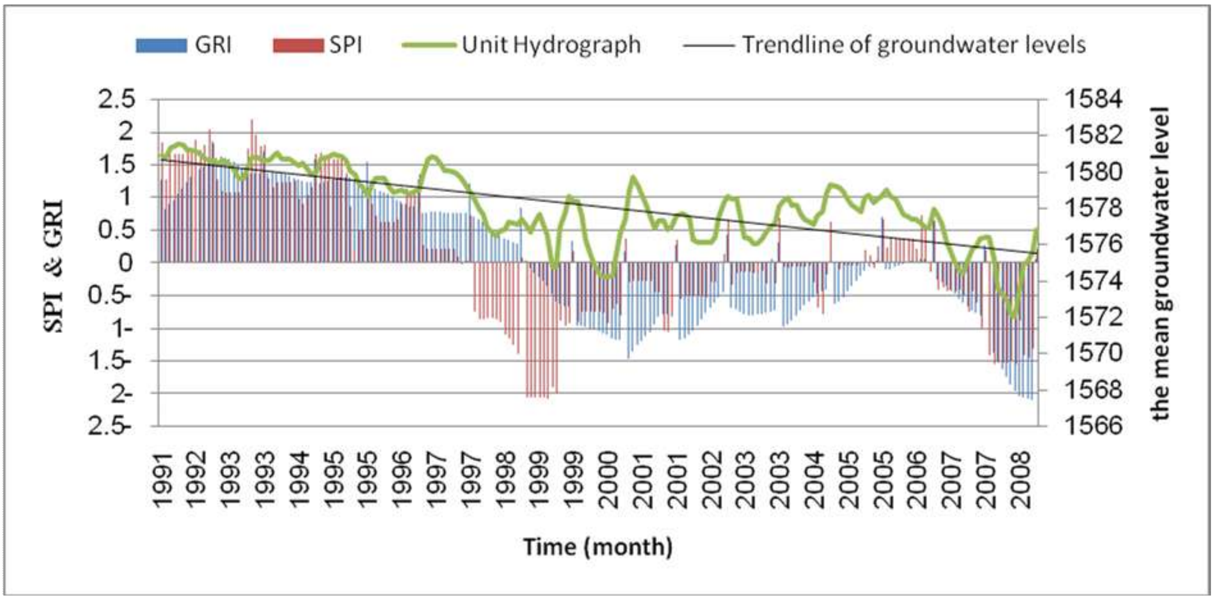
	annual SPI With Lag Time				annual SPI Without Lag Time
	One Year	Two years	Three years	Four years	
Average water table	0.606	0.767	0.596	0.451*	0.623
GRI	0.582	0.762	0.567	0.408*	0.596

* Not significant

According to Tables 5, 6, and 9, a high correlation existed between quantitative parameters of Alashtar Plain groundwater and SPI in a 24-month scale. Thus, the highest impact of meteorological drought in Alashtar Plain on groundwater resources appears averagely two years later. Changes in the water table of many aquifers, affected by factors such as rainfall and agricultural wastewaters, follow seasonal and annual patterns [21], because infiltration of rainfall into groundwater takes place with a time delay which depends on the characteristics of the region's geological formation. The results of this part of the research are consistent with the research of Mendicino *et al*. [8], Eimani and TalebiEsfandarani (2011), and Seif *et al*. [17].

Analysis of SPI values in Alashtar Plain with average groundwater level and GRI confirms this issue. Figure 5 shows the relationship between mean groundwater level and GRI with the changes in SPI in a 24-month scale. Accordingly, during meteorological droughts when SPI 24-month values were -1 or less, the average groundwater level declined and GRI showed geohydrological drought (groundwater drought). Based on the foregoing figure, both droughts (meteorological and groundwater) were occurred in the region in 2001, 2002, 2003, and 2009. Although SPI had positive values in 2006 and 2007, the plain unit hydrograph has been decreasing and GRI had also negative values. So it can be concluded that in addition to meteorological drought, other factors such as unprincipled and unmanaged exploitation of groundwater resources in various sectors, especially in agriculture are causing groundwater drought. Also, study of the plain unit hydrograph trend line showed that the average groundwater level has been declining. Decline in groundwater levels from 1992 to 2009 was estimated 5.74 m. Thus, during this period the groundwater of Alashtar Aquifer decreased 0.34 m annually.

Figure 5: Relationship of SPI in a 24-month scale without any delay with the mean groundwater level and GRI



In this study, SPI and GRI were used to determine the meteorological moisture and groundwater states of Alashtar Basin in monthly, quarterly, and annually time scales as four categories of wet, normal, dry, and very dry. Evaluation of the effect of drought on Alashtar Aquifer groundwater showed a correlation between GRI and the average water table with SPI. Statistical analysis showed that in this region the standardized precipitation index (SPI) with 24-month scale and without any time delay affected the average water table of the plain. The results obtained in this study are consistent with the results obtained by Mendicino *et al*. [8] and Seif *et al*. [17] in Fassa Aquifer, Shakiba *et al*., [18] in the East of Kermanshah Province, and Yassamani *et al*. [24] in Torbatjam Plain of Fariman.

Study of droughts magnitude revealed that meteorological and geohydrological droughts of the period between 1991 and 2010 corresponded to the winter and autumn, respectively, the reason of which was the reduction of rainfall during the winter as well as utilization of water for irrigation from groundwater resources during the spring and summer.

Alashtar Plain groundwater is affected by meteorological drought and water pumping for agricultural purposes. Therefore, in order to optimize the management of agricultural water utilization and to prevent water resources destruction, the use of appropriate simulation and optimization models is proposed for water resource allocation among different users.

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Citation of This Article

Gh. Chamanpira, Gh. Zehtabian, H. Ahmadi, A. Malekian . Effect of Drought on Groundwater Resources; a Study to Optimize Utilization Management (Case Study: Alashtar Plain). Bull. Env. Pharmacol. Life Sci., Vol 3 [10] September 2014: 48-56