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The Impact of Rainfall Fluctuations and Uncontrolled Exploitation on Groundwater Systems and Hydrogeological Drought

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ABSTRACT: Increase or decrease of the amount of rainfall than average long-term conditions causes the occurrence of two phenomena which is too important, including flood and drought. Drought is a climatic event that are represented in different forms in large parts of Iran and will affect ordinary life people in these areas. Predicting the drought could reduce as much as many fatal and lethal effects of this phenomenon. Although these predictions may have a percentage error. Considering that different forms of drought, Meteorological drought is the first type of drought which occurs, by Analysis of data different, types of drought can be predicted. Reduction in rainfall affected on groundwater systems. Knowledge of these effects is absolutely vital to planning for damage reduction and appropriate response to the effect of drought. It also helps decision makers identify and reduce vulnerability to drought. In this study, meteorological drought calculated by standardized precipitation index (SPI) in different time scales in Isfahan-Borkhar plain. Also, status of water table of aquifer indicates by groundwater resource index (GRI) in Isfahan-Borkhar aquifer. There are a significant correlation between large-scale SPI and GRI, Especially between SPI-48 and GRI. This means that the groundwater drought happens after meteorological drought with a 48-month delay. Also, The results indicate that uncontrolled exploitation of groundwater resources have a huge impact on the aquifer water levels. The results showed that wet and dry periods have occurred repeatedly at the short time scales SPI, but even when rainfall has been appropriated in some years, the groundwater level had been downward. Also, drought map zoning were provided based on GRI values, which indicates extremely dry in south, northwest and north of aquifer.

Keywords: SPI, GRI, Aquifer, Rainfall, Drought

INTRODUCTION

Population growth, better living standards, increase in agricultural and industrial activities, degradation in water quality, and many other factors continue to influence and increase our demands for freshwater around the globe. The significant spatial and temporal variability of water resources often result in water deficiencies in different regions and at different times. As a result, water planning and management is often a challenging task in many regions, and has the potential to lead to conflicts between different stakeholders (Sivakumar, 2011).

Drought is as a natural disaster and inevitable phenomenon that occurs on earth. A fundamental distinction exists between aridity, which is a long-term climatic phenomenon and droughts, which are a temporary phenomenon (water deficit). Aridity, as defined by the shortage of moisture, is essentially a climatic phenomenon that is based on average climatic conditions over a region (Agnew and Anderson 1992). Aridity is a term that most people conceptually understand, and it evokes images of dry, desert lands with sparse natural surface-water bodies and rainfall, and commonly only scant vegetation, which is adapted to a paucity of water. Aridity is a constant climatic characteristic (Sanderson, 1992). Drought is a natural event that occurs temporarily, compared to normal climate conditions. Drought is more than a physical phenomenon or natural event. Its impact results from the relation between a natural event and demands on the water supply, and it is often exacerbated by human activities. The experience from droughts has underscored the vulnerability of human societies to this natural hazard. Since the statistical indices to illustrate deviation from normal conditions are useful for drought investigation, a suitable solution should be considered in the introduction of dry regions (Damberg, 2013). Therefore, meteorological drought is a long-term period of water shortage and usually occurs in areas that receives rainfall lower than average precipitation for several months (Gocic and Trajkovic, 2014).

Drought definitions are of two types: (1) conceptual, and (2) operational. Conceptual definitions help understand the meaning of drought and its effects. For example, drought is a protracted period of deficient precipitation which causes extensive damage to crops, resulting in loss of yield.

Wilhite and Glantz (1985) classified the droughts definition according to their measuring approaches into four groups:meteorological drought, hydrological drought, agricultural drought and socioeconomic drought. Meteorological drought that called climatological drought in some references (see for example Karnauskas *et al;* 2013) occurs due to the lack or reduction of precipitation at the period of time. In other words, meteorological drought occurs when the annual precipitation is less than its long-term average. The shortage of rainfall may be evaluated to compare with a normal average of climatic zone or dry period. A long-lasting meteorological drought might change into a hydrological drought. Hydrological drought refers to a persistently low discharge and/or volume of water in streams and reservoirs, lasting months or years. Hydrological drought is a natural phenomenon, but it may be exacerbated by human activities. Hydrological droughts are usually related to meteorological droughts, and their recurrence interval varies accordingly. Changes in land use and land degradation can affect the magnitude and frequency of hydrological droughts. Data sets required to assess hydrological drought are surface-water area and volume, surface runoff, stream flow measurements, infiltration, water-table fluctuations, and aquifer parameters. After that the hydrological drought, agricultural drought occurs. Agricultural drought begins when the amount of moisture in the root zone is drastically reduced to the extent that results in plant wilting and harvest loss. Therefore, agricultural activities are the first part of human activities that affected by drought. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. Data sets required to assess agricultural drought are soil texture, fertility and soil moisture, crop type and area, crop water requirements, pests and climate. Socioeconomic drought deals with drought in terms of supply and demand, tracking the effect of water shortfall as it ripples through socioeconomic systems. Socioeconomic drought generally occurs after a very long period of meteorological drought and hydrological drought that leads to famine, death and widespread migration. This kind of drought affects different aspects of economic activities, especially a big effect on types of products and goods economic (Wilhite, 1997). Socioeconomic drought is combination of supply and demand of some economic good with elements of meteorological drought, hydrological drought and agricultural drought. The supply of many economic goods, such as water, forage, food grains, fish, and hydroelectric power, depends on weather. Socioeconomic droughts usually occur after a very long period of meteorological and hydrological droughts and causing famine, mortality and mass wide migration. This kind of drought has significant effects on various aspects of economy specially certain types of economic goods and productions (Wilhite, 1997). Data sets required to assess socioeconomic drought are human and animal population and growth rate, water and fodder requirements, severity of crop failure, and industry type and water requirements.

Groundwater is one of the main recognized resources for public water supply and irrigation in many regions of the world (Estrela *et al.,* 1996; Scheidler *et al.,* 1999). This means that the response of groundwater resources to drought is dramatically important and crucial (Calow *et al*., 1999; White *et al.,* 1999). Groundwater drought is the sustained and extensive occurrence of below average availability of groundwater. The water levels in aquifers is not often a constant. Groundwater levels first are dependent on recharge from infiltration of precipitation so when a drought hits the land surface it can impact the water levels below ground, too. Likewise, many aquifers, especially those which don't have abundant recharge, are affected by the amount of water being pumped out of local wells. Groundwater decline is a real and serious problem in many places of the Nation and the world. When rainfall is less than normal for several weeks, months, or years, the flow of streams and rivers declines, water levels in lakes and reservoirs fall, and the depth to water in wells increases. If dry weather persists and water-supply problems develop, the dry period can become a drought. This kind of drought is called groundwater drought and occurs on time scales of a few months to several years (Van Lanen and Peters, 2000). Groundwater drought occurs due to insufficient aquifer discharge.

There are many indices used to calculate drought including: Palmer drought severity index (PDSI) is based on temperature, precipitation and soil moisture (Palmer, 1965), surface water supply index (SWSI) which the storage of snow is emphasized in this index(Shafer and Dezman, 1982), standardized precipitation index (SPI) (McKee *et al*., 1993), reconnaissance drought index (RDI) that is based on climate, water level of the river, snow, surface flow, water supplies and temperature factors (Tsakiris and Vangelis, 2005). Detention of drought and use the drought monitoring system rely on the choice of the appropriate drought index.

Droughts are one of the impacts of climate change. Since drought is a regional event, the impact of climate change on drought may vary throughout the world.

Therefore, on the one hand, climate change can be assumed to drought occurrence and monitor processes in different patterns in various feature of weather or arid regions. On the other hand, although all arid areas are relatively the introduction of drought, but the potential of each region is different to deal with the drought. For example, under conditions of equal severity of drought, fragile and arid regions compared with humid and sustainable area are more vulnerable to drought. Thus, according to the study area and the purpose of reviewing drought, drought indices are selected for drought evaluation.

The Purposes of this study are evaluate the impact of uncontrolled use of groundwater by exploitation wells and the effect of rainfall fluctuations on the water level of Isfahan-Borkhar aquifer by comparing Standardized Precipitation Index (SPI) (Different time scales) and Groundwater Resource Index (GRI). In addition, the reduction of water level has been determined. Also, drought zoning maps were prepared for the study area in selected period.

METHODOLOGY

A. Drought Indices

Standardized Precipitation Index (SPI). McKee *et al.* (1993) developed the SPI for monthly drought monitoring and evaluation. The Standardized Precipitation Index is the number of standard deviations that observed cumulative precipitation deviates from the climatological average. To compute the index, a long-term time series of precipitation accumulations over the desired time scale are used to estimate an appropriate probability density function. The SPI has three important properties. The first and primary is its simplicity(only precipitation data are needed for the calculation of the index), the second is its variable time scale and the third is its standardization.(The index is a standardized measure for precipitation in different climatic regions and for seasonal differences) (Hayes *et al.*, 1999). The SPI calculation starts with a gamma probability density function (pdf) to fit climatological precipitation time series. The gamma distribution can be defined by its probability density function as follows:

$$g(x_k) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x_k^{\alpha-1} e^{-x_k/\beta} \qquad for:\ x_k > 0$$

where $\alpha > 0$ is the shape factor, $\beta > 0$ is the scale factor and $x_k > 0$ is the amount of precipitation during k consecutive months calculated as $x_k^{(i)} = \sum_{j=1}^{k} P_{ij}$, $i = 1$ to N, where P_{ij} is the precipitation of the *j*-th month of the *i*-th year and *N* is the number of years of selected time series. Also, Γ(α) is the gamma function that is defined as follows:

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy$$

Fitting the distribution to the data requires α and β to be estimated. The α and β are estimated using the approximation of Thom (1985) as follows:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right)$$

$$\beta = \frac{\overline{x_k}}{\alpha}$$

where

$$A = \ln(\overline{x_k}) - \frac{1}{n}\sum_{i=1}^{n} \ln\left((x_k)_i\right)$$

where *n* is the number of observations of precipitation.

Integrating the probability density function with respect to the $x_k$yields, in accordance with the cumulative probability for $G(x_k)$ as follows:

$$G(x_k) = \int_0^{x_k} g(x_k) dx_k = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^{x_k} x_k^{\alpha-1} e^{-x_k/\beta} dx_k$$

Replacing t instead of $\frac{x_k}{\beta}$, Eq.6 is reduced to an incomplete gamma function:

$$G(x_k) = \frac{1}{\Gamma(\alpha)} \int_0^{x_k} t^{\alpha-1} e^{-t} dt$$

Because the gamma distribution is not defined for $x_k = 0$ and the other hand, the amount of precipitation may be zero, in order to calculate the probability value zero, cumulative can be expressed as follows:

$$H(x_k) = q + (1-q)G(x_k)$$

where q is probability zero precipitation. $H(x_k)$ is cumulative probability, which then converted to standard normal random variable *Z*, with mean zero and variance one, which is the value of SPI. Abramowitz and Stegun (1965) presented an approximate conversion. Thus, *Z* and then SPI were obtained as follows:

$$Z = SPI = \left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right)$$

(9)

$$t = \sqrt{ln\left(\frac{1}{(1-H(x_k))^2}\right)}\ for\ 0.5 < H(x_k) < 1.0$$

with C_0= 2.515517, C_1= 0.802853, C_2= 0.010328, d_1= 1.432788, d_2= 0.189269 and d_3 = 0.001308.The index is negative for drought, and positive for wet conditions. As the dry or wet conditions become more severe (1) the index becomes more negative or positive. Considering that SPI is normalized, the SPI can be used to show dry and wet climate classes (Table 1).

Table 1: Drought classification according to SPI and GRI values (McKee *et al.*, 1993; Mendicino *et al.*, 2008).

Drought classes	Extremely wet	Very wet	Moderately wet	Normal	Near normal	Moderately dry	Severely dry	Extremely dry
SPI and GRI range	2 or more	1.5–1.99	1–1.49	0.99–0.0	0.0–0.99	−1 to −1.49	−1.5−1.99	−2 and less

Groundwater Resource Index (GRI)

In fact, drought analysis in groundwater systems is carried out by analysis of aquifer recharge, discharge, hydraulic head and water table (e.g. Schoups *et al.*, 2006). In this study, GRI is expressed, because it can present a multi-functional analysis to assess aquifer drought conditions throughout the particular region. A groundwater resource index has been developed by Mendicino *et al.* (2008) to quantify groundwater detention for the assessment of drought condition GRI can be calculated using the following equation:

$$GRI_{y,m} = \frac{D_{y,m} - \mu_{D,m}}{\sigma_{D,m}} \quad (11)$$

Where GRI*y,m* and D*y,m* are the values of the index and of the groundwater detention respectively for the year y and the month m. Also, µD, m and σD, m are mean and standard deviation of groundwater detention respectively for the month m and number of year y. Table 1 shows GRI classification.

STUDY AREA AND DATA COLLECTION

The Isfahan province, located in central Iran, has an area of 110378.35 km^2(6.8% of Iran's total area).In term of groundwater resources, there are several critical plains in Isfahan province than one of the most important is Isfahan-Borkhar plain. This plain is located in center of province and Isfahan city is located in south of Isfahan-Borkhar plain. (N32º34'28" to N33º17'04", E51º06'12" to E52º06'23"). The area of study plain and its aquifer are 3775.62 km^2 and 1606.00 km2respectively and Isfahan city is located in the southern part of the aquifer (Fig. 1). The elevation in the study area (Isfahan-Borkhar plain) ranges from 1533 m to 2563 m above sea level (Fig. 2c). Slope map of aquifer level illustrate that the slope of case study is between 0 and 19.45 percent. The slope is reduced from west to east (Fig. 2a). Plain geology map indicates that the vast majority of the study area is composed of quaternary alluvial deposits. Long-term average annual rainfall and temperature have been reported 134 mm and 15ºC respectively (Table 1). Also, the annual average evapotranspiration is estimated 2461 mm (Iran Water Resources Management Company., 2010).The climate of this region classified by Emberger, De Martonne, Gosen and Köppen methods respectively to be dry and cold, dry, sever semi-desert and BWhs (Mokhtari *et al.,* 2007).

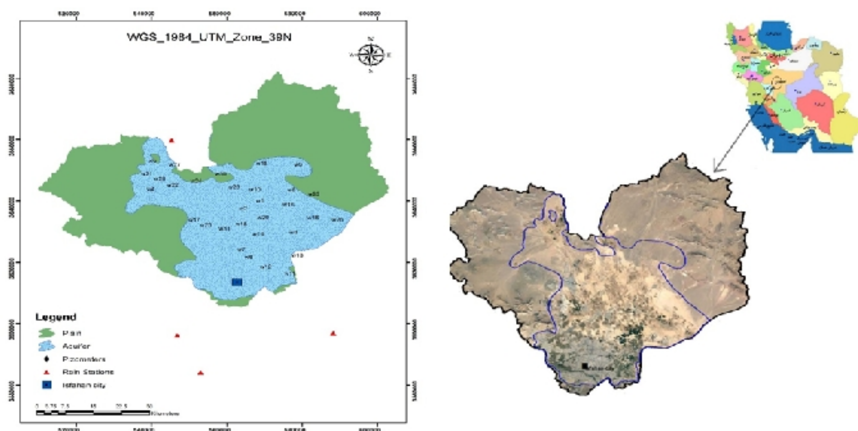
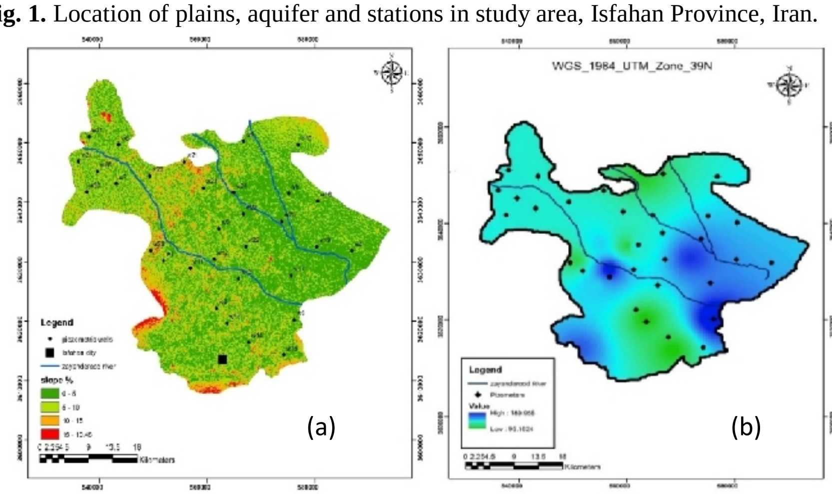


Fig. 1. Location of plains, aquifer and stations in study area, Isfahan Province, Iran.



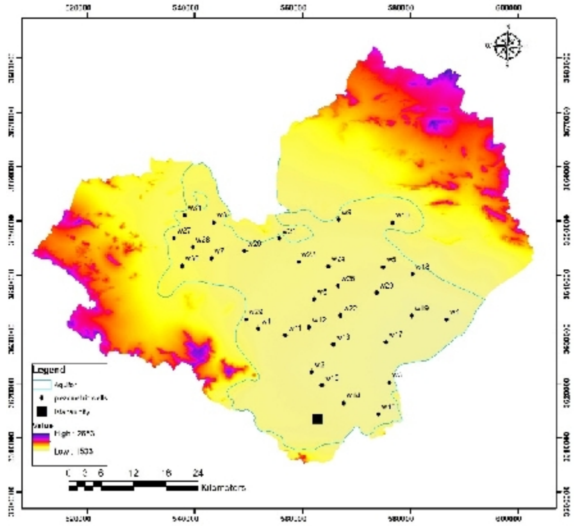


Fig. 2. Slope map(a), Hydraulic head (b) of aquifer and DEM (c) of plain.

Analysis of the data used

Data measured between 1991 and 2011 at weather stations were used to investigation in the study area. Data available from 31 observation wells piezometers were used to analyze spatio-temporal evaluation of the piezometric level of the Isfahan-Borkhar aquifer.

In addition, the discharge of pumping wells and the pumping test of exploratory holes were used in this paper. The maps used for this area including topographic, digital elevation model (DEM), hydraulic head (Fig. 2b)(to determine the direction of groundwater flow) and geological maps and satellite images.

Table 2: Details of weather stations of the study area.

River catchment	Name	Longitude	Latitude	Altitude (m)	Date of Establishment	Type of station
Zayendehrood	Isfahan	51° 67′	32° 62′	1550.4	1950	Synoptic
Zayendehrood	Isfahan-Topkhaneh	51° 67′	32° 62′	1660	1961	Climatological
Zayendehrood	Karkhaneh ghand	51° 65′	32° 63′	1563	1999	Climatological
Zayendehrood	Isfahan University of Technology	51° 47′	32° 70′	1830	1980	Climatological
Zayendehrood	Isfahan University	51° 67′	32° 65′	1604	1966	Climatological
Zayendehrood	Isfahan Refinery	51° 55′	32° 72′	1683	1983	Climatological
Zayendehrood	Khomeini shahr	51° 53′	32° 68′	1600	1967	Rain gauge
Zayendehrood	Amin abad shahreza	51° 57′	32° 77′	205	1976	Rain gauge
Zayendehrood	Dolatabad borkhar	51° 67′	32° 80′	1585	1972	Rain gauge
Zayendehrood	Isfahan	51° 69′	32° 64′	1586	1966	Rain gauge
North of Isfahan	Jafarabad	51° 62′	32° 81′	1582	1974	Rain gauge
Zayendehrood	Polekhajo	51° 68′	32° 63′	1570	1958	Rain gauge

RESULT AND DISCUSSION

The amount of monthly precipitation and groundwater level indicated in Fig. 3. Unit hydrograph aquifer were drawn in order to evaluate the status of the aquifer and analysis of water table changes. To achieve this, we used of data, such as groundwater table during different years and the area of polygon effected by each piezometric wells. In the following, the average height of the water level for each month was calculated by Eq. 12 and then, groundwater hydrograph obtained (Fig. 3).

$$\overline{H} = \frac{\sum(aH)}{A} \qquad (12)$$

where, $\overline{H}$ is the average groundwater level in meter relative to the base line level, a is polygon area affected by each piezometric wells in km^2, H is the amount of water level in each of the piezometric wells and A is area of aquifer.

Knowledge of the past and present conditions of the Isfahan-Borkhar aquifer leads to basic measures to manage the present and future of this groundwater system. According to the Fig. 3, the highest amount of rainfall has occurred in 2003. Also, the most of rainfall has happened in January 2003, February 1998 and November 1994 respectively.

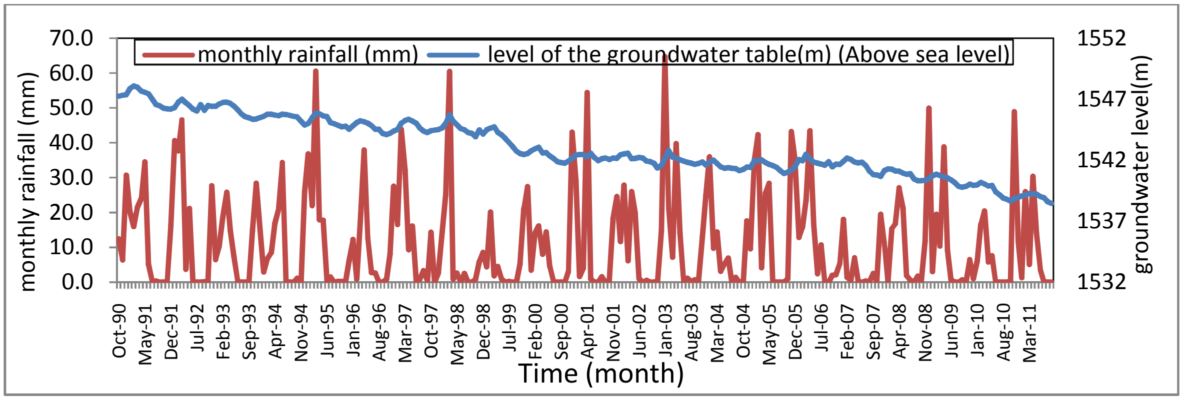
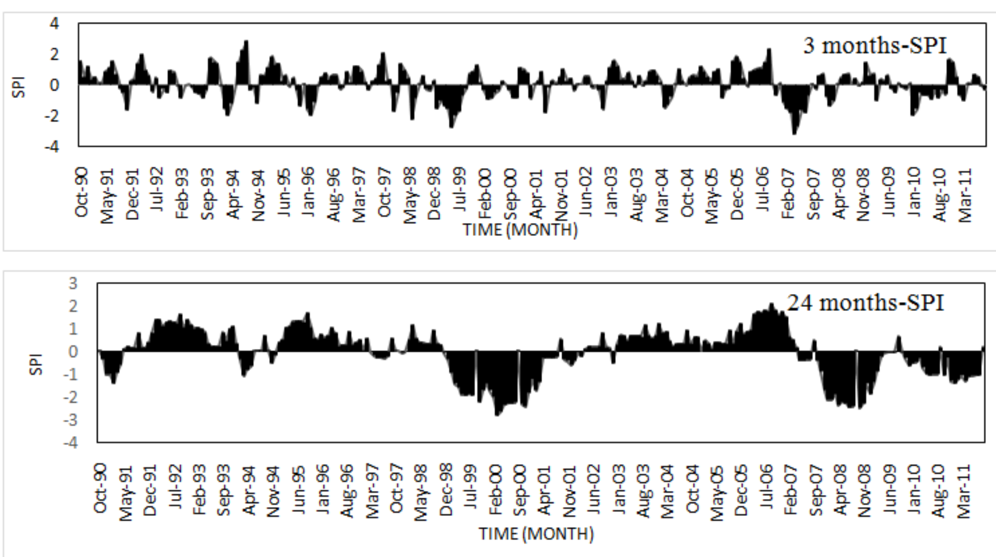


Fig. 3. The graph of monthly average rainfall in plain and unit hydrograph of aquifer.

On the other hand, the hydrograph of aquifer greatly related to fluctuations of rainfall in the region, with the difference that its sinusoidal fluctuation compared to increase and decrease in rainfall occur with a delay of time. Therefore, the overall trend of groundwater hydrograph illustrate that groundwater level steady decreased between 1991 and 2011. During the period selected, aquifer water table has dropped 9.63m. This means that water table has declined 0.46m per years. Investigated further of aquifer hydrograph, the result can be reach that the gradient of groundwater hydrograph has downward trend gradually from the beginning to 2002 and after that declined rapidly. Reason for this is that sharp decline occurred in rainfall between 2000 and 2002. After that, in accordance with an increase in rainfall between 2003 and 2007, groundwater level has partly risen between 2007 and 2008. After that again, aquifer hydrograph trend completely reduced from 2008 to the end of the period, due to the reduction in rainfall from 2008 onward. The groundwater level had been a trend towards a minimum in the late of period and decreased significantly at the end of time series, due to the severe drought has occurred in recent years and also caused by the indiscriminate and uncontrolled use of groundwater resources in recent years. In general can be expressed that downward trend of groundwater level depend on two parameters, including rainfall fluctuations and excessive exploitation of groundwater resources.

A. Meteorological Drought in Isfahan-Borkhar plain

As mentioned earlier, meteorological drought is the cause of the hydrogeological drought and reduction of the groundwater level. Due to the fact, it is necessary to analysis meteorological drought to be determined the intensity and permanence of hydrogeological drought. Meteorological drought is calculated by SPI on the different scales (3, 6, 9, 12, 18, 24 and 48-month) in Isfahan-Borkhar plain. According to SPI-3 (Fig. 4), the most severe dry and wet occurred in 2007 and 2006 respectively.



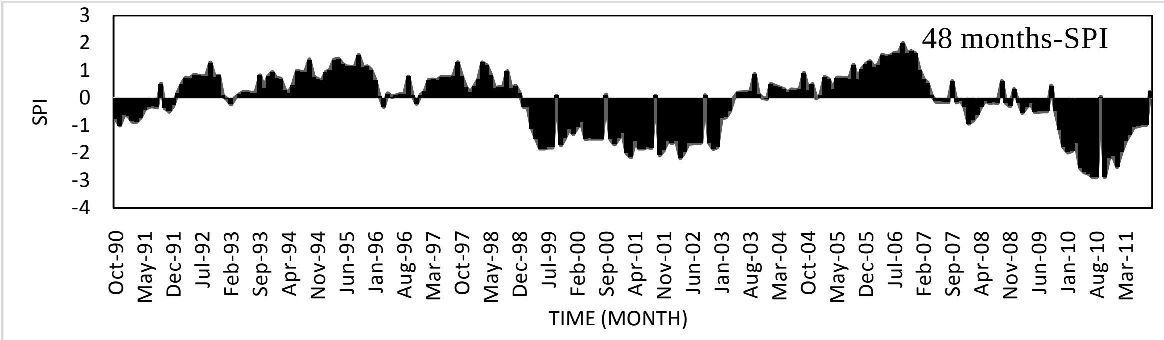


Fig. 4. Evolution of the SPI at different time scales in the study area.

On the other hand, the increasing scales to SPI-9, -12, -18, -24 and -48, the number of periods of drought dropped and increased durability. This situation is clearly in SPI-24, 48 (Fig. 4), so that by reviewing the SPI-48, it was determined that the longest period of wet year occurred between 1990 and 1993, and also the longest drought happened between 1998 and 2003. In addition, the most severe of drought period during the selected time series has occurred from 2009 to 2011. With a closer look at the SPI figures, can be came to the conclusion that persistence of droughts have been more than wet in the recent fifteen years (Fig. 4). Given that SPI-6 and older are far better to show hydrological and hydrogeological drought, therefore, it can be confirmed the probability of groundwater resources drought by this time series.

B. Groundwater resources Index (GRI) in Isfahan-Borkhar aquifer

GRI analysis indicates that the aquifer had been in severe wet condition at the beginning of period, but later on, wet statues of aquifer has fell gradually and there was an overall downward trend, as far as, situation of aquifer has reached to normal level in 2001, and after that, groundwater level has fallen. Since the beginning of 2001 to 2009, the groundwater resources were in near normal situation and moderate drought. But from 2009 onwards, the groundwater level reduced sharply and the aquifer storage reached its lowest level and very severe drought occurred (Fig. 5). This situation rely on reduction in rainfall and the over use of groundwater resources and in some cases unauthorized digging of wells in Isfahan-Borkhar plain.

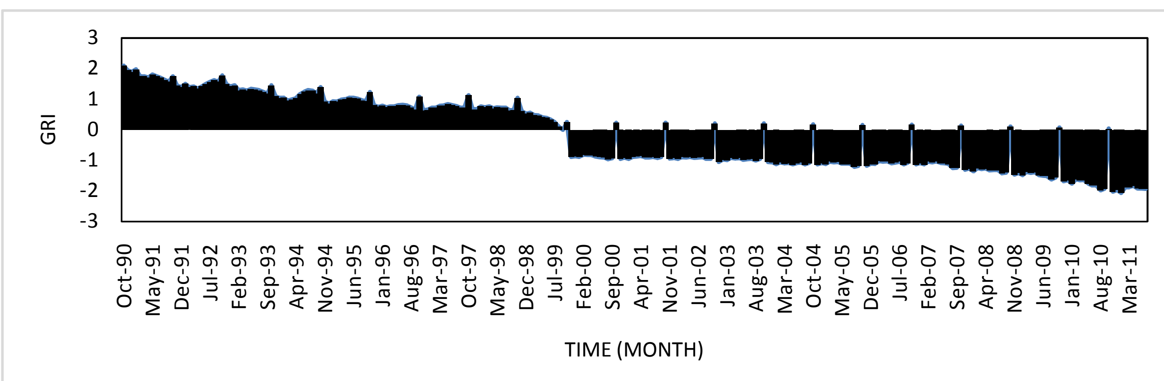


Fig. 5. Evaluation of GRI in Isfahan-Borkhar aquifer.

C. Time delay between SPI and GRI

As previously discussed, increase and decrease in groundwater level is a function of the amount of rainfall in the region. For this purpose, to investigate the time lag between meteorological drought and groundwater storage of Isfahan-Borkhar aquifer, the relationship between SPI and GRI were obtained using Pearson correlation (Table 3). In addition to this, the annual SPI and GRI changes are shown in Fig. 6. Regarding to the Table 3, the results suggest that, there is a significant correlation between SPI and GRI at different monthly scales in $P<0.01$. Also, the rising time scales leads to the increasing in correlation. According to the Table 3, the highest correlation is between SPI-48 and GRI, in 86%. In other words, it can be concluded that meteorological drought with a 48-month-delay affects groundwater resources in Isfahan-Borkhar plain. On the other hand, with a closer look at the results in Table 3, in can be argued that there is as well a suitable correlation between GRI and SPI-18 and24.

Table 3: The correlation coefficient between monthly SPI and GRI.

SPI	**SPI-3**	**SPI-6**	**SPI-9**	**SPI-12**	**SPI-18**	**SPI-24**	**SPI-48**
GRI	0.132	0.143	0.158	0.371	0.64*	0.72**	0.86**

** The significance level of 1%, *The significance level of 5%

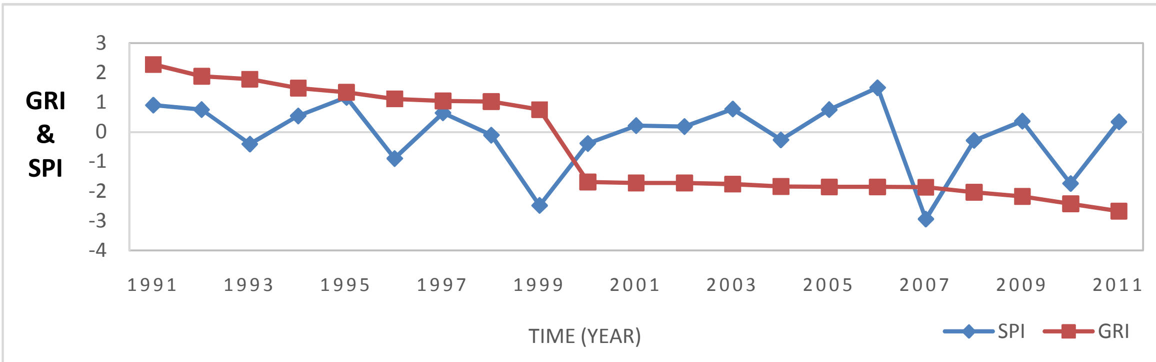
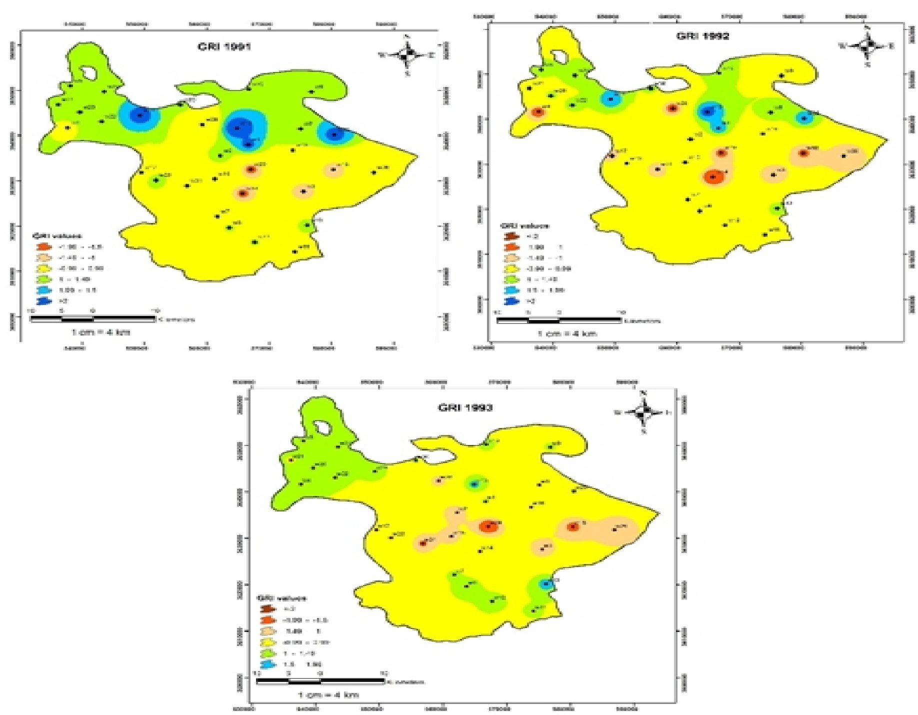


Fig. 6. The time delay between the meteorological drought and hydrogeological drought during the selected period.

Thus, can be expressed that meteorological drought with 18 to 48-month delay affects groundwater systems. Furthermore, according to the GRI diagram (Fig. 5), we can see reducing the water level of aquifer is strongly influenced by the indiscriminate and uncontrolled use of groundwater resources, compared to meteorological drought and reduction in rainfall. The reason for this argument is that although the rainfall has been appropriate and adequate in some years and wet weather has occurred, there was repeatedly downward trend in GRI during the period (Fig. 6).

D. Zoning of hydrogeological drought

Drought zoning maps were provided during the period. Zoning obtained from calculated GRI by the groundwater level data. As the maps shows, wet and normal conditions have been governed in the vast of aquifer from 1991 to 1998 and there was only a partial drought (Fig. 7).



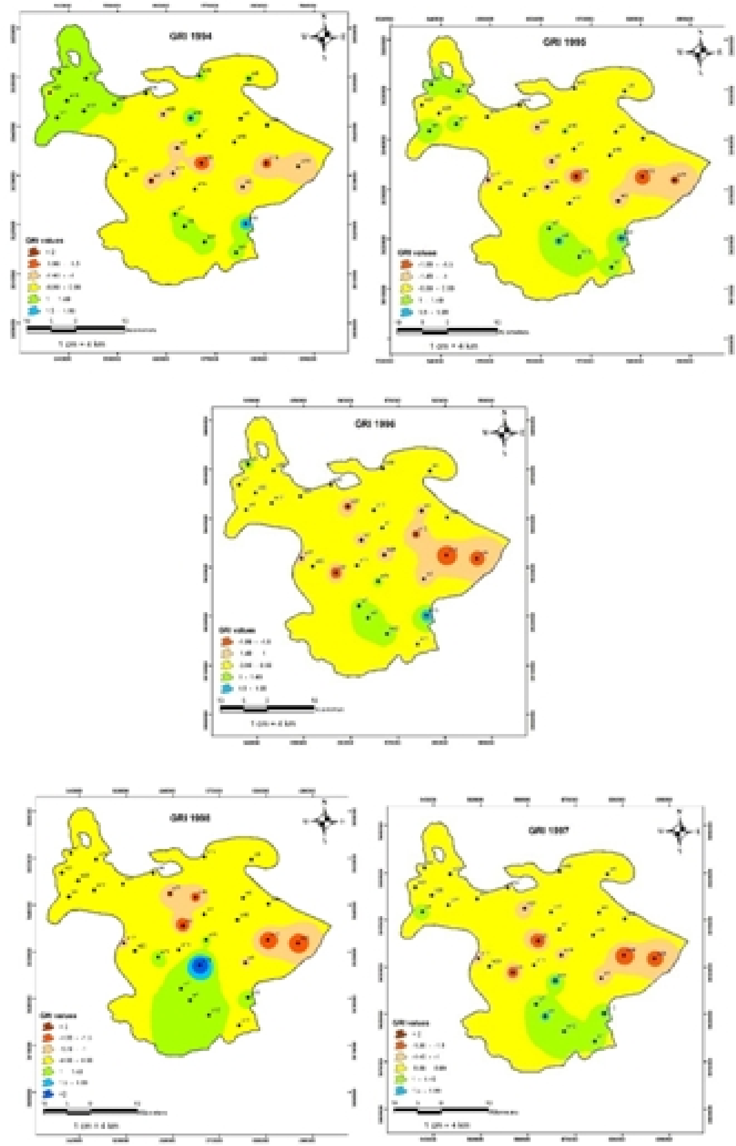
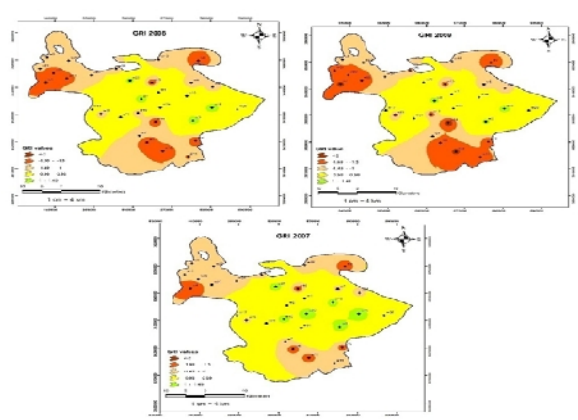


Fig. 7. Groundwater drought zoning map of Isfahan-Borkhar aquifer from 1991 to 1998.



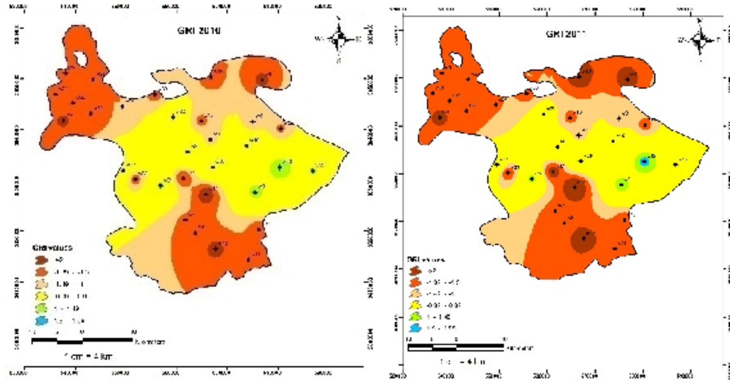


Fig. 8. Groundwater drought zoning map of Isfahan-Borkhar aquifer from 2007 to 2011.

In addition, with a glimpse of the zoning hydrogeological drought maps, it is observed that recharge is more than discharge of aquifer during 8 years at the beginning of the period, which represents wet year, and the majority of these wet years has occurred in the north of aquifer and in a limited way in the east and south.

CONCLUSION

The first kind of drought that occurs in nature is meteorological drought. Meteorological drought impacts on groundwater resources and groundwater levels are reduced and eventually leads to groundwater drought. Groundwater drought does not happen at the same time with the meteorological drought and there is a time delay. This means that after the occurrence of drought meteorological and analysis by SPI, must take the necessary measures to reduce its impact on groundwater resources. In this study, groundwater drought severity is calculated by GRI. As mentioned before, there is a correlation between GRI and SPI. There is the highest correlation between GRI and SPI-48 in Isfahan-Borkhar plain and the stress occurs on water table of aquifer with 48-month delay compared to meteorological drought. On the other hand, uncontrolled exploitation of aquifer have been led to reduction of groundwater level and land subsidence in case study. This means that the discharge is greater than recharge. This study indicated that excessive exploitation have been done from pumping wells in parts of south, north and north west of aquifer in the last years between 1991 and 2011 and in these areas the groundwater level has fallen sharply (Fig. 8). Therefore it is necessary, the managerial measures to cope with the groundwater drought be on the agenda such as Plumbed the unauthorized wells, Changes in cropping pattern, reducing the area under cultivation of crops and avoid planting crops with high water demand.

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