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Integrated assessment of the impact of drought and land use changes on ground water (Case study: Hamadan-Bahar watershed)

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Abstract

Groundwater drought denotes the condition and hazard during a prolonged meteorological drought when groundwater resources decline and become unavailable or inaccessible for human use. The aim of this study is to identify the influencial factors on groundwater drought in Hamadan- Bahar Watershed,Iran, to understand the forcing mechanisms. The Standardised Precipitation Index (SPI) has been used to quantify the evaluation of meteorological to drought effects in the reduction of ground water table. The influence of land use patterns on the groundwater table drought also has been identified using remote sensing teqnique. The results show that in recent decades ground water table trend has been negative, water table has fallen around 17.91 meters in time period of 1992-2011, that its annual average is equal 0.90 meters. Also, result shows that drought intensity is more severe during the dry years. The rainfall deficit has a significant effect on meteorological drought which has a direct relation with groundwater drought. According to the result can be found in years that severe drought occurred (1996-97, 1998-99, and 2007-2008), the level of ground water in the plain has been decreased severely(1996-97, 1998-99, and 2007-2008). In subsequent years, despite the increase in rainfall in the region, and although the SPI showed the reduced drought situation but groundwater levels has been declining. The main reason is the excessive use of groundwater, in particular, by agriculture Wells. The results of monitoring of land use change indicate an increase in the area of irrigated agriculture, 39.1 km2, in 2011 Compared with 1992. Overexploitation of groundwater for irrigation agriculture and recurrent meteorological droughts are the main causes of groundwater drought in the study area. Efficient irrigation management is essential to reduce the growing pressure on groundwater resources and ensure sustainable water management

Keywords: Groundwater drought, Meteorological drought, Remote sensing, Change detection, Hydrograph analysis.

1. Introduction

Water resources are crucial to human health and the natural environment (Birol et al., 2006). Drought can be described as a temporary decrease in water availability over a significant period of time, deviating from normal conditions (Mozafari et al., 2011; Hagman, 1984). In contrast to e.g. flooding, which has a direct and visible effect, drought is a creeping natural hazard (Wilhite, 1993; Moreira et al., 2006). Groundwater, which is found in aquifers below the surface of the earth, is one of the nations most important natural resources. Groundwater is a critical source of fresh drinking water for almost half of the world's population and it also supplies irrigated agriculture (Holger et al., 2012). Absence of rain firstly affects groundwater recharge, and subsequently groundwater storage and discharge (Castle et al., 2014). Depending on size and characteristics of these systems, impacts may lag significantly after the meteorological drought (Villholth et al., 2013; Rutulis, 1987). Groundwater drought is a specific type of drought that concerns groundwater bodies. It may have a significant adverse effect on the socio-economic, agricultural, and environmental conditions (Bloomfield et al., 2015). Investigating the effect of response different climatic and manmade factors on groundwater drought provides essential information for sustainable planning and management of water resources (Mustafa and Huysmans, 2015). Water scarcity is causing more pressure on utilization of fresh water resources in irrigated agriculture (Seckler et al., 1998)**.** Competition for water resources in agriculture is increasing with water scarcity and becoming more serious in the 21st century. The agricultural sector is one of the biggest consumers of water resources, accounting for more than 70% of the world’s fresh water use from rivers and groundwater (Ahmad et al., 2009 ; Lam et al., 2012; Laurent and Ruelland, 2011). Iran is located in semi-arid region, and its average annual precipitation is about one-third of the world. In recent decades, population growth in the country is high and this is due to the limited amount of extractable water, per capita water potential is severely threatened (Alizadeh, 2011). Hamadan, as one of the Iran tourism hub, with a population of over 500 thousand people and with an area of about 54 square kilometers is located in Hamadan- Bahar plain. Most the used water is provided through wells drilled in the plain. Drop in the level of groundwater in the plain is considered. Due to the special significance of the plain in providing water for agriculture and industry in Hamadan and Bahar and the growing need in extracting water in the coming years, the goal of this study is to do a research on drought and urbanization, to find drought trend, analyze groundwater hydrograph, and evaluate the meteorological drought effects and urbanization in the reduction of ground water table using SPI index and Landsat data in Hamadan- Bahar Watershed .

2. Materials and Methods

2.1. Study area

The main study area is Hamadan – Bahar watershed (Fig. 1). The basin is in the Western region of Iran, for which the boundaries can be given by longitudes from 48° 17' to 48° 20' east and latitudes 34° 49' to 35° 10' north. The basin has an area of 2460 km^2 with an elevation ranging from 1672 to 3372 m. Annual precipitation is about 313 mm. Mean annual temperature is 12.30 °c.

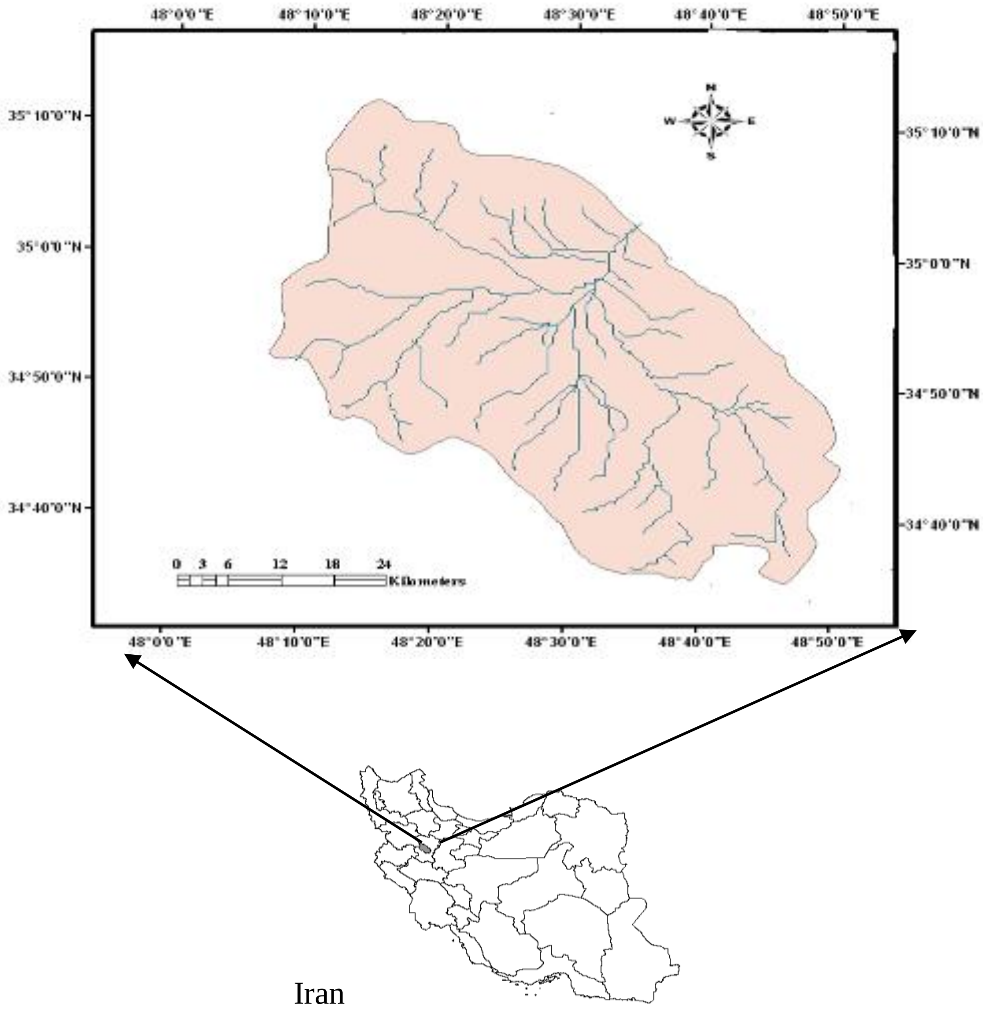

Fig1: Location of study area in Iran

2.2. Landsat imagery

Landsat (name indicating Land + Satellite) imagery is available since 1972 from six satellites in the Landsat series. These satellites have been a major component of NASA's Earth observation program, with three primary sensors evolving over thirty years: MSS (Multi-spectral Scanner), TM (Thematic Mapper), and ETM+ (Enhanced Thematic Mapper Plus). NASA's Landsat Data Continuity Mission (LDCM) launched the Landsat 8 satellite in February 2013. The satellite payload includes two sensors, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The collection of Landsat available through GLCF is designed to compliment overall project goals of distributing a global, multi-temporal, multi-spectral and multi-resolution range of imagery appropriate for land cover analysis. In this research we used three images (Table 1). The data acquisition date has a highly clear atmospheric condition, and the image was acquired through the USGS Earth Resource Observation Systems Data Center, which has corrected the radiometric and geometrical distortions of the images to a quality level of 1G before delivery.

Table 1: satellite data used in this research

format	Date	Path/row	Sensor	Landsat number	row
TIFF	29 Jun 1992	166/36	TM	5	1
	29 Jun 2000		ETM^+	7	2
	10 Jun 2011		ETM^+	7	3

2.3. Change detection

When implementing a change detection project, three major steps are involved: (1) image preprocessing including geometrical rectification and image registration, radiometric and atmospheric correction, and topographic correction if the study area is in mountainous regions; (2) selection of suitable techniques to implement change detection analyses; and (3) accuracy assessment (Lu et al. 2004).

2.4. Accuracy assessment

Accuracy assessment involves statistical estimates obtained from remote sensing classification output and an independent reference dataset in order to measure the probability of error for the classified map (Foody, 2007). Various criteria for comparison of the simulated image with ground truth due to land-use change modeling assessment have been proposed. One of the most common indices is kappa introduced by "Cohen" in 1960 (Congalton, 2009). K index is achieved from Contingency Table. This table sometimes called the error matrix determines proportion of the cells distribution in the two images. The mathematical formula of the k index is derived from equation 3, where Po and Pc, called overall accuracy and probability of chance agreement, respectively are derived from equations 2 and 3 (Congalton, 2009):

$$\hat{K} = \frac{P_o - P_C}{1 - P_C} \qquad (1)$$

$$P_O = \frac{1}{N}\sum_{i=1}^{k} nij \qquad (2)$$

$$P_C = \frac{1}{N^2}\sum_{i=1}^{k} \left(ni + n + i\right) \qquad (3)$$

where , k =number of land use classes, n_i= are the row probabilities, and n_j= are the column probabilities.in this research, a k index analysis and an overall accuracy are carried out to evaluate the outcomes against reality.

2.5. Standardized Precipitation Index (SPI)

Standardized Precipitation Index (SPI**)** is primarily a tool for defining and monitoring drought events(Karavitis et al., 2011). The SPI was developed by McKee et al. (1993, 1995) for the identification of drought events and to evaluate its severity. Multiple time scales, from 3-month to 24-month, may be used. The drought severity adopted in this study is defined in Table 2, where the severe and extremely severe drought classes are grouped. The methods used to compute the SPI and the data quality tests performed before using the precipitation data sets are reported by Paulo et al. (2003, 2005). Annual precipitation data sets were investigated for randomness, homogeneity and absence of trends using the autocorrelation test (Kendall s), the Mann–Kendall trend test and the homogeneity tests of Mann–Whitney for the mean and the variance (Helsel and Hirsch, 1992).

3. Results and Discussion

3.1. Geometric correction

In order to use the original images and the raw satellite data, and also eliminating errors caused by the earth's curvature, height and etc. action to correct the geometric images (Roodgarmi et al., 2009; Barati Ghahfarrokhi et al., 2009).Geometric correction is the compensate for these deviations (Lorestani and Shahryar, 2011). At first the number of ground control of the study area were selected from the images of Google Earth. Finally, to delete some points because of the large error (Shtaey and Abdi, 2007) , for the years 1992, 2000 and 2011 respectively 17 , 25 and 28 points were used with good distribution .That the points of intersection were often selected cross from the streets and roads (Safianinam and Madanian, 2011) so samples were taken. Resembling by using the nearest neighbor method was performed .Geometric correction was performed by using first order transformation equation. Obtained RMSE for the years 1992, 2000 and 2011 respectively are 0.2747, 0.524 and 0.2462. Pixel Error less than one pixel, is acceptable for geometric correction of satellite images. (Khosravani et al., 2012).

3.2. Images Classification

In this study, in order to perform supervised classification using Envi software, maximum likelihood supervised classification analyses were carried out on the images to identify the land use changes in the study area (Fig.2). Four different land cover classes were identified including: irrigation agriculture, dry agriculture, urban, and rangeland.

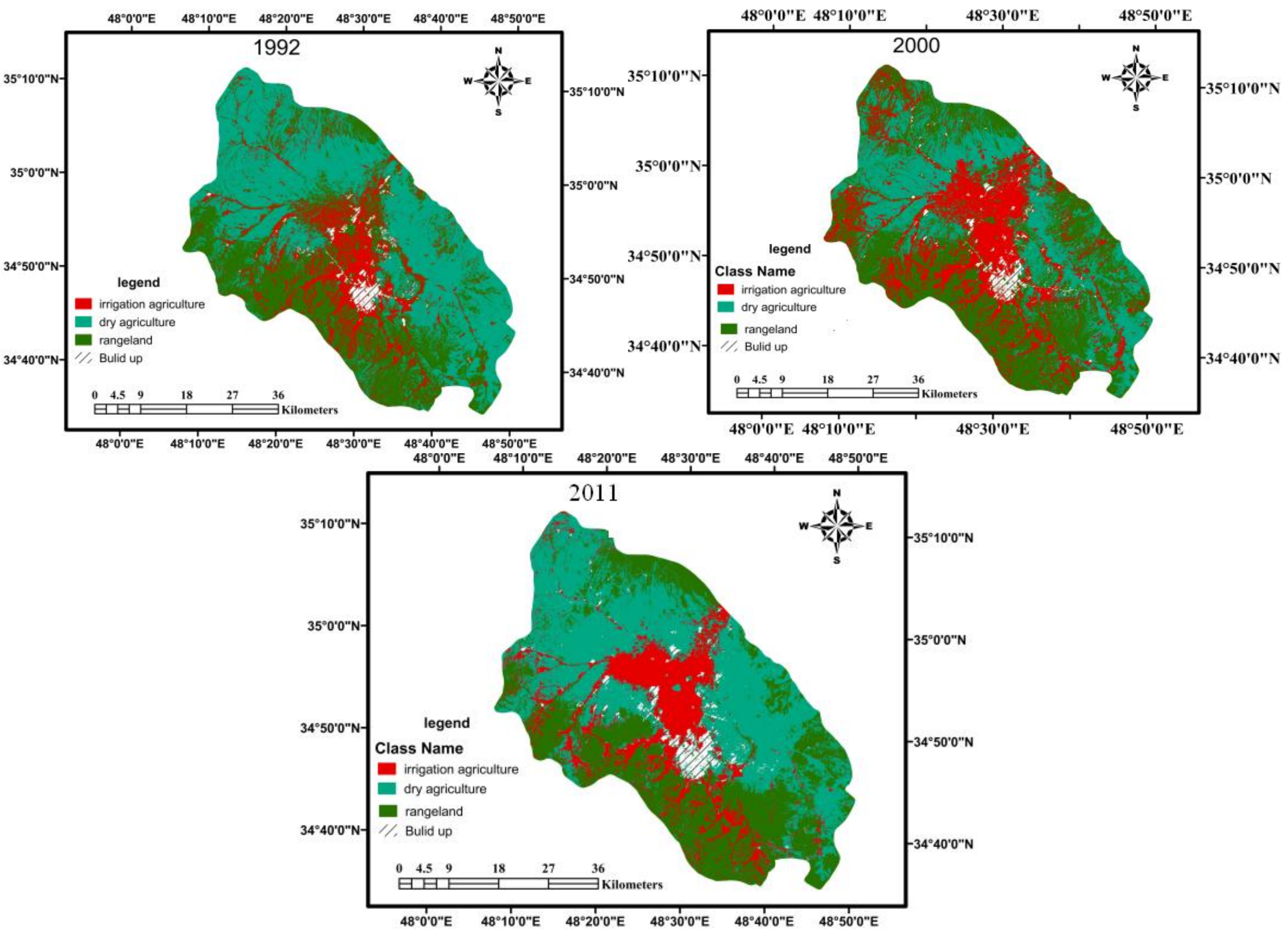

Fig.2: Maps of land use classification for years 1992, 2000 and 2011 with Maximum Likelihood method

Table2. Drought class classification of SPI (modified from McKee et al., 1993)

Code	Drought classes	SPI values
1	Non-drought	SPI > 0
2	Near normal	-1 < SPI < 0
3	Moderate	-1.5 < SPI < -1
4	Severe	-2 < SPI < -1.5
5	Extreme	SPI <-2

3.3. Evaluation of results

A stratified random sampling design was adopted for the accurate assessment of maps. The sample points were generated and their locations were chosen to represent different land use classes in the area. In all, a total of 500 pixels were selected. In order to increase the accuracy of land use mapping of the three images, all the pixels were checked and visually interpreted based on RGB color composition imagery and high spatial resolution images of Google earth. According to the table 3, K coefficient and overall accuracy in maximum likelihood method are high. The detection of change analysis is concerned with the environmental changes and the human impact. These changes have been detected and identified as Table 4. The data obtained are also shown in a chart form to be easier to understand for the normal observer and the decision maker (Fig. 3).

Table 3: overall accuracy and k coefficient

Classification method	1992		2000		2011	
	K coefficient (%)	overall accuracy (%)	K coefficient (%)	Overall accuracy (%)	K coefficient (%)	overall accuracy (%)
Maximum likelihood	0.9311	94.52	0.9000	87.43	0.8506	90.82

Table 4. The land cover changes in km^2 in 1992, 2000 and 2011

Classes	1992 Area (km^2)	2000 Area (km^2)	2011 Area (km^2)	1992-2000 Change (km^2)	2000-2011 change(km^2)	1992-2011 change (km^2)
irrigation agriculture	362	622.66	528.74	260.66	-93.92	166.37
dry agriculture	1228.72	726.92	1172.67	-501.08	445.72	-56.5
rangeland	858.88	1053.33	711.71	194.45	-147.17	-39.56
Bulid up`	41.007	56.24	69.21	15.23	12.97	28.21
Total	2490	2490	2490			

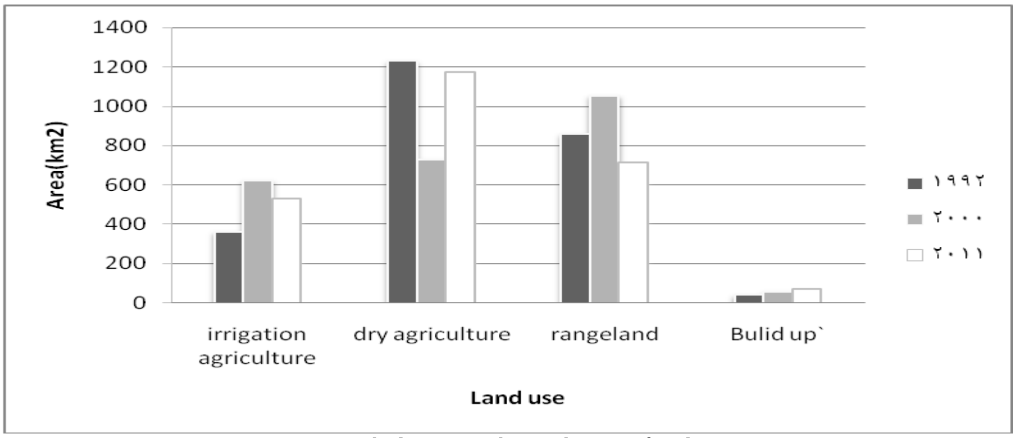

Fig.3: Each class area in km² at the time of analysis.

3.4. Meteorological Drought

In the present study, SPI has been computed separately for each of the 5 rain-gauge stations falling within the study area (Table 4).according to the Table in 1996-97, 1998-99, and 2007-2008 extreme drought occurred, for all of station.

3.5. Groundwater hydrograph

Due to the special sensitivity of study of unit hydrograph in recharge and discharge, also importance of supply water and the fluctuating aquifer level have been studied and evaluated (Table 6).

Table 5. The SPI value during 1991-2011

Year	Stations			
	Ekbatan	Aghkohriz	Koshk Abad	Maryanaj
1991-92	Near normal	Near normal	-	Near normal
92-93	Near normal	Near normal	Near normal	-
93-94	Near normal	Near normal	Near normal	Near normal
94-95	Near normal	Very wet	Moderately wet	Near normal
95-96	Moderately dry	Near normal	Near normal	Near normal
96-97	Extremely dry	Severely dry	Moderately dry	Severely dry
97-98	Near normal	Near normal	Near normal	Near normal
98-99	Extremely dry	Extremely dry	Extremely dry	Extremely dry
99-2000	Moderately dry	Moderately dry	Severely dry	Severely dry
2000-2001	Near normal	Near normal	Near normal	Near normal
2001-2002	Near normal	Near normal	Near normal	Near normal
2002-2003	Near normal	Near normal	Near normal	Near normal
2003-2004	Moderately wet	Near normal	Near normal	Near normal
2004-2005	Moderately dry	Moderately dry	Near normal	Near normal
2005-2006	Moderately dry	Near normal	Near normal	Near normal
2006-2007	Near normal	Moderately wet	Near normal	Near normal
2007-2008	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2008-2009	Near normal	Near normal	Near normal	Near normal
2009-2010	Near normal	Moderately wet	Near normal	Near normal
2010-2011	Near normal	Near normal	Near normal	Near normal

During a 20 year period (1991 to 2011), groundwater levels in the plain dropped about 17.91 m that It's annual average is equal 0.90 meters (Fig.4). This amount of loss indicates disturbing changes in reducing groundwater reserves. According to the table 6, the highest rising water level occurred in 2006-2007, equal to 2.57 m, that this amount of rising has been offsetting the amount of 64.89 million cubic meters of 286.13 million cubic meters reservoir volume fraction before this year. And the deficit of reservoir volume for this year decreased to 221.94 million cubic meters. But because of the drought happened in 2007-2008 (Table 5), groundwater level dropped in the amount of 2.15 meters (Fig.4). That causes the reservoir volume fraction equal to 58.63 million cubic meters for 2007-2008 and the volume total deficit equal to 287.54 million cubic meters. Because of the shallow groundwater table, the plain most influenced by the fluctuations in precipitation. According to Table 5 can be found in years that severe drought occurred (1996-97, 1998-99, and 2007-2008), the level of ground water in the plain has been decreased severely (1996-97, 1998-99, and 2007-2008). In subsequent years, despite the increase in rainfall in the region, and although the SPI showed the reduced drought situation but groundwater levels has been declining. The main reason is the excessive use of groundwater, in particular, by agriculture Wells. The results of monitoring of land use change (Fig. 3 and Table4) indicate an increase in the area of irrigated agriculture, 39.1 km2, in the region during 1992-2011. The general trend of groundwater hydrograph is downward that represents a sign of the continuing fall with a decrease in groundwater storage (Fig. 4).

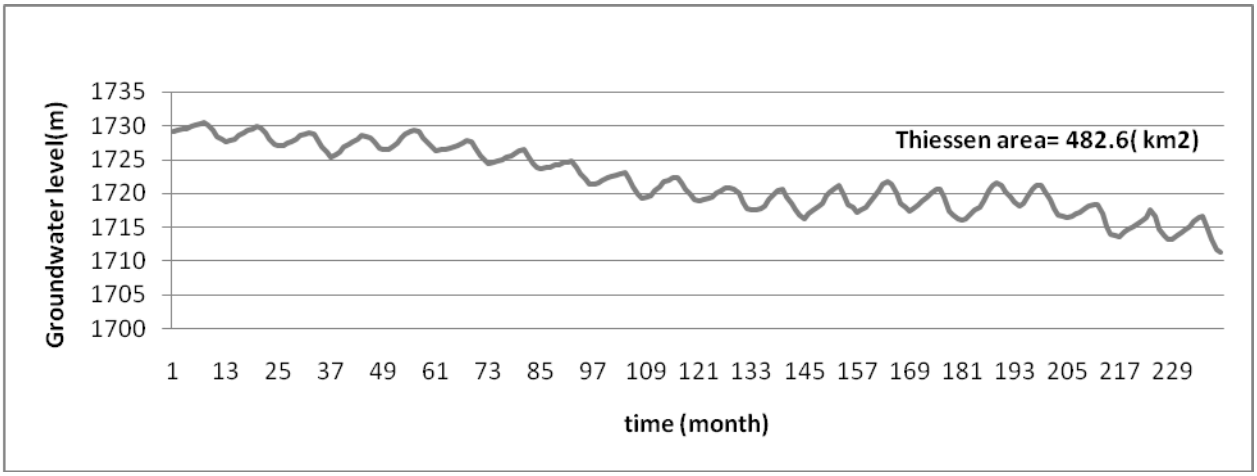

Fig.4: Groundwater unit hydrograph of study area during 1991-2011 (oct.1991 to sept.2011).

4. Conclusions

Groundwater is the source of about 33 percent of the water that county and city water departments supply to households and businesses (public supply)(March et al., 2007).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**.** Type of groundwater aquifers in the north plains of Hamadan, including Hamadan - Bahar Plain is shallow (50 m), so more influenced by the fluctuations in rainfall and climate. In order to optimal water resources management in the region, we face with challenges, although climatic factors have been the greatest impact on declining of the water table in recent years. But this crisis is the result of factors such as irregular uses. In recent years due to irregular use of water resources, the water level of the aquifer in this plain has fallen sharply.

Table 6 hydrograph value of Hamedan- Bahar plain during 1991-2011

Years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar	Apr.	May	Jun.	Jul.	Aug.	Sept.	Changes in water level(m)
1991-92	1729.20	1729.35	1729.55	1729.70	1729.90	1730.10	1730.34	1730.56	1730.10	1729.36	1728.45	1727.99	-1.49
92-93	1727.71	1727.80	1728.17	1728.57	1729.00	1729.44	1729.70	1729.93	1729.80	1729.05	1728.00	1727.41	-0.67
93-94	1727.04	1727.15	1727.48	1727.75	1728.10	1728.56	1728.90	1729.06	1728.90	1727.85	1726.90	1726.10	-1.60
94-95	1725.44	1725.70	1726.14	1726.96	1727.40	1727.70	1728.10	1728.70	1728.50	1728.20	1727.61	1726.83	1.11
95-96	1726.55	1726.55	1726.91	1727.60	1728.34	1728.84	1729.20	1729.43	1729.15	1728.34	1727.51	1726.99	-0.14
96-97	1726.41	1726.52	1726.64	1726.74	1726.92	1727.11	1727.51	1727.90	1727.73	1726.68	1725.58	1724.94	-1.87
97-98	1724.55	1724.69	1724.84	1725.02	1725.33	1725.68	1726.03	1726.28	1726.50	1725.55	1724.45	1723.94	-0.87
98-99	1723.68	1723.84	1723.96	1724.17	1724.27	1724.56	1724.70	1724.79	1723.85	1722.88	1722.16	1721.39	-2.31
99-2000	1721.37	1721.58	1721.97	1722.27	1722.49	1722.69	1723.01	1723.21	1722.17	1721.02	1719.83	1719.38	-1.97
2000-2001	1719.40	1719.75	1720.50	1721.10	1721.72	1722.03	1722.38	1722.40	1721.50	1720.56	1719.90	1719.12	-0.48
2001-2002	1718.92	1719.03	1719.22	1719.50	1720.00	1720.39	1720.77	1720.90	1720.67	1720.00	1718.80	1717.70	-1.42
2002-2003	1717.50	1717.55	1717.80	1718.11	1719.02	1719.82	1720.42	1720.65	1719.50	1718.45	1717.51	1716.90	-1.19
2003-2004	1716.31	1717.03	1717.52	1718.01	1718.63	1719.64	1720.25	1720.83	1721.18	1719.60	1718.40	1717.90	0.93
2004-2005	1717.24	1717.60	1717.96	1718.66	1719.61	1720.39	1721.39	1721.80	1721.44	1720.03	1718.53	1717.98	0.22
2005-2006	1717.46	1717.87	1718.29	1719.00	1719.53	1720.11	1720.68	1720.60	1719.54	1717.39	1716.75	1716.29	-1.35
2006-2007	1716.11	1716.28	1716.96	1717.52	1717.97	1718.95	1720.36	1721.30	1721.65	1721.25	1720.18	1719.42	2.57
2007-2008	1718.68	1718.17	1718.46	1719.46	1720.60	1721.13	1721.25	1720.18	1719.15	1717.72	1716.86	1716.58	-2.15
2008-2009	1716.53	1716.59	1716.94	1717.27	1717.72	1718.11	1718.28	1718.38	1716.94	1715.12	1713.95	1713.73	-2.86
2009-2010	1713.67	1714.31	1714.78	1715.15	1715.41	1715.80	1716.51	1717.51	1716.68	1714.72	1713.74	1713.27	-0.51
2010-2011	1713.17	1713.72	1714.22	1714.69	1715.20	1715.85	1716.47	1716.62	1714.65	1713.12	1711.76	1711.29	-1.88

Several local efforts by policy makers to control severe depletion of groundwater resources plain, but the results of these policies have not been successful, and more uncontrolled exploitation resulted in the loss of more than 17 m water level during the two past decades. The main action that should be done in the way of water use management is to prevent excessive water consumption, especially in the agricultural sector.he use of modern irrigation methods and crops with low water needs reduces the pressure on the source of supply in the long term and the possibility of recovery will be provided. Laws to limit the exploitation of water and non-issuance of new licenses by the relevant organization is also an essential step in carrying out this work.

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