ASSESSING IMPACT OF IRRIGATION AND DRAINAGE NETWORK ON SURFACE AND GROUNDWATER RESOURCES – CASE STUDY: SAVEH PLAIN, IRAN

EVALUATION DE L'IMPACT DU RESEAU D'IRRIDATION ET DRAINAGE SUR LES RESSOURCES EN EAU DE SURFACE ET SOUTERREINES - ETUDE DE CAS: PLAINE DE SAVEH, IRAN

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ABSTRACT

In the present study, the environmental impacts of Saveh irrigation and drainage network and the associated dam, especially on surface and groundwater bodies have been evaluated. Space-time changes of groundwater quality and quantity have been analyzed using Geostatistics Software version 5.1 and the relevant maps were created based on Wilcox method, involving GIS software, Version 9.3. Using Standardized Precipitation Index (SPI) for three meteorological stations in the study area including; Shah Abasi, Imamabad and Ahmadabad, it was found that extreme drought had occurred through years,1970, 1978, 1979, 1980, 1983 and 1985. According to the result, the average flow of Qarachay river after operation of Saveh dam has been reduced to 0.67 m^3/s in contrast with 6.03 m^3/s, which had been recorded before of the dam operation. Downstream of Qarachay river, water quality analysis shows that it had deteriorated from 1971 to 2006. According to Wilcox method the water quality had reduced from C3-S1 to C4-S2 class. Groundwater quality for agricultural usages in Saveh aquifer were classified into 4 including; 16% in class C4-S2, 46% in class C4-S1, 30% in Class C3-S1 and 8% in Class C2-S1. Generally speaking, the effects of irrigation and drainage networks on environment and water bodies need to be determined to have a sustainable development.

Key words: *Irrigation and drainage, River water quality, Wilcox classification, Sustainable development.*

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RESUME ET CONCLUSIONS

La basse qualité des eaux usées d'irrigation, des modifications au régime de faible débit dans les rivières en raison de la construction des barrages pour l'irrigation, les niveaux de la nappe phréatique en raison des économies d'irrigation à faible, la surexploitation des eaux souterraines et des conséquences graves tels que l'intrusion d'eau salée et l'affaissement du sol sont les principaux impacts sur les systèmes d'eau, entraînant la non-viabilité des projets d'irrigation et de drainage. L'objectif principal de l'étude en cours a été d'évaluer les impacts environnementaux de l'irrigation Saveh et réseau de drainage et le barrage associés, en particulier sur les eaux de surface et des eaux souterraines. Afin d'atteindre cet objectif, le débit et la qualité des données des deux principaux fleuves de la zone d'étude, et les rivières Qarachay Mazlaghan, les niveaux des eaux souterraines, les volumes de rejet et de la qualité des données en avant et après la construction du réseau, et les précipitations, l'évapotranspiration ont été utilisés. Il a été également porté à parvenir à une vision globale des changements dans le bilan hydrique et distincte de l'impact de l'irrigation et de drainage. Les changements spatiaux et temporels de la qualité des eaux souterraines et la quantité ont été analysées à l'aide du logiciel géostatistique version 5.1 et les cartes correspondantes ont été créés selon la méthode de Wilcox, utilisant des logiciels SIG, version 9.3. L'évaluation des résultats de la sécheresse météorologique utilisant indice normalisé de précipitations (SPI) pour trois stations météorologiques dans la zone d'étude, y compris; Shah Abasi, Imamabad et Ahmadabad a indiqué que la sécheresse extrême a été produit par des années 1970, 1978, 1979, 1980, 1983 et 1985. Les calculs de la pluie - la tendance de flux pour trois autres stations, ShahAbbasi, Razin et Jalayer, a montré qu'il y avait une tendance croissante de la pluviométrie et de tendance à la baisse du débit. Les volumes de décharge des eaux souterraines indiquent que l'exploitation des eaux souterraines par le biais de 2002 à 2009 avait aucune augmentation significative en raison d'une surveillance continue et la protection. Toutefois, dans les deux mois de chaque année, Mai et Octobre, un niveau élevé de rejets ont été enregistrées, 3 à 4 millions de mètres cubes dans l'ensemble. Selon le résultat, le débit moyen du fleuve Qarachay après l'opération du barrage de Saveh a été réduit à 0/67 m^3/s en contraste avec 6,03 m^3 / s ce qui est rapporté pour l'opération avant de barrage. analyse Qarachay la qualité des rivières montre que la qualité de l'eau de la rivière a été diminué de 1971 à 2006. Dans les autres mots, selon la méthode Wilcox la qualité de l'eau a été réduit de la classe C3-C4 à la classe S1-S2. En outre, la baisse des eaux souterraines après l'opération du barrage de Saveh (1995) a été enregistré pour être égal à 26,29 mètres. Moyenne conductivité électrique (CE), Sodium Absorption Ratio (SAR) et des matières totales dissoutes (TDS) dans l'aquifère Saveh, ont été obtenus pour être égal à 3100/6 umho/cm, 5/76 éq/mol et 1948/6 mg /l. qualité des eaux souterraines pour les usages agricoles de l'aquifère Saveh ont été classés en 4 catégories, notamment: 16 pour cent dans la classe C4-S2, 46 pour cent dans la classe C4-S1, 30 pour cent dans la catégorie C3-S1 et huit pour cent dans la classe C2-S1. Selon les résultats, la construction du barrage de Saveh a été la principale raison de la baisse des niveaux des eaux souterraines dans l'aquifère Saveh.

***Mots clés :** Irrigation et drainage, qualité de l'eau fluviale, classification Wilcox, dévelopment durable.*

(Traduction française telle que fournie par les auteurs)

1. INTRODUCTION

Groundwater is the main source for supply agricultural, domestic and industrial demands. In arid and semiarid countries, such as Iran, groundwater resources need to be more efficiently managed. In Iran, agriculture uses about 95% of fresh water out of which, 80% is supplied through groundwater (Ahmadi and Sedghamiz, 2007). In recent years, groundwater levels have been declining in many plains of Iran due to over exploitation and drought by about 0.5 to 1 m per year (Shiati, 1999). Reduced base flow of rivers due to heavy water consumption do not permit natural groundwater recharge and causes continuous water table decline.

Drought impact is analyzed through certain indices. The two most widely used indices are Palmer Drought Severity Index (PDSI) (Palmer, 1965) and the Standardized Precipitation Index (SPI) (McKee et al., 1993). The main advantages using of SPI are simplicity, variable time scale and standardization (Hayes et al., 1999). SPI is appropriate for quantifying most types of drought events, but the interaction to the groundwater level are found over long time scales; from 5 to 24 months (Bussay et al., 1998 and Szalai and Szinell., 2000). Suitability of SPI to define ongoing droughts needs to be investigated (Karl et al., 1986; Cancelliere et al., 1996, 2007; Lohani et al., 1998; Bordi et al., 2005). Due to drought, groundwater recharge and levels decline (Van Lanen and Peters, 2000). Limited groundwater data, heterogeneous aquifers and groundwater response to drought that may be asynchronous with other variables pose difficulty in assessing drought impact on groundwater.

Loaiciga (2003) deliberated a karst aquifer in Texas and considered the impact of climate change on base flow, recharge and pumping rates. Result of the study indicates that the rise in groundwater use associated with predicted population growth would display a higher hazard to the aquifer than climate change. Scibek and Allen (2006) used Visual MODFLOW to study the impact of climate change on two aquifers in Canada and the United States. The temporal impact of climate change was modeled by changing the inputs to a stochastic weather generator based on each climate scenario. Also adaptation to the spatial recharge estimates were made for one of the aquifers based on an interpolated precipitation gradient. The study showed that only a minor impact from climate change on recharge and groundwater levels at both study areas. Mendicino et al. (2008) used a Groundwater Resource Index (GRI) for monitoring and forecasting drought conditions. The GRI is resulting from a simple circulated water balance model. Their research shows that the GRI in contrast to SPI has a high spatial variability through spectral analysis. Also, performance of GRI was analyzed in forecasting the major historic drought events, finding that the GRI is a better predictor than the SPI. Khan et al. (2008) used SPI to evaluate the impact of rainfall on shallow groundwater levels in three selected irrigation areas of the Murray-Darling Basin in Australia. They showed that the SPI correlates well with fluctuations in shallow groundwater table in irrigated areas. Changes in temperature and precipitation will change groundwater recharge in unconfined aquifers as a first response to climate trends. In aquifers that are hydraulically connected to surface water, shifts in the hydrologic regime can also be expected to impact water levels, although the nature of this interaction may be more difficult to quantify (Scibek and Allen, 2006).

Saveh aquifer is a semi confined and alluvial aquifer at downstream of Qarachay river. In recent years groundwater level in the aquifer has been fast declining, by as much as 26.29 m from 1991 to 2008. Operation of Saveh dam from 1995 caused intensified drop of groundwater in the region. Because of high permeability and hydraulically connected aquifer to surface water, water table of the aquifer was affected by changing in precipitation and stream flow regime. In the analysis of the long-term hydrologic impact of stream flow on groundwater, it is necessary to include climatic data (precipitation and temperature) and groundwater withdrawals.

The overall purpose of this research was to study the performance of groundwater systems under drought stress. This study focused on the direct impacts of precipitation on groundwater level but other factors such as river flow and groundwater extraction may also have impact on groundwater.

2. MATERIALS AND METHODS

Standardized precipitation index (SPI). The Standardized precipitation index (SPI) was used by McKee et al. (1993) to measure the precipitation shortage. The SPI is computed by dividing the difference between the normalized seasonal precipitation and its long-term seasonal mean by the standard deviation (McKee et al. 1993):

$$SPI = \frac{X_{ij} - X_{im}}{\sigma} \quad ...(1)$$

Where, X_{ij} is the seasonal precipitation at the i^{th} rain gauge station and jth observation, X_{im} the long-term seasonal mean and σ is its standard deviation. Since the SPI is equal to the z-value of the normal distribution. McKee et al. (1993, 1995) proposed a seven-category classification for the SPI (Table 1).

Table1. SPI and moisture categories

SPI value	Moisture category
2.0 and more	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

3.2 Study area and Data set

The study area is in Saveh plain, in the east of Markazi province, central Iran; between 34° 45′ to 35° 03′ N latitude and 50° 08′ to 50° 50′ E longitude, at an elevation about 1100 m ams (Figure1). The average rainfall is 202 mm, the average temperature 18.2°C and the average humidity is 39%. Wheat, barley, vegetable and garden plants are extensively cultivated in this area. The Groundwater aquifer is overexploited over a region of about 1263 km^2 in the study area and hence, groundwater operation is forbidden (Iran Water Resources Management Company, 2005).

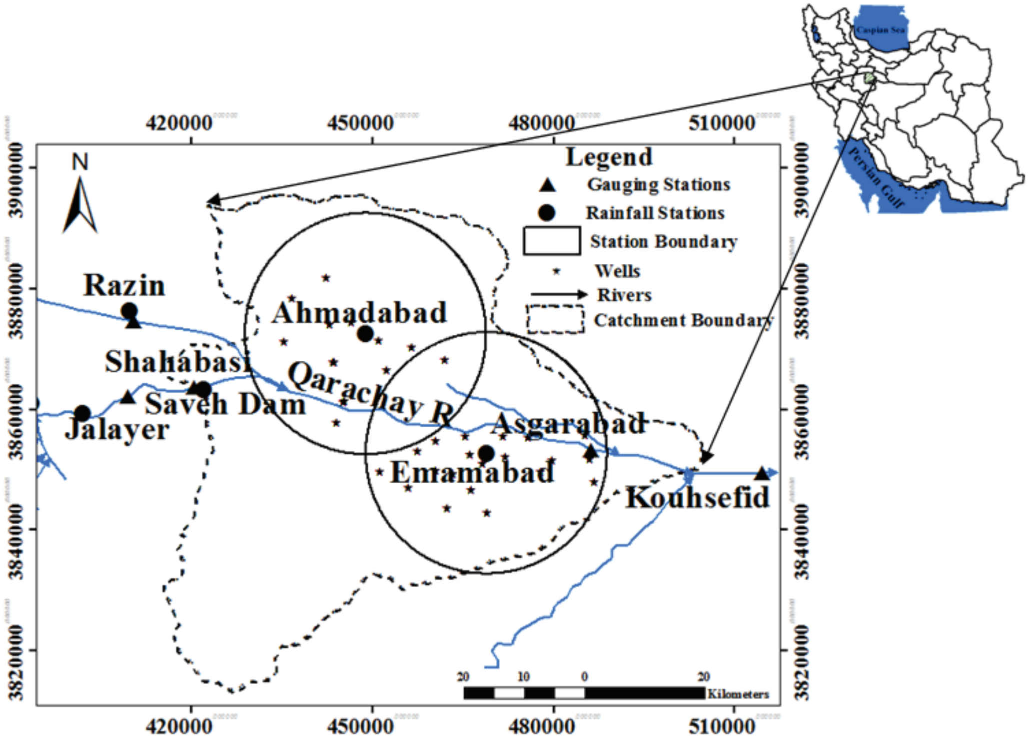

Fig. 1. Location of the Saveh Plain and Stations

Figure 1 shows the geographical location of piezometric wells. The coordinates system used in Figure 1 is Universal Transverse Mercator (UTM). The datum of this system is World Geodetic System of 1984 (WGS 1984) upon which Global Positioning System (GPS) measurements were made. Also Figure 1 shows the gauging and rainfall stations of Saveh plain. In the current research study, monthly rainfall data of 5 stations; Razin (1972- 2007), Jalayer (1982-2007), Shahabasi (1967-2007), Ahmadabad (1975-2005) and Emamabad (1970-2005), 3 gauging stations; Razin (1972- 2007), Jalayer (1982-2007) and Shahabasi (1967-2007) and groundwater level data of 32 piezometric wells were used. These mentioned data were obtained from Iran water resources management company (IWRM, 2005). The main river of the study area is Qarachay and Saveh dam is constructed on this River. The main reason of the water level drop in Saveh aquifer has been decreasing recharges from the River.

In the present study to determine the appropriate time scale Standardized Precipitation Index, the correlation SPI based on time scales of 1, 3, 6, 9, 12, 18, 24 and 48 month with the groundwater level is calculated. Also to consider time delay impact of perception on groundwater, correlation between SPI and groundwater level has been computed for 1, 2, 3, 4, 5, 6, 12 and 24 months. Moreover, the correlation coefficient has been calculated using equation (2), below.

$$\rho_{XY} = \frac{cov(X,Y)}{\sigma_X \sigma_Y} \quad ...(2)$$

In equation (2) X and Y are SPI and groundwater level parameters, respectively. σ_X and σ_Y are standard deviation of variables X and Y and ρ_{XY} is the covariance between the variables X and Y(Khan et al, 2008).

3. RESULTS

Figure 2 represents the 12 monthly Standardized Precipitation Index values during years 1970-2005 and 1975-2005 for the two rainfall stations, Imamabad and Ahmadabad, respectively.

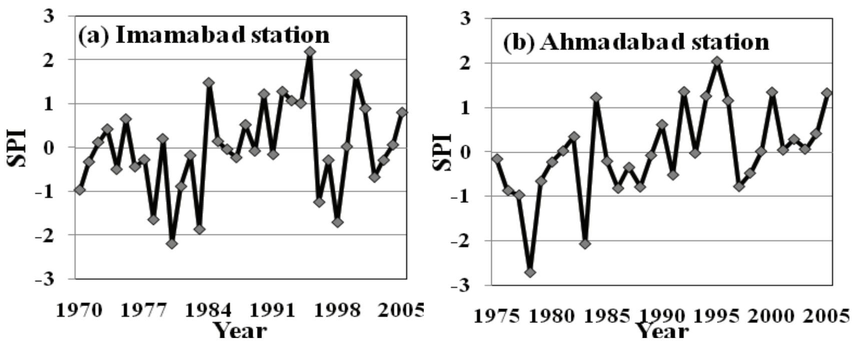

Fig. 2. 12-monthly SPI for Imamabad and Ahmadabad stations

As can be seen in Imamabad extreme drought occurred during 1980 and it experienced severe droughts in 1978, 1983 and 1998. On the other hand, in Ahmadabad, extreme droughts occurred during 1978 and 1983. Both the stations had a near normal situation (-0.99<SPI<0.99), during major part of the periods.

In order to determine relation between drought and groundwater level in Saveh aquifer for each of Ahmadabad and Imamabad station, 20 km radius area was considered and well water level changes within each area were measured.

Correlation coefficient between the SPI with time scales of 1, 3, 6, 9, 12, 18, 24 and 48 months and the average groundwater level in the Ahmadabad and Imamabad stations are calculated to determine the best time scale for the SPI (Table 2).

Table 2. Correlation coefficient between SPI and average groundwater

Time scale of SPI (month)								
Station	1	3	6	9	12	18	24	48
Ahmadabad	-0.024	0.127	0.266	0.054	0.202	0.526**	0.573**	0.490**
Imamabad	0.095	0.277	0.217	0.079	0.022	0.003	0.131	0.750**

** Correlation is significant at the 0.01 level (2-tailed)

For Ahmadabad highest correlation coefficient between the SPI and groundwater level is 0.573. However, the correlation coefficient between 18 and 48 monthly is significant at the 0.01 level and 0.526 and 0.490 respectively. In Imamabad station correlation coefficient of the 48 monthly SPI is 0.750 that is highest correlation coefficient with average groundwater level. Precipitation had affected groundwater levels with a time lag. Correlation coefficient between 24 and monthly SPI in Ahmadabad and Imamabad stations with average groundwater level in 1, 2, 3, 4, 5 and 6 months have been calculated. Table 3 shows the correlation coefficient for Ahmadabad and Imamabad stations.

Table 3. Correlation coefficient SPI and average groundwater level (2003-2006)

	Time delay between SPI and average groundwater level (month)							
Station	1	2	3	4	5	6	12	24
Ahmadabad	-0.645**	0.710**	0.757**	0.812**	0.806**	0.759**	0.687**	-0.101
Imamabad	-0.265*	0.563**	0.568**	0.658**	0.762**	0.758**	0.428**	-0.201

** and * Correlation is significant at the 0.01 and 0.05 level (2-tailed)

Table 3 indicates a high correlation between Standardized Precipitation Index and the average groundwater level with five months delay that is for Ahmadabad and Imamabad 0.806 and 0.762, respectively. However, correlation coefficient between SPI and average groundwater level with 2, 3, 4, 6 and 12 month delay is significant at the 0.01 level. Figures 3 and 4 show the change of SPI in contrast with average groundwater level in wells, which are located around Ahmadabad and Imamabad stations. For Ahmadabad station 24 monthly SPI and for Imamabad station 48 monthly SPI and average groundwater level with 5 month delay are shown.

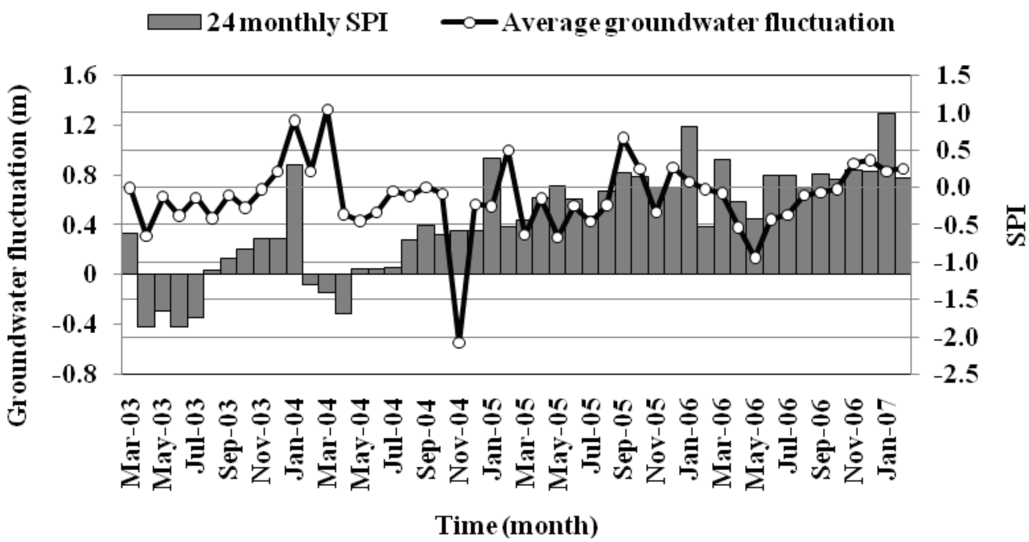

Fig. 3. 24-monthly SPI and average groundwater fluctuation of Ahmadabad station

Figure 3 show the correlation between groundwater level fluctuations with SPI in Ahmadabad from March 2003 to February 2007. Lack of rainfall in December-January 2002 has decreased the groundwater level as by 2.058 m from April to November 2003. Drought during October-November 2003 has caused the groundwater level drop of 1.275 m in April to June 2004. The decline of 2.079 m in November 2004 was probably due to exploitation because of water required in autumn. From October 2004 to March 2006 the groundwater level fluctuations show high correlation with the SPI values. Figure 4 shows 48 monthly SPI changes with the average groundwater level fluctuations in the Imamabad.

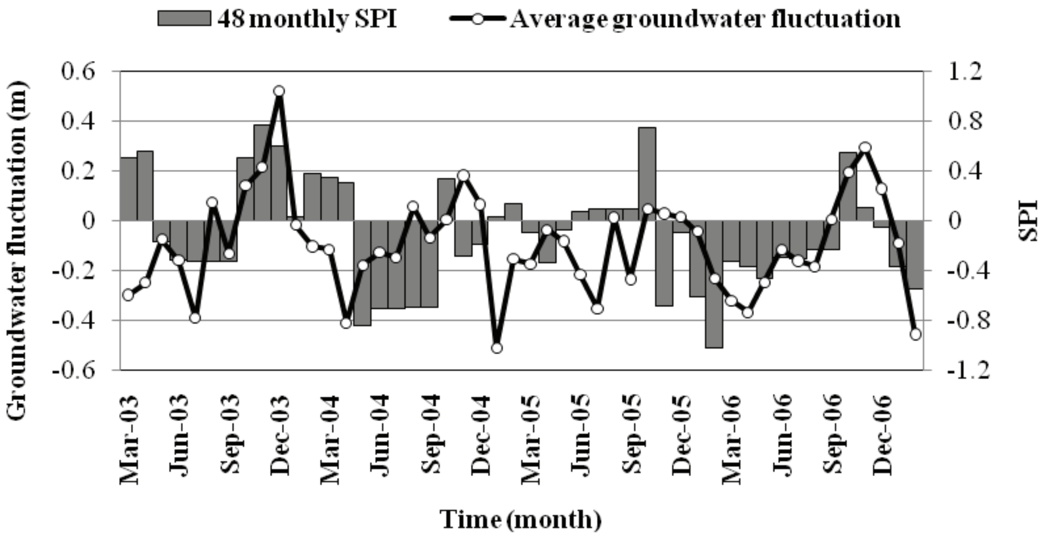

Fig. 4. 48-monthly SPI and average groundwater fluctuation Imamabad station

Average drop in groundwater levels in wells of Imamabad from April to August of 2003 has been 1.23 m due to drought from March to December 2002. Drought from January to June 2003 has decreased groundwater levels during March to September 2004 by 1.098 m. The main drought has occurred during the March to June 2004 that caused the groundwater table decline of 1.525 m in December to September 2006.

Figure 5 (a) and (b) show the changes perception and flow of Jalayer and Razin station through 1972 to 2007. Analysis of precipitation and flow in Jalayer and Razin station indicate that uptrend and downtrend, respectively. Therefore, reducing the rivers flow could have another reasons such as human activities. Water deviation and operation of dams cause decrease flow in rivers and subsequently reduce aquifers recharges. Flow of Qarachay River in Jalayer station and in Mazlaghan River in Razin station from 1997 severely reduced.

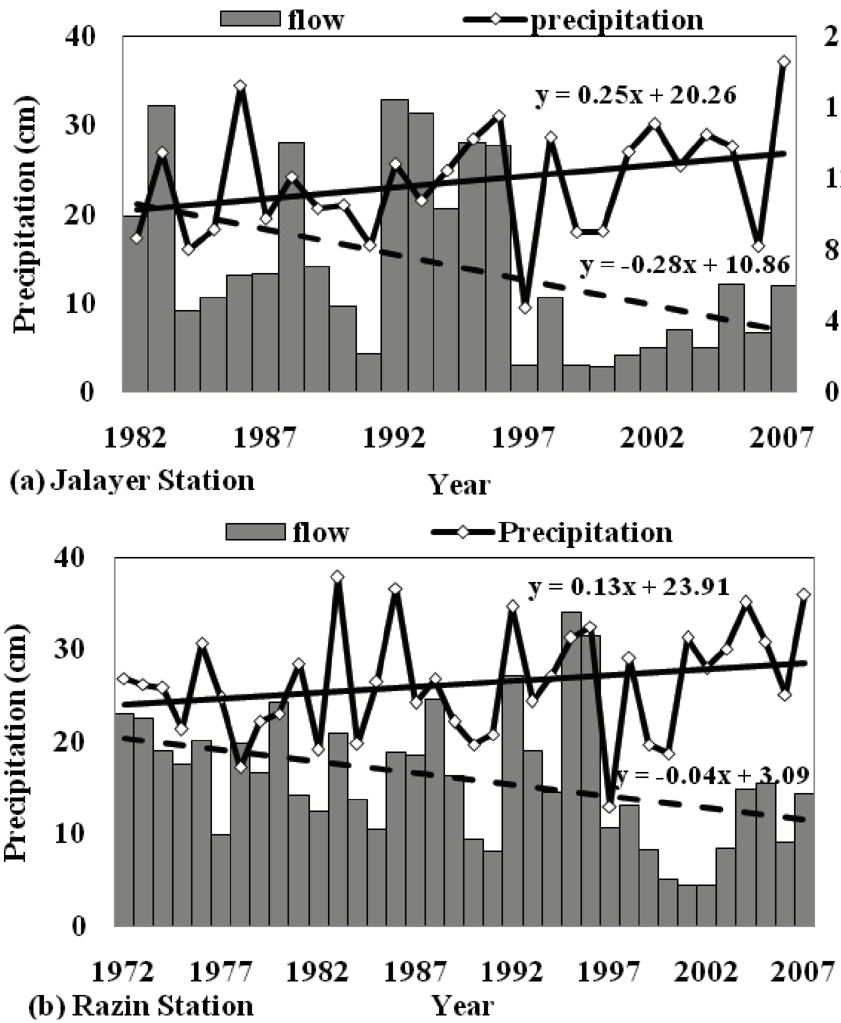

Fig. 5. Precipitation and flow Trend in Jalayer and Razin station

The fitted line to precipitation annual data and flow rate in Jalayer and Razin station according to Figure 5 (a) and (b) indicate uptrend and downtrend for precipitation and flow through the study time. Basically the relationship between precipitation and flow should be direct but inverse relationship of precipitation and flow in Figure 5 and 6 due to human activities. In order to study the impact of Saveh dam on the aquifer precipitation and flow in Shahabasi station was investigated through 1967-2007. Figure 5 shows changes in precipitation and flow in Shahabasi station that located after Savah dam on Qarachay River.

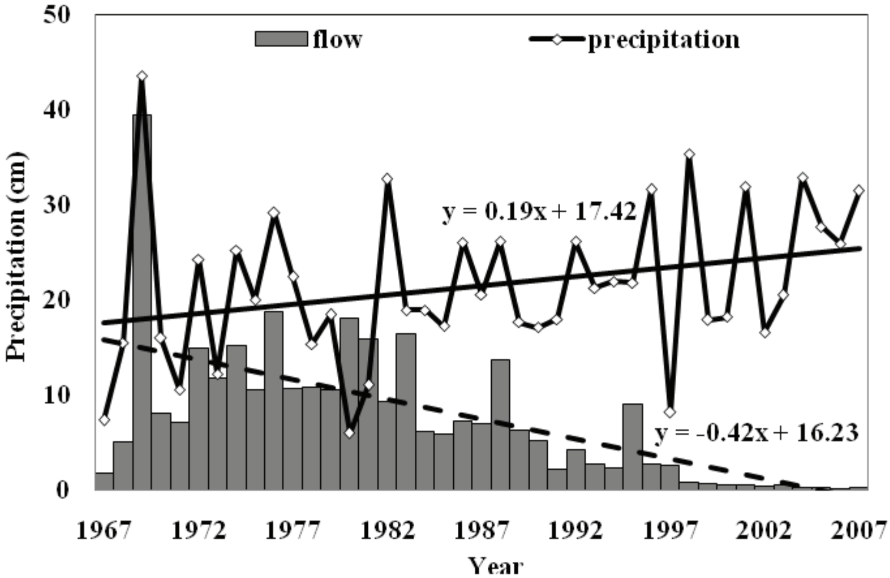

Fig. 6. Precipitation and flow Trend in Shahabasi station (1967-2007)

Figure 6 shows that after operation of Saveh dam in 1994 flow of Qarachay River severely reduced. Precipitation and flow in Shahabasi station through 1967 to 2007 show uptrend and downtrend, respectively. Qarachay River is the main of resources of groundwater recharge of Saveh aquifer.

Average annual groundwater drop in Saveh aquifer has been measured 1.46 m. Cumulative drop of groundwater through 1992 to 2008 had been equal to 26.29 m (IWRM, 2005). Figure 7 shows the drop of groundwater in Saveh aquifer.

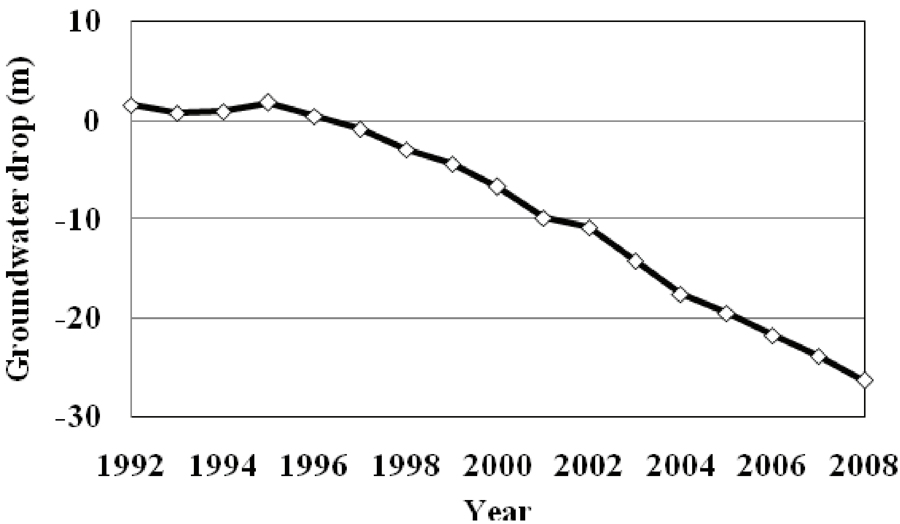

Fig. 7. Cumulative groundwater drops in Saveh aquifer (1992-2008)

Figure 7 obviously show the groundwater drop from 1995 increased. The result of study indicated that construction of Saveh dam on Qarachay River is the main reason for groundwater drop in Saveh aquifer. In order to consider the effect of groundwater discharge on the fluctuations, monthly pumpage was reviewed. Figure 8 shows monthly exploitation of Saveh aquifer from January 2002 to December 2008.

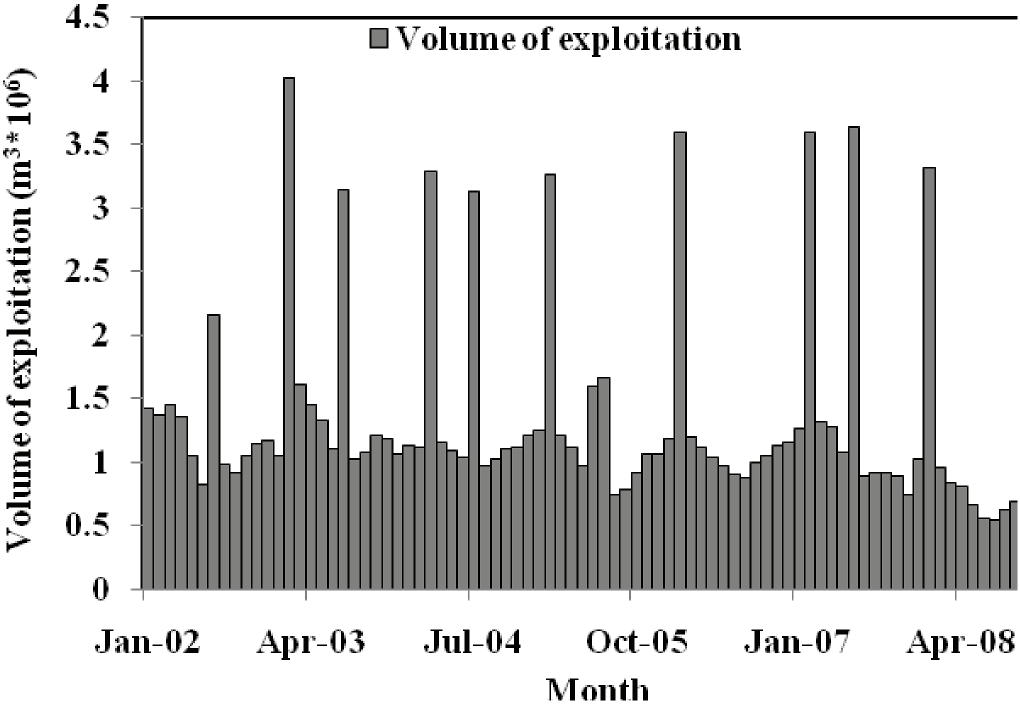

Fig. 8. Volume of exploitation of Saveh aquifer (from Jan 2002 to Dec 2008)

As the Figure shows, the total volume of exploitation did not significantly increase during 2002 - 2008. February and July has the largest exploitation of groundwater for agriculture. Also, Figure 8 indicates that groundwater drop in Saveh aquifer was not due to overexploitation. Results imply that construction of Saveh dam is one of the main reasons for groundwater drop in Saveh aquifer.

Temporal analysis of quality changes in Qarachay and Mazlaqan Rivers has showed increasing trend in their quality changes. Electrical Conductivity (a) and Sodium Absorption Ratio (b) changes from 1971 to 2005 in Razin, Jalayer and Shah Abbasi Stations was showed in Figure 9.

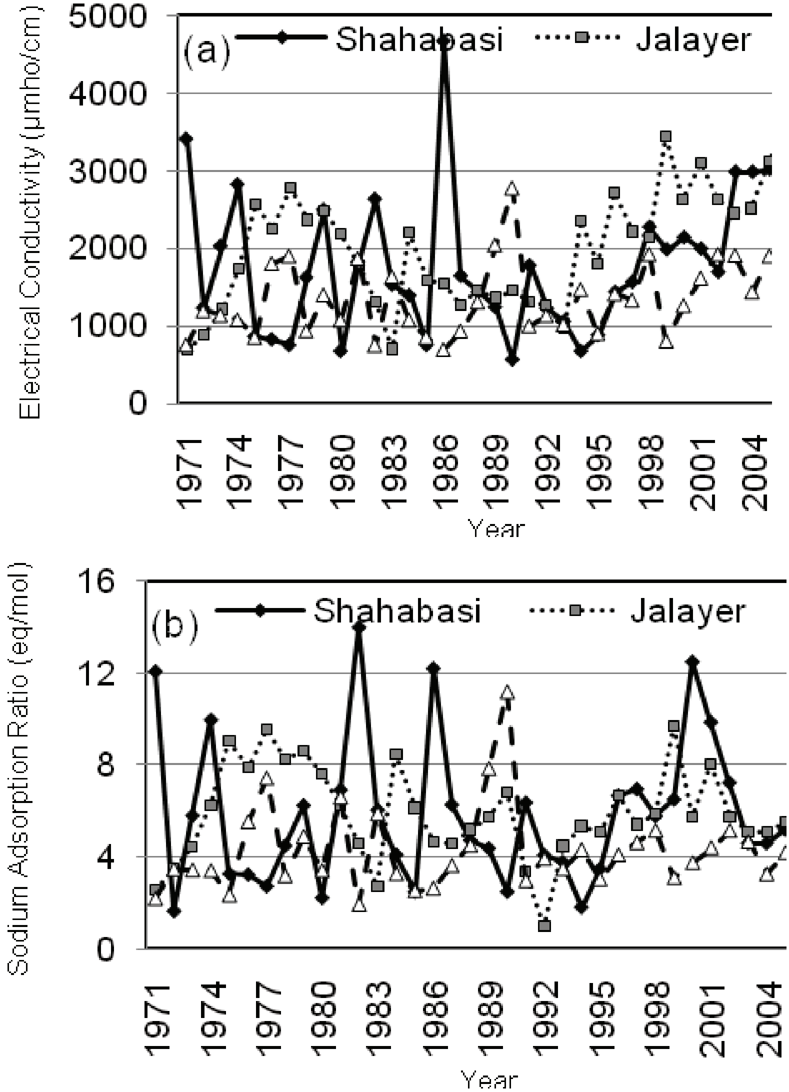

Fig. 9. Temporal changes of Electrical Conductivity (a) and Sodium Absorption Ratio (b) (1971- 2005)

According to Figure (9) Part (a), Electrical Conductivity of the Razin, Jalayer and Shahabasi stations have incremental process. Electrical Conductivity values in Shahabasi station is more than Jalayer station that its reason can be located Shah Abbasi station after Jalayer station. Qarachay river quality analysis shows that the water quality of the river has been declined from 1971 to 2005. In the other words, according to Wilcox method the river water quality had been reduced from C3-S1 class to C4-S2 class.

To evaluate temporal changes of groundwater quality of Saveh groundwater, the average annual water quality parameters from 2002 to 2008 was analyzed.

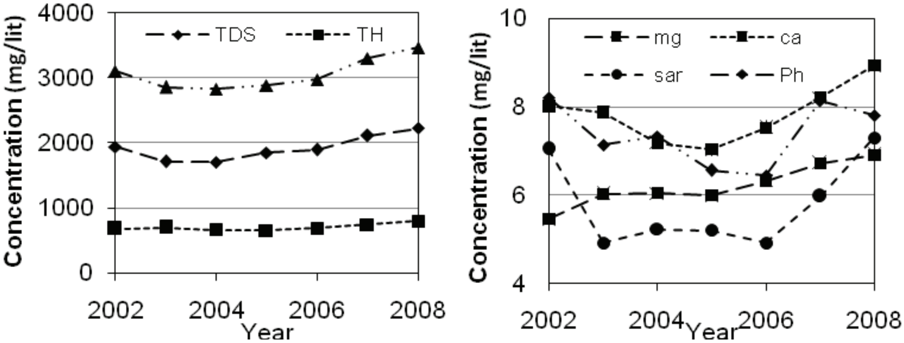

Fig. 10. Temporal changes of groundwater quality parameters (2002-2008)

Figure 10 clearly indicates higher concentrations of calcium ions (Ca), Electrical Conductivity (EC) and Total Dissolve Solutes (TDS) in Saveh groundwater during 2002 to 2008. Comparison of surface and groundwater quality in Saveh plain shows that greater equality of Electrical Conductivity and Sodium Absorption Ratio in surface water. Figure 11 show map of groundwater quality of Saveh that is plotted for agricultural purposes based on wilcox diagram.

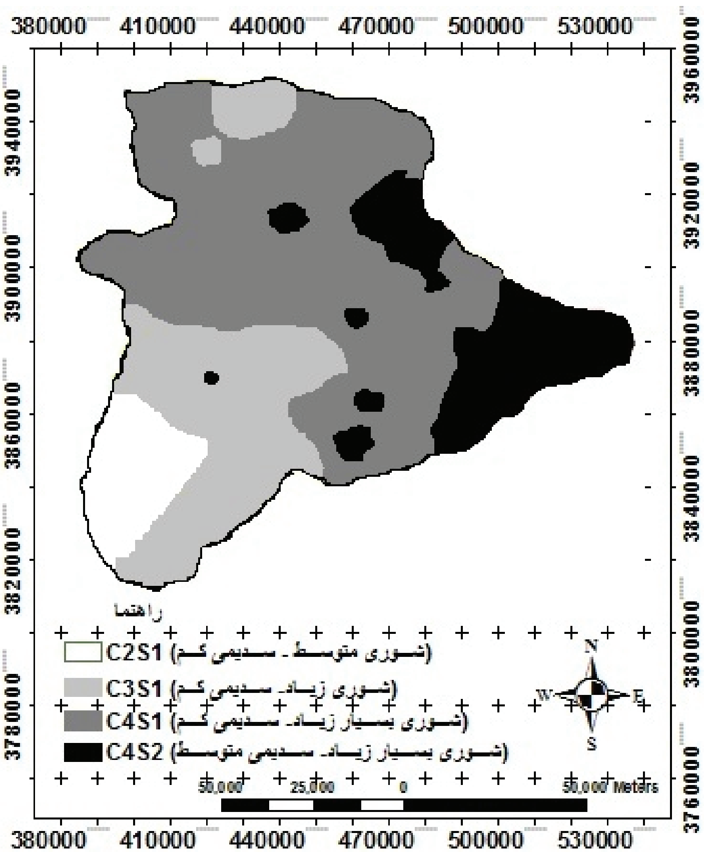

Fig. 11. Groundwater quality map for agricultural purposes (2008)

According to Figure 11 groundwater quality for agricultural use in Saveh aquifer were classified in 4 classes including; 16% in class C4-S2, 46% in class C4-S1, 30% in Class C3-S1 and 8% in Class C2-S1. According to the results, construction of Saveh dam has been the main reason of groundwater quality decline in Saveh aquifer. Generally speaking, the effects of irrigation and drainage networks on environment and water bodies need to be determined to have a sustainable development.

4. CONCLUSIONS

The importance of damage to ecosystems from irrigation and drainage networks has only been focused recently and the current capability of predicting the impacts of non-sustainable operation of such networks on the water resources is limited. Low irrigation wastewater quality, changes to the low flow regime in rivers because of dams construction for irrigation purposes, rising groundwater levels because of low irrigation efficiencies, over-exploitation of groundwater and severe consequences such as salt water intrusion and land subsidence are the main impacts on water systems, resulting in the non-sustainability of irrigation and drainage projects. The main aim of the current study has been to evaluate the environmental impacts of Saveh irrigation and drainage network and the associated dam, especially on surface and groundwater bodies. In order to achieve this aim, flow and quality data of the two main rivers of the study area, Qarachay and Mazlaghan rivers, groundwater levels, discharge volumes and quality data in prior and after the network construction, and also precipitation, evapotranspiration were used. It has been also focused to achieve a comprehensive vision of changes in water balance and distinct of impacts of irrigation and drainage system. Spatial and temporal changes of groundwater quality and quantity have been analyzed using Geostatistics Software version 5.1 and the relevant maps were created based on Wilcox method, involving GIS software, Version 9.3. The assessing results of meteorological drought using Standardized Precipitation Index (SPI) for three meteorological stations in the study area including; Shah Abasi, Imamabad and Ahmadabad indicated that extreme drought had been occurred through years,1970, 1978, 1979, 1980, 1983 and 1985. Calculations of rainfall – flow trend for three other stations, ShahAbbasi, Razin and Jalayer, showed that there was increasing trend in rainfall and decreasing trend in flow. The groundwater discharge volumes indicate that the exploitation of groundwater through 2002 to 2009 had no significant increase due to a continuous monitoring and protection. However, in two months of each year, May and October, a high level of discharges have been recorded, 3 to 4 million cubic meters in overall. According to the result, the average flow of Qarachay river after operation of Saveh dam has been reduced to 0.67 m^3/s in contrast with 6.03 m^3/s which is reported for before of the dam operation. Qarachay river quality analysis shows that the water quality of the river has been declined from 1971 to 2006. In the other words, according to Wilcox method the water quality had been reduced from C3-S1 class to C4-S2 class. Moreover, the groundwater drop after operation of Saveh dam (1995) has been recorded to be equal to 26.29 meters. Average Electrical Conductivity (EC), Sodium Absorption Ratio (SAR) and Total Dissolve Solid (TDS) in the Saveh aquifer, were obtained to be equal to 3100/6 µmho/cm, 5/76 eq/mol and 1948/6 mg/l. Groundwater quality for agricultural usages in Saveh aquifer were classified in 4 classes including; 16 percent in class C4-S2, 46 percent in class C4-S1, 30 percent in Class C3-S1 and eight percent in Class C2-S1. According to the results, construction of Saveh dam has been the main reason of groundwater drop levels in Saveh aquifer. Generally speaking, the effects of irrigation and drainage networks on environment and water bodies need to be determined to have a sustainable development.

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