

## AN INVESTIGATION ON THE EFFECTS OF CLIMATE CHANGE AND GLOBAL WARMING ON WATER RESOURCES IN DRY COUNTRIES USING REMOTE SENSING AND GIS (A CASE STUDY: IRAN)

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### ABSTRACT

For an efficient management of water resources, it is necessary to evaluate the occurrence of climate change and its country/basin wide consequences. Iran is characterized by diverse climatological and hydrological regimes. In dry countries, such as Iran, dryness is an intrinsic characteristic of climate and water resources; thus, the climate change and global warming issue is always controversial. This diversity together with the well hydrologic condition of the rivers that originate from the snowy mountainous areas of the adjacent countries intensifies this argument. In this research, using 696 concurrent images of monthly temperature and precipitation, the spatial and temporal changes of these two most important climatological variables were investigated. A long term increasing trend for temperature was obtained, and the variation of the precipitation across the country illustrated to be meaningful too. In this regard, in the north-western and south-eastern regions of Iran a decreasing trend in precipitation could be seen. The Mann-Kendal test verified the reliability of the two captured trends. The research continued to find the effects of the global warming on the hydrological regime of Iran's water resources. To fulfil the mentioned purpose, some hydrometric and gauge stations corresponding to 6 major Iranian catchments were selected and their long term average yield was computed and examined. The observed decreasing trend in the available water across the country is in agreement with the results obtained from remote sensing analysis of the temperature and precipitation variables. Examining the time evolution of SPI index also illustrated that the occurrence of the long lasting and severe/extreme droughts in recent decades in some parts of Iran, is not just a random process, but also could be a direct result of the climate change and universal global warming that could obviously lead to many negative impacts on water resources in the target area.

### 1 INTRODUCTION

The global climate change impacts on agriculture and environment could change

photosynthesis process and crop yields. The observed changes in climate might be attributed to its long term natural fluctuations or to the human activities like land use changes and green house gases emission (Sarkar and Kafatos, 2004). The effects of climate change on vegetation cover and agricultural products have been investigated by Anyambe and Eastman (1996) and Li and Kafatos (2000), showing that the climate change and global warming have undesirable effects on many countries with approximately fifty percent of the associated total losses and damages being observed in agricultural section. The CO<sub>2</sub> and the other green house gases emission caused by the anthropogenic effects are leading the globe toward an uncertain future with respect to living habitat and food security (Tan and Shibasaki, 2003). One of the most important consequences of increasing concentration of CO<sub>2</sub> in the atmosphere is the earth surface temperature rise. According to the Intergovernmental Panel on Climate Change (IPCC) the average temperature of the earth will increase about 1.4 to 5.8 degrees of centigrade at the end of the 21th century, changing spatial and temporal pattern of precipitation and the frequency of the extreme climatological events around the globe (IPCC, 2001a). Climate change also affects the hydrological cycle and its important features like available water, drought and flood (Tao et al., 2003). In such a situation, even if the total amount of precipitation stays around its long term mean, the hydrological losses such as runoff and evapotranspiration will increase regarding the other climatological factors, especially temperature. It has been proved that increasing in O<sub>3</sub> in accompanying with increasing CO<sub>2</sub> in the troposphere adversely affects the vegetation cover of the Earth (Fuhrer, 2003; Chartzoulakis and Psarras, 2005). As it has been mentioned, the climatological data and the results of the simulation models reveal that the average temperature of the earth is increasing, whereas some places of the globe has experienced a noticeable reduction in summer precipitation and also the frequency of drought and heat waves in arid and semi arid regions is increased. The environment has not been a winner in the competition field yet. In developing countries like Iran, this is the environmental requirements that have to pay the cost of water shortage. The reduction of environmental minimum requirements introduces the ecological habitats into a crisis and could destroy it completely that will intensify the consequences of the climate change (Chartzoulakis and Psarras, 2005). Research results suggest that overcoming the consequences of the climate change and lessening the oncoming losses need the provision of appropriate policies fitted to each region in respect to its climate condition.

Planning for the development of areas located on the dry belt of the earth depends mainly on the efficient management of the available water resources. For many developing countries which are confronted with water scarcity and ever growing population, food security is of vital importance. Global warming and its consequences can affect the plans and strategies taken to guide nations toward a better condition of livelihood. Undoubtedly, the global warming adverse effects might increase the crop water requirement and intensify potable water scarcity, particularly in arid and semi-arid countries like Iran. However, there is not a common consensus on the effects of the global warming or at least on its areal extent in countries like Iran that drought is their intrinsic feature.

Dryness and drought are two close words but with two different meanings. Dryness is an intrinsic feature of some environments, but drought is considered as a temporary deficiency of precipitation in a given region with respect to its long-term normal,

leading to a reduction in water availability and water scarcity for agricultural, industrial and municipal demands. Drought occurrence can be felt much faster and easier in humid regions than in the dry ones. In humid region, a deficit of 20 percents in annual precipitation with respect to the long term average can be considered as an initiated drought period. This amount of reduction for a humid region with an annual precipitation of 1500 mm is equal to 300 mm which is several times of the annual precipitation for central arid regions of Iran. For example, a 20 percents reduction in Yazd province in central part of Iran means a loss of 10 mm per year that regardless of some consequences for its flora has a minor effect on the region's water resources. The other issue that makes much intense the drought and its importance realization in dry regions is the condition of Border Rivers. When there is drought condition in the watersheds of the Border Rivers of Iran like the Helmand River and the Aras River, which emanate from the higher latitudes (humid areas), we are confronted with two types of problems: drought occurrence reduces their yield and meanwhile increases the average temperature that in turn increases crop water requirements. In such a condition, it is necessary to be conservative in water consumption by applying the policies like increasing water conveyance and application efficiency, which in turn needs to establish the belief of drought occurrence and global warming in both people and governors. Experiences showed that this task is not so easy to do in developing countries like Iran and needs a proper plan to enhance the public knowledge about this fact. Investigations about the influence of the global warming on the water resources and thermal balance in Iran are limited, and the gist of the issue and the escalating trend of drought severity and duration as an impact of the global warming are still doubtful in some respects. However, investigations on annual precipitation trend in Iran revealed that a consistent decreasing trend in annual precipitation amount was detected for most of the stations over the country during the last half century. These decreasing trends are particularly significant in western and north-western Iran (Raziei et al., 2005; Modarres and Sarhadi, 2009, paper to be added).

The present study focused on the consequences of the global warming on water resources in Iran that might appear as an increase in the ecological water requirements and also a reduction in the country's water resources due to the increasing drought frequency, duration and magnitude.

## **2 DATA AND METHODS**

To assess time behaviour of surface water resources and drought variability over the country, mean monthly stream-flow data corresponding to representative stream gages of 6 major Iranian catchments and monthly total precipitation associated to 44 synoptic and climatological stations were used (Fig. 1). The used synoptic/climatological stations have the longest historical data records (1961-2005) and are relatively regularly distributed over Iran so that all climate regimes of the country are represented. Station data are complete and were already quality controlled by the Iranian Meteorological Organization. The few missing values in some stations were estimated from the neighbouring stations time series using a linear regression method.

To investigate the trend of the flow variation across the country and detect the probable impact of climate change on the surface water resources in Iran, monthly discharge of representative gauges associated to 6 major Iranian catchments were also

analyzed on the basis of 1971-2003 common time section. Moreover, to analyze the long term trend of the mean monthly temperature across the country a collection of satellite images (696 images) from 1950 to 2007 were retrieved from the National Oceanic and Atmospheric Administration (NOAA), University of Colombia (USA) and the International Research Institute for Climate and Society (IRI) and then were processed using the following formulas proposed by IRI:

$$P = 32.468502DN \quad (1)$$

$$T = 0.3661417DN - 55 \quad (2)$$

Where: P = precipitation (mm/month), T = mean monthly temperature (°C), and DN is the digital number of each cell. By using these images the spatial pattern and long term trend of the precipitation and temperature variables across Iran were captured.

The long term trend of the time series of the aforementioned variables was examined using the Mann-Kendal (MK) trend test. The MK test is based on the comparison of the number of residuals that are greater than the remaining elements of the series and is considered as one the most powerful methods for detecting monotonic trend (Raziei et al., 2005; Rodriguez da Silva, 2004; Modarres and Sarhadi, 2009). This test is used in many fields, including hydrology and climatology, to investigate the linear /nonlinear trend of the studied time series (Chen et al., 2007; Cannarozzo et al., 2006; Gadgil and Dhorde, 2005). The MK test is independent of any assumption about the distribution of input data and the outliers have no important effects on its results (Lazante, 1996).

For investigating the probable effects of the climate change on the surface water resources, it is required to study the hydrological balance of the watersheds. The simplest way to accomplish this task is to study the time variability of the yield of the rivers and examine the embedded trend using a dimensionless index. The well known percentage of normal index which compares each individual value of the time series to its long-term mean is used by the Ministry of Power of Iran to define the hydrological condition of the rivers, as a basis for the decisions made by the responsible organizations, to manage water resources considering the long term and short term governmental policies. Accordingly, the hydrological condition of the rivers is classified into critical, shortfall, Stress, and tolerable classes by using pre-defined thresholds as illustrated in Table 1. If there is not any shortage in the river, the hydrological condition will be considered as the wet condition.

Dry and wet conditions at meteorological stations have been assessed by applying the Standardized Precipitation Index (SPI; McKee et al., 1993) at 12 months time scale. The SPI is widely used in drought monitoring centres and in several drought studies. It is a useful tool for capturing the climate variability associated with water shortage or surplus in different areas, and has several advantages (Keyantash and Dracup, 2002; Heim, 2002). It is based on precipitation alone and its computation requires a long-term precipitation record. For each month, the corresponding precipitation time series is fitted to a Gamma probability distribution (Guttman, 1999) that is normalised through an equal-probability transformation. SPI values between -0.99 and +0.99 denote near normal conditions, between -1 and -1.49 moderately dry, between -1.5 and -1.99 severely dry and less than -2 extremely dry conditions. The same applies to positive values, i.e., wet classes (Bordi and Sutera, 2004). To investigate drought tendency in the

studied meteorological stations the SPI at 12 months time scale (hereafter SPI-12) was considered. The annual weighted cumulative drought severity in each station was estimated by multiplying the annual sum of SPI in months with negative SPI values by the probability of drought occurrence for each year. The probability of annual drought occurrence for each year and each station is obtained by dividing the number of months that have negative SPI value by 12 (Kim et al., 2002; Loukas and Vasiliades, 2004). Time series of weighted cumulative drought severity of the studied stations were then examined for drought tendencies and trends using linear least square method and MK trend test.

**Table I.** Classification of the hydrological condition of Rivers

| Condition | Percents of shortage |
|-----------|----------------------|
| Critical  | 60 – 85              |
| Shortfall | 40 – 60              |
| Stress    | 30 – 40              |
| Tolerable | < 30                 |

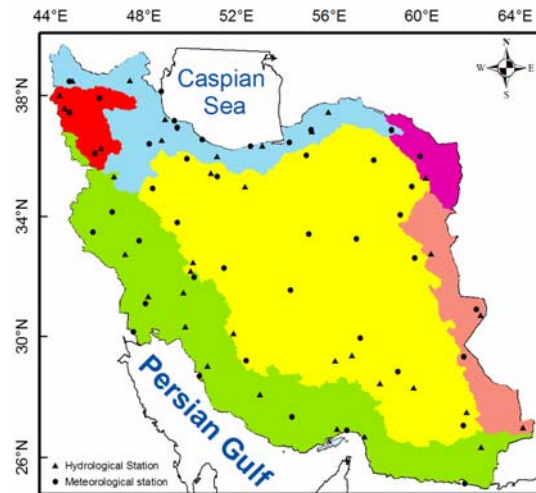


**Figure 1.** The used meteorological and hydrological stations distributed over the six major watersheds of Iran.

### 3 RESULTS

To analyze the time series of temperature and precipitation associated to the pixels of the images, the whole 2600 pixels of each image covering the whole country, for each month and each variable, were processed via eq. (1) and (2) and the amount of monthly temperature and precipitation were extracted and tabulated. The MK trend test was then applied to the time series of each pixel and the results were mapped to

illustrate the spatial pattern of MK trend coefficient associated to both precipitation (Fig. 2) and temperature (Fig.3).

Figure 2 illustrates the spatial pattern of Mann-Kendal coefficient for precipitation variable in which the negative (positive) values represent a descending (ascending) trend, ranging from -10 to 7. In this regard, the north, northwest, south, and southeast parts of the country have experienced a reduction in monthly precipitation, while the other parts have observed an ascending trend. For the southeast of Iran, this finding is compatible with that of Modarres and Rodriguez da Silva (2007) and Raziei et al. (2005), while there is not such a coincidence for the other parts of the country. It must be noted that the map of MK does not give any information about the amount of precipitation; thus, the ascending trend of the precipitation in the central parts of Iran could not be translated as a meaningful increase in the amount of monthly precipitation. Contrarily, in Fig. 3 the MK trend test takes only the positive values from 5 to 13, showing an ascending trend in mean monthly temperature in the whole country. The south-eastern part of Iran, which is mainly located in Sistan and Balouchestan Province, on the border of Afghanistan and Pakistan, is experiencing the highest temperature rise. However, as is illustrated in Figures 2 and 3, the consequent results of increasing temperature in accompany with decreasing precipitation in most parts of Iran (e.g., south-eastern region) altogether inversely affect the target area via increasing environmental water demand and intensifying water imbalance in the country.

To investigate the trend of the yield of the rivers across the country the percent of normal index was used. To keep the paper in an acceptable extent, just the results of the 6 main watersheds are illustrated. By assigning a number to each category of Table 1 the qualitative categories were substituted with the quantitative measures to ease representing the time behaviour of the yield of the rivers graphically (Fig. 4). In this regard, the categories of Wet, Tolerable, Stress, Shortfall, and Critical were replaced by numbers 5 to 1, respectively. The descending trend of the yield of the rivers for the whole country, based on the 6 main watersheds, could be seen in Figure 4. The negative slope of the trend line in conjunction with the positive slope of the temperature trend line may confirm this claim that the global climate change has affected Iran's hydro-climatological conditions.

Figure 5 and 6 also show the time variability of weighted annual cumulative drought severity for SPI-12 in some selected stations characterized by positive and negative trends, respectively. According to Fig. 5, Abadan and Bushehr stations in the coast of Persian Gulf and Isfahan and KhooreBiabanak in the central part of Iran are characterized by positive trend, showing a tendency towards wetter condition. Inversely, the negative trends were observed in Khoy, Orumieh and Sanandaj stations in the north-western and also in Bam, Iranshahr and Zahedan in the south-eastern part of Iran, indicating that these stations tend towards a drier condition. However, considering the MK trend test the observed trend is statistically significant at  $\alpha=0.01$  in only KhooreBiabanak (positive trend) and Khoy (negative trend) stations. This finding is consistent with those we already obtained by analysing the satellite images and also is in agreement with the previous studies (e.g., Modarres and Rodriguez da Silva, 2007; Raziei et al., 2005).

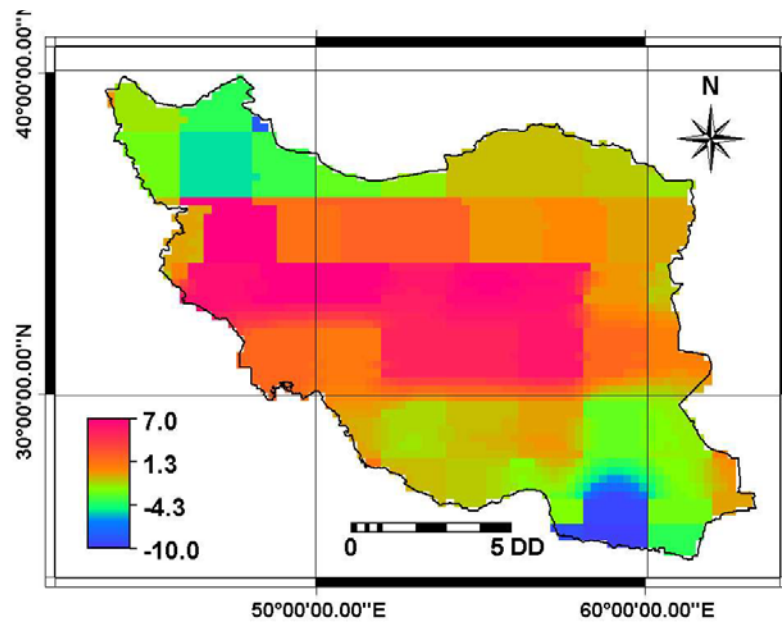


**Figure 2.** Spatial distribution of the Mann-Kendal coefficient for total monthly precipitation

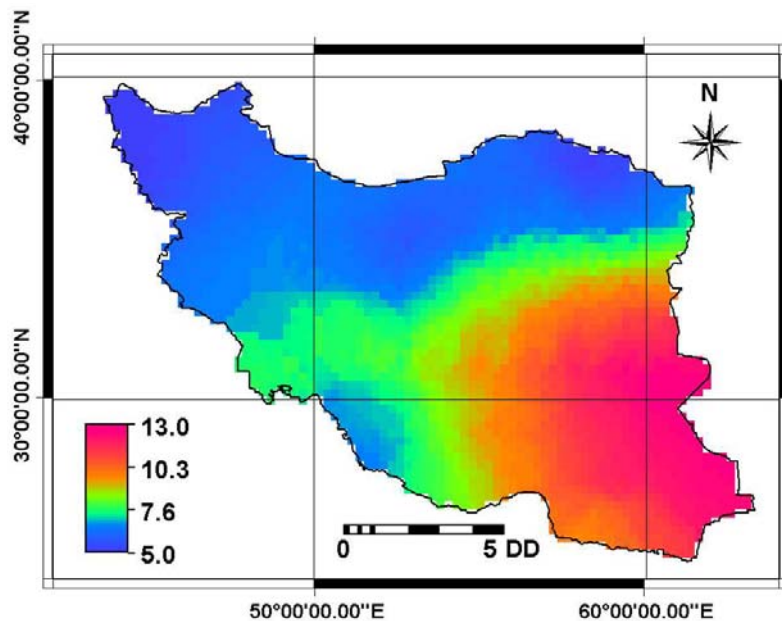


**Figure 3.** Spatial distribution of the Mann-Kendal coefficient for mean monthly temperature

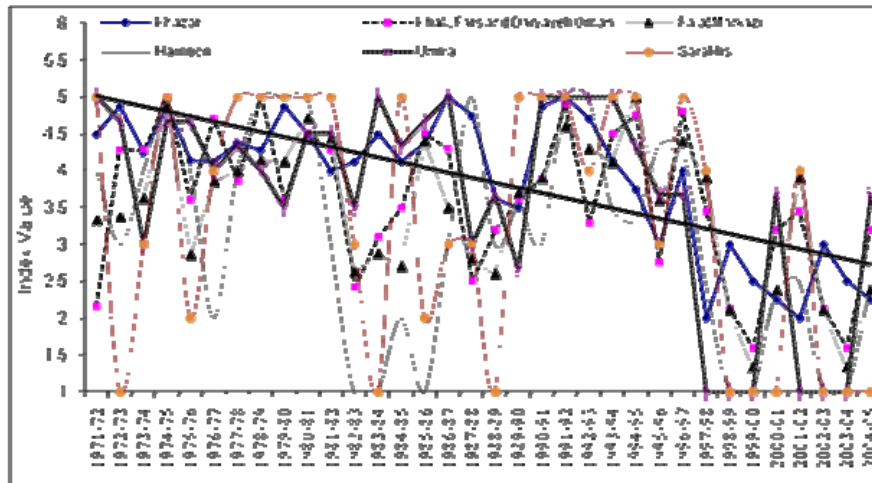


**Figure 4.** The Hydrological trend of the surface water resources in six major Iranian watersheds

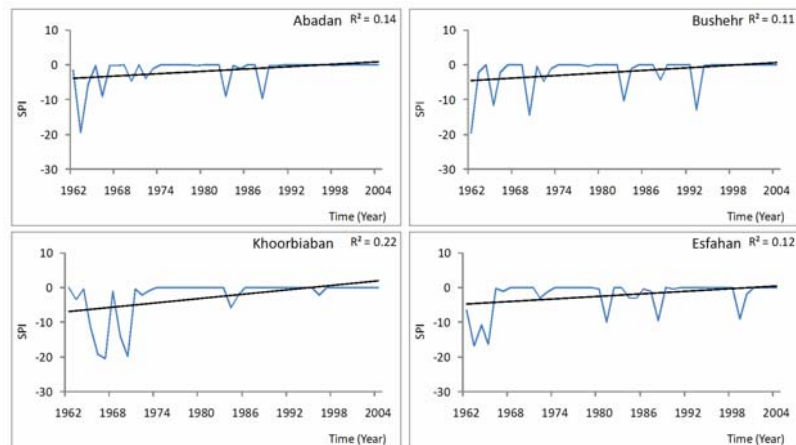


**Figure 5.** Time variability of weighted annual cumulative drought severity for SPI-12 in some selected stations characterized by positive tendency toward wetter condition

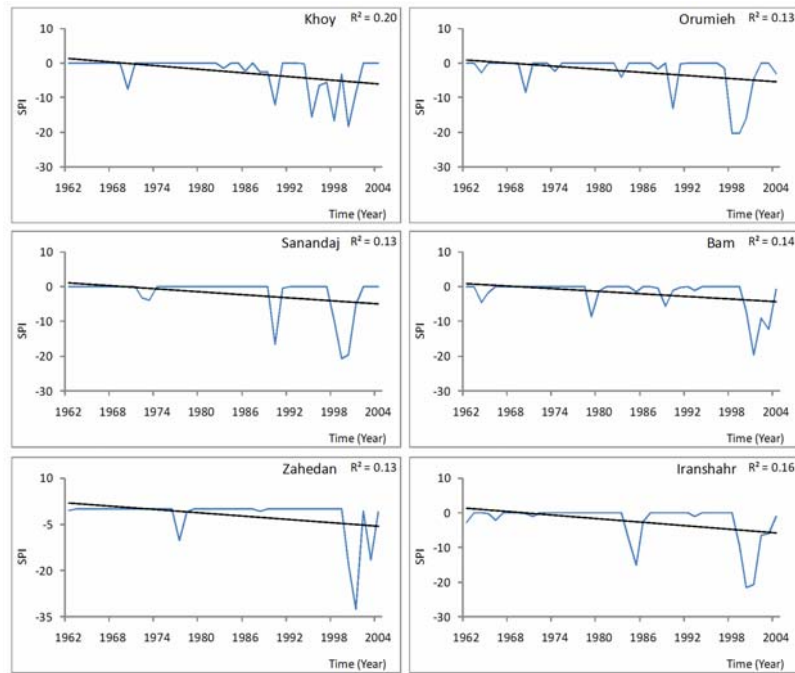


**Figure 6.** Time variability of weighted annual cumulative drought severity for SPI-12 in some selected stations characterized by negative tendency toward dryer condition

#### 4 CONCLUSIONS

In this research, time variability of precipitation and temperature, as the most important and representative climatological parameters were used to investigate the occurrence of the climate change in Iran and to chase the influences of the global warming in the country. In this research, two sets of the satellite images (696 images) of monthly mean temperature and total precipitation from 1950 to 2007 were used to analyze the corresponding temporal and spatial pattern across Iran. To examine if the temperature and precipitation variables across the whole country have experienced any change due to global warming and climate change phenomenon the Mann-Kendal trend test was applied to the time series of each pixel of the satellite images and the results were then mapped. The Mann-Kendal trend test result indicated that the temperature variable has been increased significantly (at  $\alpha=0.01$ ) over the whole country, whereas the precipitation variable at most parts of Iran have experienced a decreasing trend during the past 60 years. To illustrate the consequences of the observed changes in these two climatological variables as an indication of the climate change and global warming over Iran, the variation of the yield of the rivers were studied. For this purpose, the most representative stream flow gages of 6 major Iranian watersheds that are not influenced by the anthropogenic effects were selected for further investigation. The result reveals that the surface flow over the main watersheds of Iran is experiencing such a negative trend, being in agreement with the observed negative trend in precipitation variables over almost all parts of Iran. The observed decreasing trend in the surface flow of the

main watersheds of Iran can be attributed to the adverse effects of decreasing trend in precipitation and increasing trend in the temperature over Iran. It is worth to mention that the increasing temperature trend leads to an increase in the environmental water demands in the form of evapotranspiration, while the decreasing trend in precipitation is responsible for a considerable reduction in the stream flow input sources which totally appear as a shortage in the stream flow amount.

The results of the analysis of the satellite images for precipitation gave no firm conclusion about the climate change influences over Iran. Thus, the SPI, as a tool for drought monitoring based on the cumulative precipitation, was used in this research to capture the trend of drought duration and intensity for the whole country. The SPI analysis was in agreement with the general trend observed in the images. The results show that the drought severity, though not so significant, is increasing in the most parts of the country through the past 30 years. Based on this research one can say that Iran has been influenced by the climate change and global warming during the past decades. Accordingly, it is necessary to include this phenomenon and universal findings in the long term national policy for water management and reducing the probable nations' vulnerability due to future water scarcity.

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