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Changes of extreme drought and flood events in Iran

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ABSTRACT

Located in an arid and semi-arid region of the world, Iran has experienced many extreme flood and drought events in the last and current century. The present study aims to assess the changes in Iran's flood magnitude and drought severity for 1950–2010, with some time span variation in some stations. The Mann-Kendall test for monotonic trend was first applied to assess changes in flood and drought severity data. In addition, to consider the effect of serial correlation, two Pre-Whitening Trend (PWT) tests were also applied. It was observed that the number of stations with statistically significant trends has increased after applying PWT tests. Both increasing and decreasing trends were observed for drought severity and flood magnitude in different climate regions and major basins of Iran using these tests. The increase in flood magnitude and drought severity can be attributed partly to land use changes, an annual rainfall negative trend, a maximum rainfall increasing trend, and inappropriate water resources management policies. The paper indicates a critical situation related to extreme climate change in Iran and the increasing risk of environmental changes in the 21st century.

1. Introduction

There is a globally growing interest in investigating extreme climate changes during recent decades, as the human, economic and ecological impacts of these events are large and potentially serious. The global effect of climate change on climatic variables such as precipitation (Costa and Soares, 2009; Kunkel, 2003; Norrant and Douguédroit, 2006) and temperature (Frich et al., 2002; Su et al., 2006) is evident. Caprio et al. (2009) found an increasing trend in the extreme temperature indicators of northwestern of the United States. You et al. (2008) applied 12 indices for extreme climate events in the eastern and central Tibetan plateau (TP) during 1961 to 2005 and reported increasing trends in temperature and most precipitation indices in the southern and northern TP and decreasing trends in the central TP. Aguilar et al. (2009) examined extreme temperature and precipitation in western and central Africa and found that temperature was clearly increasing and total precipitation was decreasing. Zhang et al. (2009) applied the Mann-Kendall test to detect trends in the Pearl River basin, China, and found significant increasing trends in the total precipitation and frequency of extreme precipitation intensity.

The above climate extreme indices can be placed in the first group of extremes, which are based on simple climate statistics and include very low or very high values (Easterling et al., 2000). The changes in the second group, which includes more complex event-driven extremes such as floods and droughts, have not yet been adequately investigated on a global scale. From the temporal and spatial points of view, the effects of changes in climatic variables of the first group can be observed after a long time, e.g., decades or centuries, and usually on a largely global scale, while the extreme flood and drought events happen in a limited area or region and do not last long. In addition, some regions may suffer from both flood and drought events. These bipolar extreme events can increase vulnerability and risk of extremes to human populations very rapidly in a nonlinear manner and decrease the efficiency of water resources management. Therefore, it is very critical to study the extremes in both high and low directions, especially in arid and semi-arid regions of the world (Forzieri et al., 2016; Peterson et al., 2013; Singh et al., 2014).

Relatively little work has been carried out on extreme flood and drought changes on the global scale. In southern Italy, for example, the frequency of severe drought periods has changed during the last 30 years (Piccarreta et al., 2004). Sheffield et al. (2012) demonstrated that little change has occurred in global drought over the past 60 years. Across the USA, hydrologic drought trend analysis has shown a negative trend in both drought duration and severity in the eastern regions and a positive trend in the western regions of the continental United States (Andreadis and Lettenmaier, 2006). Recent studies demonstrate changes are occurring in terms of hydro-meteorological extremes (flood, low flows, and rainfall) in Canada, and further changes can be expected in future under the impact of climate change (Burn et al., 2010, 2011; Burn and Whitfield, 2015). Wang et al. (2008) found a significant positive trend for extreme streamflow variables of the Dongjiang River basin in southern China using the Mann-Kendall test. Collins (2009) investigated the trend of flood magnitude in England

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and showed a strong evidence for an increase in flood magnitudes after 1970.

The climate change and changes in the extreme climate variables of the Middle East, including some parts of Iran, have also been investigated by some studies. For Turkey, Tayanç et al. (2009) found an increasing temperature trend and a decreasing precipitation trend. The effect of rainfall change on streamflow and groundwater was investigated by Samuels et al. (2009) in the Jordan River. Evans (2010) predicted precipitation and temperature increases for western Iran using General Circulation Models (GCMs).

In recent years, the number of studies on climate change in Iran has been growing rapidly. Looking at the changes in temperature indices such as maximum and minimum temperature reveals climate warming of the country during the last half century. An increasing trend is observed for both maximum and minimum temperature over the whole country except some small areas. The warm nights and days and warm spell duration also indicate a positive trend across almost the entire country (Nasri and Modarres, 2009; Rahimzadeh et al., 2009; Zhang et al., 2005). More recently, Raziei et al. (2014) investigated trends in rainfall indices and showed positive trend for maximum daily rainfall and negative trend of below 75th rainfall quantiles.

Flood and drought trend analyses in Iran have not been investigated thoroughly, even though their impacts have been very seriously increasing. Two examples of the extreme flood and drought events in recent years are given here to illustrate the risk of extreme flood and drought events in Iran.

On Friday, 10 August 2001, a 200-year return period flash flood occurred in Golestan province, in the northern territories, with the peak flow rate of 3017 m^3/s. This catastrophe affected more than 27,000 people, rendered 10,000 homeless, and killed 247 (United National Office of the Coordination of Humanitarian Affairs, Draft interagency Mission report: Floods in Golestan, Iran, 2001, http://ochaonline.un.org). The financial loss of this destructive flood was estimated at US$ 77.25 million. Although a heavy storm was one of the main reasons for this flood, 50% deforestation and considerable land use change in northern Iran during the last 30 years were assumed as effective factors for this disaster.

In contrast, during 1997 to 2001, a severe 40-year return period drought affected half of the country's provinces, with a loss in the agricultural sector estimated at more than US$ 10 billion (National Center for Agricultural Drought Management, http://www.ncadm.ir). Most of the major rivers and lakes of the country went completely dry during this drought period (Foltz, 2002) and a Gross Domestic Product (GDP) reduction of about 4.4% was reported (Salami et al., 2009).

The more recent severe drought period (2007–2009) devastated the country on a larger scale than the previous drought period. A US$ 19 billion loss in the agricultural division has been reported during 2006 to 2008, and a 20% average reduction of rainfall has been reported for 2008 compared with a 30-year average. The drought severity was higher in the northwestern to the southwestern territories of the country than other parts of the country in 2009 and moved towards the center of Iran (National Center for Agricultural Drought Management, http://www.ncadm.ir). In spite of these drought effects, very few studies have shown drought trend in Iran. For example, Raziei et al. (2009) and Abarghouei et al. (2011) indicated changes in Standardized Precipitation Index (SPI) as a drought index for different parts of Iran. Yet, they did not consider the fact that SPI shows both wet and dry conditions rather than drought severity.

Although the occurrence of extreme events are increased in recent decades, that does not imply they are specifically caused by climate change. Since extreme droughts and floods are occurring in different parts of Iran and resulting in extensive damages in various sectors, it is important to study the changes and reasons of these natural hazard phenomena. Therefore, the aim of this paper is to investigate flood magnitude and drought severity trends in Iran during the last half and the current century to show the direction of the changes in flood and drought risks for the 21st century in Iran. The rest of the paper is organized as follows: Sections 2 and 3 give the data and methods of study. Results are presented in Section 4 and a brief conclusion is given in Section 5. Some recommendations for future studies are given in Section 6.

2. Data

Iran is a relatively large country (1,648,195 km^2) lying between approximately 25°N and 40°N and 45°E and 65°E. It consists mainly of the Iranian plateau, which features two major folded mountain belts in the northern and western regions, Elburz and Zagros mountains, respectively. Along with these mountainous regions, which block moisture from reaching the central Iran plateau, the climate of the country is driven by both large atmospheric systems (such as subtropical high pressure) and local effects (such as proximity to the sea). These local and large physical and atmospheric factors cause a large spatial and temporal variability in climatic and hydrologic characteristics over the country.

2.1. Drought variable

The drought variable in this study is based on a standardized precipitation index (SPI) calculated using monthly rainfall data collected at 150 synoptic stations launched by the Iran Meteorological Organization (IRIMO). The recorded monthly-based precipitation time series span from 1950 to 2010. Fig. 1 shows the spatial location of the synoptic stations within different climate regions of Iran. The climate regions have been identified based on rainfall statistical characteristics and frequency distribution functions (Modarres and Sarhadi, 2011). These regions are representative of different atmospheric and local rainfall systems such as subtropical high pressure in arid and semi-arid regions (G1), proximity to the sea (G4, G6 and G8) and mountainous rainfall (G2, G3, G5 and G7).

Using the 12-month SPI time series for the synoptic stations, the drought variable is calculated for trend assessment. The drought variable in this study is drought severity calculated by applying the following equation:

$$S = -\sum_{i=1}^{D} \mathrm{SPI}_i \quad (1)$$

where drought duration, D, is the number of months with consecutive negative SPI, and drought severity, S, is then the cumulative values of SPI within the duration of a drought. For convenience, drought severity is multiplied by -1 to make a positive value. In this method, the SPI = 0 is selected as the threshold of a drought event.

2.2. Flood variable

The flood data used in this study include the observed annual maximum flow rate or the peak flows of 462 gauged stations on the unregulated rivers, distributed over major hydrologic divisions for the period of 1950–2010. The network of the gauging stations within the major basins used in our study is shown in Fig. 2.

The hydrographic network of Iran drains the country in different regions with different densities. It is divided into six major basins (Fig. 2). The first major basin or the Kashafrud basin drains the northeastern regions of Iran. The second one is the largest basin of Iran and drains the central arid and semi-arid region of Iran into internal basins. The third major basin drains the eastern territories of Iran into Hamoon Lake in southeastern of Iran. The fourth basin covers the north and the northwestern regions and drains into the Caspian Sea. The fifth watershed drains some parts of the northwestern regions into Urmia Lake, and the sixth watershed drains water through the western and southern