Multivariate Drought Index, Case Study: Najafabad Plain, Iran

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ABSTRACT

Drought is an extended period of deficient rainfall that causes damage to crops and reducing their performance, causes temporary scarcity of water for human/livestock consumption and influences the economic renewable resources. Because of the spatial and temporal variability and multiple impacts of drought, it is necessary to develop an integrated index for assessment of vulnerability of this phenomenon. Vulnerability includes physiographic, social, environmental and other factors like coping ability, awareness and regional economic activities. Over the years, various indices have been developed to identify onset, characterize and quantify the attributes of meteorological, hydrological and agricultural drought by various researchers. Anyway, an integrated index for assessment of vulnerability to drought is important especially for developing countries. The aim of this paper is presenting an integrated hydro-meteorological index for assessment of vulnerability to drought using multiple factors which includes hydrological, meteorological, land use and social factors. Spatial information of various factors was categorized in to various sub classes and maps were prepared in spatial domain using Geographic Information System (GIS). Different layers of above independent indicators and rainfall deficiency have been integrated using a weighing scheme. The study area is Najafabad plain a part of the Zayandehrood River Basin located in west-central Iran with semi-arid region. The long-term climate data (1991-2011) used for assessment. The results have been validated with intensive field surveys.

Keywords: Drought vulnerability, Rainfall, Index, SPI, Water utilization.

1. INTRODUCTION

Drought is a stochastic natural phenomenon that arises from considerable deficiency in precipitation. Among natural hazards, drought is known to cause extensive damage and affects a significant number of people (Wilhite 1993). On the other hand, drought occurs in every climate with varying frequency and characteristics. Drought damages could be high in regions with high water supply dependencies and cause serious regional impact. Thus, prediction of drought reduces its effects, in fact, there are many supply and demand issues that should be considered in evaluating the severity of droughts, depending on the perception of hydrologists, meteorologists, water resources engineers, agricultural researchers, economists, and a wide range of stakeholders.

Initial studies of drought aspects have been done by Palmer (1965), palmer used the meteorological parameters and soil moisture properties in order to define the indices for determining the drought severity and duration. PDSI was the first comprehensive index.

Droughts affect more people than any other natural hazards on the earth (Wilhite and Vanyarkho 2000). It is a normal characteristic of climate and its occurrence is inevitable. Rainfall is the primary indicator of drought and is the basis for most drought index. The occurrences of droughts are generally depended on deficit precipitation, low soil moisture, deficit river flows or groundwater as compared to their corresponding normal values. Drought is defined as the deficiency of surface water and groundwater that injuriously affects the usual crops, causes temporary scarcity of water for human consumption and influences the economic reproducible resources. Over the years, various index has been proposed to identify onset, characterize and quantify the attributes of meteorological, hydrological and agricultural droughts by various researchers like Palmer (1965), Rossi et al. (1992), McKee et al. (1993), Byun and Wilhite (1999), Tsakiris et al. (2007), and many other researchers.

Vulnerability refers to the degree of sensitivity to a hazard either as the result of varying exposure to the hazard or because of variation in the ability to cope with its impact. Region that have high exposure and low coping capabilities would have the highest risk from a given drought event and those with low exposure and high coping abilities would have the lowest risk. It is now being realized that a methodical planning is essential including followings options to cope with drought: (1) integrated information for strategic planning and management control and (2) reactive to proactive strategies for coping with drought.

There is different drought index such as SPI, PDSI and SWSI that as meteorological, agricultural, hydrological, and socio-economic drought. Hybrid indices such as HDI (Karamouz et al. 2008) that calculate drought vulnerability used drought damages and DVI (Pandey et al. 2010), that estimate drought vulnerability used physiographic factors. Hence there are no clearly adopted indices for vulnerability of drought. This study presents an integrated index for assessment of drought in time and space domain and presets in Najafabad plain in Iran.

2. Case Study

The study area is Najafabad plain a part of the Zayandehrood River Basin located in west-central Iran with semi-arid region (Fig. 1). In recent years, water has become increasingly scarce and the Zayandehrood Basin has shown signs of salinization of agricultural land and increased pollution in the lower reaches of the river. The Najafabad plain has an area of approximately 1720 km^2 with geographical coordinates between 50^0 57' to 51^0 44' north longitudes and 32^0 20' to 32^0 49' east latitudes. Elevation of the Najafabad plain varies from 2900 m above sea level in the northwest to 1580 m in the southeast. The Najafabad plain aquifer is recharged by irrigation percolation; canals and river seepage and precipitation directly on the plain. Aquifer recharge incidental to irrigation is a significant component of the water budget and has varied as irrigation practices have evolved (Safavi et al. 2010).

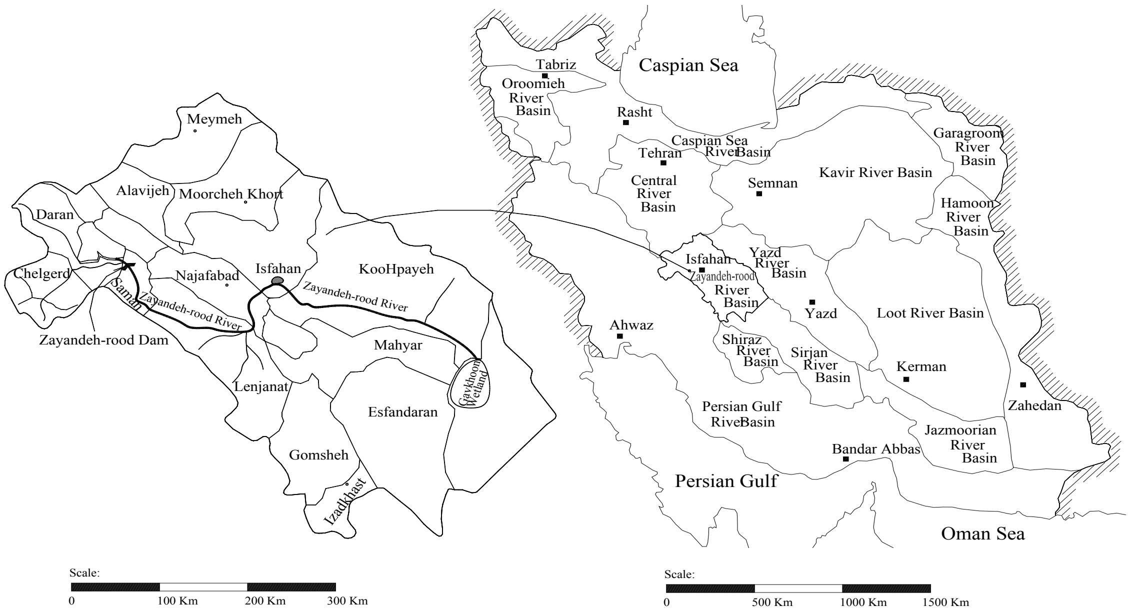

Figure. 1. Najafabad plain in the Zayandehrood River Basin

The total annual precipitation in the Najafabad plain during 1991-2011 is shown in Table 1. This table shows the variation of yearly precipitation in 20-year period from 62.4 to 271.8 mm.

Table 1. Annual precipitation in Najafabad plain

Year	1991	1992	1993	1994	1995	1996	1997
Precipitation (mm)	119.9	230.5	250.2	172.6	223.2	217.0	125.2
Year	1998	1999	2000	2001	2002	2003	2004
Precipitation (mm)	230.3	142.8	84.0	150.3	202.8	200.4	219.5
Year	2005	2006	2007	2008	2009	2010	2011
Precipitation (mm)	196.2	271.8	251.4	62.4	170.3	193.9	100.5

The Najafabad plain has a predominately semi-arid climate. Average rainfall is only 150 mm per year and most of the rainfall occurring in the winter months from December to April. During the summer there is no effective rainfall. Annual potential evapotranspiration is about 1950 mm (Jamab Consulting Engineers 2002).

As shown in Figure 1, a part of the Zayandehrood River with length of 36 km passes the west side of plain as a main source of surface water. The average width of this reach of the river is 45 m. This reach of the river recharges the aquifer.

In the past 20 years, a variability of rainfall occurred in the head of the Zayandehrood Basin, combined with a growing demand of water, has triggered in water management at this basin. Hence drought vulnerability and drought management are important at this basin.

3. INTEGRATED INDEX FOR DROUGHT ASSESSMENT

Because of the variability and significant multiple impacts of drought, it is necessary therefore to develop an integrated index capable of capturing the spatial and temporal dimensions of drought. The usual definition for drought is determined by the Standardized Precipitation Index (SPI, McKee et al., 1993) as a meteorological index. Fig. 2 shows the SPI for 12-month time for Najafabad plain for the period during 1991-2011. The values of SPI, as a statistical z-score or number of standard deviation of gamma probability distribution, between $1>z>-1$ shows the near normal precipitation event. Further the z-score -1 or less indicates the drought events. When the value of z-score goes lower than -1.5, it is the indication of severe drought condition. Based on SPI index, Najafabad plain had 13 normal years, 5 drought years and 3 wet years. But really we had more drought conditions in Najafabad plain in 21 years ago. Because in SPI, we can see only the role of precipitation or meteorological condition. Therefore, we need an integrated index including other factors such as hydrological, agricultural, water availability (surface water and groundwater), and environmental conditions. To produce an integrated index we need two major layers representing the static and dynamic factors affecting to drought vulnerability. Static layer consists of land use, slope, and soil type. Dynamic layer consists of precipitation, evaporation, mean temperature, groundwater availability, environmental needs, and surface water storage. The concept for derivation of drought vulnerability was originally described in the AVD methodology for drought assessment (Pandey et al. 2010). All layers representing spatial maps of different factors were prepared using Arc-GIS software. For example Fig. 3 and Fig. 4 present the soil type and precipitation over the Najafabad plain as a static and dynamic layer, respectively.

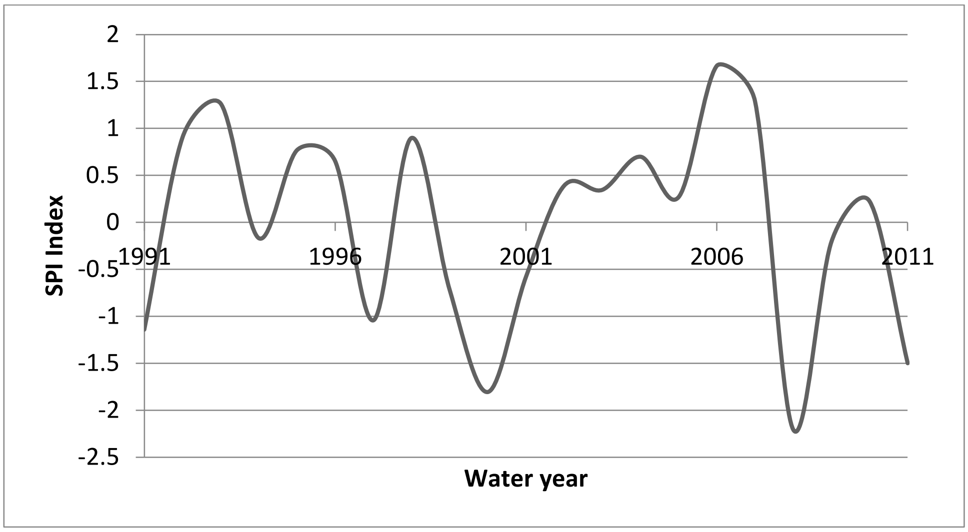

Figure. 2. SPI index value for Najafabad plain

Each of static or dynamic factors has been categorized in to various sub-classes to distinguish their degree of susceptibility to drought. Each factor has been assigned a relative numeric weight between 0 to 10. The weight value of 0 indicates a given factor is least vulnerable to drought and weight value of 10 indicates highly vulnerable to drought. All of layers except precipitation (eight layers), has uniform weighting equal to 1, but precipitation layer has weighing equal 2. Hence the variation range of vulnerability index is between 0 to 100. Based on the value of integrated index, drought triggers is shown in Table 2 (Khoshoei Esfahani, 2012).

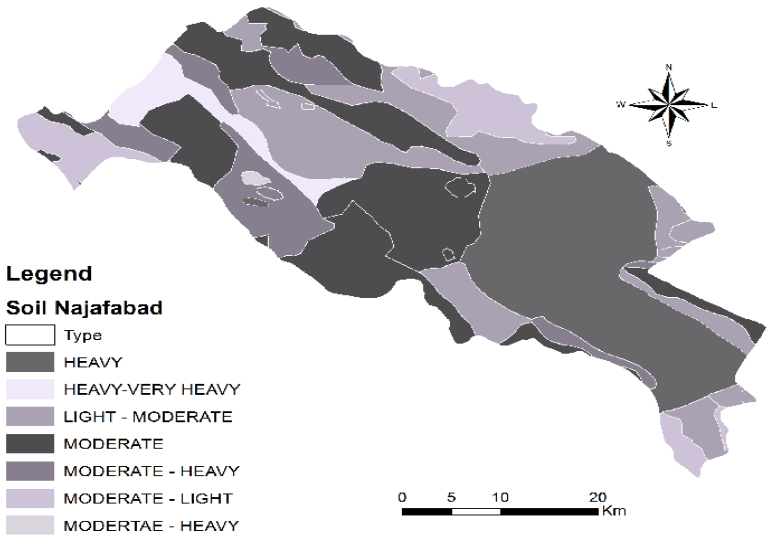

Figure. 3. Soil type map of Najafabad plain

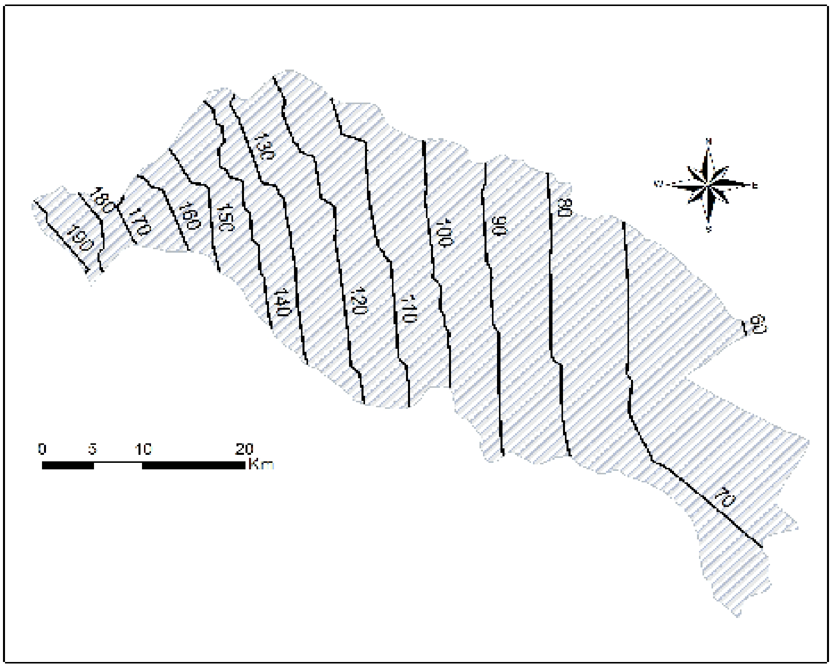

Figure. 4. Precipitation in Najafabad plain in water year 2011

Table 2. Drought triggers

Drought	Very extreme severe	>70
	Extreme severe	50-69.99
	Moderate	40-49.99
	Negligible severity	35-39.99
Normal		30-34.99
Wet	Negligible	25-29.99
	Moderate	20-24.99
	Extreme	15-19.99
	Very extreme	<15

4. CONCLUSION

Fig. 5 shows the values of integrated index for drought assessment based on all of static and dynamic factors for 21 years (1991-2001) for Najafabad plain.

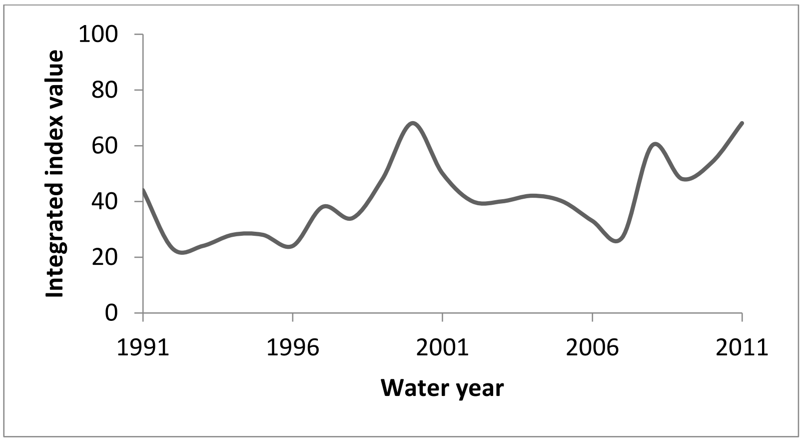

Figure. 5. Integrated index values for assessment of drought in Najafabad plain

This figure indicates that the drought vulnerability is extreme sever in 2000 and moderate wet in 1993 and totally we had drought conditions 11 years from 21. On the other hand, based on SPI we had 5 drought years in Najafabad plain.

Fig 6. compares SPI and integrated index for number of drought years for Najafabad plain from 1991 to 2011. The integrated index provides reasonable estimates of vulnerability to drought based on observed conditions of drought in last two decades in Najafabad plain.

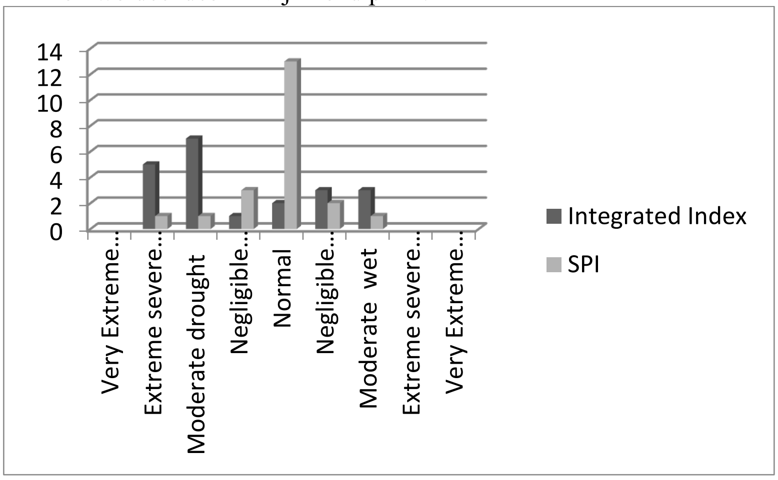

Figure. 6. Comparison between SPI and integrated index for assessment of drought in Najafabad plain

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