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GIS analysis for vulnerability assessment of drought in Khuzestan province in Iran using standardized precipitation index (SPI)

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ABSTRACT- The Standardized Precipitation Index (SPI) is a widely used drought index to provide good estimations of the intensity, magnitude and spatial extent of droughts. The objective of this study was to analyze the spatial pattern of drought by SPI index. In this paper, patterns of drought hazard in Khuzestan are evaluated according to the data of 17 weather stations during data recording. The influenced zone of each station was specified by the Thiessen method. Then, it was attempted to make a new model of drought hazard using GIS. Three criteria for drought were studied and considered to define areas of vulnerability. Drought hazard criteria used in the present model included: maximum severity of drought in the period, trend of drought, and the maximum number of sequential arid years. Each of the vulnerability indicators was mapped. These maps along with a final hazard map were classified into 5 hazard classes of drought included none, slight, moderate, severe and very severe classes. The final drought vulnerability map was prepared by overlaying three criteria maps in GIS, and the final hazard classes were defined on the basis of hazard scores, which were determined according to the means of the main indicators. The final vulnerability map showed that severe hazard areas (29% of the province) which were observed in the northern and central parts of study area are much more widespread than areas under the slight hazard class. Nevertheless, approximately more than half (64%) of the province area was determined to be moderate hazard class for drought.

INTRODUCTION

In Iran, drought is one of the main natural hazards affecting the economy as well as the environment (Bruce, 1994; Obasi, 1994; Wilhite, 2000). Droughts cause crop losses (Austin et al., 1998; Leilah and Al-Khateeb, 2005), urban water supply shortages (DeGaetano, 1999), social alarm (Morales et al., 2000), degradation and desertification of land (Nicholson et al., 1988; Pickup, 1998; Evans and Geerken, 2004), and forest fires (Flannigan and Harrington, 1988; Pausas, 2004). Drought is a complex phenomenon which involves different human and natural factors which contribute to the risk of and vulnerability to drought. Although the definition of drought may be very complex (Wilhite and Glantz, 1985), it is usually related to a long and sustained period in which water is scarce (Dracup et al., 1980; Redmond, 2002). Drought can essentially be considered as a climatic phenomenon (Palmer, 1965; Beran and Rodier, 1985) related to an abnormal decrease in precipitation (Oladipo, 1985; McKee et al., 1993).

Crucially, efforts toward the development of methodologies to quantify different aspects related to droughts have been made. Further efforts have been made to develop drought indices which allow for the earlier identification of droughts, their intensity and potential surface extents of the drought. During the twentieth century, several drought indices were developed which were based on different variables and parameters (Heim, 2002). Drought indices are very important for monitoring droughts continuously in time and space, and early warning systems for droughts are based primarily on the information that drought indices provide (Svoboda et al., 2002).

The majority of drought indices have a fixed time scale. For example, the Palmer Drought Severity Index (PDSI, Palmer, 1965) has a time scale of about 9 months (Guttman, 1998) though it does not allow for the identification of droughts within shorter time scales. Moreover, this index has many other problems related to its calibration and spatial comparability (Karl, 1983; Alley, 1984; Guttman et al., 1992). To solve these problems, McKee et al. (1993) developed the Standardized Precipitation Index (SPI) which can be calculated for different time scales in order to forecast droughts based on the monitoring of different usable water resources. Moreover, the SPI is applicable to any time scale and is not specific to any one location (Hayes et al., 1999; Lana et al., 2001; Wu et al., 2005).

The SPI was published in 1993 following a careful developmental procedure (Redmond, 2002), and due to its robustness, it has already been widely used to study droughts in different regions, including the USA (Hayes et al., 1999), Italy (Bonaccorso et al., 2003), Hungary (Domonkos, 2003), Korea (Min et al., 2003), Greece (Tsakiris and Vangelis, 2004), Spain (Vicente-Serrano and Begueria, 2003; Lana et al., 2001), and Iran (Noruzi, 2007). SPI has also been included in drought monitoring systems and management plans (Wu et al., 2005). In general, different studies have indicated the usefulness of the SPI to quantify different drought types (Edwards and McKee, 1997; Hayes et al., 1999; Komuscu, 1999). The long time scales (over 6 months) are considered as hydrological drought indicators (river discharges or reservoir storages) (McKee et al., 1993; Hayes et al., 1999).

The purpose of this study was to establish a spatial pattern for drought using a multi-temporal assessment of SPI in Khuzestan. For this purpose, different aspects of drought hazard including the maximum severity of drought in the period, trend of drought, and the maximum number of sequentially arid years were prepared in the GIS which deploying a new model. This new model was the first attempt of its kind in Khuzestan. Preparing such hazard maps may be useful for regional planners and policy makers to use in agricultural and environmental strategies not only in Khuzestan but also in other provinces facing similar problems of water shortage.

MATERIALS AND METHODS

Study Area

Khuzestan was selected as the study area for the test assessment of drought vulnerability. It covers an area of 63633 km^2, which lies between the latitudes of 29°59′ and 33°01′ N and the longitudes of 46°48′ and 50°30′ E. The population of the province has increased from 2 million in 1978 to 4 million in 2006, with an effective doubling of the population in less than thirty years. The elevation is from sea level to around 3500 m in the SefidKuh and Mangast. Climate condition are different widely but most parts of the province are arid and average of precipitation is 266 mm per year, but mean annual rainfall reached to 950 mm in the north eastern parts of the province. The main period of precipitation is during the winter. Temperature in most parts reaches above 50°C during summer.

Data and Methodology

The meteorological data used in this study, consisting of monthly precipitation measurements for 17 synoptic and rain stations distributed fairly evenly throughout the province (Fig. 1), which were obtained from the Iran Meteorological Organization (IMO) and water organization of the province. An exhaustive list of the selected stations is given in Table 1.

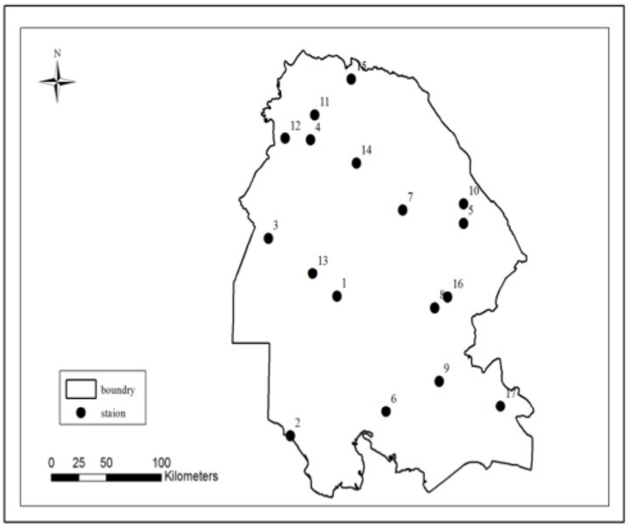

Fig. 1. Locations of weather stations of this study

In the next stage, annual precipitation and SPI were calculated for each year of each station using the following equation:

$$SPI= (P_i - P)/SD \quad (3)$$

Pi: total precipitation in each year;

P: average precipitation in the period

SD: standard deviation of annual precipitation in the period

To check the normality of the data for each station, MINITAB.14 software was used. *P*-values of Normality Test within the software were determined - values>0.05 indicated that the distribution of data for the period of record was normal, while amounts less than this value indicated that the distribution of the data was not normal. In the current assessment, 90% of stations were determined to have normal data, which was acceptable for further statistical assessment.

The assessment of hazard of drought was attempted to identifying first the main criteria of drought in the study area, and then, to establish the thresholds (class limits) of severity for criteria and at the end to analyze the hazard. Recommendations appearing in some literature (e.g., Zehtabian and Jafari, 2002; Masoudi et al., 2007; Zareiee, 2009b) as well as the statistically suitable parameters of the region, such as average and standard deviation for the trend data, was also taken into consideration while fixing the thresholds of the five classes of severity (ratings scores between 1 to 5) for each indicator. Three criteria (Table 2) were processed in the GIS to arrive at the hazard map for each criterion.

Criteria used for drought hazard in the present model included: maximum severity of drought in the period, trend of drought, and the maximum number of sequential arid years. The amounts of SPI ≤-0.5 were considered in order to represent drought conditions and dry years. These thresholds helped to evaluate the secondary and tertiary criteria. To determine trends of hazards for each station or its Thiessen polygon, the period of data recording was divided into two equal periods, and in each period, the percentage of dry years was calculated. Then, the trend of hazard was calculated using the following equation:

Percentage of trend= [(% of dry years in the second period - % of dry years in the first period)/% of dry years in the first period] × 100 (4)

In order to ensure that the effect of all criteria got projected in the final hazard map, the overlays of the individual hazard criterion maps, as derived from three criteria, were analyzed step by step. The severity of hazard assigned to each polygon was assessed using the mean of all the attributes (rating scores) of criteria used in the GIS. The following equation was applied to the GIS in order to assess the hazard map of meteorological drought:

Hazard score for drought= (maximum severity of drought + trend of drought + maximum number of sequential arid years) / 3 (5)

The hazard score in each polygon denoted the cumulative effect of all the criteria for qualifying the five severity classes (Table 3). This facilitated the production of final hazard map which showed the different degrees of drought hazard.

RESULTS AND DISCUSSION

Some studies, previously carried out in Iran and throughout the rest of the world (e.g., Ensafi Moghaddam, 2007; Raziei et al., 2007), have based their estimation on the 'present state' of hazard of drought during a specific year, and using some indices like SPI and PNPI. Such indicator maps or information based solely on the present state of hazard derived from small number of recent years data are inadequate for the representation of areas which are more vulnerable to hazard (Masoudi, 2010). The adequate representation of such areas requires a combination of more indices of hazard, like the maximum number of sequential years of hazard in a period, and also an important index of trends showing different aspects of hazard.

Table 1. Name and characteristics of the selected stations over the study area

Map location code	Station name	Latitude	Longitude	Elevation (m)
1	Ahvaz	31°19' N	48°39' E	22.5
2	Abadan	30°21' N	48°14' E	6.6
3	Bostan	48°0' N	31°42' E	7.8
4	Dezfol	48°22' N	34°23' E	82.5
5	Izeh	49°51' N	31°50' E	840
6	Mahshahr	49°8' N	30°32' E	6.2
7	Masjedsoliyman	49°16' N	32°55' E	230.5
8	Ramhormoz	49°35' N	31°15' E	150.5
9	Omidiye	49°38' N	30°45' E	27
10	Sosan	49°51' N	31°58' E	600
11	Sadedez	48°25' N	32°34' E	525
12	Paypol	48°08' N	32°24' E	90
13	Hamidiye	48°25' N	31°29' E	12
14	Gotvand	48°49' N	32°14' E	76
15	Talezang	48°46' N	54°16' E	440
16	Rodzardmashin	35°12' N	32°49' E	354
17	Shohadabehbahan	50°13' N	30°35' E	333

Table 2. Criteria used for the hazard assessment of drought using SPI

Indicators	Class limits and their rating score				
	None (1)	Slight (2)	Moderate (3)	Severe (4)	Very severe (5)
Maximum severity of drought in the period	>-0.5	-0.5 to -0.99	-1 to -1.49	-1.5 to -1.99	≤-2
Increasing trend (%)	≤0	1 to 32	33 to 65	66 to 99	≥100
Maximum number of sequential arid years in the period	0 to 1	2	3	4 to 5	≥6

SPI, Standardized Precipitation Index

Table 3. The severity classes of hazard map produced in the GIS

Class	None (1)	Slight (2)	Moderate (3)	Severe (4)	Very severe (5)
Hazard score	<1.49	1.5 to 2.49	2.5 to 3.49	3.5 to 4.49	≥4.5

This kind of classification using different criteria was the first attempt of its kind to define areas with a higher risk of drought in Khuzestan Province. GIS analysis not only facilitated model development but also allowed for the evaluation of spatial correlations and the production of hazard maps.

Table 4 describes the hazard criteria maps used in the model; 'maximum severity of drought in the period' showed the most hazardous of three criteria used in the model. This indicator was assessed based on the worst droughts or the least amount of SPI in a year, which occurred during the periods of study for each station. 76% of the area in this hazard map (Fig. 2) was categorized as being under severe or very severe risk of drought, indicating that most parts of the province have experienced significant droughts in the period of the study. The areas least affected by drought were some territories to north and to south in coastal areas. These results are in good agreement with other results regarding drought assessment in different regions of Iran (Ensafi Moghaddam, 2007; Raziei et al., 2007; Sarhadi et al., 2008; Asrari et al., 2012). But most parts of the hazard map (Fig.3) showing ‘maximum number of sequential arid years in the periods under none to moderate hazard classes (73%) compared to severe and very severe hazard classes indicated period of droughts did not continue so long (a little more than three years) in most parts of the province. It seems that impacts of drought regarding this condition were observed more in the south-western parts. Just this aspect of drought were used to show vulnerability to drought in regions, showing importance of this criterion in the hazard assessment (Feiznia et al., 2001; Zehtabian and Jafari, 2002).

While the drought hazard map (Fig.4) based on the increasing trend appeared to be the least hazardous among the three criteria used in the model, 35 % of the area in this hazard map was categorized as having slight or no hazard classes. The percentage of land falling under the category of "None class" was 27%, indicating that drought occurring was reduced in the second data period, as compared to the first period. However, this indicator showed a trend of elevating drought conditions in the province, confirming studies of the region which have indicated that climate changes resulted in drier conditions (Zareiee, 2009a; Asrari and Masoudi, 2010; Masoudi and Afrough, 2011). In the generated map, hazardous conditions were observed more in some parts of central and northern parts of the province.

On the other hand, the final hazard map of the province (Fig.5) showed three different hazard classes. From Fig. 6, a general conclusion can be derived that in Khuzestan a higher proportion of land (93 %) was under severe and moderate classes of drought, compared to the areas under slight risk of drought (7%). Hazardous lands were observed more in north and central parts of the province. This pattern was observed in another study which reported that climate changes lead to drier conditions (Zareiee, 2009b). One of the impacts of climate change and the occurrence of drought conditions is desertification which can be strongly observed.

Table 4. Percentage of areas under each hazard class, based on three criteria used in the model of drought

	Hazard Class				
Indicators	None	Slight	Moderate	Severe	Very severe
Maximum severity of drought	0.0	0.0	24.4	63.7	12.4
Increasing trend (%)	27.1	7.7	40.4	2.9	21.7
Maximum number of sequential arid years	6.9	35.3	31.2	26.4	0.0
Maximum severity of drought	0.0	0.0	24.4	63.7	12.4

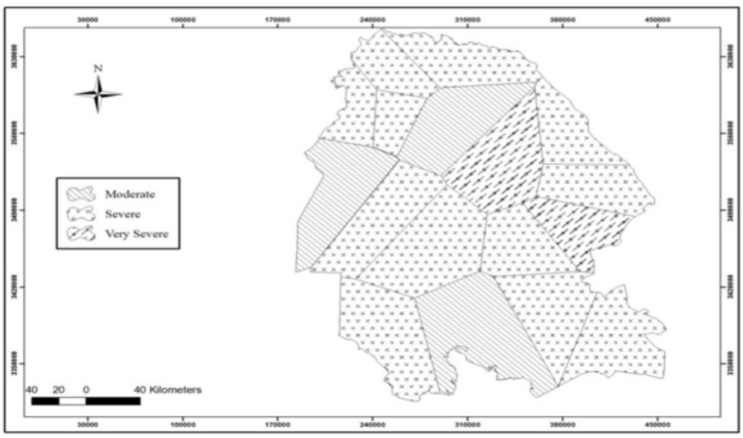

Fig. 2. Hazard map of “maximum severity of drought in the period.”

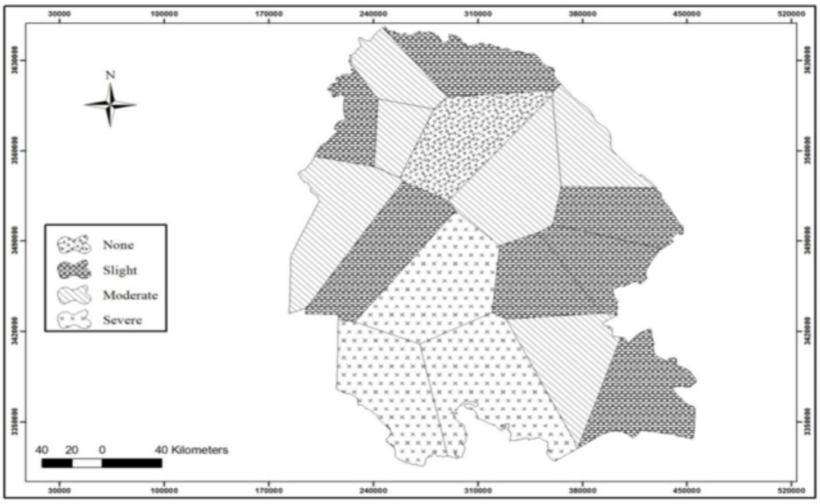

Fig. 3. Hazard map of "maximum number of sequential arid years in the period."

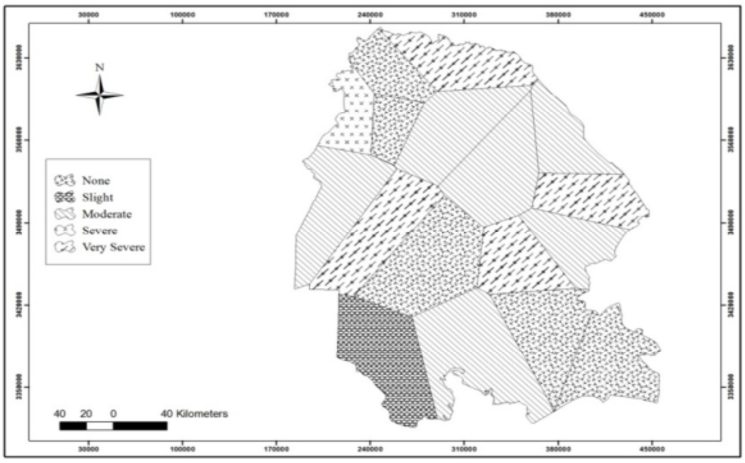

Fig. 4. Hazard map of increasing trend in the period.

CONCLUSIONS

Every year, droughts affect agriculture, water resources, and ecosystems of Iran. Most parts of Iran suffer from water scarcity, and droughts can substantially exasperate the pressure on the water resource systems. Water resource systems are sensitive to climatic change and variability and, hence, changes in droughts could affect water availability.

On this basis, this study offered an SPI index in order to analyze the regional drought in Khuzestan, Iran. The final vulnerability map showed that severe hazard areas (29% of the province) which were observed in the Northern and central parts of the study area were much more widespread than areas under slight hazard class although approximately more than half of the province (64%) was determined to be moderate hazard class for drought.

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تحلیل سامانه اطلاعات جغرافیایی به منظور ارزیابی آسیب پذیری خشکسالی در استان خوزستان ایران با استفاده از شاخص بارش استاندارد

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خوزستان

شاخص بارش استاندارد

چکیده- شاخص خشکسالی بارش استاندارد بطور گسترده‌ای برای برآورد مناسب شدت، بزرگی و محدوده مکانی خشکسالی‌ها بکار گرفته می‌شود. هدف از این مطالعه، تجزیه و تحلیل الگوی مکانی خشکسالی با استفاده از شاخص SPI بود. در این مقاله، الگوهای خطر خشکسالی در استان خوزستان با توجه به داده‌های ۱۷ ایستگاه هواشناسی مورد بررسی قرار گرفت. محدوده تحت تاثیر هر ایستگاه با استفاده از روش تیسن مشخص شد. سپس نسبت به تهیه یک مدل جدید خطر خشکسالی با استفاده از GIS مبادرت شد. سه معیار خشکسالی برای تعریف مناطق آسیب پذیر، مطالعه و در نظر گرفته شد. معیارهای خطر خشکسالی که در مدل فعلی استفاده شد شامل حداکثر شدت خشکسالی در دوره، روند خشکسالی، و حداکثر تعداد پی‌درپی سال‌های خشک است. هر یک از شاخص‌های آسیب‌پذیری نقشه‌سازی شدند و همچنین این نقشه‌ها به‌عنوان یک نقشه خطر نهایی به ۵ کلاس خطر خشکسالی شامل بدون خطر، خطر خفیف، متوسط، شدید و بسیار شدید طبقه بندی شدند. نقشه نهایی آسیب‌پذیری خشکسالی با تلفیق سه نقشه معیار در GIS تهیه شد و طبقات خطر نهایی بر اساس امتیاز خطر که با توجه شاخص‌های اصلی تعیین شد، مشخص شدند. نقشه آسیب‌پذیری نهایی نشان می‌دهد که مناطق با خطر شدید (۲۹ درصد از استان) که در بخش‌های شمالی و مرکزی منطقه مورد مطالعه مشاهده می‌شود، بسیار گسترده@تر از مناطق تحت کلاس خطر کم است. اگرچه تقریبا بیش از نیمی از استان (۶۴٪) در کلاس خطر متوسط خشکسالی تعیین شد.