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GIS overlay analysis for hazard assessment of drought 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, the patterns of drought hazard in Iran are evaluated according to the data of 40 weather stations during 1967-2009. The influenced zone of each station was specified by the Thiessen method. 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 were mapped and these as well as a final hazard map were classified into 5 hazard classes of drought: one, slight, moderate, severe and very severe. The final drought vulnerability map was prepared by overlaying three criteria maps in a 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 shows that severe hazard areas (43% of the country) which are observed in the west and eastern parts of country are much more widespread than areas under other hazard classes. Overall, approximately half of the country was determined to be under severe and very severe hazard classes for drought.

Key words: drought, GIS, hazard map, Iran, Standardized Precipitation Index

INTRODUCTION

Within Iran, drought is one of the main natural hazards affecting the economy and 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. 1998, 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 identi-

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fication 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 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 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 Beguería 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 is to establish a spatial pattern for drought using a multi-temporal assessment of SPI in Iran. For this purpose, different aspects of drought hazard, namely, the maximum severity of drought in the period, trend of drought, and the maximum number of sequentially arid years have been prepared in the GIS, deploying the new model. It is the first attempt of its kind in Iran, and preparing such hazard maps may prove to be useful for regional planners, and policy makers for agricultural and environmental strategies, not only in Iran but also in other countries facing similar problems of water shortage.

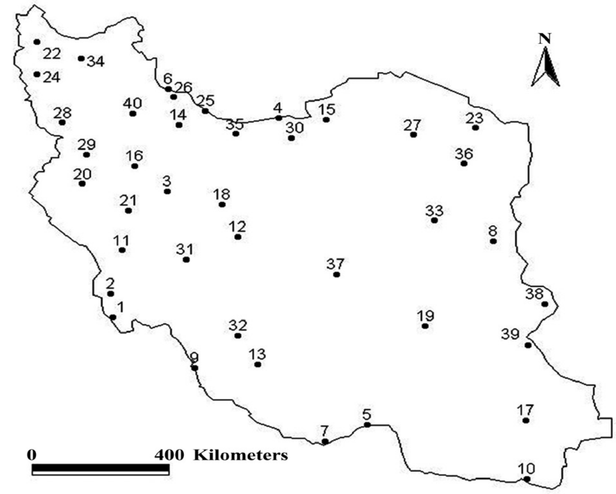

Fig. 1. Locations of weather stations of this study.

MATERIALS AND METHODS

Study area

Iran was selected as a study area for a test assessment of drought vulnerability. It covers an area of 1,648,195 km^2, which lies between the latitudes of 25°14′ and 39°42′ N and the longitudes of 44°10′ and 63°11′ E. The population of the country has increased from 34 million in 1978 before of the revolution to 68 million in 2006, with an effective doubling of the population in less than thirty years. The elevation varies from sea level to around 5,500 m in the Damavand Mountains, and the climate differs widely but most parts of the country are arid or semi arid, with a mean annual rainfall of 50-2,000 mm. The average precipitation in Iran is 245 mm per year, and the main period of precipitation is during the winter (60% of total rainfall).

Data and methodology

The meteorological data used in this study, consisting of monthly precipitation and temperature measurements for 40 synoptic stations distributed fairly evenly throughout the country (Fig. 1), were obtained from the Iran Meteorological Organization (IMO). In the present work, to determine the adequate quantity of stations with suitable scatter formula 1 was used. An exhaustive list of the selected stations is given in Table 1.

$$N = \left(\frac{CV\%}{E\%}\right)^2 \qquad CV\% = \frac{SD}{\overline{P}} \times 100 \qquad (1)$$

N: minimum of adequate station number (in this study:

$N = 40$)

CV%: average of coefficient of variations of annual precipitation for synoptic stations of Iran

E%: acceptable faults (%) for the determination of correct number, for this work E% is considered to be 15%

SD: standard deviation of annual precipitation for synoptic stations of Iran

$\overline{P}$: annual precipitation average for synoptic stations of Iran

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

Map location (code)	Station name	Latitude	Longitude	Elevation (m)
1	Abadan	30°22′ N	48°15′ E	6
2	Ahvaz	31°20′ N	48°40′ E	22
3	Arak	34°6′ N	49°46′ E	1,708
4	Babolsar	36°43′ N	52°39′ E	-21
5	Bandar Abbas	27°13′ N	56°22′ E	10
6	Bandar Anzali	37°28′ N	49°28′ E	-26
7	Bandar Lenge	26°32′ N	54°50′ E	23
8	Birjand	32°52′ N	59°12′ E	1,491
9	Bushehr	28°59′ N	50°50′ E	20
10	Chabahar	25°17′ N	60°37′ E	8
11	Dezful	32°24′ N	48°23′ E	143
12	Esfahan	32°37′ N	51°40′ E	1,550
13	Fassa	28°58′ N	53°41′ E	1,288
14	Ghazvin	36°15′ N	50°3′ E	1,279
15	Gorgan	36°51′ N	54°16′ E	13
16	Hamedan	35°12′ N	48°43′ E	1,697
17	Iran Shahr	27°12′ N	60°42′ E	591
18	Kashan	33°59′ N	51°27′ E	982
19	Kerman	30°15′ N	56°58′ E	1,753
20	Kermanshah	34°21′ N	47°9′ E	1,318
21	Khoram Abad	33°26′ N	48°17′ E	1,147
22	Khoy	38°33′ N	44°58′ E	1,103
23	Mashhad	36°16′ N	59°38′ E	999
24	Oroomieh	37°32′ N	45°5′ E	1,315
25	Ramsar	36°54′ N	50°40′ E	-20
26	Rasht	37°15′ N	49°36′ E	-6
27	Sabzevar	36°12′ N	57°43′ E	977
28	Saghez	36°15′ N	46°16′ E	1,522
29	Sanandaj	35°20′ N	47°0′ E	1,373
30	Semnan	35°35′ N	53°33′ E	1,130
31	Shahre Kord	32°17′ N	50°51′ E	2,048
32	Shiraz	29°32′ N	52°36′ E	1,484
33	Tabass	33°36′ N	56°55′ E	711
34	Tabriz	38°5′ N	46°17′ E	1,361
35	Tehran	35°41′ N	51°19′ E	1,190
36	Torbat Hydarieh	35°16′ N	59°13′ E	1,450
37	Yazd	31°54′ N	54°17′ E	1,237
38	Zabol	31°2′ N	61°29′ E	489
39	Zahedan	29°28′ N	60°53′ E	1,370
40	Zanjan	36°41′ N	48°29′ E	1,663

To determine the common duration of the suitable statistical period for all the stations, formula 2 (Mahdavi 2002) was used. Through this formula we determined that 37.5 years is the least number of years which are needed for the current study. The duration of the data used in this study includes that from 1 January 1967 to 31 December 2009 for all stations.

$$N = (4.3t \times \log R)^2 + 6 \tag{2}$$

N: minimum necessary annual data (in this paper: N = 37.5 years)

t: t student with the freedom degree of n-6

R: ratio of return period precipitation of 100 years to 2 years

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

$$\mathrm{SPI} = (\mathrm{P}i - \mathrm{P})/\mathrm{SD} \tag{3}$$

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 was used. P-values of normality test within the software were determined. P-values > 0.05 indicate that the distribution of data for the period of record is normal, while amounts less than this indicate that the distribution of the data is 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 has been attempted by first identifying the main criteria of drought in the study area, and then by establishing the thresholds (class limits) of severity for criteria, and finally, by analyzing the hazard through X analysis. 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, have also been 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) have been processed in the GIS to arrive at the hazard map for each criterion.

Criteria used for drought hazard in the present model include: 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 help in the evaluation of 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 trend of hazard was calculated using 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 gets 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 has been 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 denotes the cumulative effect of all the criteria for qualifying the five severity classes (Table 3). This facilitated the production of final hazard map which shows the different degrees of drought hazard.

RESULTS AND DISCUSSION

Some studies previously carried out in Iran and throughout the rest of the world have based their estimation on the 'present state' of hazard of drought during a specific year, and using some indices like SPI and PNPI (e.g., Ensafi Moghaddam 2007, Raziei et al. 2007). 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 important index of trends showing different aspects of hazard. This kind of classification using different criteria is the first attempt of its kind to define areas with a higher risk of drought. GIS analysis not only facilitated model development but also allowed for the evaluation of spatial

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

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

Indicators	Hazard class				
	None	Slight	Moderate	Severe	Very severe
Maximum severity of drought	0.0	0.0	9.5	53.9	36.6
Increasing trend (%)	0.0	34.8	26.6	28.0	10.6
Maximum number of sequential arid years	0.0	34.8	26.6	28.0	10.6

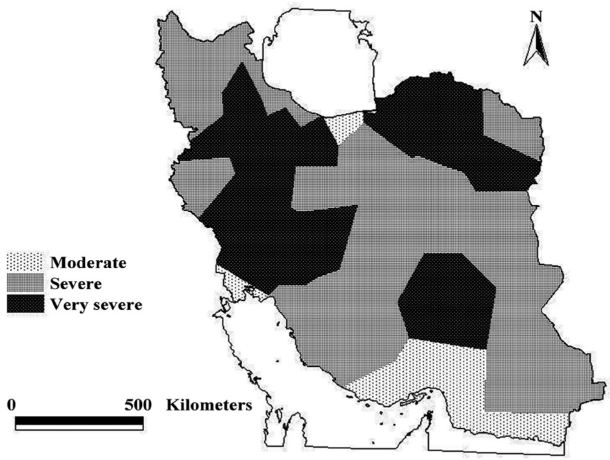

Fig. 2. Hazard map of "maximum severity of drought in the period."

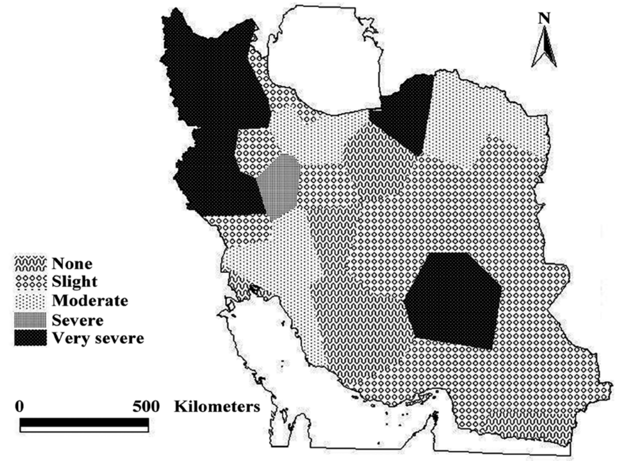

Fig. 4. Hazard map of "% of increasing trend in the period."

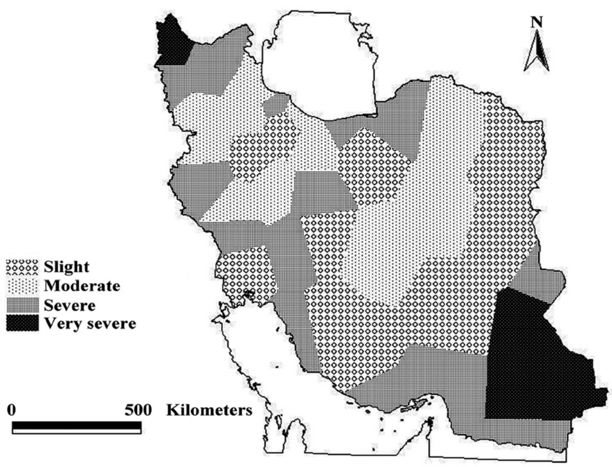

Fig. 3. Hazard map of "maximum number of sequential arid years in the period."

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' shows the most hazardous of three criteria used in the model. This indicator is assessed based on the worst droughts or the least amount of SPI in a year, which has occurred during the period of study (1967-2009) for each station. Ninety percent of the area in this hazard map (Fig. 2) is categorized as being under severe or very severe risk of drought, indicating that most parts of the country have experienced significant droughts in the period of study. The areas least prone to drought are coastal areas as well as some territories to the north and to the south. 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).

But the most parts of hazard map (Fig. 3) showing 'maximum number of sequential arid years in the period' is under slight and moderate hazard classes (61%) compared to severe and very severe hazard classes, indicating period of droughts doesn't continue so long (more than three years) in the most parts of country. It seems impacts of drought regarding to this condition are observed more in the south-eastern parts and parts in the north and the west compared to the central parts. This aspect of drought have been used alone to show vulnerability to drought in regions, showing importance of this criteria in the hazard assessment (Feiznia et al. 2001, Zehtabian and Jafari 2002).

While the drought hazard map (Fig. 4) based on the '% of increasing trend' appears to be the least hazardous among three criteria used in the model. Fifty eight percent of the area in this hazard map is categorized as having slight or no hazard classes. However, the percentage of land falling under the category of "None class" is 16%, and the area of land classified as hazard of "none" was reduced in the second data period, as compared to the first. This indicates a trend of elevating drought conditions in the country, confirming studies of the region which have indicated that climate changes is resulting in drier conditions (Zareiee 2009a, Asrari and Masoudi 2010, Masoudi and Afrough 2011). In all of the generated maps, hazardous conditions are observed more in the north-western parts of the country.

On the other hand the final hazard map of the country (Fig. 5) shows four different hazard classes. From Fig. 6, a general conclusion can be derived that in Iran an almost equal proportion of land (47%) is under severe or very severe classes of drought, compared to the areas under

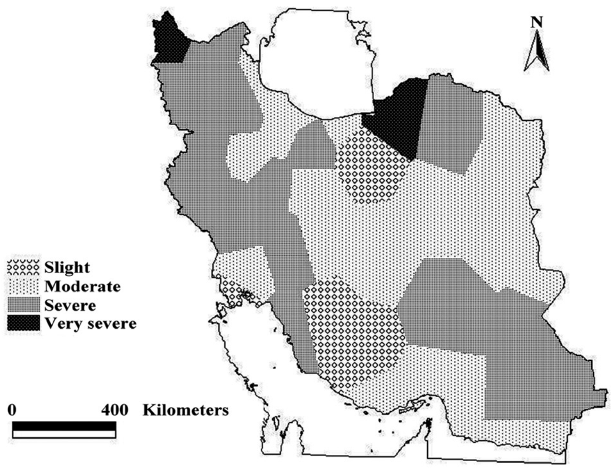

Fig. 5. Hazard map of drought vulnerability.

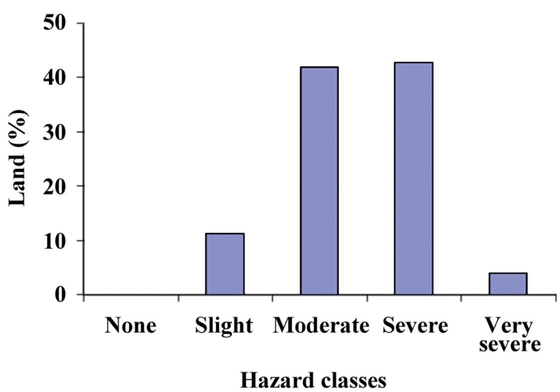

Fig. 6 . Percent age of areas under hazard classes of drought vulnerability.

slight or moderate risk of drought (53%). Hazardous lands are observed more in western, north-eastern and south-eastern parts of country, while northern parts show more risk compared to southern parts. This pattern is observed in another study which reports that climate changes is leading to drier conditions, especially in northern parts of country (Zareiee 2009b). One of the most risk prone zones is in the north-western parts of country where the impact of climate change and the occurrence of drought conditions such as drying of the biggest lake of country, Orumieh Lake, can be strongly observed.

LITERATURE CITED

Alley WM. 1984. The Palmer Drought Severity Index: limitations and assumptions. J Clim Appl Meteorol 23: 1100-1109.

Asrari E, Masoudi M. 2010. Hazard assessment of climate changes, a case study area: Fars Province, Iran. Int Pollut Res 29: 275-281.

Austin RB, Cantero-Martínez C, Arrúe JL, Playán E, Cano-Marcellán P. 1998. Yield-rainfall relationships in cereal cropping systems in the Ebro river valley of Spain. Eur J Agron 8: 239-248.

Beran MA, Rodier JA. 1985. Hydrological Aspects of Drought. Studies and Reports in Hydrology, 39. UNESCO-WMO, Geneva.

Bonaccorso B, Bordi I, Cancelliere A, Rossi G, Sutera A. 2003. Spatial variability of drought: an analysis of the SPI in Sicily. Water Resour Manag 17: 273-296.

Bruce JP. 1994. Natural disaster reduction and global change. Bulleti Am Meteorol Soc 75: 1831-1835.

DeGaetano AT. 1999. A temporal comparison of drought impacts and responses in the New York City metropolitan area. Clim Change 42: 539-560.

Domonkos P. 2003. Recent precipitation trends in Hungary in the context of larger scale climatic changes. Nat Hazards 29: 255-271.

Dracup JA, Lee KS, Paulson EG Jr. 1980. On the definition of droughts. Water Resour Res 16: 297-302.

Edwards DC, McKee TB. 1997. Characteristics of 20th Century Drought in the United States at Multiple Time Scales. Atmospheric Science, Paper No. 634. Colorado State University, Fort Collins, CO.

Ensafi Moghaddam T. 2007. An Investigation and assessment of climatological indices and determination of suitable index for climatological droughts in the Salt Lake Basin of Iran. Iran J Range Desert Res 14: 271-288.

Evans J, Geerken R. 2004. Discrimination between climate and human-induced dryland degradation. J Arid Environ 57: 535-554.

Feiznia S, Gooya AN, Ahmadi H, Azarnivand H. 2001. Investigation on desertification factors in Hossein-Abad Mish Mast plain and a proposal for a regional model. J Biaban 6: 1-14.

Flannigan MD, Harrington JB. 1988. A study of the relation of meteorological variables to monthly provincial area burned by wilfire in Canada (1953-1980). J Appl Meteorol 27: 441-452.

Guttman NB. 1998. Comparing the Palmer drought index and the Standardized Precipitation Index. J Am Water Resour Assoc 34: 113-121.

Guttman NB, Wallis JR, Hosking JRM. 1992. Spatial comparability of the Palmer Drought Severity Index. Water Resour Bull 28: 1111-1119.

Hayes MJ, Svoboda MD, Wilhite DA, Vanyarkho OV. 1999. Monitoring the 1996 drought using the Standardized Precipitation Index. Bull Am Meteorol Soc 80: 429-438.

Heim RR Jr. 2002. A review of twentieth-century drought indices used in the United States. Bull Am Meteorol Soc 83: 1149-1165.

Karl TR. 1983. Some spatial characteristics of drought duration in the United States. J Appl Meteorol 22: 1356-1366.

Komuscu AU. 1999. Using the SPI to analyze spatial and temporal patterns of drought in Turkey. Drought Network News 11: 7-13.

Lana X, Serra C, Burgueño A. 2001. Patterns of monthly rainfall shortage and excess in terms of the Standardied Precipitation Index for Catalonia (NE Spain). Int J Climatol 21: 1669-1691.

Leilah AA, Al-Khateeb SA. 2005. Statistical analysis of wheat yield under drought conditions. J Arid Environ 61: 483-496.

Mahdavi M. 2002. Applied Hydrology. Tehran University Press, Tehran.

Masoudi M. 2010. Risk Assessment and Remedial Measures of Land Degradation, in Parts of Southern Iran. Lambert Academic Publishing (LAP), Saarbrücken, p 220.

Masoudi M, Afrough E. 2011. Analyzing trends of precipitation for humid, normal and drought classes using Standardized Precipitation Index (SPI), a case of study: Fars Province, Iran. Int J AgriSci 1: 85-96.

Masoudi M, Patwardhan AM, Gore SD. 2007. Risk assessment of lowering of ground water table using GIS for the Qareh Aghaj Sub Basin, Southern Iran. J Geol Soc India 70: 861-872.

McKee TBN, Doesken NJ, Kleist J. 1993. The relationship of drought frequency and duration to time scales. Eight Conference on Applied Climatology, 1993 Jan 17-22, Anaheim, CA, pp 179-184.

Min SK, Kwon WT, Park EH, Choi Y. 2003. Spatial and temporal comparisons of droughts over Korea with East Asia. Int J Climatol 23: 223-233.

Morales Gil A, Olcina Cantos J, Rico Amorós AM. 2000. Diferentes percepciones de la sequía en España: adaptación, catastrofismo e intentos de corrección. Invest Geogr 23: 5-46.

Nicholson SE, Tucker CJ, Ba MB. 1998. Desertification, drought, and surface vegetation: an example from the west African Sahel. Bull Am Meteorol Soc 79: 815-829.

Noruzi R. 2007. Assessment and preparation of critical condition map of rround water resources using GIS. MSc Thesis. Tehran University, Tehran, Iran.

Obasi GOP. 1994. WMO's role in the international decade for natural disaster reduction. Bull Am Meteorol Soc 75: 1655-1661.

Oladipo EO. 1985. A comparative performance analysis of three meteorological drought indices. Int J Climatol 5: 655-664.

Palmer WC. 1965. Meteorological Droughts. Research Paper 45. US Department of Commerce, Washington, DC.

Pausas JG. 2004. Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean basin). Clim Change 63: 337-350.

Pickup G. 1998. Desertification and climate change: the Australian perspective. Clim Res 11: 51-63.

Raziei T, Daneshkar Arasteh P, Akhtari R, Saghafian B. 2007. Investigation of meteorological droughts in the Sistan and Balouchestan Province, using the Standardized Precipitation Index and Markov Chain Model. Iran-Water Resour Res 3: 25-35.

Redmond KT. 2002. The depiction of drought. Bull Am Meteorol Soc 83: 1143-1147.

Sarhadi A, Soltani S, Modarres R. 2008. The analysis of drought extension over Isfahan province based on four drought indices. J Iran Nat Res 61: 555-570.

Svoboda M, Le Compte D, Hayes M, Heim R, Gleason K, Angel J, Rippey B, Tinker R, Palecki M, Stooksbury D, Miskus D, Stevens S. 2002. The drought monitor. Bull Am Meteorol Soc 83: 1181-1190.

Tsakiris G, Vangelis H. 2004. Towards a drought watch system based on spatial SPI. Water Resour Manag 18: 1-12.

Vicente-Serrano SM, Beguería S. 2003. Estimating extreme dry-spell risk in the middle Ebro valley (Northeastern Spain): a comparative analysis of partial duration series with a General Pareto distribution and Annual maxima series with a Gumbel distribution. Int J Climatol 23: 1103-1118.

Wilhite DA. 2000. Drought as a natural hazard: concepts and definitions. Drought Glob Assess 1: 3-18.

Wilhite DA, Glantz MH. 1985. Understanding the drought phenomenon: the role of definitions. Water Int 10: 111-120.

Wu H, Hayes MJ, Wilhite DA, Svoboda MD. 2005. The effect of the length of record on the Standardized Precipitation Index calculation. Int J Climatol 25: 505-520.

Zareiee AR. 2009a. Climate Changes in Iran. Shiraz University, Shiraz.

Zareiee AR. 2009b. Vulnearibility Assessment of Drought Using GIS in Qareh Aghaj Basin, Southern Iran. Shiraz University, Shiraz.

Zehtabian G, Jafari R. 2002. Evaluation of water resources degradation in Kashan area using desertification model. J Ecol 30: 19-30.