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A new model for vulnerability assessment of drought in Iran using Percent of Normal Precipitation Index (PNPI)

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Abstract

The Percent of Normal Precipitation Index (PNPI) is a widely used drought index to provide good estimations about the intensity, magnitude and spatial extent of droughts. The objective of this study was analyzing spatial pattern of drought by PNPI index. In this paper, according to the data of 40 stations in Iran, during 1967-2009, the pattern of drought hazard is evaluated. Influenced zone of each station was specified by Thiessen method. An attempt was made to create a new model of drought hazard using GIS. Three criteria for drought were studied and considered to define areas under vulnerability. Drought hazard criteria used in the present model include: maximum severity of drought in the period, trend of drought, and the maximum number of sequential arid years. Both the vulnerability indicator map and also final hazard map are classified into 5 hazard classes of drought: None, slight, moderate, severe and very severe. The final drought vulnerability map was prepared by overlaying three criteria maps in the GIS and the final hazard classes were defined on the basis of hazard scores arrived at by the mean of the main indicators, deploying the new model. The final vulnerability map shows that severe hazard areas (58% of the country) which are observed more in the northwestern, southeastern and central parts of the country are much more widespread than areas under other hazard classes.

Keywords: Drought; PNPI; GIS; hazard map; Iran

1. Introduction

Drought is one of the main natural hazards affecting the economy and the environment of large areas (Obasi, 1994; Bruce, 1994; Wilhite, 2000). Droughts cause crop losses (Austin et al., 1998; Leilah and Al-Khateb, 2005), urban water supply shortages (De-Gaetano, 1999), social alarm (Morales et al., 2000), degradation and desertification (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 that determine the risk and vulnerability to drought. Although the definition of drought is very complex (Wilhite and Glantz, 1985), it is usually related to a long and sustained period in which water availability becomes scarce (Dracup et al., 1980; Redmond, 2002). Drought can be considered to be essentially a climatic phenomenon (Palmer, 1965; Beran and Rodier, 1985) related to an abnormal decrease in precipitation (Oladipo, 1985; McKee et al., 1993).

Important efforts for developing methodologies to quantify different aspects related to droughts have been made. More efforts have been made to develop drought indices, which allow an earlier identification of droughts, their intensity and surface extent. During the twentieth century, several drought indices were developed, based on different variables and parameters (Heim, 2002). Drought indices are very important for monitoring droughts continuously in time and space, and drought early warning systems 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), which does not allow identification of droughts at shorter time scales. Moreover, this index has many other problems related to calibration and spatial comparability (Karl, 1983; Alley, 1984; Guttman et al., 1992). To solve these problems, scientists developed other indices like the Standardized Precipitation Index (SPI) and Percent of Normal Precipitation Index (PNPI), which can be calculated at different time scales to monitor droughts in the

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different usable water resources (McKee et al., 1993).

The purpose of this study is to establish spatial pattern of drought using multi-temporal assessment of PNPI in Iran. For that, different aspects of drought hazard namely, maximum severity of drought in the period, trend of drought, and the maximum number of sequential 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 problem.

2. Material and methods

2.1. Study Area

Iran was selected as a study area for a test assessment of drought vulnerability. It covers an area of 1648195 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 the Islamic revolution to 68 million in 2006, showing a 2-fold increase during a period of less than thirty years. The elevation varies between the sea level to around 5,500m in Damavand mountain. The climate differs but in most parts of the country is arid and semi arid with a mean annual rainfall range of 50-2000 mm. Average precipitation of this country is 245 mm per year. The main period of precipitation is during winter (60% of total rainfall).

2.2. Data and methodology

The meteorological data used in this study, consisting of monthly precipitation and temperature measurements for 40 synoptic stations distributed fairly evenly in the country (Fig. 1), were collected from the Iran Meteorological Organization (IMO). In the present work, to determine the adequate quantity of station with suitable scatter, formula 1 (Mahdavi, 2002) was used. An exhaustive list of the selected stations is given in Table 1.

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

N = minimum of adequate station number
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 15%
SD = standard deviation of annual precipitation for synoptic stations of Iran
$\overline{P}$ = annual precipitation average for synoptic stations of Iran
In this study: N=40

To determine the common duration of the suitable statistic period for all the stations, formula 2 (Mahdavi, 2002) was used. Using that, 37.5 years is the at least number of years needed for the current study. The length of the data used in this study include from 1 January 1967 to 31 December 2009 for all of the stations.

2. $$N = (4.3t \times \log R)^2 + 6$$

N = minimum necessary annual data
t = t student with the freedom degree of n-6
R= Ratio of return period precipitation of 100 years to 2 years
In this paper: N=37.5 years

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	1708
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	1491
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	1550
13	Fassa	28° 58' N	53° 41' E	1288
14	Ghazvin	36° 15' N	50° 3' E	1279
15	Gorgan	36° 51' N	54° 16' E	13

16	Hamedan	35° 12' N	48° 43' E	1697
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	1753
20	Kermanshah	34° 21' N	47° 9' E	1318
21	Khoram Abad	33° 26' N	48° 17' E	1147
22	Khoy	38° 33' N	44° 58' E	1103
23	Mashhad	36° 16' N	59° 38' E	999
24	Oroomieh	37° 32' N	45° 5' E	1315
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	1522
29	Sanandaj	35° 20' N	47° 0' E	1373
30	Semnan	35° 35' N	53° 33' E	1130
31	Shahre Kord	32° 17' N	50° 51' E	2048
32	Shiraz	29° 32' N	52° 36' E	1484
33	Tabass	33° 36' N	56° 55' E	711
34	Tabriz	38° 5' N	46° 17' E	1361
35	Tehran	35° 41' N	51° 19' E	1190
36	Torbat Hydarieh	35° 16' N	59° 13' E	1450
37	Yazd	31° 54' N	54° 17' E	1237
38	Zabol	31° 2' N	61° 29' E	489
39	Zahedan	29° 28' N	60° 53' E	1370
40	Zanjan	36° 41' N	48° 29' E	1663

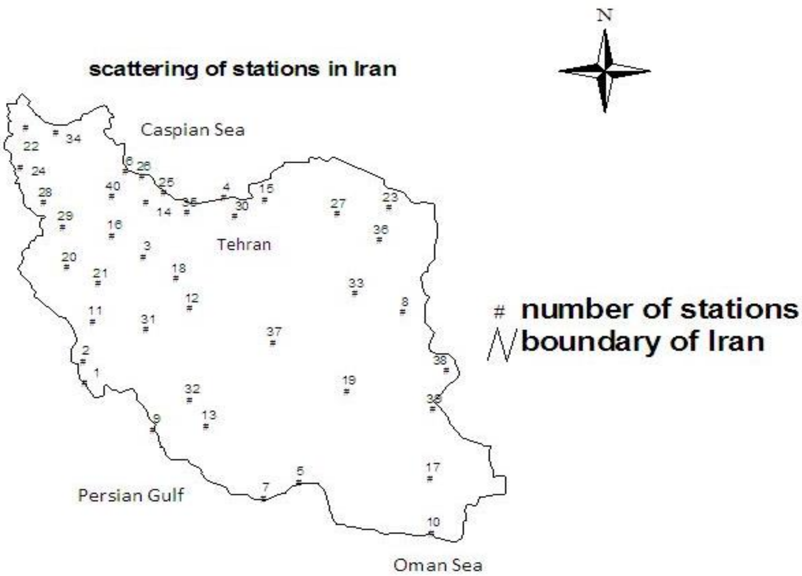

Fig. 1. Scattering of stations in Iran map

In the next stage, for each station in every year, annual precipitation and Standardized Precipitation Index (SPI) have been calculated using the following equation:

3. PNPI= (Pi / P) × 100

Pi = total of precipitation in each year; P= average of precipitation in the period

To check normality of the data for each station, "MINITAB.14" software has been used. P-values from option of "Normality Test" have been analyzed. Amounts more than 0.05 indicate distribution of data in the period of record is normal while amounts less than this indicate distribution data is not normal. In the current assessment 90% of stations have normal data that is acceptable for the assessment.

The assessment of hazard of drought has been attempted by first identifying the main criteria of drought in the study area and then establishing the thresholds (class limits) of severity for criteria and in the end analyzing the hazard. The recommendations appearing in some literature (like Willeke et al., 1994; Zehtabian and Jafari, 2002; Masoudi et al., 2007; Asrari et al., 2012) as well as the statistically suitable parameters of region like 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. Amounts of PNPI less than 80% have been taken into consideration to show drought condition and dry year (Willeke et al., 1994). This threshold helps to evaluate second and third criteria. To find the trend of hazard for each station or its Thiessen polygon, period of data recordings has been divided to two equal periods and in each period percent of dry years was evaluated. Then trend of hazard has been calculated using the following equation:

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

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

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

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 Fig. 3 that showed the different degrees of drought hazard.

Table 2. Criteria used for the hazard assessment of drought using PNPI (Willeke et al., 1994; Asrari et al., 2012)

Indicators	Class limits and their rating score				
	None(1)	**Slight (2)**	**Moderate (3)**	**Severe (4)**	**Very severe (5)**
1) maximum severity of drought in the period	>80	71 - 80	55 - 70	41 - 55	≤ 40
2) % of increasing trend	≤0	1 - 32	33 - 65	66 - 99	≥100
3) maximum number of sequential arid years in the period	0 - 1	2	3	4 - 5	≥6

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 – 2.49	2.5 – 3.49	3.5 – 4.49	≥ 4.5

3. Results and Discussion

Most studies done so far in Iran and in the world have based their estimation on the ‘present state’ of hazard of drought during a specific year using some indices like SPI and PNPI (Raziei et al., 2007; Ensafi Moghaddam, 2007). Such Indicator maps or information alone based on the present state of hazard derived from the specific year are inadequate to show those areas which are more vulnerable to the hazard (Masoudi, 2010). It requires a combination of more indices of hazard like maximum number of sequential years of hazard in a period and also important index of trend showing different aspects of hazard. This kind of classification using different criteria is the first attempt of its kind for defining areas with higher risk drought. The GIS analysis not only facilitated the model development but also allowed the evaluation of spatial correlation and hazard map production.

Figure 2 shows among the hazard criteria maps used in the model; 'maximum severity of drought in the period' shows the most hazardous among three criteria used in the model. 71 % of area in this hazard map is under very severe class, indicating most parts of the country experienced the worst droughts in the period of study. Other results regarding drought assessment in different regions of Iran show the same results (Raziei et al., 2007; Ensafi Moghaddam, 2007; Sarhadi et al., 2008).

The main hazard class of the hazard map of 'maximum number of sequential arid years in the period' is under slight hazard class (45%), almost half of the country is under slight and none hazard classes (50 %) compared to other hazard classes, indicating period of droughts does not continue so long (more than two years) in half of the country. This aspect of drought has been used alone to show vulnerability to drought in regions, which shows the importance of this criteria in the hazard assessment (Feiznia et al., 2001; Zehtabian and Jafari, 2002).

While drought hazard map based on the '% of increasing trend' shows the least hazardous among three criteria used in the model. 56 % of the area in this hazard map is under slight and none hazard classes. Although per cent amount of only "None Class" is 22%, indicating a lesser part of the country showing equal or decreasing trend of occurrence of drought in the second part of the period compared to the first part. This indicates trend of occurrence of drought condition in the study area is an increasing trend, confirming those studies in the region showing climate change is progressing toward a drier condition (Zareiee, 2009; Asrari and Masoudi, 2010; Masoudi and Afrough, 2011).

On the other hand the final hazard map of the country (Fig. 3) shows three different hazard classes. From the Fig. 3 a general conclusion can be derived that in Iran a smaller proportion (42%) is under slight and moderate hazards of drought while the widespread areas are under severe risk of drought (58%). Hazardous lands are observed more in north western, north eastern, south eastern and central parts of the country. This work provides the evidence demonstrating the link between the drought hazard and the intensification of aridity in most parts of Iran especially in the severe areas. This corresponds to more desertification (Masoudi, 2010), degradation and lowering of water resources especially ground water (FAO, 1994), social and economic impacts of drought like immigration from villages in recent decades, those studies show climate changes progressing toward to drier condition and observe lost lakes like Orumieh lake during the last decade in the study area.

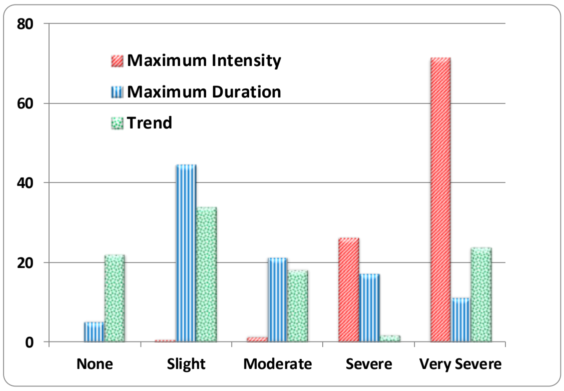

Fig. 2. Per cent areas under hazard classes of three criteria used in the model of drought in Iran

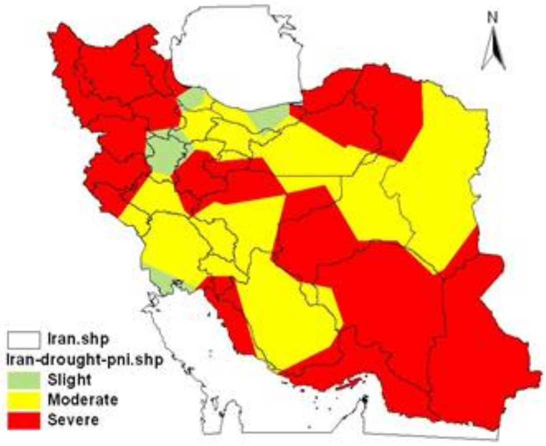

Fig. 3. Hazard map of drought vulnerability in Iran

4. Conclusion

Annual precipitation data for 40 meteorological stations from 1967–2009 in Iran have been analyzed for vulnerability assessment of drought. A hazard classification for drought hazard assessment for the first time is introduced in the research that can be used in the other countries. Three criteria for drought were studied and considered to define areas under vulnerability using PNPI index. Drought hazard criteria used in the present model include: maximum severity of drought in the period, trend of drought, and the maximum number of sequential arid years. Overall results derived from the work and based on this kind of classification indicate that areas under severe hazard are more extensive than the other hazard classes.

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