IJBPAS, December, 2015, 4(12), Special Issue: 440-452

ISSN: 2277–4998

International Journal of Biology, Pharmacy and Allied Sciences (IJBPAS)

'A Bridge Between Laboratory and Reader'

www.ijbpas.com

ASSESSMENT ON MULTI-INDEX AGRICULTURAL DROUGHT VULNERABILITY AND SPATIAL CHARACTERISTICS ANALYSIS

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ABSTRACT

Drought events have huge harmful impact on socio-economic and environmental conditionsand occur when an area does not receive significant precipitation for a sustained period of time. Drought causes damage to agriculture, ecosystems, and freshwater supplies. The increase in drought hazard may result from an increased duration and severity of meteorological drought, which then may lead to increased societal vulnerability to drought. In this study, the spatial analysis of drought severity and duration indices of meteorological droughts in Isfahan Province, Iran was carried out from vulnerability concept. The climatic pattern of study area displayed an arid and semiarid regions and assessment of drought vulnerability was essential due to water deficiency. The annual rainfall varied from 800 mm in western region to 75 mm eastern arid region. A set of 21 weather station with monthly rainfall recording for at least 30 provided a detailed analysis of the spatial distribution to identify drought areas. The SPI method was used to detail geographical variations in the drought vulnerability based on severity and duration of drought events at 3-month time steps. IDW interpolation technique was used to obtain SPI values where no station data existed. Because drought damage differed in the counties of study area, a comparison was made for the amount of damage between counties in agricultural areas. Finally, the agricultural drought vulnerability was evaluated by considering the agricultural areas. The results showed that drought phenomenon created more vulnerable environment for the agricultural sector in Isfahan Province. The maximum severity of drought was observed in counties of west while the spatial analysis of drought duration indicated that counties in east and a part of north and south of Isfahan experienced drought duration more than other areas. To consider both characteristics, the majority of counties such as Kashan, Aran va Bidgol and Semirom were found to be affected by severity and duration of drought. Agriculture vulnerability of drought in counties of Isfahan and Barkhar va Meimeh were maximum while these counties had low vulnerability compared with the entire region. The study also revealed that when agriculture area of each county is taken into consideration, the trend of drought changes.

Keywords: Indices of drought, Agricultural drought vulnerability, SPI, Isfahan Province.

INTRODUCTION

Drought is an important disaster and one of the most damaging climate-related hazards and usually its impacts on agriculture are enormous. The drought events also have huge harm to socio-economic and environments. A drought occurs when an area does not receive significant precipitation for a sustained period of time. The most basic definition of drought is that of a section of low precipitation that causes damage to agriculture, ecosystems, and freshwater supplies [23].

It is very difficult to isolate the beginning of a drought, as drought development is slow and very often it is not recognized until human activities, or the environment, are affected. Moreover, the effects of a drought can persist over many years after it has ended [26]. Assessment of drought vulnerability is very important for humans because of high economic cost and social vulnerability of drought problem. These have led to increasing attention to the drought vulnerability issue in recent years [23], [10]. Agriculture drought is one of the most important types of drought because it directly affects farmers and the economy of country. According to the WMO (1975) definition, agricultural drought is "a deficit of precipitation in respect to the long period mean, affecting a large area for one or several seasons or years that reduce primary production in rain-fed agriculture".

Drought is predominantly controlled by air temperature and precipitation and can be classified into four categories as meteorological, hydrological, agricultural and socio-economic [2], [22]. Since there are so many different definitions of drought, over the years, operational definitions of drought formulated in form of indices have emerged to answer such questions as; when, how long, and how severe a drought is [14]. These questions can be answered through drought monitoring that is usually done with the use of drought indices. There are more than 50 drought indices available in practice [8]. Although no drought index has satisfied all definitions of drought, the Standard Precipitation Index (SPI) is commonly used and accepted. Keyantash and Dracup (2002) reviewed 14 well-known drought indices which have been used for assessing the frequency and severity of meteorological, hydrological, and agricultural droughts and found the SPI as a highly valuable estimator of drought frequency, severity and duration.

Several studies have been done on drought indices around the world and especially in Iran [6], [18], [5], and [3]. Morid et al. (2006) compared seven drought indices for drought monitoring in the Tehran province of Iran. Percent of Normal (PN), Rainfall Deciles (RDs), Statistical Z Score (Z-Score), Standardized Precipitation Index (SPI), China-Z Index (CZI), Modified China-Z Index (MCZI), and Effective Drought Index (EDI) were used. Comparisons showed that SPI and EDI performed better in detecting the onset of drought, and these were recommended to the Tehran drought monitoring system. Sanainejad et al. (2003) studied drought periods in northeast Iran (Mashhad) over a 32 year period (1968–1999) using the SPI. They showed that there is a severe and long (more than a year) drought period in every 10 years. The trend of 32 years precipitation data revealed that in recent years the duration and frequency of drought events have increased for all time scales, but their severity has decreased.

Considerable research efforts have been put into the quantification of drought severity because drought is usually characterized by its duration, severity, and affected area. Various kinds of drought indices have been developed to express drought severity such as PDSI (Palmer Drought Severity Index) developed by Palmer (1965) and SPI (Standardized Precipitation Index) developed by Mckee et al. (1993). Ansari et al. (2010) used the SPI for drought monitoring in Khorasan (northeast of Iran) using 33 years of climate data (1968–2000). They showed that during 1968–2000 drought occurrence has been more frequent and also lasted longer than in the earlier years. They indicated that the severity of drought has been reduced and its duration and severity was higher in the southern area than in central and northern parts of Khorasan province. Many studies performed recently have emphasized the importance of comprehensive assessment of the drought risk by combining the hazard and vulnerability [25], [21], [9].

The objective of this article is assessment of agricultural drought vulnerability to address multi-nature aspects of drought with its several features including severity and duration of drought occurrence and its spatial distribution to identify drought areas and drought vulnerability at 3-month time steps.

2. MATERIAL AND METHODS

2.1. Study Area

This study was conducted in Isfahan Province, which is located in the center of Iran (Fig. 1) and covers a total area of 107045 km^2. The climatic pattern of study area displays an arid and semiarid region. The eastern regions of the province are located in the western margins of arid and semi-arid regions of Iran. The western regions of the province lay in the eastern hill slopes of Zagrous Mountains. The mean annual temperature is 13.6 ˚C and the total average annual precipitation is 160 mm. The annual rainfall varies from 800 mm in western region to 75 mm eastern arid region. Impact of drought in the low and variable rainfall regions of the area can be widespread, affecting such diverse sector as agriculture.

In this study, a 30 year period from 1975 to 2005 was selected to calculate SPI based on precipitation records. Total monthly precipitation record is prepared in the study area. Fig. 1 shows the location of meteorological stations.

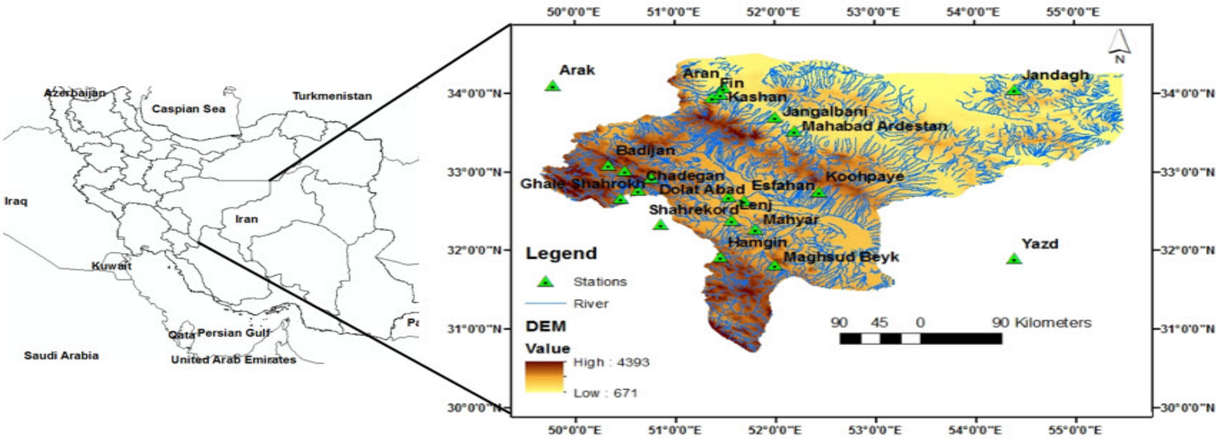


Figure 1. Relief configuration and spatial distribution meteorological stations of Isfahan Province, Iran

2.2. Standardized precipitation index (SPI)

McKee et al. (1993) developed the Standardized Precipitation Index (SPI) to identify and monitoring drought through recorded precipitation data. The SPI index may be computed with different time steps (1, 3, 6, 12, 24, 48 month SPI, etc.); the longer time scales relate to hydrological drought and the shorter time scales may represent agricultural drought. Although SPI is more suited to monitoring meteorological and hydrological droughts rather than agricultural droughts, it is flexible to inform on some aspects of agricultural droughts [7]. For several reasons SPI is favored over the other indexes, e.g., it only requires rainfall data, it is easy to calculate, reliable, and able to address a variety of drought related issues. Essentially, SPI is an index of the standard deviation of a given precipitation deficiency. Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation. Values generally are between ± 2.0. Table 1 shows the SPI thresholds defined by McKee et al. (1993). A drought event is signaled any time the SPI values are continuously negative and reach an intensity of -1.0. The drought event ends when the SPI values return to positive. Based on normalized SPI values, an event is considered mild, moderate, severe, or extreme [13].

Table 1: SPI drought severity classes for wet and dry periods

SPI Classes	SPI Value
Extremely wet	> 2
Severely wet	1.5 - 1.99
Moderately wet	1 - 1.49
Normal	-0.99 - 0.99
Moderately dry	-1.49 - -1
Severely dry	-1.99 - -1.5
Extremely dry	< -2

Computations in SPI are conducted using a software program developed at the University of Nebraska which is available in the website of the National Drought Mitigation Center (NDMC, 2005). Comprehensive information and complete formulation of the SPI calculation was provided by Loukas and Vasiliades (2004). The SPI was defined on each of the time scales as the difference between precipitation on the time series (x_i) and the mean value $(\bar{x})$, divided by the standard division (s):

$$SPI = \frac{x_i - \bar{x}}{s} \quad (1)$$

In this research, 30 years of monthly rainfall data were collected from 22 stations in arid and semi-arid regions of Isfahan Province, Iran to evaluate the severity and duration of SPI. Drought analysis was carried out by means of the standardized precipitation index, at a 3-month temporal scale.

2.3. Inverse Distance Weighted (IDW)

Inverse Distance Weighted interpolation clearly executes the assumption that things that are close to one another are more alike than those that are farther apart. In order to predict a value at an unmeasured location, surrounding points are considered based on a number of points within a certain radius. This is a deterministic method and no estimate concerning the accuracy of prediction is available. Weights are assigned to each of these points as an inverse function of their distance from this point. The formula to obtain this exact interpolator is [2]:

$$\lambda_i = \frac{(\frac{1}{d_i^p})}{(\sum 1/d_i^p)}$$

Where λ_i is the coefficient value to be used for a particular point at a distance (di) from the point whose value is to be interpolated. These coefficients are calculated for all points within a certain radius or a specified number of points. Mozafari et al. 2011 showed that IDW method with the power of two is more appropriate for spatial analysis of SPI index in Boushehr province of Iran. In this study, IDW interpolation technique was used to obtain SPI values where no station data existed. This method produces visually appealing contour and surface plots from irregularly spaced data.

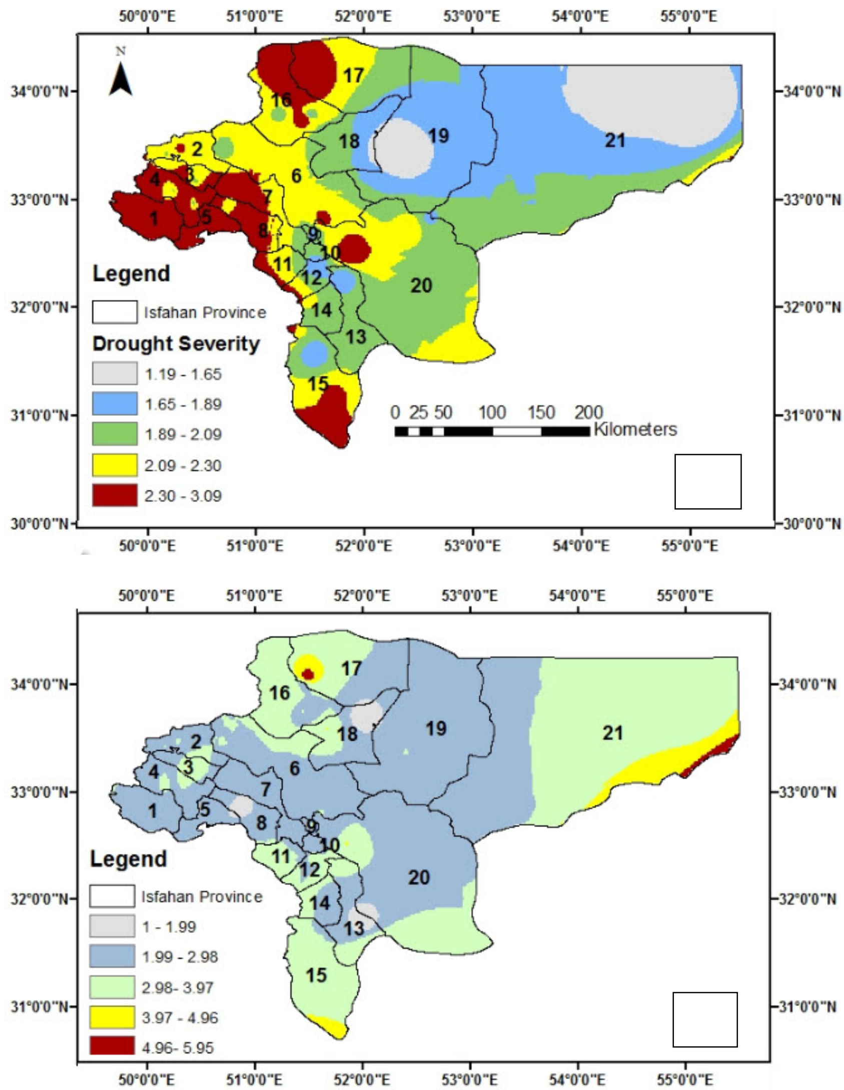
3. DISCUSSION

Similar to other natural hazard risks, drought risk depends on a combination of the physical nature of drought and the degree to which a population or activity such as agriculture is vulnerable to the effects of drought [20]. Therefore, in order to assess drought vulnerability, it is essential to quantify the frequency and spatial extent of droughts [20]. This quantitative assessment of drought risk is utilized to help managers to do better of development works when drought happens. In this study, at first drought frequently is calculated for each county and then agricultural drought vulnerability based on agricultural areas in each county is instigated.

3.1. Calculation of drought severity and duration

In this study, drought occurrences in Isfahan have been investigated based on severity and duration for each drought category at 3-month time steps. The resulting SPI values at corresponding drought categories were mapped for each county using an inverse distance weighting (IDW) interpolator in ArcGIS software for drought frequency per year in Isfahan Province. IDW method is chosen for all the data interpolation processes, because it provides a reasonable level of accuracy in data prediction while it is much less time consuming comparing to other interpolation methods such as Kriging.

Drought characteristics of severity and duration with county locations are shown in Figure 1. The spatial analysis of severity and duration were interpolated by IDW method for region. As can be seen from the figure there were different distributions for these characteristics. The highest severity of drought are located in counties of west (such as Fereydoun Shahr, Chadegan and Najafabad) while it is lowest in the east.



Names of counties	ID
Fereydoun Shahr	1
Golpayegan	2
Khansar	3
Fereydan	4
Chadegan	5
Barkhar va Miemeh	6
Najafabad	7
Tiran va Karvan	8
Khomeini Shahr	9
Felavarjan	10
Lenjan	11
Mobarakeh	12
Shahreza	13
Semirom Soflia	14
Semirom	15
Kashan	16
Aran va Bidgol	17
Natanz	18
Ardestan	19
Isfahan	20
Naeen	21

Figure 2. Drought severity and duration per year in Isfahan Province (a: drought severity, b: drought duration)

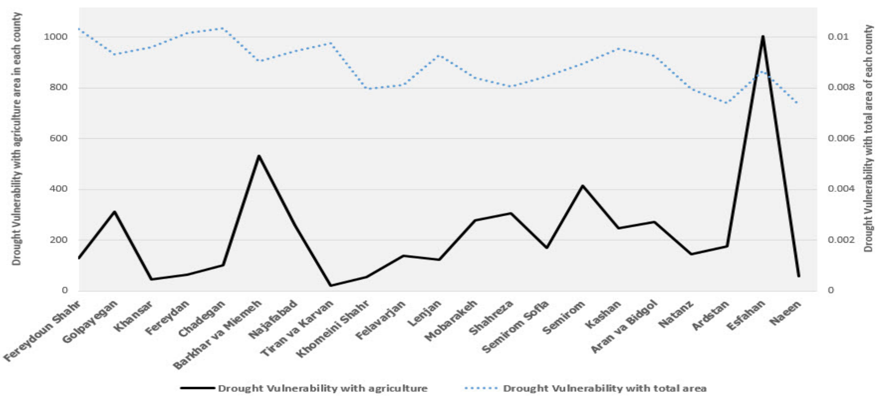
The spatial analysis of drought duration indicates that counties in east and a part of north and south of Isfahan (Especially in Naeen, Semirom, Kashan and Aran va Bidgol) have more durable droughts than other areas while in the central part of the study area drought duration is less (Fig. 2). Considering both characteristics, the majority of counties such as Kashan, Aran va Bidgol and Semirom are affected by severity and duration of drought. Because damage of drought differs among counties of Isfahan Province, the amount of damage was studied between counties in agricultural areas.

3.2. Drought Vulnerability and risk

Area of each county and agriculture areas along with vulnerability of agriculture drought severity and duration are shown in Table 1. To calculate vulnerability of agriculture, first area of each county was calculated. Then, area of agriculture was extracted and vulnerability of agriculture drought severity and duration were determined.

Table 2: Area of each county and agriculture areas in Isfahan Province

Name	Area of each county (Ha)	Area of agriculture (Ha)	Vulnerability of agriculture drought severity	Vulnerability of agriculture drought duration
Fereydoun Shahr	215872	12481.9	128.5934	139.2902
Golpayegan	163427	33306.34	310.5895	384.3647
Khansar	95780	4874.6	46.822	62.19183
Fereydan	200419	6436	65.47768	69.10641
Chadegan	119020	9753.3	100.794	87.43673
Barkhar va Miemeh	697071	58721	531.215	707.1916
Najafabad	238759	27501.8	259.5148	291.1911
Tiran va Karvan	168872	2209.7	21.59031	21.49871
Khomeini Shahr	17580	6784.9	54.02945	86.21556
Felavarjan	32428	16992.12	138.0174	204.4586
Lenjan	117250	13112.7	121.9003	169.9895
Mobarakeh	109399	33208	278.3528	415.2527
Shahreza	279550	37965.3	305.9764	417.3393
Semirom Sofla	142642	20020.1	168.9827	241.2636
Semirom	527142	46226.9	414.2633	615.8703
Kashan	440618	25826.1	246.1175	345.9946
Aran va Bidgol	610075	29208.5	270.5521	393.7872
Natanz	341838	17989.3	143.4035	191.5029
Ardstan	1259050	23761	176.115	251.9245
Isfahan	1570649	115744.21	1003.242	1322.476
Naeen	3355277	7942.8	58.19425	106.1241



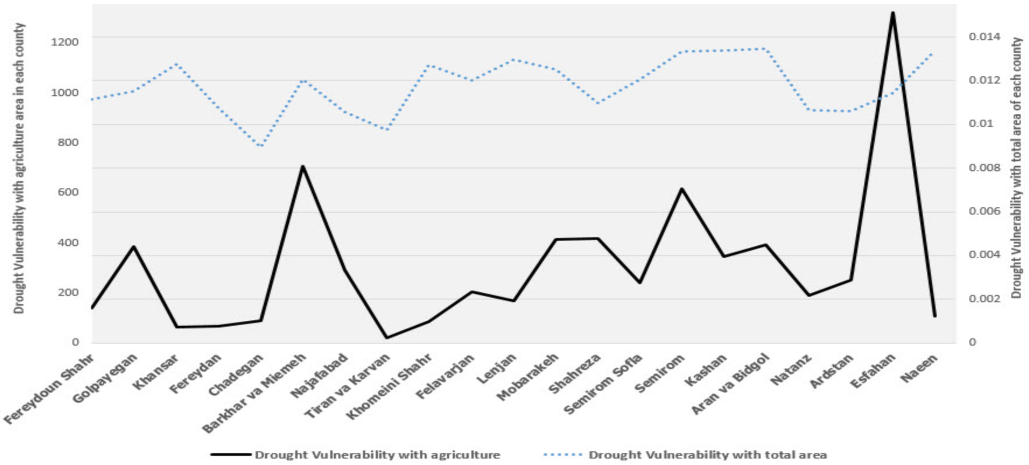


Figure 3: Drought vulnerability of severity and duration with total area of each county and agriculture area Province (a: drought severity, b: drought duration)

Figure 3 shows vulnerability of drought in different counties. Although drought vulnerability with total area is different regarding each characteristic, it seems more homogeneous considering only agricultural areas. Agriculture vulnerability of drought in counties of Isfahan and Barkhar va Meimeh were maximum (Black line) while these counties in total area had low vulnerability (Fig 3). This shows that when agriculture area of each county is applied, the trend of drought will change. Moreover, some counties have more agriculture areas with less of total area compared with the counties that have more total area with less agriculture. In these counties areas of agriculture can be very effective on drought vulnerability such as Tiran va Karvan, Khomeini Shahr and Naeen.

Among counties of Isfahan province, those which had more agricultural areas and orchards, were more deeply affected by drought particularly those located in center, west and south (Fig. 2) and this circumstance is more important for counties with smaller area such as Khomaini shahr and Felavarjan. Due to damages to people living in agricultural areas, they gradually turned to other careers, abandoned agriculture and it is observed that in the west and the south agriculture is a popular occupation for people which during drought, poses more vulnerability threats. In Felavarjan County the majority of people live through agricultural and gardening and this county is the second smallest tawn in area after Khomeini Shahr.

In Isfahan and Felavarjan counties rice is cultivated in paddy fields. Rice needs a lot of water for growth and due to drought in the past years, there was a cut in the yields of this product and, therefore, drought in these counties has had a more devastating effect.

4. CONCLUSION

A set of 21 rain gauges in Isfahan Province in the center of Iran with monthly rainfall recording for at least 30 years has facilitated a detailed analysis of the spatial distribution to identify drought areas. Isfahan Province is located in arid and semi-arid regions and assessment of drought vulnerability is essential due to water deficiency. Drought was categoried by employing SPI approach at 3-month time steps.

In summary, this paper has shown that SPI is a simple and effective tool for the study of Isfahan Province drought. The results showed that drought phenomenon created more vulnerable environment for the agricultural sector in Isfahan Province. The highest severity of drought is observed in counties of west while it least severe regions were found to be located in east. Also, the spatial analysis of drought duration indicates that counties in east and a part of north and south of Isfahan have drought duration more than other areas while in the central part of the study area drought duration is less. Regardingboth characteristics, majority of counties such as Kashan, Aran va Bidgol, and Semirom are affected by severity and duration of drought. Agriculture vulnerability of drought in counties of Isfahan and Barkhar va Meimeh were maximum while these counties in total area had low vulnerability. It was found that when agriculturearea of each county is applied, the trend of drought changes.

The results confirmed that the higher the damage factors level which are caused from the severity and duration of previous drought events, the larger the agriculture drought vulnerability is. It is obvious that an improved understanding of drought occurrence such as its severity could help identify risks associated with the drought. This study offers some new insight into drought phenomenon in Isfahan Province and helps us to plan for the drought in each county a take appropriate measures.

Attention should be paid strictly to drought, particularly in overcrowded counties which need water and land resources to develop. This is an essential step toward addressing the issue of agricultural drought vulnerability for mitigation purposes. Identifying regional vulnerabilities can lead to adjustment in practices in agriculture and water-dependent sectors and can help decision makers to take the drought into account for hazards it poses. In order to better manage droughts in the future, it is suggested that the impact of climate change on drought also be investigated.

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