Journal of Water Sciences Research,
ISSN: 2251- 7405 eISSN: 2251-7413
Vol. 3, No.1, Summer 2011, 37-43

JWSR

Drought Monitoring Using Climatic Indices and Geostatistic Technique (Case Study: Hossein Abad Plain, Sarbisheh, Iran)

Hossein Ghasemi [1], Abbas Ali Gholami [2*], Gholamreza Hadarbadi[3], Hossein Ebrahimi[4]

1. M. Sc. Graduate of Combating Desertification, Birjand, Iran
2. M. Sc. of Water instruction, Islamic Azad University, Ferdows, Iran
3. PHD Student of Environmental Management, Department of Environmental and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran
4. Assistant Professor, Islamic Azad University, Ferdows, Iran

Received: 17 Apr. 2011 ; Accepted: 25 Jun. 2011

ABSTRACT

Of the many climatic events that influence the Earth's environment, drought is perhaps the one that is most linked with desertification. Drought is the consequence of a natural reduction in the amount of precipitation received over an extended period, usually a season or more in length. Drought monitoring is an essential component of drought risk management. It is normally performed using various drought indices that are effectively continuous functions of rainfall and other climatic variables. A number of drought indices have been introduced and applied in different countries to date. This paper compares the performance of two indices for drought monitoring in Hossein Abad Plain which includes several catchments and villages. The indices used include deciles and standard precipitation indexes. The comparison of indices is based on drought cases and classes that were detected in the12 synoptic stations over the 11 years of data, as well as over the latest 1998–2001 drought spell. Then by using ArcGIS 9.2 software were planned drought and wetness maps. The method of interpolate was Kriging (one of suitable Geo statistical methods).The results show that SPI respond slowly to drought onset. DI appears to be very responsive to rainfall events of a particular year, but it has inconsistent spatial and temporal variation. The SPI was found to be able to detect the onset of drought, its spatial and temporal variation consistently, and it may be recommended for operational drought monitoring in the country and SPI was found to be more responsive to the emerging drought and performed better.

Keywords

Drought monitoring, Climatic indices, Geostatistical methods

1. Introduction

Drought is perhaps the most complex natural hazard. It is often generally defined as a temporary meteorological event that stems from the lack of precipitation over an extended period of time compared with some long-term average condition (e.g. precipitation). But droughts that develop slowly, are difficult to detect and have many facets in any single region. The success of drought preparedness and mitigation depends, to a large extent, upon timely information on drought onset, progress and areal extent. These types of information may

* Corresponding Author Email: (ghloami@yahoo.com)

be obtained through drought monitoring. Monitoring is normally performed using drought indices. Drought indices provide decision makers with information on drought severity and can be used to trigger drought contingency plans, if they are available. Many drought indices have been developed to date. These include the Palmer Drought Severity Index (PDSI – Palmer, 1965), which is widely used in the United States, the decile index (Gibbs and Maher, 1967), which is operational in Australia, the China-Z index (CZI), which is used by the National Metrological Center of China (Wu et al., 2001), the Surface Water Supply Index (SWSI – Shafer and Dezman, 1982) adopted by several states in the United States, and standardized precipitation index (SPI – McKee et al., 1993), which has gained world popularity, etc. Most of these indices are calculated using climate data (rainfall and, in some cases (PDSI), temperature). The review of drought indices can be found in several sources including: http:// www.drought. unl.edu/whatis/indices.htm, Alley (1984), Wu et al. (2001), S akhtin and Hughes (2004). No index is ideal and/or universally suitable. The choice of indices for drought monitoring in a specific area should eventually be based on the quantity of climate data available and on the ability of the index to consistently detect spatial and temporal variations during a drought event. Iran is frequently hit by recurring droughts. The most recent drought of 1998–2001 was the worst in the last 36 years with rainfall deficits consistently exceeding 60% of the mean annual rainfall in most of the country. The severity of this drought placed an extreme strain on water resources, livestock and agriculture. The Iranian Emergency Agency reported that 278 cities and 1050 villages had been affected. Also, the crops from a rain fed area of 4 million ha as well as those from an irrigated area of 2.7 million ha were completely destroyed. The total agricultural and livestock losses by the year 2001 were estimated to be US$2.6 billion. Eighteen out of the 28 provinces of the country were affected, but the impact of the drought differed throughout the country and some of the provinces were more hit than others.

1.2. Study area

The study area, known as the Hossein abad plain, lies in eastern Sarbisheh, approximately 100 km south of Birjand, the capital of Southern Khorasan, Iran. The center of the study area is roughly located at 59º 55’E to 60º 15’E and 32º 4’ N to 32º 37’ N. The study area covers about 103806.21 ha of Hossein Abad plain. Most of the areas are thinly populated with approximately 383 households dispersed over 14 villages and 9 rangeland scopes (Fig. 1). Livestock herding is the main occupation of the local inhabitants. The study region is one of countries' heavily degraded areas.

Hossein Abad plain is also prone to high Sistani winds lasting over 120 days from April to July causing extensive erosion with maximum speed up to 120 km/hr displacing large quantities of sand into the area and causing considerable damages to natural vegetation and crops. The area is also subject to the effects of recurring droughts.

This paper has attempted to evaluate value of DI and SPI meteorological indices and compares the performance of to indices for drought monitoring in Hossein Abad Plain.

2. Method and Material

2.1. Rainfall data and drought indices

Observed yearly rainfall data from 12 meteoro-logical stations located in different parts of plain, have been selected for this study. The length of the available records at these stations is from January 1998 to December 2008. The accuracy of all data sets was evaluated using nonparametric tests described in Pilon et al.

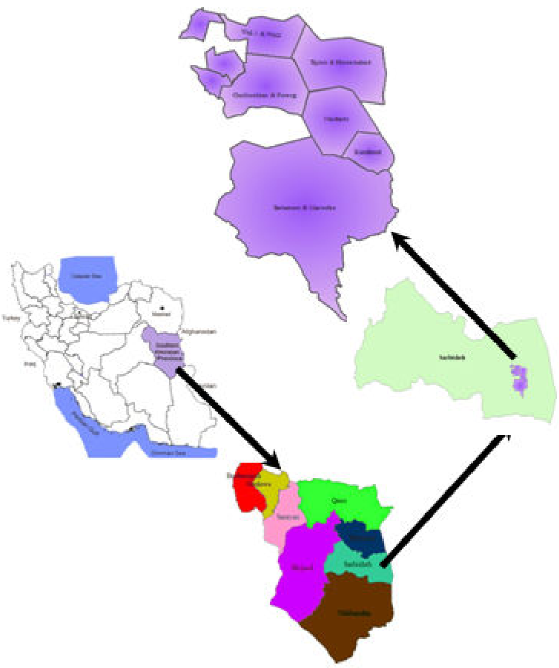

Fig. 1. Location map of the study area in the country

(1985),including Mann- Whithney (for homogeneity), Spearman (for in-dependence and trend) and Runs (for randomess). The SPI and DI drought indices for this study have been calculated on the basis of these rainfall data and using Drought Index Package (DIP) software (Morid et al., 2005). The brief description of the two indices is given below:

2.2. The standardized precipitation index (SPI)

To calculate the SPI, a long-term precipitation record at the desired station is first fitted to a probability distribution (e.g. gamma distribution), which is then trans-formed into a normal distribution so that the mean SPI is zero (McKee et al. 1993 and 1995; Edwards and McKee 1997). The SPI may be computed with different time steps (e.g. 1 month, 3, 6, 12 and 24 months). Guttman (1998) showed that the use of SPI at longer time steps was not advisable as the sample size reduces even with originally long-term data sets. The use of different timescales allows the effects of a precipitation deficit on different water resource components (groundwater, reservoir storage, soil moisture, stream flow) to be assessed. Positive SPI values indicate greater than mean precipitation and negative values indicate less than mean precipitation. The SPI may be used for monitoring both dry and wet conditions. The 'drought' part of the SPI range is arbitrarily split into 'near normal' (0.99 > SPI > -0.99), 'moderately dry' (-1.0 > SPI > -1.49), 'severely dry' (-1.5 > SPI > -1.99) and 'extremely dry' (SPI < -2.0) conditions. A drought event starts when SPI value reaches -1.0 and ends when SPI becomes positive again. The positive sum of the SPI for all the years within a drought event is referred to as 'drought magnitude'. This index is presently used as one of the indices for drought monitoring in the entire United States (http://www.drought.unl.edu/monitor/spi.htm).Also, a number of studies evaluated the performance of this index (e.g. Wu et al. (2001) – in China, Ansari (2003) – in Iran, etc.).

2.3. The decile index (DI)

In this approach suggested by Gibbs and Maher (1967) and widely used in Australia (Coughlan 1987), yearly precipitation totals from a long-term record are first ranked from highest to lowest to construct a cumulative frequency distribution. The distribution is then split into 10 parts (tenths of distribution or deciles).

The first decile is the precipitation value not exceeded by the lowest 10% of all precipitation values in a record. The second decile is between the lowest 10 and 20% etc. Comparing the amount of precipitation in a year (or during a period of several months) with the long-term cumulative distribution of precipitation amounts in that period, the severity of drought can be assessed. The deciles are grouped into five classes, two deciles per class. If precipitation falls into the lowest 20% (deciles 1 and 2), it is classified as much below normal. Deciles 3 to 4 (20 to 40%) indicate below normal precipitation, deciles 5 to 6 (40 to 60%) indicate near normal precipitation, 7 and 8 (60 to 80%) indicate above normal precipitation and 9 and 10 (80 to 100%) indicate much above normal precipitation. In the current study, yearly rainfall time series are normalized using the Box–Cox transformation (McMahon 1986).

However, the ranges of the DI differ from that of the SPI. To make them comparable with the SPI classes, the DI values have been categorized into similar classes (Table I). Original DI classes of 30–40% (slightly below normal), 50–60% (normal) and 60–70% (slightly above normal) have been added up to form a broader 'normal' DI class of 30–70% (corresponding to the 'normal' SPI range).(Table I).

3. Results

3.1. Comparison of the DI and SPI

The evaluation has been used for the DI (Fig. 2); the frequency of dry and wet cases differs from that of the SPI (Fig. 3), especially in the 'normal classes.

All class of the DI is much larger than that of the SPI. Conversely, this fact points to a larger sensitivity of the DI to changes in precipitation, compared to the SPI. The magnitude of normal class in the DI is higher than in the SPI. Source: Presented by Gibbs and McKee.

3.2. Evaluation of indices drought in the 2005

In this section, the performance of the DI and SPI has been assessed in the 2005 which the study region experienced an extreme and long-lasting drought event.

3.4. Mapping the spatial extent of 2005

Maps of drought conditions for 2005 have been drawn using GIS facilities (Arc Gis 9.2). The spatial interpolation method used in this study is Ordinary Kriging Method (OKM).

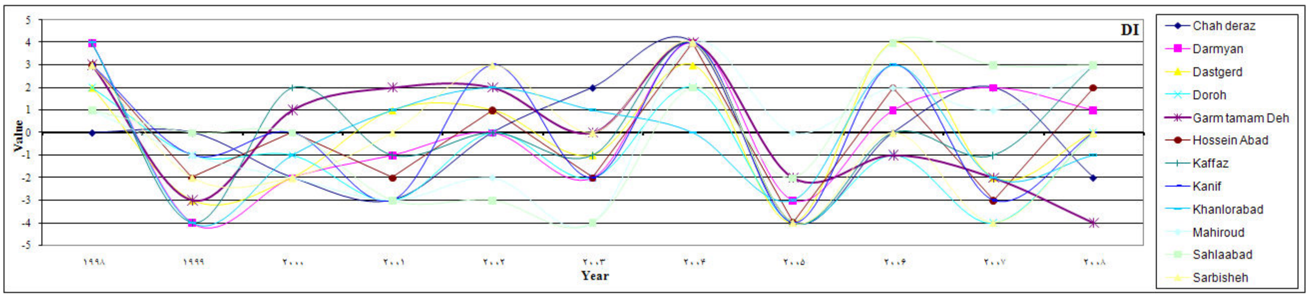

Fig. 2. Fluctuation of DI values of stations from 1998 to 2008

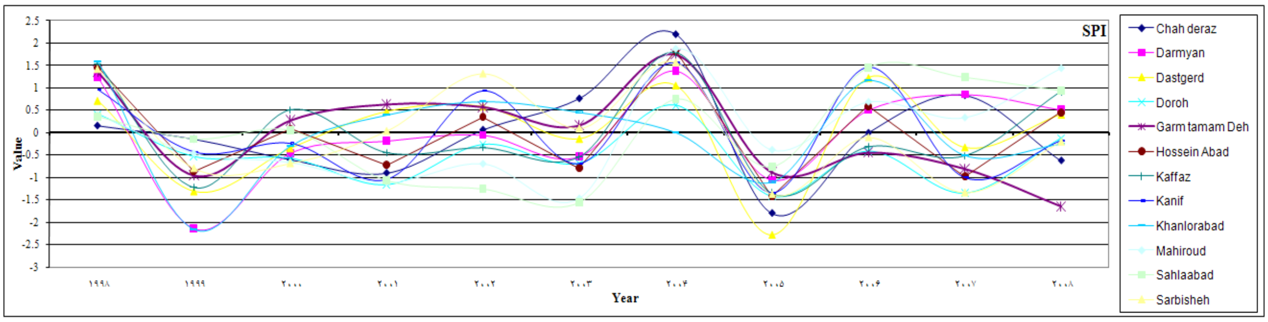

Fig. 3. fluctuation of SPI values of stations from 1998 to 2008

3.4. Mapping the spatial extent of 2005

Maps of drought conditions for 2005 have been drawn using GIS facilities (Arc Gis 9.2).

The spatial interpolation method used in this study is Ordinary Kriging Method (OKM). This method is a stochastic technique and local interpolator that uses the semi-variogram. Weights of this method are obtained by solving a system of linear equations, which is known as 'ordinary kriging system'. More details can be found in Isaaks and Srivastava (1989) or Goovaerts (1997).

The structure of data may be described by four parameters: the sill, range, nugget and anisotropy. The variance value at which the curve reaches the plateau is called the sill. The total separation distance from the lowest variance to the sill is known as range. The nugget refers to variance at separation distance of zero. In theory, it should be zero. However, noise or uncertainty in the sample data may produce variability that is not spatially dependent. Anisotropy of the dataset describes spatial continuity with respect to the defined direction. It may be equal in all directions, which is known as an omni-directional semivariogram. A more detailed description of kriging is available in Goovaerts (1997). Figs. 3 and 4 show drought pattern in Hossein abad palin for 2005.

In comparison, DI index has high sensitivity to rainfall than SPI. On the other hand, slight fluctuations of rainfall could be able to have striking effect in final values of DI index. While, long-term changes in precipitation are considered in SPI Index. Then by using DI indices, drought classes in the 2005 more than SPI.

Fig. 4 shows a drought map by using DI indices. The inconsistent spatial change within the country is obvious. While by using SPI most of the Hossein Abad is in the 'Moderately dry' to 'Severely dry' condition (Fig. 3). Analysis of these maps revealed an inconsistent spatial and temporal behavior of the DI in response to drought.

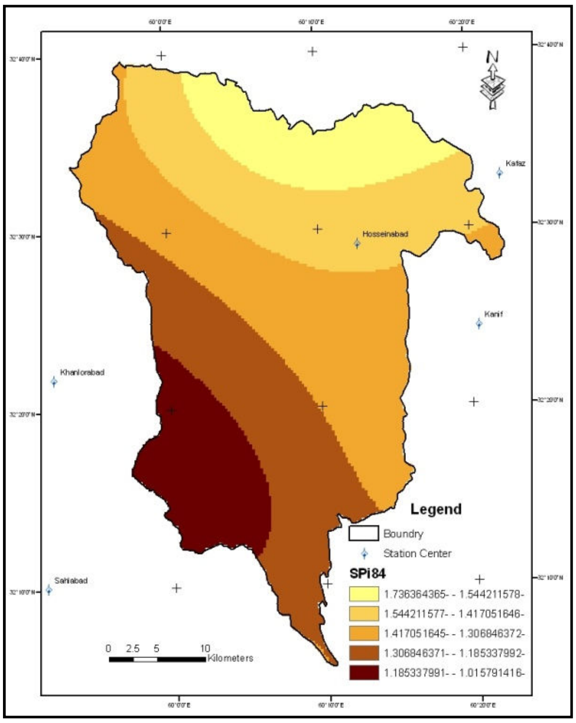

Fig. 3. Drought class of the SPI indices during in 2005 in Hossein Abad Plain

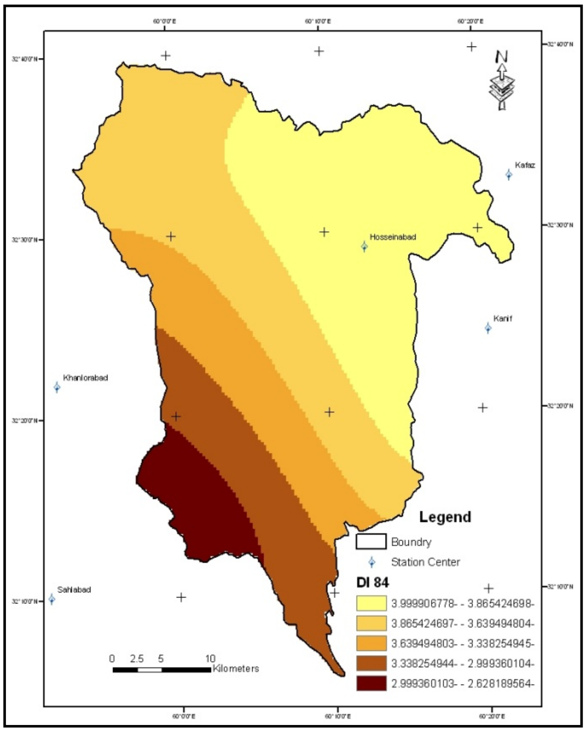

Fig. 4. Drought class of the DI indices during in 2005 in the Iran

5. Conclusions

Important of results are as follows:

- Iran has experienced an extreme and long-lasting drought event in 2005.
- All classes of drought in DI index are much larger than of the SPI.
- Slight flections of rainfall have sharp changes in drought values of DI. In which case there are not accurate evaluations of drought occurrences in Hossein Abad Plain. Conversely, SPI has less effectiveness to low changes of rainfall. Then by using DI indices, drought classes in the 2005 more than SPI.
- The evaluation has been used for the DI; the frequency of dry and wet cases differs from that of the SPI, especially in the 'normal classes'.
- SPI responds slowly to drought onset. DI appears to be very responsive to rainfall events of a particular year, but it has inconsistent spatial and temporal variations.
- The SPI was found to be able to detect the onset of drought, its spatial and temporal variation consistently, and it may be recommended for operational drought monitoring in the Hossein Abad Plain and SPI was found to be more responsive to the emerging drought and performed better than the DI index.

Refrerences

Alley W. M., (1984). The palmer drought severity index: limitations and assumptions. Journal of Climate and Applied Meteorology 23: 1100–1109.

Ansari H., (2003). Monitoring and zoning of drought using fuzzy logic and GIS, PhD dissertation, Tarbiat Modarres University.

Byun H.R., Wilhite D.A., (1996). Daily quantification of drought severity and duration. Journal of Climate 5: 1181–1201.

Byun H.R., Wilhite D.A., (1999). Objective quantification of drought severity and duration. Journal of Climate 12: 2747–2756.

Coughlan M.J., (1987). Monitoring drought in Australia. In Planning for Drought: Toward a Reduction of Societal Vulnerability, Wilhite DA, Easterling WE (eds). West View Press: Boulder, CO; 131–144.

Edwards D.C., McKee T.B., (1997). Characteristics of 20th century drought in the United States at multiple time scales. Atmospheric Science Paper 634: 1–30.

Fahmi H., (2001). Assessment of the 1998–2000 Drought Spell on Water Resources of Iran. Ministry of Energy: Tehran; 49.

Gibbs W.J., Maher J.V., (1967). Rainfall Deciles as Drought Indicators, Bureau of Meteorology bulletin No. 48. Commonwealth of Australia: Melbourne; 29.

Goovaerts P., (1997). Geostatistics for Natural Resources Evaluation.Oxford University Press: New York.

Goovaerts P., (2000). Geostatistical approaches for incorporating elevation into the spatial inter-polation of rainfall. Journal of Hydrology 228: 113–129.

Guttman N.B., (1998). Comparing the palmer drought index and the standardized precipitation index. Journal of the American Water Resources Association 34: 113–121.

Kendall M.G., Stuart A., (1977). The Advanced Theory of Statistics. Charles Griffin & Company: London, High Wycombe; 400–401.

McKee T.B., Doesken N.J., Kleist J., (1993). The relationship of drought frequency and duration to time scales. In Proceeding of the 8th Conference on Applied Climatology, American meteorological society: Boston, 179–184.

McKee T.B., Doesken N.J., Kleist J., (1995). Drought monitoring with Multiple Time scales. In Proceeding of the Ninth

Conference on Applied Climatology, Dallas, TX, American Meteorological Society: 233–236.

McMahon T.A. (1986). River and Reservoir Yield. Water Resources Publications: Littleton, Colorada, USA; 56.

Mir Abolghasemi H., Morid S., Ghaemi H., (2001). Integrated drought plans, the lost component in water management of Iran. In Proceeding of the First National Conference on “Water Crisis Mitigation Strategies”, Zabol; 443–454.

Palmer W.C., (1965). Meteorological Drought, Research Paper No. 45. U.S. Department of Commerce Weather Bureau: Washington, DC.

Shafer B.A., Dezman L.E., (1982). Development of a Surface Water Supply Index (SWSI) to assess the severity of drought conditions in snow packs runoff areas. Proceedings of the Western Snow Conference. Colorado State University: Fort Collins, CO; 164–175.

Smakhtin V.U., Hughes D.A., (2004). Review, Automated Estimation and Analyses of Drought Indices in South Asia, IWMI Working Paper 83 – Drought Series Paper N 1. IWMI: Colombo; 24.

Wu H., Hayes M.J., Welss A., Hu Q., (2001). An evaluation the standardized precipitation index, the china-z index and the statistical z-score. International Journal of Climatology 21, 745–758.