Environmental Resources Research
Vol. 2, No. 1, 2014

GUASNR

Hydrological Drought Analysis Using SDI Index in Halilrud Basin of Iran

F. Soleimani Sardou[1], A. Bahremand[2]
[1]MSc Graduate, Natural Resources Department, University of Jiroft, Iran
[2]Associate Professor, Gorgan University of Agricultural Sciences and Natural Resources

Received: May 2013 Accepted: December 2013

Abstract

Nowadays, drought is considered as damaging environmental phenomenon which affects natural resources and social communities. Therefore, it is important to assess the magnitude and effects of these phenomena and consider it in the relevant management efforts. To do this we used L-moment method for regional homogeneity testing. The Stream-flow Drought Index (SDI) as a hydrologic drought was used for investigating probability of drought occurrence in Halilrud basin as one of the important basins in arid and semi-arid regions of Iran. This area annually suffers from drought damages. Results showed that drought magnitude range is varied from mild to severe across basin from upstream to downstream. Frequency of drought occurrence is concentrated in southern of basin. Results also showed high correlation between Standardized Precipitation Index (SPI) as a meteorological index with hydrologic index (SDI).

Keywords: Hydrological drought index, SDI, SPI, Lmoment, Halilrud basin.

---

*Corresponding author: fsolaimani@ujiroft.ac.ir

1. Introduction

Drought is a naturally occurring phenomenon related to a significant decrease of water availability during a significant period of time and over a large area. Drought affects man's economic activities, lives and various elements of the environment such as the earth's ecosystems. The origin of drought is impossible to define. Conventionally, decrease of precipitation is considered as the origin of drought. This leads to a reduction of storage volumes and fluxes involved in the hydrological cycle. Depending on the choice of the hydrological variable or variables of interest, drought is characterized as meteorological, hydrological or agricultural (Beran and Rodier, 1985). Hydrological drought is defined as a significant decrease in the availability of water in all its forms appearing in the land phase of the hydrological cycle. Various hydrological variables are used to describe these forms but stream-flow is, by far, the most significant variable from the viewpoint of quantity of water. Hence, a hydrological drought episode is related to stream-flow deficit with respect to normal conditions. Each drought event is characterized through four attributes: (a) its severity expressed by a drought index, (b) its time of onset and its duration, (c) its areal extent, and (d) its frequency of occurrence. According to the methodology proposed by Nalbantis and Tsakiris (2008) the four-dimensional relationship of drought severity –duration–frequency –area is reduced into a much simpler two dimensional relationship of severity versus frequency. First, an index called Stream-flow Drought Index (SDI) was proposed which characterizes drought severity while fulfilling all requirements of such indices. Second, the time of onset and duration of drought events was eliminated through properly treating time. Third, the frequency of drought occurrence was kept as a significant parameter. The areal extent of a drought event, although very useful for meteorological drought, is not of interest for hydrological drought since water managers are interested on stream flow only at a small number of points in space (basin outlets, reservoir inlets and outlets etc). Evidently, stream-flow at these points provides an integrated measure of spatially distributed runoff, measures for water resources protection and management. Investigation on probability of hydrologic drought occurrence using the SDI index in the Halilrud river basin is the scope of this study.

2. Materials and methods

Study site

The study area is located in the south eastern semi-arid region of Iran, with an area of 11847 km2 and a main stream of 271.5 km. The Halilrud river basin is one of the major basins of Kerman Province (Figure 1). Due to being situated in arid climate, the hydrology and water availability of the Halilrud basin demonstrate flash flood seasons as well as intermittent flow and severe hydrologic drought periods. Hydrologic drought characteristics such as drought period and drought severity fluctuate year to year, and summer drought is dominant in the region.

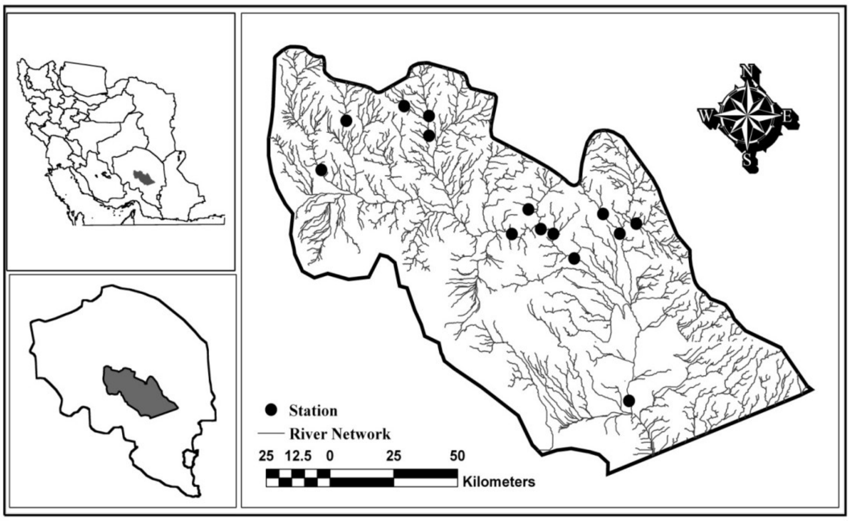

Figure 1. Location of the study area and gauging stations

Methods

Indices for characterizing a hydrological drought such as Palmer Hydrological Drought Index (PHDI), Surface Water Supply Index (SWSI) or the index proposed by Palfai (2002) are, in general, data demanding and computationally intensive. On the contrary, the proposed index SDI keeps the advantage of simplicity and effectiveness found in indices of meteorological drought such as the Standardized Precipitation Index (SPI) (Mckee *et al.*, 1993; Tsakiris and Vangelis 2005; Tsakiris *et al.*, 2007). Exclusive use of stream-flow is made as the key variable for assessing hydrological droughts.

L-moment method

The method of L-moments is now a popular method in regional hydrologic frequency analysis. Details about the method can be found in Hosking and Wallis (1997). The mathematical formulation of L-moments using Probability Weighted Moments (PWM) is briefly presented below. Hosking and Wallis (1997) present the following relationships:

(1) $$\lambda_1 = \beta_0$$

(2) $$\lambda_2 = 2\beta_1 - \beta_0$$

(3) $$\lambda_3 = 6\beta_2 - 6\beta_1 + \beta_0$$

(4) $$\lambda_4 = 20\beta_3 - 30\beta_2 + 12\beta_1 - \beta_0$$

Where λ_r are L-moments and β_r are PWMs defined as

(5) $$\beta_r = \int_0^1 x(F)F^r dF$$

Where F is the non-exceedance probability.

L-moments are directly interpretable as measures of the scale and shape of probability distribution models. Clearly λ_1 ; the mean, is a measure of location. λ_2 is a measure of scale or dispersion of the random variable.

In order to make the L-moments independent of the units of measure of X, it is often convenient to standardize the higher moments as

(6) $$\tau_r = \lambda_r / \lambda_2 \quad \text{for r= 3, 4.}$$

Analogous to the conventional moment ratio, such as the coefficient of variation, the L-coefficient of variation, *LCv*, is defined as

(7) $$LCv = \lambda_2 / \lambda_1$$

The corresponding L-coefficient of skewness (*LCs* or τ_3) reflects the degree of symmetry of a sample. It has limits $-1 < LCs < 1$; and symmetric distribution models have $LCs = 0$. Similarly, LCk, or τ_4, is a measure of peakedness and is referred to as the L-coefficient of kurtosis.

Homogeneity measure (H)

Hosking and Wallis (1993), derived heterogeneity statistics for estimation of the degree of heterogeneity in a group of sites. For heterogeneity test of a group, a four parameter Kappa distribution is fitted to the regional data set generated from series of 500 equivalent region data by numerical simulation. The test compares the variability of the L-Statistics of actual region to those of the simulated series (Hosking and Wallis, 1993).

There are three heterogeneity measurements (Hi), namely H1, H2 and H3, which are calculated by the following equation:

(8) $$H_i = (V_{obs} - \mu_V)/\sigma_V$$

Where μ_V and σ_V are the mean and standard deviation of N_{sim} values of *V*, N_{sim} is the number of simulation data, V_{obs}, is calculated from the regional data and is based on the corresponding V-statistic, defined as follows:

(9a) $$V_1 = \sum_{i=1}^{N} (n_i (L-CV_i - \overline{LCV})^2) / \sum_{i=1}^{N} n_i$$

(9b) $$V_2 = \sum_{i=1}^{N} (n_i \left[(L-CV_i - \overline{LCV})^2 + (\tau_{3i} - \bar{\tau})^2 \right]^{1/2}) / \sum_{i=1}^{N} n_i$$

(9c) $$V_3 = \sum_{i=1}^{N} (n_i \left[(\tau_{3i} - \overline{\tau_3})^2 + (\tau_{4i} - \overline{\tau_4})^2 \right]^{1/2}) / \sum_{i=1}^{N} n_i$$

Based on Homogeneity measurements, a region is declared acceptably homogenous when H<1, possibly heterogeneous when 1≤H<2 and definitely heterogeneous when H≥2.

Based on H1 measurement which has a much better discriminatory power than either H2 or H3 (Hosking and Wallis, 1993) we can judge about homogeneity.

Discordancy test

Discordancy measure, Di, is based on L-Moments and can be used to determine the unusual site. Di, is defined as:

(10) $$D_i = \frac{1}{3}(u_i - \bar{u})^T S^{-1}(u_i - \bar{u})$$

Where u_i is the vector of L-moments, LCv, LCs and LCk, for a site *i*;

(11) $$S = (N_s - 1)^{-1} \sum_{i=1}^{N_s} (u_i - \bar{u})(u_i - \bar{u})^T$$

(12) $$\bar{u} = N_s^{-1} \sum_{i=1}^{N_s} u_i$$

N_S is the total number of sites. If the D_i exceeds 3, the site is considered as a discordant station.

Stream-flow Drought Index (SDI)

It is assumed that a time series of monthly stream-flow volumes Qij is available where I denotes the hydrological year and j the month within the hydrological year and j the month within that hydrological year (j=1 for October and j=12 for September). Based on this series we obtain:

(13) $$V_{i,k} = \sum_{j=1}^{3k} Qi.j$$

$$i = 1,2,3,... \qquad j = 1,2,....,12 \qquad k = 1,2,3,4$$

Where *Vi,k* is the cumulative stream-flow volume for the i-the hydrological year and k-the reference period *k*=1 for October-December, *k*=2 for October-March, *k*=3 for October-June, *k*=4 for October – September.

Based on cumulative stream-flow volumes *Vi,k* the Stream-flow Drought Indx (SDI) is defined for each reference period k of the i-th hydrological year as follows:

(14)
$$SDIi,k = \frac{Vi,k - \overline{V}k}{Sk}$$
$$k = 1,2,3,4 \qquad i = 1,2,\ldots,$$

Where *Vk* and *Sk* are respectively the mean and the standard deviation of cumulative stream-flow volumes of reference period k as these are estimated over a long period of time. In this definition, the truncation level is set to *Vk* although other values could be used.

Based on SDI, states of Hydrological drought are defined which are identical to those used in the meteorological drought indices SPI and SDI. Five states are considered which are denoted by an integer number ranging from 0 (non-drought) to 4 (extreme drought) and are defined through the criteria of Table 1.

Table1. Definition of state of hydrological drought with the aid of SDI

State	Description	Criterion	Probability (%)
0	Non-drought	$SDI \geq 0.0$	50
1	Mild drought	$-1.0 \leq SDI < 0.0$	34.1
2	Moderate drought	$-1.5 \leq SDI < -1.0$	9.2
3	Severe drought	$-2.0 \leq SDI < -1.5$	4.4
4	Extreme drought	$SDI < -2.0$	2.3

Estimation of frequency drought states

Starting from historical stream-flow series, SDI is computed which yields a series of drought states. The underlying state process is assumed to possess the structure of a non-stationary Markov chain. Markov chains have been widely applied to predicting droughts (mainly meteorological ones) (Lohain and Loganathan, 1997, Lohain et al 1998, Ochola and Kerkides, 2003, Paulo and Pereira, 2006). Let $Q_{i,j}$ (i=1,2…..n,j= 1,2,…12) be the observed time series of monthly stream flow volumes for the river basin under study, where N is the number of hydrological years. First, the cumulative stream-flow volumes $V_{i,k}$ (i=1,2…..n, k= 1,2,3,4) are calculated via equation 1. Second, the series $SDI_{i,k}$ of the SDI index is calculated based on equation 2 or 3. Third, the series of states $X_{i,k}$ ($i = 1,2,\ldots,N$, $k = 1,2,3,4$) is obtained according to the criteria of Table 1. For each k, the related state process $X_{i,k}$ takes discrete values $m \in [0,1,2,3,4]$. Fourth, the frequency of appearance of each state m in each reference period k, $F_{m,k}$ is estimated as

(15)
$$F_{m,k} = \frac{n_{m,k}}{N}$$

Where $n_{m,k}$ is the number of occurrences of state m in reference period *k* within the available sample of *N* year.

3. Results and discussion

Homogeneity and heterogeneity

H and D criteria were used for investigating the heterogeneity of 11 study stations. The results of these measures are presented in Table 2.

Moment ratio diagrams of the study area are given in Figure 2. As shown in these figures, distribution of L-moment statistic around mean point is not in good state. Despite this, we used H and D criteria for testing of heterogeneity of stations. Results of D statistic showed no heterogeneous stations in regions and H statistic also revealed that the study area is considered as acceptable homogeneous region.

Table 2. Descriptive statistic of L-momentT

Stations' Numbers	Stations' Name	Sample Size	LCv	LCs	LCk	D
1	*Aroos*	10	1.31	3.12	12.87	1.49
2	*Dehrood*	30	0.69	0.72	2.93	0.5
3	*Hanjan*	30	0.69	0.7	2.91	0.5
4	*Hossien Abad*	37	1.15	1.35	3.93	1.22
5	*Kahnak*	18	1.53	1.21	3.29	1.17
6	*Kenaruieh*	10	0.75	-0.05	2.08	1.78
7	*Meidan*	17	1.83	2.37	8.62	1.48
8	*Ramoon*	10	0.98	1.03	3.97	0.19
9	*Soltani*	33	1.59	2.91	11.91	0.83
10	*Tigh-siah*	16	0.7	1.2	4.87	0.76
11	*Zarrin*	19	1.59	2.5	9.16	0.82
		All Stations H_1=0.87 H_2=1.06 H_3=0.72				

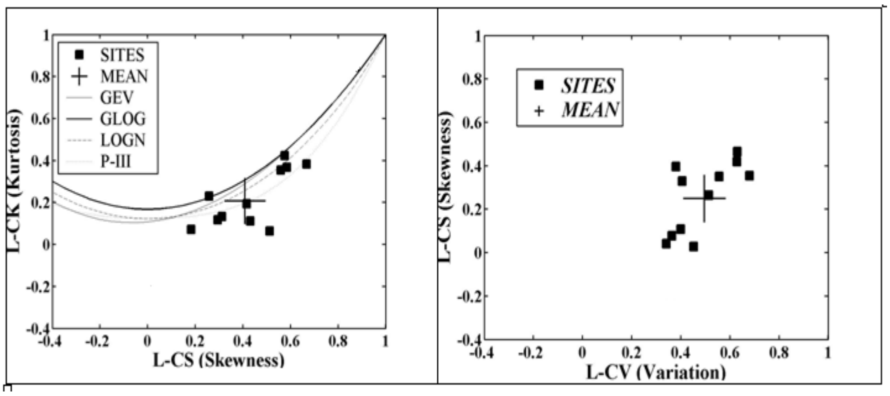

Figure 2. Moment ratio diagram of the study stations

Estimation of frequency values of different drought conditions using SDI index

Using monthly data of gauging stations in the desired 12-month time series (k=4), the SDI index values were calculated. Using Table 1 these values were changed to different drought conditions, and different frequencies of drought conditions ranging from drought to lack of drought were calculated according to equation 15. In other words, when the devastating drought is occurred in the region, mild drought occurrence in Raman is higher than other stations. The frequency of drought condition of moderate, severe and very severe occurrence in Meidan, Raman and Kahnak have been shown in Figure 3.

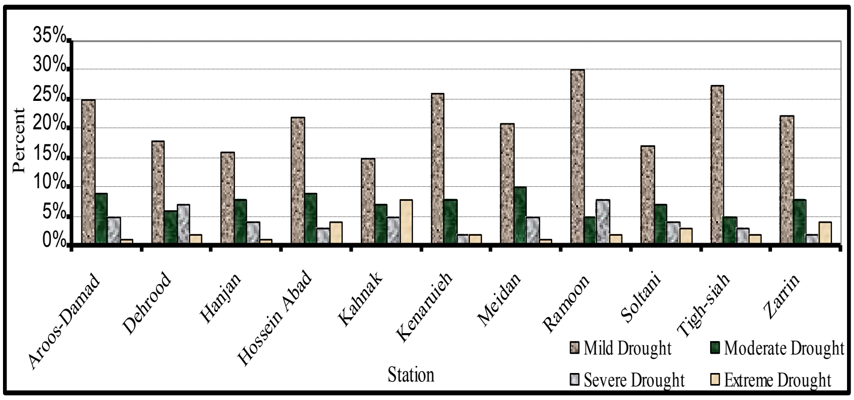

Figure 3. Frequency values of different drought conditions

The results also showed that the occurrence probability of mild drought in the northern areas of the basin where main branches is higher than other parts. Towards the southern parts of the basin the probability of mild drought is decreased and occurrence probability of severe drought is increased. Therefore, when monitoring drought it must be noted that water resources management should be accomplished based on priorities of sensitive regions than drought occurrences (Fig. 4).

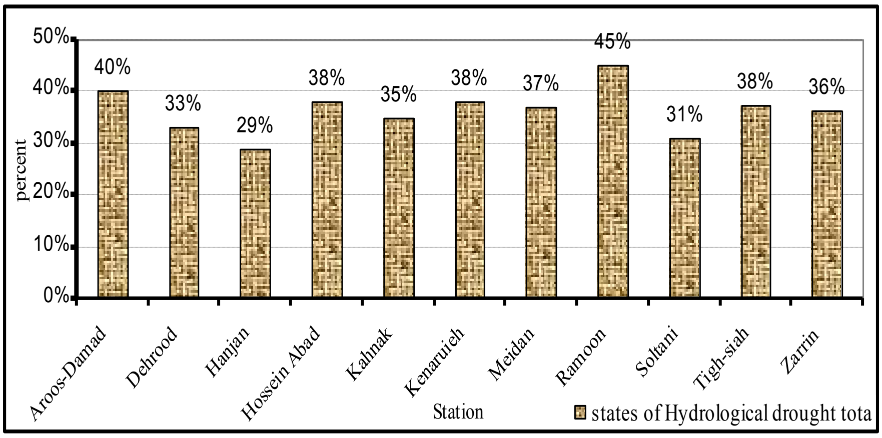

Figure 4. The number of drought events

Relationship of hydrologic droughts and SPI index

To evaluate the SDI results, we used standard precipitation index which is a common used meteorological index for investigating the drought occurrence. Time series of SPI 12 months was plotted and the result of this index was compared with the results of SDI. The results showed that correlation coefficient between these indices is almost 0.85.

To establish relationship between these two indices, we used multiple linear regressions. Equation 16 shows this linear regression.

(16) $$y = 1.8x - 0.135$$

In which y is SDI value and X is SPI value.

Using this model, we are able to predict hydrologic drought condition (SDI) through SPI index. In other words, this model helps us to predict hydrological drought occurrence after meteorological drought events (Fig. 5).

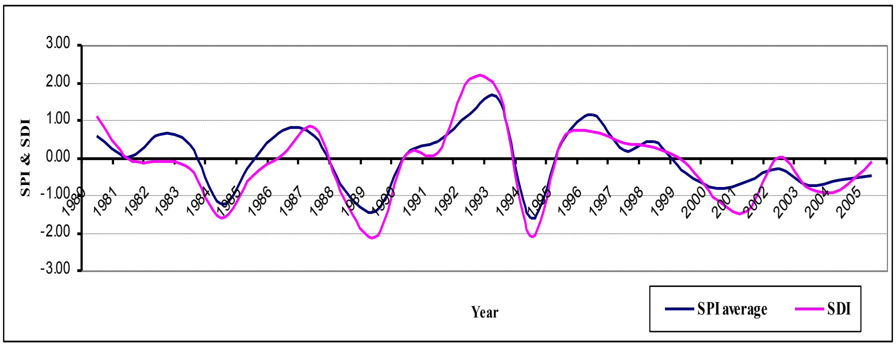

Figure 5. Time series of SPI and SPI in Raman station

4.Conclusion

Results showed that SDI is an efficient and reliable index for analyzing of hydrological drought conditions. In this study, it was shown that in Halilrud basin the probability of drought occurrence is higher than other parts of basin and upstream parts are usually exposed to mild drought events. Concentrations of these events in the upstream branches lead to very severe drought which may occur in downstream. Finally, these events may damage the natural ecosystems. According to the results most of the areas which are affected by severe drought events must be put in the priority of drought combating projects for water risk resources management. The results also showed that indicators used in meteorological and hydrological drought studies, can have a close association with each other. As shown in this study, SDI as a hydrologic drought index had a good relationship with SPI as a meteorological index in predicting drought condition in arid and semi-arid regions.

References

Ben-Zvi, A. 1987. Indices of hydrological drought in Israel. Journal of Hydrology. 92(1-2): 179-19.

Beran, M.A., and Rodier, J.A. 1985. Hydrological aspects of drought. In: UNESCO-WMO Studies and Report in Hydrology. 149 p.

Cancelliere, A., Di Mauro, G., Bonaccorso, B., and Rossi, G. 2007. Drought forecasting using the Standardized precipitation Index. Water Resources Management. 21: 801-819.

Efstratiadis, A., Nalbantis, I., and Mamassis, N. 2000. Hydrometeorological data processing .In: Modernization of the supervision and management of the water resource system of Athens. Department of Water Resource, Hydraulic and Maritime Engineering – National Technical University of Athens. 8:129 p

Lohani, V.K., and Loganathan, G.V. 1997. An early warning system for drought management using the palmer drought index. Journal of the American water Resources Association. 33(6):1375-1386.

Lohani, V.K., Loganathan, G.V., and Mostaghimi, S. 1998 Long-term analysis and short-term forecasting of dry spells by the palmer drought severity index. Nordic Hydrology. 29(1):21-40.

Mckee, T.B., Doeskin, N.J., and Kleist, J. 1993. The relationship of drought frequency andduration to time scale. Proceeding of the Eighth Conference on Applied Climatology, Anaheim, CA January 17-23, 1993. American Meteorological Society Boston MA, pp: 179-184

Nalbantis, I., Mamassis, N., and Koutsoyiannis, D. 1994. Le phemomene recent de secheresse parsistante et lalimentation en eau de la cite d Athenes. Conptes-rendus du 6eme *collooque* L. Association International de Climatology, Thessalonique. P: 8.

Nalbantis, I., and Tsakiris, G. 2008. Assessment of Hydrological Drought Revisited. Water Resources Management. 29(1):21-40

Ochola, W.O., and Kerkides, P. 2003. A Markov chain simulation model for predicting critical wet and dry spells in Kenya: Analyzing rainfall event in the Kano plains. Irrigation and Drainage. 52(4):327-342.

Palfai, I. 2002. Probability of drought occurrence in Hungry. Idujaras (edition of Hungarian Meteorological Services). 106(3-4): 265-275

Paulo, A.A., and Pereira, L.S. 2007. Prediction of SPI Drought Class Transitions Using Markov Chains. Water Resources Management. 21:1813-1827

Snedecor, G.W., and Cochran, W.G. 1967. Statistical Methods. The Iowa University Press. Iowa, USA. 100p.

Tsakiris, G., and Vangelis, H. 2004. Towards a Drought watch System based on spatial SPI. Water Resources Management. 18:1-12

Tsakiris, G., and Vangelis, H. 2005. Establishing a Drought Index Incorporating Evapotranspiration. European Water. 9(10):3-11

Tsakiris, G., Pangalou, D., and Vangelis, H. 2007 regional Drought assessment based on the Reconnaissance Drought Index (RDI). Water Resources Management. 21:821-833

Wilhite, D.A., Svoboba, M.D., and Hayes, M.J. 2007. Understanding the complex impacts of drought: A key to enhancing drought mitigation and preparedness. Water Resources Management. 21:763-774.