Suitability of Various Indices for the Analysis of Drought: An Overview

Dr. V. M. Devappa[1]

Professor & Head of P.G. Courses, Civil Engg. Department, BKIT Bhalki,-585328, Dist. Bidar, Karnataka (India)

Abstract: ***Most parts of the world, drought remains as a threat that may occur with little or no warning. It occurs somewhere in the world in one part or the other almost every year. The monitoring and analysis of drought using well known drought indices would help to gain a better understanding of the impacts of droughts. For proper monitoring and assessment of droughts different drought indices are used. It was observed that there are number of drought indices according to the purpose and area of interest of investigators, but no particular index has been accepted worldwide. Therefore, it is necessary that the most important drought indices must be tested in different regions and selects only those indices, which are appropriate for a particular region. In this study an attempt is made to overview the different drought indices and there feasibility for monitoring and analysis of drought conditions.***

Keywords: Drought, monsoon, indices, rainfall, percentage of departure

1. Introduction

Drought is a natural hazard. Drought creates a situation of scarcity and distress usually caused by failure of monsoon. There is no single definition for drought. Its onset and termination is difficult to determine. However, identifying various indicators of drought, and tracking these indicators provides a crucial means of monitoring drought. Continuous monitoring of metrological and hydrological conditions and analysis of drought using well known drought indices would help to gain a better understanding of the impacts of short term and long term droughts in various parts of the world. Which incorporate and weigh various types of data in various combinations, equally important in choosing these indicators is a consideration of the type or of water shortage facing the planners. Any monitoring system is ultimately aimed at meaningful action plans to overcome the distress. Generally drought studies are made using the parameters such as rainfall, temperature, relative humidity, potential evapotranspiration, soil moisture, critical crop growth, stage of crop, crop yield, land use/land cover, stream flow, reservoir levels, and ground water levels etc.

2. Methods of analysis of drought

Identification and development of drought threshold indices, for various activities like water resources, agriculture, and energy etc., are important to formulate and initiate the drought management strategy appropriate for a given region [1]. For this purpose there are a number of drought indices developed according to the purpose and area of interest of investigators. But no particular index has been accepted worldwide. Therefore, it is necessary that the most important drought indices must be tested in different agro-ecological regions of the world and selects only those indices which are appropriate for a particular agro ecological region for monitoring and analyzing the drought conditions.

2.1 Analysis based on percentage of departure of rainfall and co-efficient of variation.

The Indian meteorological department which has divided the country into various meteorological sub-divisions adopted the total seasonal rainfall less than 75 per cent of the normal value, it is considered to be affected [2] by drought. If the seasonal rainfall deficiency is “between” 20 per cent to 30 per cent of normal, it is further classified as moderate and more than 50 per cent deficiency as severe drought. depending on the percentage of departure from normal rainfall using the conditions given by annual rainfall [3] deficiency, according to Indian meteorological department [4] and national commission on agriculture[5], the droughts were classified on the basis of annual rainfall deficiency under three conditions were calculated for pre-monsoon, south-west monsoon, north-east monsoon and for annual rainfall.

- **Mild drought**: annual rainfall deficiency from normal ranges between ---00-20 percent
- **Moderate drought**: annual rainfall deficiency from normal ranges between----20-50 percent
- **Severe drought**: annual rainfall deficiency from normal is more than -- 50 percent

Percentage of departure from normal rainfall	Intensity of meteorological drought	code
0 and above	no drought	m_0
00.0 to (-20.0)	mild drought	m_1
-20.1 to (-50.0)	moderate drought	m_2
-50.1 or less	severe drought	m_3

The areas subjected to drought are those in which variation in annual rainfall are relatively greatest. These areas therefore show high co-efficient of variation (CV) in annual rainfall.

The extremities of rainfalls can be represented and compared by the factor know as co-efficient of variation. Co-efficient of variation = (standard deviation/mean) x 100
Given a long term record of rainfall the arithmetic mean is the average i.e.

$$\overline{x}=\sum(x/n)\ldots\ldots\ldots\ldots\ldots\ldots\ldots)$$

n = number of years
x = annual rainfall
$\overline{x}$ = arithmetic mean
Standard déviation = $\sigma = \sqrt{\sum (x - \overline{x})^2 / (n-1)}$ ….. (2)
Higher extremities either + ve or - ve bring large value of deviation denoted by (σ)

Coefficient of variation CV = $(\sigma/\bar{x})$ X100……………. (3)

One of the disadvantage of using the percent [6] of departure from normal precipitation is that the mean or average, precipitation is often not the same as median precipitation.

2.2 Monthly Rainfall Deficiency

Krishna Rao classified drought on the basis of monthly departure from normal monthly rainfall as follows [3]:

Excess rainfall:	10% or more
Normal rainfall:	+10% to-10%
Slight drought:	-11% to-25%
Moderate drought:	-26% to-40%
Severe drought:	-41% or less

2.3 Weekly Rainfall Deficiency

khambete and Biswas inferred from their drought study over dry forming tract of Maharashtra that agricultural drought occurs when there is a rainfall deficiency of less than 18 mm per week during the month of June to October[3]. They classified the drought in to four categories based on drought proneness index (di). Index of drought proneness is defined as:

Di= (p^*p_1) / (1-p)* 100where p is initial probability of wet week (=p_0/ [1-(p_1-p_0); p_0 is probability of wet week preceded by dry week; and p_1 is probability of wet week preceded by wet week.

Drought index of	**Drought prominences**
Chorionic	di≤ 20
Severe	20<di≤35
Moderate	35<di≤50
Mild	50<di≤70
Occasional	70<di

2.4 Folly drought index

In Australia folly [7] computed residual mass curves of rainfall departures and developed a dimension less “index of drought severity.” This is a variation of the residual mass curve in which departures of rainfall from average for specified period e.g. Monthly values are cumulated [2]**.** The method divides each monthly departure by the average annual rainfall, and then divides by 1000 and cumulative the dimension-less “units” so obtained. This method is very useful for temporal presentation of drought data.

2.5 Decile Technique

In this method, [8] the limits of each less per cent (or Decile) of the distribution are calculated from a cumulated frequency curve or an array of data. Thus the first Decile is that rainfall amount which is not exceeded by 10 per cent [2] of totals and the second Decile is the amount not exceeded by 20 per cent of total and so on. The fifth Decile or the median is the amount not exceeded on 50 per cent of occasions. The Decile ranges are the ranges of value between Deciles. Thus the first Decile range is that below the first Decile. The eight Decile range is between Decile seven and eight. By stating the values of nine Deciles of annual or seasonal rainfall, it is possible to have a reasonably complete picture of a particular rainfall distribution over a region. By determining the Decile range into which a particular total falls, one may obtain useful indication of departure from the normal. The classification given by them as follows

Decile range	**Descriptions**
1	very much below average
2	much below average
3	below average
4-7	average
8	above average
9	much above average
10	very much above average

The Decile technique was selected measurement of drought within the Australia. One of the disadvantages of the Decile is that a long record is needed to calculate the Decile accurately

2.6 Aridity index

Index of aridity first was developed by [9] martonne using precipitation p (mm) and mean monthly temperature t (0 c) as:

$i = p/(t + 10)$……….. (1)

and modified as $i = n\,p/t + 10$……….... (2)

Where n is the number of days during a certain [2] period from few days to a year and p is daily mean precipitation i is index of aridity in the period. This index was mainly used in Germany to compute aridity. Seyani now gave an index.

$k = p/(t+10)$…..… …… (3)

Where p is the sum of rainfall (mm) during those months when mean temperature is above 10^0c and t is the sum of the daily mean temperature above 0^0c for the same period. The period when k is less than 0.5 is considered to be drought.

II) Subramanian et al [10] made use of aridity index of Thornthwaite to define drought characteristics and classified the drought into varying intensities using standard deviation of aridity index (σ). The yearly variation of aridity index was plotted and the amplitude of departure of the index from its normal value was taken to represent the severity of the drought on annual basis.

Aridity index is defined as the ratio of annual water deficiency to annual water need expressed as percentage.

Thus aridity index

(I A) = (PE – AE) / PE X 100……… (4)

PE = potential evapotranspiration

AE = actual evapotranspiration

Employing purely statistical procedure the drought years were classified as below.

Departure of aridity index from Normal	**Drought category**
Less than ½ σ	moderate
½ σ to 1 σ	large
1 σ to 2 σ	severe
Greater than 2 σ	disastrous

2.7 Humidity index

Humidity index is defined as the ratio of annual moisture surplus to annual potential evapotranspiration. Humidity index, IH = (annual moisture surplus/annual PE) x 100…. (1)

Moisture index IM = IP – IA ……………. (2)

Where IP is annual potential evapotranspiration and ia is aridity index is Seth et al. [15] used aridity index and moisture index values, applying Thornthwaite and Mather have given [16] book keeping procedure for water balance to study the frequency of drought in north western India.

2.8 Moisture adequacy index (IMA)

It is (IMA) defined as ratio of actual evapotranspiration (AE) to potential evapotranspiration expressed as percentage. This was [2] first studied by subrahmanyam at.al. [10] (1963) to study agricultural droughts in India. They incorporated the minimal value of IMA, above which yield would be lower than the average yield for each individual year. The yield was marked against the corresponding IMA value. A line was drawn parallel to x-axis above which the yields are always higher than the average and vice-versa.

The departure of the IMA expressed as percentage from the minimal required value was used to classify agricultural drought which are different for different crops and regions.

Departure of IMA below the minimal value	**agricultural drought intensity**
Less than 10	moderate
10 to 20	large
20 to 30	severe
More than 30	disastrous

This may not be applicable during seed germination at the beginning of specific crop's growing season

2.9 Drought frequency analysis

The type iii Exterimal distribution was [2] first proposed by Gumbel for drought frequency analysis. Gumbel defined the drought as the smallest annual values of the mean (lowest) daily rainfall/discharge of a river. For smallest values, equation for type iii distribution is as follows.

F_z (z) = 1-e $^{-(z - \epsilon/u- \epsilon)\,k}$………..$z \geq \epsilon$…….. (1)

F_z (z) = (k/u- ϵ) (z- ϵ /u- ϵ) $^{k-1}$ e $^{-(z- \epsilon /u- \epsilon)\,k}$.... (2)

The moments are $m_z = \epsilon + (u - \epsilon)\,\gamma\,(1 + i/k)$ … (3)

$\sigma^2 = (u - \epsilon)^2\,[\gamma\,(1+z/k) - \gamma^2\,(1 + i/k)]$ …. (4)

$e^{(z - \epsilon)\,l} = (u - \epsilon)^l\,\gamma\,(1\text{-}l/k)$ … (5)

In this distribution, three parameters are involved. The parameter 'ϵ' is the lower limit called the minimum drought. The parameter 'u' is called the drought characteristic. The parameter 'k' has no particular name with reference to the drought; the reciprocal is a scale parameter which defines skew ness. Droughts have been studied by setting ϵ = 0 by Gumbel for ϵ = 0, the form of the distribution simplifies greatly and we have.

F_z (z) = i – e $^{-(z/u)\,k}$…..$z \geq 0$ … (6)

And mean $m_z = u\,\gamma\,(1\text{-}1/k)$ … (7)

Variance $\sigma^2 = u^2\,[\gamma\,(1\text{-}2/k) - \gamma^2\,(i - 1/k)$ … (8)

Co-efficient of variation $=vz^2 = \gamma\,(1 + 2/k) / \gamma^2\,(1 + 1/k) - 1$... (9)

With the help of equation ii and iii the parameters u and k can be evaluated solving gamma functions and equation (2.17) can be fitted. The recurrence interval tr can be found.

tr = 1 / 1 - f_z (z) ………………..…. (10)

In applying Gumbel's method to drought solution, the graph can be plotted on log- Exterimal probability paper. If ϵ = 0 the plot should have a straight line trend.

2.10 Palmer drought index

Palmer drought index model is an elaborate one computing the severity of droughts on the basis of current and [18] antecedent rainfall, evapotranspiration, and soil moisture. It requires a month–by–month water balance accounting for a long record, such as 30 years or more. Palmer used two-layer soil model and the Thornthwaite method of computing potential evapotranspiration. However, the methodology does not require any particular method of computing potential evapotranspiration. Palmer gave the following criteria for describing the intensity of drought.

Index value	**intensity of drought**
-1.00 to -1.99	mild drought
-2.0 to -2.99	moderate drought
-3.0 to -3.99	severe drought
-4.00	extreme drought

This index has been widely used in USA [6]. In other parts of the world the researchers have presented various limitations viz: end and beginning of wet spell, its sensitivity to AWC, two soil layer approaches, its PDSI, or PHDI value, underestimation of the runoff, using Thornthwaite method for the computation of potential evapotranspiration etc.

2.11 Herbst technique

In this analysis it has been assumed that farming in any regions adapted to the prevailing climatic pattern so that maximum [2] advantage is taken of the months of high average rainfall, but that is due to variations in mean monthly rainfall. A seasonal drought of a certain intensity and duration is often a normal feature of the particular climate and as such should not be included in an assessment of damaging droughts. Likewise, as the rainfall of any one month varies from year to year, it is assumed that farming is adjusted to the average variability and that only rainfall deficits exceeding the average deficit of any month should be included in an evaluation of harmful drought.

1) In this technique the monthly rainfall data is taken from a rainfall station for a given number of years. This data is used to evaluate the drought parameters specified below:

I) the onset of drought ii) the formation of drought iii) the duration of drought

IV) Drought intensity and v) weighted drought index. The following variables are computed before the evaluation of the above parameters are taken up

A) Mean monthly rainfall---rain (12)

B) Mean annual rainfall—an rain=$\sum_1^{12}$ rain

C) The weighting factor used to calculate the carry over effect was derived as follows.

W (i) = 0.1 (1 + m (i)/1/12x map) …………………... (1)

Where: w (i) = weighting factor for month i

M (i) = mean rainfall for month i

Map = mean annual rainfall.

2.12 Standardized precipitation index (SPI)

This index is developed by: McKee, et al. The SPI is an index based on the probability of precipitation for any time scale. Many [20] drought planners appreciate the SPI's versatility. The SPI can be computed for different time scales, can provide early warning of drought and help to assess drought severity, and is less complex than the palmer drought index. It understands that a deficit of precipitation has different impacts on groundwater, reservoir storage, soil moisture, snow pack, and stream flow. The SPI was designed to quantify the precipitation deficit for multiple time scales.

SPI values

2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

McKee et al. Also defined the criteria for a drought event for any of the time scales. A drought event occurs any time if the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the spi becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The positive sum of the spi for all the months within a drought event can be termed the drought's "magnitude." It is relatively [6] new index. It has not been widely applied or tested.

Conclusion

1. It is necessary that the most important drought indices must be tested in different regions and selects only those indices, which are appropriate for a particular region for monitoring and analysis of drought conditions.
2. The combination of more than one index may give batter results.
3. Extension and awareness activities should reinforce awareness that droughts recur_and the focus should be more on sustainable natural resource management even before drought comes, rather than responding to the drought when it is imminent.

Reference

[1] Subhash Chander, S.K.Spolia And A. Kumar, Water Management During Droughts, International Symposium on Hydrological Aspects of Drought Vol. 1, 3-7 December 1979, New Delhi, Pp 305-331.
[2] G.Jagmohan Das and K.Ramakrishna, a Report On Analytical Study of Drought Aspects Of Anantapur District Of Andhra Pradesh, Centre For Drought Management Dept. of Civil Engineering, JNTU College Of Engineering Ananthapur (A.P), July 1991, Pp. 1-20
[3] Shakir Ali, Drought Indices in India- A Review, Hydrology Journal, 20(3) September 2003, Pp. 31-38.
[4] IMD (1971) Rainfall and Drought in India, Indian Metrological Department: Note Prepared and Submitted By D.G. Of Observatories To The Irrigation Commission and Power Poona
[5] NCA (1976) Agricultural Commission Report, National Commission on Agriculture, Ministry of Agriculture, Govt. Of India, and New Delhi.
[6] Www.File:////Pasta-Kaustubh/C/Eshwar/Docs/Drought2.Html, Bureau of Reclamation Drought Assistance Report, Reclamation of State Drought Assistance Act of 1988, Report to the President and the Congress of the USA Feb 1991.
[7] J.C. Foley, Drought in Australia, Review of Records from Earliest Years of Settlement to 1955, Australian Bureau of Metrology, Bull.No.43, 1957, Pp. 281.
[8] Gibbs.W.J. and J.V.Maher, Rainfall Deciles as Drought Indicators, Bureau of Meteorology, Melbourne, Australia, Bull.No. 48, 1967, Pp. 5-28.
[9] Selyaninov G.T, Methods of Agricultural Climatology, In Agricultural Climatology No.22, 1930, Pp. 4-20.
[10] Subrahmanyan.V.P. B.Subarao and A.R.Subramaniam, Moisture Adequacy in Relation to the Distribution of A Few Crops in India, Proc. Berkeley (Cali) Symp. Int. AGR. Hydro. 1963, Pp.462-467.
[11] Seth. S.M. N.C. Varshney and J.D. Patel, Study Of Drought Climatology in North-West India, Proceedings. International Symposium on Hydrological Aspects of Drought, Vol.1 3-7 December New Delhi, 1979, Pp. 339-346.
[12] Thornthwaitec. W and Matherj. R, the Water Balance Publication Climatology, 8 (1) Drexel Inst. of Tech, New Jersey U.S.A, 1955, Pp. 104.
[13] Rao.K.N, C.J.George, and K.S.Ramashastri, the Climatic Water Balance of India. Memoirs of IMD Vol. XXXII, Part. III.
[14] Palmer Wayne. C, Meteorological Drought, U S Weather Bureau Research Paper No 45. 1965, Pp. 1-45.
[15] WMO, 1975 A Drought And Agriculture, Technical Note No 138.
[16] Www.Drought.Com

Author Profile

Dr. V. M. Devappa received the B.E. and M.E. degrees in Civil Engineering from BKIT Bhalki, in 1988 and 1999,under Gulbarga University Gulbarga respectively. Awarded the PhD degree from VTU Belgam in the year 2010. Since 1987 he is working as a site engineer, lecturer, asst. professor/professor and head of civil engg. Dept and head of P.G. courses