Identification of Drought Spell with Indices for Districts Uttarakhand

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Abstract—*Drought is one of the main natural hazard which affect the economy and environment of large areas. Droughts cause crop losses, water supply shortages, social alarm, degradation, desertification & forest fires. It 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 it is usually related to a long and sustained period in which water availability becomes scarce. Drought can be considered to be essentially a climatic phenomenon related to an abnormal decrease in precipitation and it occurs when moisture supply is abnormally below average for periods of up to two years.*

Drought indices assimilate data on rainfall, snowpack, stream flow and other water supply indicators into a comprehensible big picture. A drought index value is typically a single number, far more useful for decision-making than raw data. Although none of the major indices is inherently superior, some indices are better suited for certain regions or uses than others. For example, the Palmer Drought Severity Index (PDSI) is useful for large areas of uniform topography and is widely used by the U.S. Department of Agriculture to determine when to grant emergency drought assistance. On the other hand, decision makers in western states, with mountainous terrain and complex regional microclimates, often supplement PDSI values with other indices such as the Surface Water Supply Index, which takes snowpack and other unique conditions into account and the Standardized Precipitation Index (SPI) identifies emerging droughts sooner than PDSI and is computed on various timescales.

1. INTRODUCTION

Drought is a temporary aberration within the natural variability and may be regarded as an insidious hazard of nature. However, a precise, unambiguous definition of drought remains elusive. A drought is an extended period when a region notes a deficiency in its water supply **(Beran and Rodier, 1985)**. Generally, this occurs when a region receives consistently below average precipitation. It can have a substantial impact on the ecosystem and agriculture of the affected region. Although droughts can persist for several years, even a short, intense drought can cause significant damage. It is not possible to avoid drought but drought preparedness can be developed and drought impacts can be managed. The success of these both depends amongst others on how well the droughts are defined and their characteristics are quantified **(Smakhtin and Hughes, 2004).** Droughts have often resulted in famine, displacement of people, homelessness, ill health, social disorder and in advanced stages, deaths as well **(Odongkara, 2002)**. The carrying out of drought analysis would enable us to predict drought occurrence and plan appropriately some ways of its mitigation.

Drought distresses large areas, lasts for long periods of time and affects most climates. Droughts are expected to increase in frequency and severity, which will have serious impacts on the economic, social and environmental sectors of effected populations of virtually all nations **(IPCC, 2012)**. In order to reduce drought impacts it is important to avoid most commonly used reactive (crisis management) and promote proactive (risk management) approach **(Wilhite, 2000)**. The World Meteorological Organization (WMO), the Food and Agriculture Organization of the United Nations (FAO), the United Nation Convention to Combat Desertification (UNCCD) and other United Nations agencies have promoted the establishment of national drought policies (NDP) with an ultimate goal to create drought resilient societies. One of the essential elements of NDP is the implementation of proactive drought management systems including effective monitoring and early warning systems to deliver timely information to decision makers of all levels.

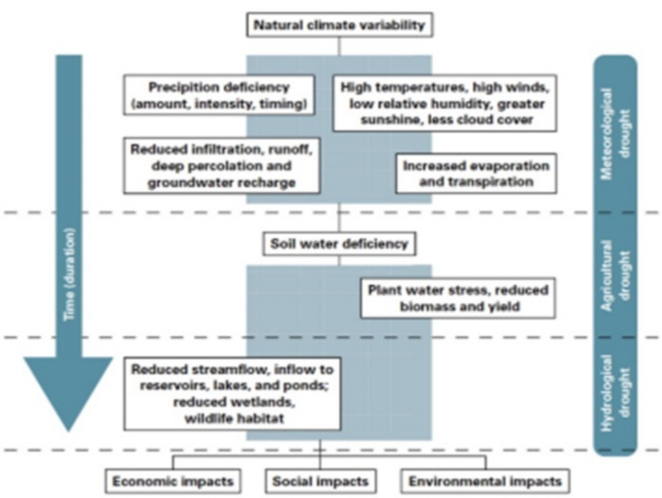
As one of the most important parts of a proactive drought management system, drought indicators characterize drought conditions and help to guide appropriate responses to reduce impacts **(Steinemann and Cavalcanti, 2006)**. Drought indicators, including indices, are used to assess and measure drought. Even though a drought index value is more useful than raw data for decision-making, indicators and triggers often suffer from deficiencies, such as temporal and spatial inconsistencies, statistical incomparability and operational indeterminacy **(Steinemann, 2003)**.

There is no universal drought indicator measuring all types of drought effectively **(Heim, 2002)**. Numerous specialized indices have been proposed to measure drought in different ways. Extensive listings of drought indices are available **(WMO 1975a, b; Hayes *et al.* 1999; Heim, 2002)**. Some studies explore the effectiveness of drought indices to measure drought on a global scale

(Vicente-Serrano *et al*., 2012) and other rank drought indices in terms of usefulness for the assessment of drought severity **(Keyantash and Dracup, 2002)**. No studies have been found that compare drought indices to the evaluations by drought management committees in drought management programs.

Drought is a naturally reoccurring climatic variability. With a changing climate, droughts are likely to become more severe and occur more often. Drought, in contrast to aridity, affects almost all climates in the world **(WMO, 2006)**. There is no universal definition of drought **(Heim, 2002)** however; a common theme in defining drought is a deficit in normal precipitation for a region over a period of time sufficient to cause impacts.

Impacts are the primary ways to measure drought severity. Based on impacts, the WMO defines four major drought types as meteorological, agricultural, hydrological and socio-economic. All droughts originate from a deficiency of precipitation and begin as meteorological drought. Other types of drought and their impacts cascade from meteorological drought to other types **(WMO, 2006)**. All types of drought have distinctive characteristics that vary across different locations, climate types, populations and economic vulnerabilities.



(*Source*: National Drought Mitigation Center, University of Nebraska-Lincoln, U.S.A.)

Commonly accepted drought types occurrence and impacts sequences

The ability of societies to reduce drought effects and build resilience is a grave significant concern on a global level. The WMO and other United Nations agencies promote an implementation of NDP that will provide practical insight into useful, science-based actions to address key drought issues. Such policies are intended to engender cooperation and coordination at all levels of government in order to increase their capacity to cope with extended periods of water scarcity in the event of a drought **(Sivakumar *et al.*, 2011)**.

An effective drought monitoring system has the ability to deliver an early warning in a case of the drought's onset, successfully measure drought severity and spatial extent and communicate facts to decision-making groups in a timely manner **(Hayes *et al.*, 2011)**.

In view of above, the present study was undertaken with following objectives for Almora and Chamoli districts of Uttarakhand:

- To identify drought spells by using different indices namely, Dependable Precipitation Index (DPI)
- To determine the occurrence of drought spells on monthly and yearly basis.

2. METHODS TO MEASURE DROUGHT

Palmer (1965) developed one of the most widely used drought indicators, called as Palmer Drought Severity Index (PDSI). The different classes of PDSI range from wet conditions (positive values) and dry conditions (negative values) and are given as:

Drought classes	Range
Extremely wet	≥ 4.00
Very wet	3.00 to 3.99
Moderately wet	2.00 to 2.99
Slightly wet	1.00 to 1.99
Incipient wet spell	0.50 to 0.99
Near normal	0.49 to -0.49
Incipient dry spell	-0.50 to -0.99
Mild drought	-1.00 to -1.99
Moderate drought	-2.00 to -2.99
Severe drought	-3.00 to -3.99
Extreme drought	≤ -4.00

2.1 Dependable precipitation index (DPI)

Dependable precipitation index is a meteorological drought index and is calculated by using equation:

$$\mathbf{DPI} = 0.8 \times \sqrt[n]{P_1 \times P_2 \times P_3 \times \ldots \ldots \ldots P_n}$$

Where, DPI = dependable precipitation index;

P = years rainfall (mm);

n = number of observations; and

0.8 = constant coefficient.

With the help of DPI, the drought intensity can be obtained on the basis of variation in rainfall intensity in terms normal rainfall (NR), dry-year threshold (D) and wet-year threshold (W), given as:

Classification	Range
Normal rainfall	DPI≤P≥GM
Dry year	P<DPI
Wet year	P>GM

Where, P = years rainfall; and

GM = geometric mean of rainfall values observed during study period.

2.2 Precipitation Departure Index (PDI):

It is a meteorological drought index and is defined as the measure of annual variability and long term trends can be achieved by plotting rainfall departure from arithmetic mean for the period of record taken into consideration.

$$\text{PDI} = \frac{P_i - \bar{P}}{100}$$

Where, P_i = annual rainfall in i^{th} year (mm); and

$\bar{P}$ = average rainfall (mm).

2.3 Standard Index of Annual Precipitation (SIAP)

The values of SIAP can be computed by using equation:

$$\text{SIAP} = \frac{P_i - \bar{P}}{PSD}$$

Where, P_i = annual rainfall in i^{th} year (mm), $\bar{P}$ = average rainfall; and PSD = standard deviation of rainfall during the study period. The trend of drought and wet years can be ascertained on the following basis:

Classification	SIAP value
Extremely wet	≥ 0.84
Wet	0.52 to 0.84
Normal	-0.52 to 0.52
Drought	-0.84 to -0.52
Extreme drought	≤ -0.84

2.4 Standard Precipitation Index (SPI)

The SPI is a simple, powerful and flexible rainfall index based on probability of rainfall for any timescale. In order to calculate this index, rainfall data series is fitted to gamma distribution function (pdf), given as:

$$f_{(x)} = \frac{x^{(a-1)} e^{\left(-\frac{x}{b}\right)}}{b^a \, \Gamma(a)}$$

Where, “a” and “b” (both greater than 0) are shape and scale parameters and $\Gamma(a)$ = gamma function. The aim to fitting distribution to data is to estimate parameters “a” and “b”. By integrating pdf with respect to “x” and inserting estimated values of “a” and “b”, the gamma cumulative distribution function is computed at each value of “x” which is then transformed into standard normal distribution to yield SPI values. The drought intensities resulting from SPI classifies drought events as:

Classification	Range
Extremely wet	≥ 2.00
Very wet	1.50 to 1.99
Moderately wet	1.00 to 1.49
Near normal	-0.99 to 0.99
Moderately dry	-1.49 to -1.00
Severely dry	-1.99 to -1.49
Extremely dry	≤ -2.00

2.5 IMD Method

With this method, the drought can be assessed on the basis of percentage deviation of rainfall (D_i) from long-term average rainfall (PM), expressed mathematically as:

$$D_i = 100 \times [(P_i - PM)/PM]$$

Where, P_i = rainfall (mm) in time period “i” (month or year); and

PM = long-term average rainfall (mm).

The values of D_i and categorisation of drought prescribed by IMD, Pune are given hereunder as:

Percentage deviation (D_i)	Category
>0	No drought
0 to -25	Mild
-25 to -50	Moderate
<-50	Severe

2.6 Revised IMD Method

In this method, the drought can be assessed **(Ravikumar and Kaarmegam, 1996)** on the basis of per cent deviation of cumulative long-term average rainfall (CD_i), expressed mathematically as**:**

$$CD_i = 100 \times [(PC_i - PCM_i)/PM]$$

Where, PC_i = cumulative actual rainfall (mm);

PCM_i = cumulative long-term average rainfall (mm); and

PM = long-term average rainfall.

2.7 Drought Investigation on Monthly and Yearly Basis

Variation of drought on the monthly and yearly basis by considering criterion proposed by **Ramdas and Mallik (1948)** and **Sharma *et al.* (1979**) mentioned below as:

- **Normal month:** if actual rainfall is lies in between 50% and 200% of average monthly rainfall;

- **Abnormal month:** any month receiving rains more than twice of average monthly rainfall;
- **Drought month:** if actual rainfall is less than 50% of average monthly rainfall;
- **Normal year:** if year receiving rainfall in between (P_{av}-SD) and (P_{av}+SD);
- **Abnormal year:** if year receiving rainfall more than or equal to (P_{av}+SD); and
- **Drought year:** if year receiving rainfall less than or equal to (P_{av}-SD).

Where, P_{av} = average annual rainfall (mm); and

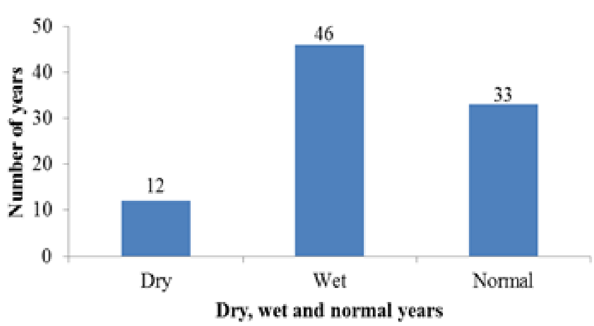
SD = standard deviation of annual rainfall

3. RESULTS AND DISCUSSIONS

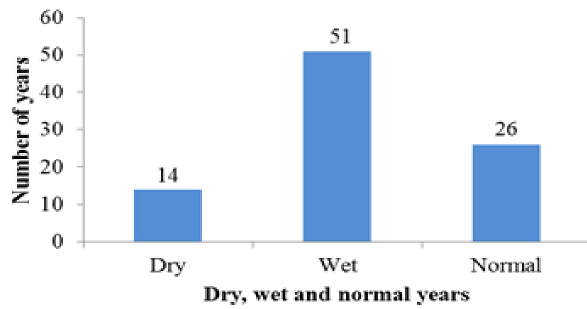
This chapter deals with investigation of drought spells for Almora and Chamoli districts of Uttarakhand on monthly and yearly basis in terms of different drought indices (DPI, PDI, SIAP, SPI) and the criterion prescribed by **Ramdas and Malik (1948)** and **Sharma *et al*. (1979)** as:

3.1 Dependable Precipitation Index (DPI)

The value of DPI was calculated with annual rainfall data series of 91 years (1923-2013) for Almora and Chamoli districts and the number of dry, wet and normal years was obtained. It is evident from **Fig 4.1(a)** and **4.1(b)** that the districts of Almora and Chamoli experienced 14 and 12 years as dry, 51 and 46 years as wet, whereas, 26 and 33 years were observed as normal years.



(a) Variation in DPI values observed at Chamoli district



(b) Variation in DPI values observed at Almora district

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