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Assessment of the Rainfall Trend and Drought Estimation for the Small Catchment of Karnataka-Hassan

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ABSTRACT : The study presents analysis of drought and groundwater recharge at Hassan district of Karnataka, India. Drought conditions were assessed for yearly time steps using rainfall data and groundwater level data for twenty one years (1996 to 2016) at Hassan district viz. Arsikere, Belur, Hassan, and Sakleshpura. According to the India Meteorological department (IMD) an area/region is considered to be drought if it receives seasonal total rainfall less than 75% of its normal value. The 21 years of rainfall records in all four stations mentioned above were subjected to various kind of analysis including seasonal & annual rainfall departures, probability distribution and dry spell analysis etc. For identification of drought years and the extent of deficit of annual rainfall, the annual rainfall departure analysis has been carried out. From the analysis it is observed that in years 2001,2003,2012 and 2016 is a drought year. It means that year after every 3 to 4 year is a drought year. The groundwater recharge for the identified drought periods are calculated through precipitation and rainfall infiltration method.

KEYWORDS: Droughts, Probability distribution, Rainfall departure, Rainfall infiltration.

I. INTRODUCTION

Rainfall is the important element of Indian economy. Although the monsoons affect most part of India the amount of rainfall varies from heavy to scanty on different parts. There is great regional and temporal variation in the distribution of rainfall. Rainfall variability is a major factor influencing the agricultural productivity and sustainability in tropics. Drought is one of the major environmental disasters, which have been occurring in almost all climatic zones & damage to the environment & economies of several countries have extensive. There are a number of classifications for drought. One of the classifications is according to its physical aspects namely, Meteorological, Hydrological and Agricultural. According to the India Meteorological Department (IMD), meteorological drought occurs when the seasonal rainfall received over an area is less than 75% of its long-term average value. If the rainfall deficit is between 26 - 50%, the drought is classified as 'moderate', and 'severe' if the deficit exceeds 50%. Hydrological drought is a deficiency in surface & sub-surface water supply. It is measured as stream flows and also as lake, reservoir and ground water levels. The meteorological drought analysis is carried out using rainfall departure (RD) and Standardized precipitation index method (SPI). The hydrological drought analysis is carried out using Standardized groundwater level index(SGI).Groundwater recharge is defined as water that infiltrates through the subsurface to the zone of saturation beneath the water table. It results in the increase of groundwater storage and contributes to groundwater flow. Three empirical formulae showing rainfall recharge relationship were selected for the estimation of recharge based on the work of Chaturvedi (1936) in Kumar (2009) which was later modified, Krishna Rao (1970) in Kumar (2009) and Kumar and Seethapathi (2002).Recharge through groundwater levels is calculated using rainfall infiltration method.

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II. STUDY AREA AND DATA COLLECTED

Hassan district is located on the border of the Western Ghats, in the southern part of Karnataka state. It is located between 12° 30' and 13° 35' North latitude and 75° 15' and 76°40' East longitude with an aerial extent of 6,845 Km² (Fig 1). It includes 8 taluks namely Alur, Arkalgud, Arasikere, Belur, Channarayapatna, Hassan, Holenarsipur and Sakleshpur with general ground elevation of 943 m above MSL. For the present study the station chosen are Arasikere, Belur, Hassan, Sakleshpur depending upon their rainfall variation. Since Arasikere station receives very low rainfall compared to other stations of Hassan district, Hence, it is considered as a drought area for the present study.

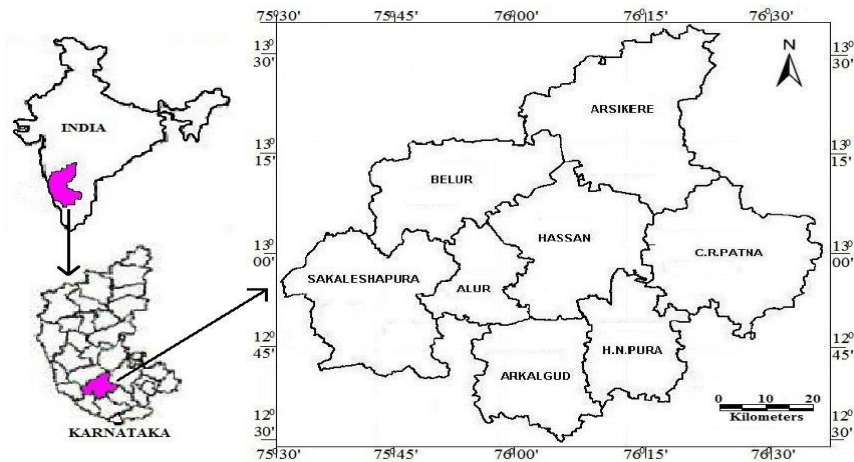


Fig.1 Location map of study area

The rainfall records of 21 years for Arasikere, Belur, Hassan and Sakleshpura were obtained from the District Statistical Department, Vijayanagar, Hassan, Karnataka state and the Groundwater level data were obtained from Central Ground Water Board (CGWB), Bangalore, Karnataka state.

III. RESEARCH OBJECTIVES

1. To know the variation in the intensity of rainfall over the years and intern to get the rainfall pattern
2. To identify the drought period
3. To analyse the type of drought (Meteorological or Hydrological drought)
4. Meteorological and Hydrological recharge estimation in the identified drought period

IV. METHODOLOGY

Rainfall pattern determination and intern identifying the drought year is very much important to estimate recharge during the identified drought period. The 21 years of rainfall records in all four stations mentioned above were subjected to various kind of analysis including seasonal & annual rainfall departures, probability distribution and dry spell analysis etc. A detailed methodology of identifying meteorological and hydrological drought and intern calculation of recharge in the identified drought period is discussed below.

RAINFALL VARIATION

PRECIPITATION CONCENTRATION INDEX (PCI): Precipitation is one of the important climatic variables due to its changes in the intensity and the amount affecting appearing of the hydrological hazards such as flood and drought. In this study, the precipitation concentration index (PCI) is analyzed. The PCI allows quantifying the relative

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distribution of Precipitation patterns. PCI and its category is as shown in the Table1 and PCI can be calculated using the Equation given below. Thus the obtained rainfall data are plotted in bar plots using PCI method to know the rainfall variation pattern over the years.

Formula used to find Precipitation Concentration Index is:

$$PCI = 100 \frac{(\sum Pi)^2}{P^2} \tag{Eq. 1}$$

Where, Pi= Monthly Precipitation, mm, P= Annual Precipitation, mm

Table .1 PCI and its Rainfall category

PCI	Category
8.3 – 10	Uniform
10 – 15	Moderately seasonal
15 – 20	Seasonal
50 – 100	Irregular

Further PCI calculations and bar plots plotted for 21 years of rainfall records to know the variation in the intensity of rainfall and classifying the PCI value obtained according to its category given in the Table are discussed in detail in next section.

METEOROLOGICAL DROUGHT

Meteorological drought is defined usually on the basis of the degree of dryness (in comparison to some normal or average amount) and the duration of the dry period. The Rainfall Departure (RD) and Standardised Precipitation Index (SPI) methods are used in the calculation and analysis of meteorological drought.

RAINFALL DEPARTURE (RD)

The difference between the actual value for the day and the normal is the departure. The cumulative rainfall departure from normal rainfall is a concept sometimes utilized to evaluate the temporal correlation of rainfall with surface water or groundwater levels. Table2 shows rainfall departure values and its drought category.

CALCULATION OF RAINFALL DEPARTURE

$$\text{Departure from mean rainfall} = \frac{(\text{Annual rainfall of year} - \text{mean rainfall})}{\text{mean rainfall}} * 100 \tag{Eq.2}$$

STEPS ADOPTED FOR THE CALCULATION OF RAINFALL DEPARTURE

1. Take the annual rainfall data for the selected station and calculate the mean of annual rainfall data
2. Calculate standard deviation for the rainfall data
3. For calculating the departure, substrate the annual rainfall data of a year from the mean rainfall of the year
4. Find out the 75% of mean rainfall and calculate the drought year. For calculating the drought year , compare the annual rainfall .If the value of annual rainfall of year with 75% of mean rainfall ,then it is called Drought year but if the value of annual rainfall of year is greater than 75% of mean rainfall then it is called the NO drought year. After calculating the drought year, calculate the departure from mean rainfall and finally calculate the class of severity of the particular block

Table.2 RD and its drought category

RD	Category
0.0 to -25	No drought condition
-26 to -50	Moderate drought condition
>-50	Severe drought condition

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Further RD calculations, for which the bar plots plotted to identify the class of severity and the drought year of the particular block according to the Table.2 are discussed in detail in the next section.

STANDARDIZED PRECIPITATION INDEX (SPI)

The Standardized Precipitation Index (SPI) expresses the actual rainfall as standardized departure from rainfall probability distribution function. In this study, severity and spatial patterns of meteorological drought is analyzed using the formula as shown in Equation. SPI categorized based on their range values is shown in Table.3. This method is used for observing and describing drought based on 21 year precipitation data.

$$SPI = \frac{(X - X_m)}{\sigma} \tag{Eq.3}$$

Where, X= Precipitation for the station, X_m= Mean Precipitation

σ = Standard deviation, where $\sigma = \sqrt{\frac{\sum(X - X_m)^2}{N - 1}}$, N= Number of years

Table.3 SPI and its drought category

SPI	Category
0 to -0.99	Mild drought
-1 to -1.49	Moderate drought
-1.5 to -1.9	Severe drought
< or = -2	Extreme drought

Positive SPI values point to normal condition to wet condition and negative values indicate normal condition to dry condition. The SPI derived at the end of each year are compared using the given drought range for which bar plots are plotted to identify the drought year and its drought category are explained in detail in next sections. For the identified drought years from RD and SPI methods groundwater recharge and the recharge coefficient (% recharge) were determined for the study area using empirical methods.

ESTIMATION OF RECHARGE THROUGH PRECIPITATION

Three empirical formulae showing rainfall recharge relationship were selected for the estimation of recharge based on the work of Chaturvedi (1936), which was later modified by Kumar (2009); Krishna Rao (1970) and Kumar (2009); and Kumar and Seethapathi (2002).The formulae were selected because of the similarities between the Indian monsoons and the humid sub-tropical climate of southwest Nigeria, study area adopted in the above mentioned papers. The evolution of the empirical equations is discussed below.

1 Modified Chaturvedi formula (1936)

Chaturvedi derived an empirical equation which expresses recharge as a function of annual precipitation, thus:

$$Rr = 2.0 (P - 15)^{0.4} \tag{Eq.4}$$

Where, Rr = net recharge due to precipitation during the year, in inches, P = annual precipitation, in inches.

This formula was later modified by further work at the U.P. Irrigation Research Institute, Roorkee and the modified form of the formula is:

$$Rr = 1.35 (P - 14)^{0.5} \tag{Eq.5}$$

2 Kumar and Seethapathi Formula (2002)

The following empirical relationship (similar to Chaturvedi formula) was derived by fitting the estimated values of rainfall recharge and the corresponding values of rainfall in the monsoon season through the non-linear regression equation.

$$Rr = 0.63 (P - 15.28)^{0.76} \tag{Eq.6}$$

Where,

Rr = Groundwater recharge from rainfall in monsoon season (inch), P = Mean rainfall in monsoon season (inch).

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3 Krishna Rao (1970)

Krishna Rao gave the following empirical relationship in 1970 to determine the groundwater recharge in limited climatological homogeneous areas:

$$R_r = K (P - X) \tag{Eq.7}$$

Where, R_r = Recharge, K = constant, P = Precipitation, X = No of point rainfall

The following specific empirical equations were applied to different parts of Karnataka:

$R_r = 0.20 (P - 400)$; for areas with annual normal rainfall (P) between 400 and 600 mm

$R_r = 0.25 (P - 400)$; for areas with P between 600 and 1000 mm

$R_r = 0.35 (P - 600)$; for areas with P above 2000 mm

Where, R_r and P are expressed in millimeters.

HYDROLOGICAL DROUGHT: Hydrological drought occurs when low water supply becomes evident, especially in streams, reservoirs, and groundwater levels, usually after many months of meteorological drought. Hydrological drought takes much longer to develop and then to recover. The main reasons for occurrence of hydrological drought are reduced stream flow, inflow to reservoirs, lakes, and ponds; reduced wetlands, wildlife habitat. The standardized groundwater index (SGI) is used in the analysis and calculation of hydrological drought.

STANDARDIZED GROUNDWATER INDEX (SGI): A new index for standardizing groundwater level time series and characterizing groundwater droughts, the Standardized Groundwater level Index (SGI), is described. Calculation of SGI is made using the Equation. Drought is categorized based on SGI values given in the Table4. The SGI builds on the Standardized Precipitation Index (SPI) to account for differences in the form and characteristics of groundwater level and precipitation time series.

$$SGI = \frac{(W - W_m)}{\sigma} \tag{Eq.8}$$

Where, W = Groundwater level for the station

W_m = Mean Groundwater level

σ = Standard deviation, where $\sigma = \sqrt{\frac{W - W_m)^2}{N - 1}}$, N = Number of years

Table 4 SGI and its drought category

Category	SGI
Extreme drought	SGI >2.0
Severe drought	SGI >1.5
Moderate drought	SGI >1.0
Mild drought	SGI >0.0
Non drought	SGI <0.0

Positive anomalies correspond to drought and negative anomalies correspond to no-drought or normal condition. The SGI derived at the end of each year are compared using the given drought range for which bar plots are plotted to identify the drought year and its drought category are explained in detail in next sections.

RECHARGE THROUGH GROUNDWATER LEVELS

Groundwater Resource Estimation Committee (GEC-97) recommends two approaches to assessment of recharge to groundwater. These are (i) Groundwater level fluctuation method, and (ii) Rainfall infiltration factor method, of which Rainfall infiltration factor method is adopted for the present study.

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1 RAINFALL INFILTRATION METHOD (Source; Engineering Hydrology-K.Subramanya)

In areas where groundwater level monitoring is not adequate in space and time, rainfall infiltration method may be used. Rainfall infiltration is calculated using the Eq.9. The recharge from rainfall in monsoon season is taken as a percentage of normal monsoon rainfall in the area. Norms for the selection of Rainfall factor f is as shown in the Table Thus

$$R_{rf} = fA P_{nm} \tag{Eq.9}$$

Where, R_{rf} = Recharge from rainfall in monsoon season

f = Rainfall infiltration factor

A = Area of computation for recharge

P_{nm} = Normal rainfall in monsoon season

The study area chosen consists of hard rock areas with weathered granite, gneiss and schist with low clay content. The recommended value for selection of rainfall factor f is taken as 11.

V. RESULTS AND DISCUSSIONS

The results for Hassan district viz. Arsikere, Belur, Hassan and Sakleshpura was evaluated and found that the results of SPI, RD and SGI have quite similar results as per their categories. The recharge estimation using precipitation were determined from the above mentioned formulae and it was found that the recharge estimated in the identified drought year using Krishna Rao (1970) formula was accurate when compared to other two since it includes ranges of precipitation. The average recharge in the identified drought period in all 4 stations considered under present study is estimated as 21.8%.

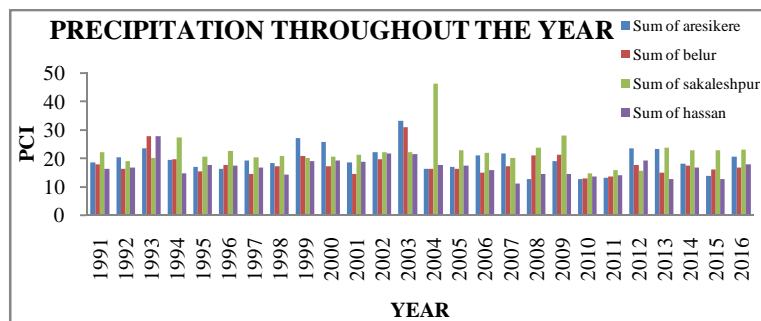


Fig.2 Rainfall variation over 26 years for all 4 stations considered under study

The rainfall variation was determined using Precipitation Concentration Index (PCI) for the 4 stations considered under study is as shown in Fig 2 for Belur, Arsikere, Sakaleshpura and Hassan.

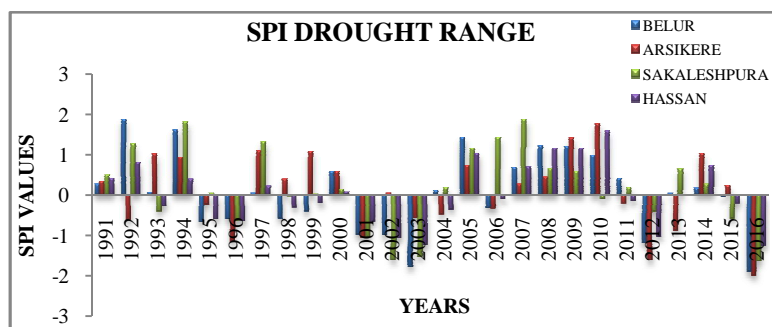


Fig.3 SPI values for all 4 stations considered under study

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SPI values were determined to identify Meteorological drought in all the 4 stations is as shown in Fig .3. The negative anomalies indicate drought years.

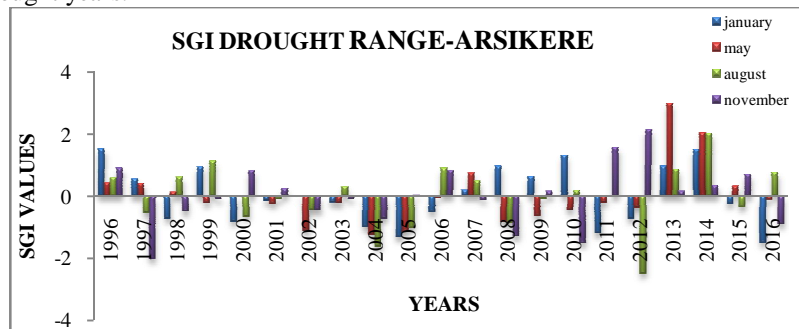


Fig.4 SGI values for Arsikere station (Pre monsoon, Monsoon and Post monsoon)

SGI values were determined to identify Hydrological drought in all 4 stations is as shown in Fig.4 for Arsikere station, similarly SGI values for other 3 stations were calculated. It is noticed that the drought years include 2001, 2003, 2012 and 2016.

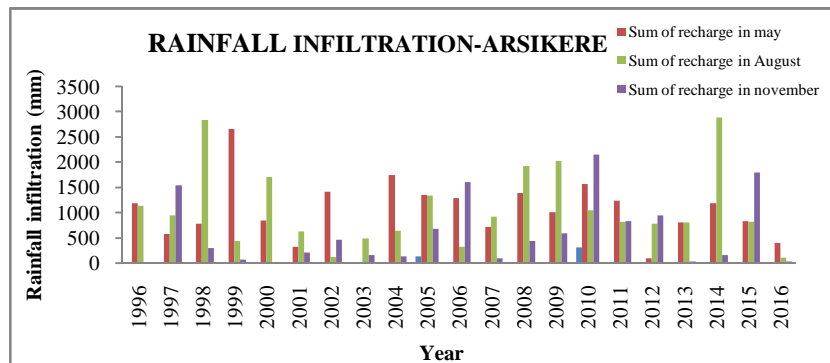


Fig.5 Seasonal variation of recharge for Arsikere through rainfall infiltration method

The recharge estimation through Rainfall Infiltration method during Pre –monsoon, Monsoon and Post –monsoon for all four stations were determined, Fig.5 shows seasonal variation of recharge for Arsikere, similarly for other 3 stations were also determined.

VI. CONCLUSION

The SPI, RD and SGI gives better result without other climatic parameters like minimum and maximum temperature, humidity, and potential evapo-transpiration and sun hours as it uses only precipitation data and groundwater level data and gives accurate result. These methods are better for agricultural applications since it is simple and effective. It is noticed that year after every 3-4 year is a drought year and recharge in identified drought year was estimated as 21.8% only. Since the agricultural activity in the study area mainly depends on monsoon season which is not uniform throughout Hassan district, it is necessary to conserve the water in the form of water conservation methods.

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