Assessment of historical drought by two different tools for the Bagalkot and Vijaya Pura Districts, Karnataka, India
Original Study

Bharath A. L.[1], **B.Venkatesh**[2] ✉
[1]*Research Scholar,* [2]*Scientist, National Institute of Hydrology, Main Road, Visvesvaraya Nagar,Belagavi,*
Karnataka-590019 ✉*bvenki30@gmail.com*

Abstract

The current study looks into past droughts and rainfall trends in the Bagalkot and Vijayapura districts of North Karnataka. It includes 11 meteorological stations in an area that is primarily dry region, with annual rainfall ranging from 512.67mm to 663.97mm. The data for a period of 38 (1981-2018) years were collected from the Karnataka State Natural Disaster Mitigation Centre in Bengaluru and are used for analysis.Two methodologies were used to compute droughts. 1) Standard Precipitation Index (SPI), 2) Meteorological Drought Severity Index (MDSI). The result obtained indicate that, Bagalkot district has 34% Mild Drought, 26% Moderate Drought, and Jamakhandi has the greatest proportion of Number of Drought.Sindagi has suffered mild drought in the 1-Month timeline, severe drought in the 3 and 6-Month timescales, and severe drought in the 1 and 6-Month timescale at all eleven stations in the study area, according to the standard precipitation index tool.

Keywords : *Standard Precipitation Index, Meteorological drought Severity index, Mann - Kendell test*

1. INTRODUCTION

According to the Indian Meteorological Department, droughts are divided into three categories: 1) meteorological droughts, 2) hydrological droughts, and 3) other droughts. 3) Drought in the agricultural sector. Droughts are caused by a lack of precipitation, which has a variety of effects on the country's economy, agricultural operations, ground water depletion, and soil fertility. It takes a lot of time and effort to recover from the effects of drought. Magnitude, severity, duration, and frequency are used to classify it. Different policymakers use planning and policy development to manage and reduce drought risk. Drought assessment and forecasting can be done in a variety of ways. This provides various insights into the precipitation shortfall, and drought monitoring can be done accordingly.The Standard Precipitation Index (Mc Kee et al 1993), the Palmer Drought Severity Index (PDSI) (Palmer 1960), and their variations. The Palmer Hydrological Drought Index and the Z-Score Index are two different drought indicators that can be used to forecast future droughts and assess historical droughts using Hidden Markov models, Timeseries, Fourier series, and Artificial Neural Networks (ANN). These are the most commonly used indicators to forecast droughts. This application mostly uses accessible datasets, with SPI relying solely on precipitation data and other indices relying on precipitation, temperature, evapo-transpiration data, and other water balance datasets.The standard Precipitation index also gives insights of short term to long term timescales 1-month, 3-month, 6-month, 12-month. The SPI is widely used tool for drought assessment and gives insight of historical drought assessment. Information of drought severity, magnitude and duration and Precipitation concentration index(PCI) is used to different the variations of rainfall distribution in Annual timescale, Pre-Monsoon, Monsoon and Post Monsoon timescale, which identifies the variations in rainfall in particular regions, it is classified in Uniform distribution, Moderate distribution, Strong irregular Precipitation distribution and Standard precipitation Index indices takes continues negative values in the analysis to identify the intensity of drought and total duration in monsoon month. The Dry spell from starting to ending month.

This study is intended to investigate the 1) Systematic approach to Drought assessment 2) How Meteorological drought severity index works to identify drought assessment.

2. STUDY AREA

The study area comprises of Two districts which is located in between North-Karnataka commonly known as Kalyan Karnataka, Bagalkot and Vijayapura with 11 Meteorological stations. These districts are influenced by monsoon season begins in June and lasts until October in the district. The bulk of the rainfall is received during the monsoon season with mean annual rainfall ranging from 512.67mm to 663.97mm. The annual average rainy days in these districts vary between 30-40 days. The highest mean annual rainfall is observed at Basavanabagewadi and lowest at Mudhol (Figure 1). Historically the study area is reeling under the drought (Jayashree and Venkatesh 2015) with varying degree of severity. Agro-climatically this region falls under northern semi-arid region with high temperature and low humidity. The economy of this region is driven by agricultural related business and farming of cash crop such as grapes and Pomegranate. Most of these farming and agricultural cultivation is the major part of the (>70) arable land is on rain-fed and remaining land is irrigated by the irrigation projects constructed on river Krishna and Bhima.

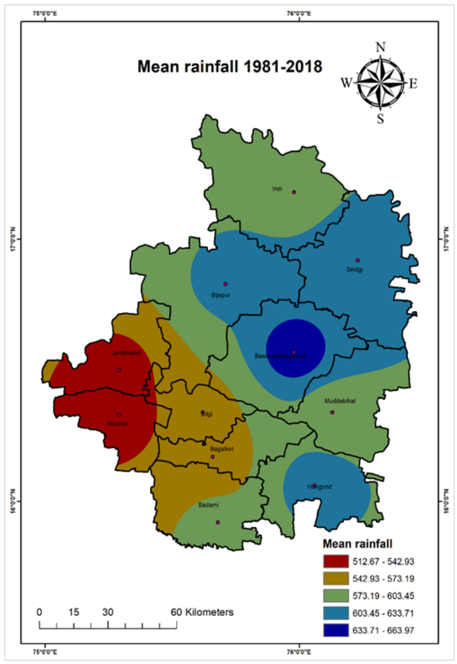

Figure 1: Shows the Mean rainfall data of the Study area

3. METHODOLOGY

3.1 Standard Precipitation Index

The SPI utilises monthly rainfall data to assess the dry and wet conditions, The standard Precipitation Index is tool which accounts only Precipitation data to Measure the dry and wet periods,The SPI period is flexible (McKee et al.,1993). The continues dry or wet periods can be calculated for the Drought or Wet Condition, The gamma probabilities were transformed into standardized normal distribution using equi-probability transformation techniques (Abramowitz and Stegun, 1965). The SPI has different classes of Timescales 1-Month, 3-Month, 6-Month and 12-Month timescales, which assess short- and long-term drought or wet conditions. SPI Measures the standard deviation of rainfall from short term to long term. The SPI Can be calculated with the Rainfall data alone, which gives the different severity levels and Durations.

$$SPI=((x_{ij}-\bar{x})/\sigma) \quad (1)$$

The SPI can be processed with different periods (e.g., 1, 3, 6, and 12 months) (Pandey and Srivastava, 2019). Its probability density function or frequency defines the gamma distribution:

$$SPI = \left(\frac{x_{ij}-\bar{x}}{\sigma}\right) \quad (1)$$

The SPI can be processed with different periods (e.g., 1, 3, 6, and 12 months) (Pandey and Srivastava, 2019). Its probability density function or frequency defines the gamma distribution:

$$G\,(x) = \frac{1}{\beta^{\alpha} * \Gamma^{\alpha}} x^{\alpha-1} * e^{-x/b} \quad (2)$$

Where, $\beta > 0$, β is a scale factor and $\alpha > 0$, α is a shape factor

$$\Gamma(\alpha) = \int_0^\infty y^{a-1} e^{-y} dx \quad (3)$$

Where Γ (α) is the gamma function

Calculation of the SPI esteem includes fitting a gamma likelihood thickness capacity to a given frequency distribution of precipitation total for a station. Adjusting the data set needs the α and β parameters to be estimated through the maximum likelihood estimation (Thom, 1966)

$$\hat{\alpha} = \frac{1}{4A} \quad (4) \qquad (\hat{\beta}) = \frac{\bar{x}}{\hat{\alpha}} \quad (5) \qquad A = In(\bar{x}) - \frac{\sum In(x)}{n} \quad (6)$$

n = number of rainfall observations. The cumulative probability distribution function

$$G(x) = \int_0^x g(x)\,dx = \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})} \quad (7)$$

Substituting t for

$$G(x) = \frac{1}{\Gamma\hat{\alpha}} \int_0^x t^{\hat{\alpha}-1} e^{-t} dt \quad (8)$$

The gamma function is indeterminate for x=0. The cumulative probability distribution function becomes:

$$H(x)=q+(1-q)*G(x) \quad (9)$$

q = is the probability of a zero. The drought and wetness severity adopted in the study based on the range values is shown in Table 2 (Mishra and Nagarajan, 2011).

Table-1 Categorization of Standardized Precipitation Index values

SPI Range Values	Category
+ 2 to more	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 to less	Extremely dry

SPI with negative values specifies less than mean precipitation, and the positive values indicate vice-versa. The SPI range for the drought part is segregated into -0.99 to 0.99 (near normal), -1.0 to -1.49 (Moderately dry), -1.5 to -1.99 (Severely dry), and -2 to less (Extremely dry).

3.2 Indian Meteorological department Method (IMD)

Prominent decline in rainfall from the normal precipitation, according to IMD, 25% less than normal rainfall is termed as Meteorological drought. IMD Method is employed to assess the drought severity and classes. Normally the percentage deviation of total annual rainfall from 38-year annual mean.

Table-2 IMD Classification

>0	M0	No Drought
0 to -25	M1	Mild Drought
-25 to -50	M2	Moderate Drought
<-50	M3	Severe Drought

Table-3 Range of Drought Severity in MDSI

SL. No	Range	Drought Severity
1)	1.34-1.64	No Drought
2)	1.64-1.94	Mild Drought
3)	1.94-2.24	Mild Drought
4)	2.24 -2.54	Severe Drought

3.3 Meteorological Drought Severity Index

The meteorological drought severity index is a value that is calculated using frequency analysis. It is the number of times the precipitation deviates from the region's mean rainfall in a given period. The method entails a frequency analysis of distinct drought severity groups.

Drought severity classes 'No drought,' 'Mild drought,' Moderate drought,' and 'Severe drought,' respectively, are assigned weightages 1, 2, 3, and 4. The MDSI is calculated by multiplying the frequency of each type of drought severity by the weightage assigned to it. Based on the range of drought severity indexes, four drought severity classes were established.

3.4 Mann-Kendall Trend Test (MK)

The study looks on changes in Rainfall trends in the chosen area (Bagalkot and Vijayapura). Mann (1945), Kendall (1975), and Gilbert (1987) developed the Mann-Kendall test (MK) for detecting trends in precipitation data. The M-K test, according to the World Meteorological Organization, takes into account data distribution and can handle exceptions. The MK test looks for a monotonic rising or downward trend in Y values in data collected over time. The MK test determines whether to reject the null hypothesis (H0) or accept the alternative hypothesis (Ha), with H0 indicating that no monotonic trend existed in the investigated time series and Ha indicating that a monotonic trend did exist in the investigated time series (Tatli, 2015).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn(x_j - x_i), \quad (10)$$

$$\text{Where, } Sgn(x_j - x_i) = \begin{cases} +1, & x_j > x_i \\ 0, & x_j = x_i \quad (11) \\ -1, & x_j < x_i \end{cases}$$

n = sample size; S = large positive value of S exhibits a strongly increasing trend, whereas the large negative value of S exhibits a strong decreasing trend. When the MK test is applied to a time series with many values, the Z test can be used to determine whether a trend is significant or not significant (Ahmad et al., 2015).

$$Z = \begin{cases} \dfrac{s-1}{\sqrt{\dfrac{n(n-1)(2n+5)-\sum_{j=1}^{q} t_j(t_j-1)(2t_j+5)}{18}}} & if\ S > 0 \\ 0 & if\ S = 0 \quad (12) \\ \dfrac{s-1}{\sqrt{\dfrac{n(n-1)(2n+5)-\sum_{j=1}^{q} t_j(t_j-1)(2t_j+5)}{18}}} & if\ S < 0 \end{cases}$$

n = sample size, q = number of zero difference groups in the data set, the p-value of 0.05 is used as the significance of a trend. Sen's Slope estimator of rainfall trend is a nonparametric technique applied to evaluate the trends in rainfall data. A positive and negative Sen Slope value indicates increasing and decreasing trends in the time series (Gocic and Trajkovic, 2013).

$$Q_i = \frac{x_j - x_k}{j - k} \text{ for } i = 1, \ldots, N \ldots (13)$$

4. RESULTS AND DISCUSSIONS

The statiscal analysis was done to understand the maximum and minimum rainfall in the study area where, Basavanabagewadi of Vijayapura district has got highest rainfall in 38-year time period and Minimum amount of rainfall was witnessed in Mudhol taluk of Bagalkote district.The values of Skewness indicate that the rainfall data have a positively skewed distribution. The degree of peakedness (kurtosis) of rainfall distribution indicates a peaked distribution (Nyatuame et al., 2014). The distribution of CV across the study area indicates lower values in the higher rainfall area and larger CV values in lower rainfall area. This suggests that, the rainfall in the in this area are not continuous and may of smaller amount over larger time period. These larger variations could be due to; (i) many of these stations falls in the transition zone, i.e., from sub-humid to semi-arid zone in the district; and (ii) the stations in semi-arid are characterised by longer dry period with intermittent rainfall.

Table-4 indicates the amount of mean rainfall, standard deviation, coefficient of Variation, Kurtosis and Skewness.

Station Name	Mean	SD	CV	Kurt	Skew
Sindagi	614.31	184.54	0.30	0.10	0.00
Muddebihala	585.53	181.73	0.31	0.70	0.40
Indi	597.69	169.98	0.28	0.87	0.73
Vijayapura	615.93	191.96	0.31	-0.14	0.27
Bagewadi	663.99	185.42	0.28	1.04	0.42
Badami	581.22	175.34	0.30	-0.59	0.37
Bagalkote	548.97	185.27	0.34	-0.07	0.46
Bilgi	557.07	185.05	0.33	-0.09	0.38
Hunugund	623.26	177.58	0.28	0.97	0.63
Jamakhandi	528.09	157.75	0.30	0.37	0.70
Mudhol	512.66	182.10	0.36	1.48	1.07

As it is seen from Table 4, These two districts fall on Northern Dry Zone of Agro-climatic zones of Karnataka as per Krishnan (1984). The State Receives 80% of the annual rainfall in the southwest monsoon period, 12% in the Post-Monsoon Period, 7% in the summer and only 1% in winter. Bagewadi of Vijaya Pura districts receives 663.99 mm of rainfall, Sindagi taluk witness 614.31 mm of rainfall in the district and in Bagalkotdistrict maximum of 623.26 mm of rainfall is witnessed in Hunugund taluk and least of 512.66mm of rainfall is witnessed in Mudhol taluk.

4.1 Trend analysis

The Sen's slope and Mann-Kendall test were utilised at 11 stations in the twin cities of Vijayapura and Bagalkote in North Karnataka. The rainfall data used for the analysis ranged from 1981 to 2018, a total of 38 years. To see the significant variations, the data is divided into annual and monsoon seasons. In the annual season, the entire 12-months will be utilised to discover trends, whereas only four months will be used in the monsoon season (June-sept). Sen's slope positive signals indicate an upward tendency, while decreasing signs indicate a downward trend.

Table-5 Mann-Kendell Non-Parametric trend test for annual and monsoon season

District	Station	Annual		Monsoon	
		P-value	Sen's slope	P-Value	Sen's slope
	Sindagi	0.68	-1.64	0.19	-10.43
	Muddebihala	0.07	-4.86	0.27	-3.00
	Indi	0.07	-4.17	0.09	-19.53
	Vijayapura	0.08	-4.75	0.19	-15.07
Vijayapura	Bagewadi	0.75	-0.98	0.71	13.30
	Badami	0.65	1.47	0.56	5.65
	Bagalkote	0.97	-0.13	0.95	-4.15
	Bilgi	0.39	-2.50	0.32	-8.78
	Hunugund	0.26	-2.79	0.23	-8.61
	Jamakhandi	0.54	-1.32	0.63	-6.05
Bagalkote	Mudhol	0.46	-1.83	0.87	-0.44

Implies Mann-Kendell Non Parametric Trend Test, which says Negative signs implies decreasing trend and Positive signs implies Positive trend, The analysis part was done into annual season and Monsoon season, in Vijayapura district the average of 38 years signifies negative trend throughout the district due to various reasons, and in Bagalkote district Badami taluk has shown positive sign trend which is increasing in trend and rest of 5 taluks intends to decline trend in annual season, whereas in Monsoon season, Bagewadi taluk has shown positive incline trend in rainfall and rest 4 taluks has continued to be in declining trend and Bagalkote district Badami taluk has continued to be in Positive trend and rest 5 taluks has continued to be in declining trend.

4.2 IMD Method

Drought frequency can be computed using the IMD Method, which uses 38 years of rainfall data from 1981 to 2018, as shown in Table 6. The average rainfall of 38-years data and the average rainfall of Individual Year are used to determine percentage deviations. During this time span, the Jamakhandi taluk of Bagalkote district has had 52.6 percent of no drought, whereas Mudhol taluk has experienced a minimum of 36.8% of no drought. The mudhol region saw the most severe drought, with Badami recording 26.9%, Bagalkote 28.9%, Bilgi 29.9%, Hungund 32.9%, and Jamakhandi 29.9%. Drought percentages were moderate in Mudhol taluk and minimal in Bilgi taluk. Severe Drought, according to the IMD Methods, there has been no severe drought in the 38 years of data.

Table- 6 Shows the drought occurrence and Frequency of droughts in the study area

Occurrence and Frequency of Drought								
	No Drought		Mild Drought		Moderate Drought		Severe Drought	
	Occurrence	Frequency	Occurrence	Frequency	Occurrence	Frequency	Occurrence	Frequency
Badami	19	0.5	10	0.263	9	0.23	0	0
Bagalkote	18	0.473	11	0.289	9	0.23	0	0
Bilgi	19	0.5	11	0.29	5	0.13	3	0.079
Hungund	18	0.473	12	0.32	7	0.184	1	0.026
Jama Kandi	20	0.526	11	0.29	6	0.158	1	0.026
Mudhol	14	0.368	13	0.34	10	0.263	1	0.026

4.3 Meteorological Drought Severity Index

The IMD Method displays the Drought Classes. The yearly rainfall and average rainfall across a region are determined by these factors. For 38 years, the annual average rainfall in the Badami region has been 581.22mm. Mild Drought has been observed in the region, according to Table 7. Drought Severity Index is 1.762. With a slight drought, Bagalkote received 548.90mm of yearly average rainfall. Hungund station has received 623.26mm of rain and is experiencing a mild drought. Jamakhandi is free of drought, whereas Mudhol taluk is suffering from a mild drought

Table - 7 Shows the meteorological Drought severity index and their classes

Meteorological Drought Severity Index							
Name of the Station	Average Annual Rainfall (mm)	Probability of drought severity class				Drought Severity Index	Drought Severity Class
		No drought	Mild	Moderate	Severe		
Badami	581.22	0.525	0.263	0.237	0	1.762	Mild
Bagalkot	548.90	0.473	0.289	0.23	0	1.741	Mild
Bilgi	557.07	0.5	0.29	0.132	0.079	1.476	No Drought
Hunugund	623.26	0.473	0.32	0.184	0.026	1.665	Mild Drought
Jamakandi	528.09	0.526	0.29	0.158	0.026	1.58	No Drought
Mudhol	512.66	0.368	0.34	0.26	0.026	1.828	Mild Drought

Table-8 Shows the Occurrence and frequency of Drought for Vijayapura districts.

Occurrence and frequency of drought								
Name of the station	No Drought		Mild Drought		Moderate Drought		Severe Drought	
	Occurrence	Frequency	Occurrence	Frequency	Occurrence	Frequency	Occurrence	Frequency
Sindagi	18	0.473	13	0.342	4	0.105	3	0.062
Muddebihala	19	0.5	11	0.289	6	0.158	3	0.078
Indi	15	0.394	18	0.474	4	0.105	1	0.026
Vijayapura	19	0.5	10	0.263	8	0.211	1	0.026
Bagewadi	20	0.526	10	0.263	8	0.211	1	0.026

Table 8 shows that Vijayapura districts with 5 taluks shows maximum no drought condition in Bagewadi and Viiyapura taluk with 52.3% and 50% of No drought condition. Mild Drought were observed more in Indi taluk and less in Vijayapura taluk as shown in table 9, Muddebihala experiences 7% of Severe Drought.

Table - 9 Shows the Meteorological Drought severity Index

Meteorological Drought Severity Index							
Name of the Station	Average Annual Rainfall (mm)	Probability of drought severity class				Drought Severity Index	Drought Severity Class
		No drought	Mild	Moderate	Severe		
Sindagi	614.30	0.473	0.342	0.105	0.0625	1.722	Mild
Muddebihala	585.50	0.5	0.289	0.158	0.0789	1.8676	Mild
indi	597.67	0.394	0.474	0.105	0.0263	1.7622	Mild
Vijayapura	615.92	0.5	0.263	0.211	0.026	1.763	Mild
Bagewadi	663.98	0.526	0.263	0.211	0.026	1.789	Mild

Table 10: The MDSI Method shows that there is no significant changes in the drought classes and describes there is no other drought than the Mild Drought due to Topographical region and less amount of Rainfall but almost same rainfall for all the five stations, which says that Sindagi records 614.30mm, Muddebihala records 585.50mm of Rainfall, Indi records 597.67mm of Rainfall, Vijayapura records 615.92mm of Rainfall and Bagewadi records 663.98mm of Rainfall.

Table-10 Shows the SPI drought severity and 1-month, 3-month, 6-month, 12-month timescales.

Station Name	latitude	Longitude	1-MONTH	3-MONTH	6-MONTH	12-MONTH
Sindagi	16.92	76.23	-1.33	-1.65	-1.59	-1.50
Muddebihala	16.34	76.13	-1.63	-1.70	-1.73	-1.53
Indi	17.18	75.98	-1.60	-1.57	-1.55	-1.22
Vijayapura	16.83	75.71	-1.60	-1.61	-1.60	-1.53
Bagewadi	16.57	75.98	-1.55	-1.23	-1.65	-1.48
Badami	15.92	75.68	-1.63	-1.60	-1.59	-1.52
Bagalkote	16.17	75.66	-1.60	-1.66	-1.62	-1.48
Bilgi	16.34	75.62	-1.80	-1.68	-1.69	-1.53
Hunugund	16.06	76.06	-1.56	-1.56	-1.53	-1.48
Jamakhandi	16.5	75.29	-1.56	-1.59	-1.60	-1.54
Mudhol	16.33	75.29	-1.68	-1.58	-1.54	-1.48

The SPI Severity indicates that 1-Month SPI Mild Drought has been occurred in Sindagi taluk and rest all the ten stations exhibits severe Drought in 1-month timescales. Mild drought has occurred in Bagewadi of Vijayapura district and rest all the stations exhibits Severe Droughts in 3-month Time scales, and SPI-6-Month Timescales all the stations performs Severe Drought in Both the districts and Long Term drought assessment by SPI 12-Month timescales shows that , Sindagi, Muddebihala, Indi Badami, Bilgi, Jamakhandi taluk witnessed Severe Drought and Vijayapura, Bagewadi, Bagalkote, Hungund, Mudhol taluks witnessed Mild Droughts in the study area due to various reasons.

5.0 CONCLUSION

This research has been undertaken to find the intensity and drought with two different tools mainly Standard Precipitation Index andMeteorological drought severity Index Method as it falls in the Northern Dry Zone. The Drought is not only dependent on rainfall but also Geographical features of the area. The study area is basically in North Dry zone which has maximum annual mean rainfall of 663.99mm in Bagewadi and Minimum of 512.66mm of rainfall in Mudhol taluk, this implies less production in agriculture. Lack of Rainfall leads to meteorological and hydrological droughts. This study was undertaken to analysehistorical drought events and the rainfall trend by Mk Test. To assess the historical droughts two different methods were employed in this study, 1) MDSI By IMD and 2) SPI With different timescales. The rainfall trend were observed that except Badami station all other stations were inclined to be in Decreasing trend or negative trend for the complete study period of 1981-2018, whereas in Monsoon season, Badami has showed up to continue in positive trend and rest other stations to be in Declining trend. The study also assessed the classes of drought by MDSI Method and SPI Methods and most of the stations were shown with Mild drought and No drought condition, but in SPI Method all the stations were performed Mild to Moderate station in the two districts 11 stations. Keeping in view of the above discussion, it may be concluded that,

(i) The Vijayapur district recorded the declining rainfall duirng the study period compared to Bagalkot district

(ii) The study area experiences the mild to moderate drought with higher frequency than the severe droughts which have very low frequency

In all it seen that, the Vijayapura district has recorded the steepest decline in rainfall with mild to moderate drought. This information is vital for planning the agricultural activities and to develop appropriate strategies for conserving the water in the district.However, there are few limitation to the method being used in the present study, they are (i) the methods used primarily use the rainfall data to compute the intensity of drought, however, temperature of the region also play an important role, which is not used while computation; and (ii) the SPI method use a probability distribution, there is no specific mention of distribution to be used. The use of different probability distribution will yield different results. However, the distribution used in the study, is standard distribution used in other studies carried out elsewhere and hence it is adopted in the presented study. The computed statistics on the drought of the region may of use to the local authorities to monitor the progress of the drought over the period, as well as to develop contingence plan to mitigate the impact of drought in the region.

Legend

x_{ij} = Precipitation of Months

$\bar{x}$ = Mean Precipitation

σ = Standard Deviation

β = scale factor

α = shape factor

$\Gamma(\alpha)$ = gamma function

n = number of rainfall observations

q = probability of a zero

S = large positive value of S exhibits a strongly increasing trend

6. ACKNOWLEDGMENT

We wish to say thank you for National Institute of Hydrology, Hard Rock Region, Belagavi, Karnataka, where the complete research work was carried out and we wish to say heartfelt thanks to Department of Economics and statistics, Karnataka State Natural disaster mitigation centre, Government of Karnataka, India for providing us required dataset and I wish to say thank you to Dr B Venkatesh, Scientist & Head, National Institute of Hydrology, Belagavi, India for continuous support for the carried research work.

REFERENCES

1) Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica: Journal of the econometric society,* pp.245-259.
2) Abramowitz, M.,&Stegun, I. A. (1965). *Handbook of mathematical functions with formulas, graphs, and mathematical table*. US Department of Commerce; National Bureau of Standards Applied Mathematics Series, 55.
3) Thom, H. C. S. (1966). Distribution of maximum annual water equivalent of snow on the ground. *Monthly weather review,* 94(4), pp. 265-271.
4) Gilbert, R. O. (1987). *Statistical methods for environmental pollution monitoring.* John Wiley & Sons.
5) McKee, T. B., Doesken, N. J., & Kleist, J. (1993, January). The relationship of drought frequency and duration to time scales. In Proceedings of the 8th *Conference on Applied Climatology* (Vol. 17, No. 22, pp. 179-183).
6) Hamed, K. H., & Rao, A. R. (1998). A modified Mann-Kendall trend test for autocorrelated data. J*ournal of hydrology,* 204(1-4), pp.182-196.
7) Mishra, S. S., & Nagarajan, R. (2011). Drought assessment in Tel watershed: An integrated approach using run analysis and SPI. IEEE, *Earthzine,* 1, 8-8.
8) Jayashree, V., & Venkatesh, B. (2012). Evaluating the hydrological response to land cover change: Dasanakatte catchment of Varahi river, Western Ghats, Karnataka. *International Journal of Water Resources and Environment Management*, 3(1), pp. 23-32.
9) Valli, M., Sree, K. S., & Krishna, I. V. M. (2013). Analysis of precipitation concentration index and rainfall prediction in various agro-climatic zones of Andhra Pradesh, India. *Int Res J Environ Sci*, 2(5), pp. 53-61.
10) Gumus, V., Avsaroglu, Y., &Simsek, O. (2022). Streamflow trends in the Tigris river basin using Mann− Kendall and innovative trend analysis methods. *Journal of Earth System Science*, 131(1), 1-17.

11) India Meteorological Department (2002) *Southwest Monsoon End-of-Season Report*, India
12) Sreedevi, R., Ramesh, B.R. (2022). Study on Rainfall Trends and Water Requirement for Crops in Bellary District of Karnataka, India. In: Nandagiri, L., Narasimhan, M.C., Marathe, S., Dinesh, S. (eds) Sustainability Trends and *Challenges in Civil Engineering*. Lecture Notes in Civil Engineering, vol 162. Springer, Singapore. https://doi.org/10.1007/978-981-16-2826-9_44