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Analysis of Rainfall Trend in North Interior Karnataka (NIK) Meteorological Subdivision of Karnataka by Non-Parametric Methodologies

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present study analyzed the trend in the month-wise, seasonal and annual rainfall employing three non-parametric tests *viz.* Mann-Kendall (M-K), Modified Mann-Kendall (MM-K) tests and Sen's slope estimator for North Interior Karnataka (NIK) meteorological subdivision of Karnataka using 60 years (1960-2019) rainfall data. The M-K test results revealed that there is no monotonic trend in all data sets which indicates that there may exist the influence of serial correlation in the rainfall data. The MM-K test was applied to rainfall data of the NIK subdivision, the result of the test revealed that January, February, March and August months have a monotonic increasing trend whereas April, May, July and September months have a monotonic decreasing trend whereas

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June, October, November and December have no monotonic trend in monthly rainfall data. The winter season has a monotonic increasing trend, monsoon and post-monsoon seasons have a monotonic decreasing trend, and the pre-monsoon season has no monotonic trend in seasonal rainfall data. The MM-K test statistic (Tau) value for the NIK (-0.12) subdivision was found to be significant and negative indicating that there is a monotonic decreasing trend. Larger negative Sen's slope values for NIK (-1.40) subdivision indicate the high decreasing rate of change of rainfall for annual rainfall data. Therefore, to know the trend in rainfall data most accurately in the presence of outliers and serial correlation, the Modified Mann-Kendall (MM-K) test and Sen's slope estimator are recommended instead of Mann-Kendall (M-K) and Sen's slope estimator.

Keywords: Indian rainfall; monsoon; parametric; non-parametric test; mann-kendall test; modified mann-kendall; sen's slope; Karnataka; meteorological subdivision.

1. INTRODUCTION

India is influenced by different climatic conditions in different parts of the country. Therefore, there is significant variability in rainfall in both space and time. Southwest monsoon season normally brings almost 80 per cent of the rainfall, while the northeast monsoon season brings a significant portion of the rest, and summer and winter contribute almost no rainfall [1]. "The amount and duration of water availability are the most important limiting factors for biological and agricultural activities. Seasonal changes in rainfall patterns may alter the cropping pattern and cropping system" [2]. "Irregular rainfall and soil infertility are the main problems of such areas which restrict the production of crops. The use of rainwater in agriculture is one of the greatest techniques to overcome these problems" [3]. "Hence, an adequate understanding of the spatial and temporal dynamics of rainfall, and proper knowledge of rainfall trend and their variability at local and regional dimensions is a prerequisite for various decision-making such as planning and management of agriculture-related activities" [4].

"Karnataka state is facing frequent drought conditions due to uncertainty in rainfall and spatio-temporal variation in different regions. Frequent droughts and floods have caused heavy losses to crops and lives, while society loses its livelihood and rhythm of life and people are forced to migrate for their sustenance" [5]. Therefore, studying the characteristics of rainfall will provide insight into rainfall variability and help in improving the range of rainfall forecasts. An accurate understanding of rainfall characteristics is critical to optimizing farm production and to precision farming.

"Trend analysis is one of the most commonly used tools for detecting changes in rainfall patterns" [6]. "The subject of trend detection in rainfall data has received a great deal of attention in the present situation, especially in connection with the anticipated changes in the global climate. For trend analysis, Parametric tests are more effective in detecting significant trend in rainfall time series data but required data should be independent and normally circulated, which is rarely possible for time series data" [7,8]. "To this end, more powerful nonparametric tests are employed to analyze the trend in the time-series data especially rainfall data, which does not require the stringent assumption of parametric test, and can also tolerate the effect of outliers in the data. The non-parametric Mann-Kendall (MK) test and Sen's slope estimator are the most commonly and widely used nonparametric tests to determine the strength of monotonic trend in rainfall time series data. Several previous studies have investigated the variability and trend of rainfall over India based on annual and seasonal rainfall data using the M-K test for understanding the overall changes in rainfall and detected no significant trend for annual, seasonal and monthly rainfall data" [9]. "Even though the M-K test is very popular and exceptionally helpful for identifying the significant monotonic trend of long-term time series data, the presence of serial correlation in time series will alter the variance of the M-K test statistic which in turn will affect the ability of the test to assess the significance of the trend correctly because the M-K test and the Theil Sen tests are unable to consider the effect of autoregression (1) process of the time-series" [10]. "To overcome this problem several researchers have proposed many alternative ways" [11,12]. Bayazit and Onoz [13] have proposed a simple "pre-whitening" procedure for serially correlated data as it prevents the false detection of non-existing trend, without significant power loss in identifying a trend that exists in the data. "New Effective Sample Size (ESS) for variance correction, which modifies the M-K test statistic and eliminates the effect of serial correlation on it also proposed" [14,15]. "The results of the M-K test, and modified M-K tests along Sen's slope estimator showed that there were increasing and decreasing trend in the monthly rainfall in the river basin of Orissa" [16]. "The Sequential M-K (SQM-K) test statistic can also be employed to identify any fluctuations in the trend over time and to detect the possible points of change in the rainfall series. The results of the SQM-K test revealed a decreasing seasonal rainfall trend after the early 1990s for the majority of the stations in northern Bangladesh" [17]. Recently Hu *et al*. [18], proposed "an improved M-K test for rainfall data with both positive and negative autocorrelation. They modified the variance and distribution patterns of '*S*' under the scaling hypothesis. This improved M-K test was proven more advantageous than other trend detection methods". Therefore, in the present study, an attempt was made to identify underlying trends in rainfall data for the North Interior Karnataka (NIK) subdivision of Karnataka.

2. MATERIALS AND METHODS

Karnataka State has a humid to sub-humid monsoonal climate on the West Coast and the Western Ghats and a semi-arid to arid climate in central and northern districts of the plateau region [19]. The average annual rainfall of Karnataka is 1248 mm, Agumbe and Hulikal receive the highest annual rainfall whereas Bagalkot receives the lowest annual rainfall in Karnataka. According to the Karnataka State Natural Disaster Monitoring Center (KSNDMC) based on the common rainfall distribution pattern, the Karnataka state is classified into four meteorological subdivisions namely 1) North Interior Karnataka (NIK), 2) South Interior Karnataka (SIK), 3) Coastal subdivision and 4) Malnad subdivision, same is depicted in Fig. 1. North Interior Karnataka (NIK) subdivision comprises 13 districts *viz*. Bagalkote, Ballari, Bidar, Kalburgi, Koppala, Bidar, Raichur, Vijayapura, Belagavi, Dharwad, Gadag, Haveri, and Yadgiri. This subdivision has an average annual rainfall of about 731 mm. The secondary data of monthly rainfall (mm) of NIK was collected from All India Coordinated Research Project (AICRP), Agro-Meteorology, UAS, GKVK, Bengaluru and KSNDMC, Yelahanka, Bengaluru for the period of 60 years from 1960-2019. Monthly rainfall data was converted into seasonal (winter, pre-monsoon, monsoon and post-monsoon) and annual data to analyze trend in rainfall data.

2.1 Mann-Kendall (M-K) Test

"Mann–Kendall test is a nonparametric test, which is an alternative method to the parametric method of trend analysis was first developed by Mann in 1945 and then expanded and developed by Kendall in 1970" [20,21,22]. It is the most suitable test for detecting the trend for rainfall data. Since there will be high fluctuation present in the weather parameters, the non-parametric M-K test is useful as its statistic is based on the sign of differences, not directly on the values of random variables and therefore trend determined is less affected by the fluctuations and extreme rainfall values.

Test procedure:

Null Hypothesis (H_0) = There is no presence of a monotonic trend in the rainfall data.

Alternative Hypotheses (H_1) = There is a presence of a monotonic trend (either decreasing or increasing) in the rainfall data.

The Mann-Kendall statistics *'S'* is given as $S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n}\mathrm{sign}(x_j-x_k)$

Where

$$sign(x_j - x_k) = \begin{cases} +1 & if \quad (x_j - x_k) > 0 \\ 0 & if \quad (x_j - x_k) = 0 \\ -1 & if \quad (x_j - x_k) < 0 \end{cases}$$

and x_k and x_j are the sequential data values and for all $k, j \le n$ with $k \ne j$ and *n* is the length of the rainfall data set.

The mean and variance of *S* are given by: $\mathrm{E}(S) = 0$ and $\mathrm{Var(S)} = \frac{1}{18}[n(n-1)(2n+5)]$

If ties are present in the data, then the variance of *S* is as follows:

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(i)(i-1)(2i+5)\right]$$

Where, t_i is the number of ties of extending *i* [3,23].

Tau (τ) measures the strength of the monotonic relationship between x_i and x_{i+1}. Kendall's tau correlation coefficient is given by:

$$\tau = \frac{S}{n(n-1)/2}$$

If sample size *n* > 10, the standard normal variate z is computed:

$$z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases}$$

In a two-sided test for trend, H_0 is accepted if $|z| \leq z_\alpha/2$ at the α level of significance. A positive value of *'S'* indicates an 'upward trend', likewise a negative value of *'S'* indicates a 'downward trend' and a zero value of *'S'* indicates 'no trend'.

2.2 Modified Mann-Kendall (MM-K) Test

"Even though the M-K test is the most commonly used test for detecting a trend in rainfall data, it assumes that sample data is serially independent. However, it is well known that from many previous studies, most rainfall time-series data exhibit serial correlation. The presence of positive autocorrelation in the data increases the probability of detecting a trend even though actual data have no trend, and vice versa" [15]. To this end, Yue and Wang [15,22] developed "the Modified Mann-Kendall (MM-K) test, which eliminates the effect of serial correlation present in the time-series data on the M-K test statistic by correcting the variance using ESS. The accuracy of the modified test in terms of its empirical significance level was found to be superior to that of the original Mann-Kendall trend test without any loss of power".

Therefore, the modified variance $V^*(S)$ using ESS is given by:

$$V^*(S) = V(S) \cdot \frac{n}{n^*}$$

Where *n* is the Actual Sample Size (ASS) of data, n/n^* is termed the Correction Factor (C.F) and n^* is the ESS, proposed by Lettenmaier in 1976 [24] and computed by:

$$n^* = \frac{n}{1 + 2\rho_k \sum_{k=1}^{n-1}(1 - \frac{k}{n})}$$

Where ρ_k is the lag-*k* serial correlation coefficient, which can be estimated by the sample lag-*k* serial correlation coefficient (r_k) given by:

$$r_k = \frac{\frac{1}{n-k}\sum_{t=1}^{n-k}(x_t - \bar{x}_t)(x_{t+k} - \bar{x}_t)}{\frac{1}{n}\sum_{t=1}^{n}(x_t - \bar{x}_t)^2}; \quad \bar{x}_t = \frac{1}{n}\sum_{t=1}^{n} x_t$$

Next variance of the M-K test is replaced by a modified variance and proceed with the M-K test procedure is to identify the presence or absence of a trend in rainfall data.

2.3 Sen's Slope Estimator

Sen's slope estimator has been widely used for determining the magnitude of a trend. Sen's slope estimator is a linear slope estimator that works most effectively on monotonic data. Unlike linear regression, it is not greatly affected by data errors, outliers, or missing data. Here, the slope (T_i) of all data pairs can be computed by:

$$T_i = \frac{x_j - x_k}{j - k} \text{ for } i = 1,2, \ldots, n$$

where x_j and x_k are considered as data values at time *j* and k ($j > k$) correspondingly. The median of these n values of T_i is represented as Sen's estimator of the slope, which is given as:

$$Q_{Med} = \begin{cases} T_{\frac{N+1}{2}} & if\ N\ is\ odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & if\ N\ is\ even \end{cases}$$

In the end, T_{med} is computed by a two-sided test at $100(1-\alpha)\%$ confidence interval and then a true slope can be obtained by this non-parametric test. Positive value of Q_{Med} indicates an upward or increasing trend and a negative value of Q_{Med} gives a downward or decreasing trend in the time series [16].

3. RESULTS AND DISCUSSION

To determine the nature of the trend in month-wise, seasonal and annual rainfall data for the period of 60 years *i.e.,* from 1960-2019 for the NIK subdivision of Karnataka, non-parametric tests *viz.* Mann-Kendall (M-K) and Modified Mann-Kendall (MM-K) tests were employed. Before trend analysis, the significance of the serial correlation coefficient was tested to check the presence of the serial correlation in all rainfall data series. This test revealed that most of the rainfall data series have a significant serial correlation. Therefore, to eliminate the effect of serial correlation on acceptance or rejection of Kendall Tau (τ), the Modified Mann-Kendall (MM-K) test for variance correction is used.

Rainfall trend is analyzed using '*modifiedmk*' package in 'R' software.

3.1 Analysis of Month-Wise Rainfall Data

"For month-wise, seasonal and annual rainfall data of NIK subdivision respectively, M-K Tau value, Correction Factor (C.F), Sen's slope estimator (Q) and p-values for M-K and MM-K tests are presented in Tables 1, 2 & 3. The M-K test statistic (Tau) values in all three tables were found to be non-significant at a 5 per cent level of significance (p-values ≥ 0.05) for all three data sets viz. monthly, season-wise and annual data sets, which indicates that there is no monotonic trend in any of the above-mentioned rainfall data sets. This may be due to the influence of serial correlation in the month-wise rainfall data. Therefore, to overcome the effect of serial correlation, if any, the MM-K test was employed" [5].

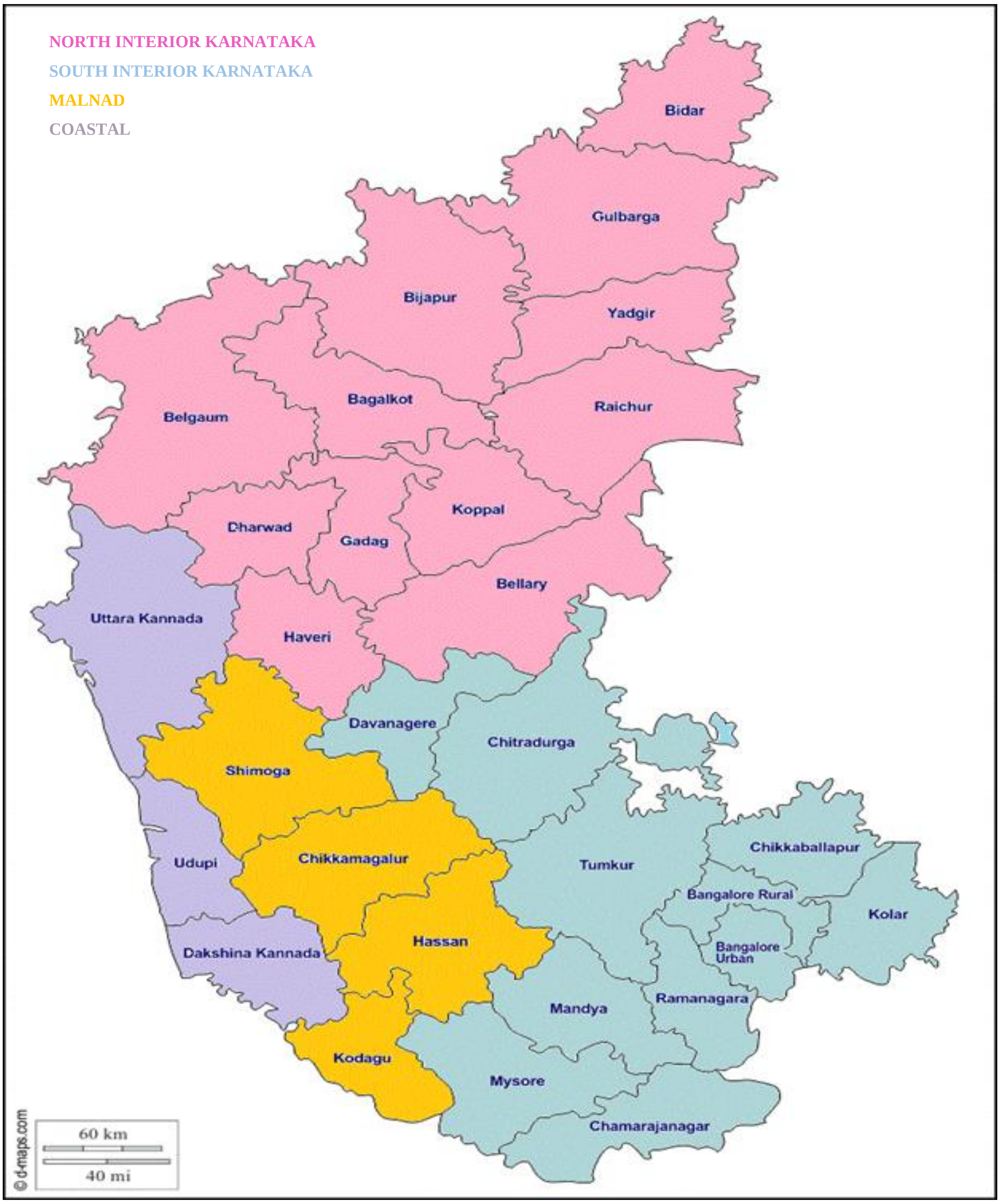

Fig. 1. Map showing districts under four meteorological subdivisions of Karnataka

Table 1. M-K test statistic (Tau) and Sen's slope estimate for NIK subdivision for monthly rainfall (mm) data from 1960-2019

Period	M-K test statistic			Sen's slope
	Tau	p	Trend	
January	0.10 NS	0.26	No Trend	0.00
February	0.12 NS	0.18	No Trend	0.0008
March	0.04 NS	0.64	No Trend	0.01
April	-0.05 NS	0.61	No Trend	-0.06
May	-0.07 NS	0.44	No Trend	-0.17
June	0.03 NS	0.77	No Trend	0.05
July	-0.13 NS	0.15	No Trend	-0.50
August	0.06 NS	0.50	No Trend	0.20
September	-0.09 NS	0.32	No Trend	-0.50
October	-0.05 NS	0.57	No Trend	-0.26
November	-0.04 NS	0.66	No Trend	-0.04
December	0.04 NS	0.64	No Trend	0.001

Table 2. M-K test statistic (Tau) and Sen's slope estimate for NIK subdivision for seasonal rainfall (mm) data from 1960-2019

Period	M-K test statistic			Sen's slope
	Tau	p	Trend	
Winter	0.05 NS	0.57	No trend	0.03
Pre-monsoon	-0.06 NS	0.53	No trend	-0.19
Monsoon	-0.09 NS	0.30	No trend	-0.64
Post-monsoon	-0.12 NS	0.19	No trend	-0.69

Table 3. M-K test statistic (Tau) and Sen's slope estimate for NIK subdivision for annual rainfall (mm) data from 1960-2019

	M-K test statistic			Sen's slope
	Tau	p	Trend	
Annual rainfall data	-0.12 NS	0.16	No trend	-1.40

**Significant at 5% level of significance, **Significant at 1% level of significance, NS: Non-Significant*

MM-K test statistic (Tau) values in Table 4 for January (0.10), March (0.04), April (-0.05) and August (0.06) months were found to be significant at 5 per cent level of significance ($p \leq 0.05$), and February (0.12), May (-0.07), July (-0.13) and September (-0.09) months found to be significant at 1 per cent level of significance ($p \leq 0.01$), whereas remaining months namely June (0.03), October (-0.05), November (-0.04) and December (0.04) found to be non-significant. “Significance and non-significance values of MM-K test statistic (Tau) respectively indicate the presence and absence of a monotonic trend in the month-wise rainfall data for the NIK subdivision. The positive sign of MM-K (Tau) value for January, February, March and August months revealed that there is a monotonic increasing trend and the negative sign of MM-K (Tau) value for April, May, July and September months showed that monotonic decreasing trend in month-wise rainfall data. The remaining months June, October, November and December have no monotonic trend in month-wise rainfall data. Sen's slope values towards zero indicate the negligible rate of change of rainfall for month-wise rainfall of the NIK subdivision” [5]. The results obtained in the study are in accordance with the results obtained by Chakraborty *et al.* [25].

3.2 Analysis of Seasonal Rainfall Data

The MM-K test statistic (Tau) values in Table 5 for the winter (0.05) season were found to be significant at a 5 per cent level of significance ($p \leq 0.05$), and monsoon (-0.09) and post-monsoon (-0.12) seasons found to be significant at a 1 per cent level of significance ($p \leq 0.01$), whereas the pre-monsoon (-0.06) season was found to be non-significant. The positive sign of the MM-K

(Tau) value for the winter season revealed that there is a monotonic increasing trend and the negative sign of the MM-K (Tau) value for monsoon and post-monsoon revealed that monotonic decreasing trend in seasonal rainfall data. In addition, pre-monsoon season has no monotonic trend. Sen's slope values towards zero indicate the negligible rate of change of rainfall for seasonal rainfall of the NIK subdivision.

3.3 Analysis of Annual Rainfall Data

The MM-K test statistic (Tau) value in Table 6 for the NIK (-0.12) subdivision was found to be significant at a 1 per cent level of significance ($p \leq 0.01$). The negative sign of the MM-K (Tau) value for the NIK subdivision indicates there is a monotonic decreasing trend. Chakraborty *et al.* [25] and Sharma and Saha [26] reported a decreasing trend in the annual rainfall data of their study region. Larger negative Sen's slope values for NIK (-1.40) subdivision indicate the high decreasing rate of change of rainfall for annual rainfall data.

The result of the present study indicated that rainfall time-series data exhibited serial correlation. Therefore, the Modified Mann-Kendall (MM-K) test was employed, which eliminates the effect of serial correlation present in the rainfall time-series data by correcting the variance using ESS. The accuracy of the MM-K test in terms of its empirical significance level was found to be superior to that of the original Mann-Kendall trend test without any loss of power.

Table 4. MM-K test statistic (Tau) and Sen's slope estimate for NIK subdivision for monthly rainfall (mm) data from 1960-2019

Period	MM-K test statistic				Sen's slope
	Tau	C.F	p	Trend	
January	0.10*	0.20	0.01	Increasing	0.00
February	0.12**	0.14	<0.01	Increasing	0.0008
March	0.04*	0.43	0.05	Increasing	0.01
April	-0.05*	0.16	0.02	Decreasing	-0.06
May	-0.07**	0.08	0.01	Decreasing	-0.17
June	0.03 NS	0.22	0.05	No trend	0.05
July	-0.13**	0.06	<0.01	Decreasing	-0.50
August	0.06*	0.08	0.01	Increasing	0.20
September	-0.09**	0.10	<0.01	Decreasing	-0.50
October	-0.05 NS	0.17	0.17	No trend	-0.26
November	-0.04 NS	0.22	0.34	No trend	-0.04
December	0.04 NS	0.33	0.41	No trend	0.001

Table 5. MM-K test statistic (Tau) and Sen's slope estimate for NIK subdivision for seasonal rainfall (mm) data from 1960-2019

Season /Period	MM-K test statistic				Sen's slope
	Tau	C.F	p	Trend	
Winter	0.05*	0.07	0.03	Increasing	0.03
Pre-monsoon	-0.06 NS	0.33	0.28	No trend	-0.19
Monsoon	-0.09**	0.11	<0.01	Decreasing	-0.64
Post-monsoon	-0.12**	0.21	<0.01	Decreasing	-0.69

Table 6. MM-K test statistic (Tau) and Sen's slope estimate for the NIK subdivision for annual rainfall (mm) data from 1960-2019

	MM-K test				Sen's slope
	Tau	C.F	p	Trend	
Annual rainfall	-0.12**	0.10	<0.01	Decreasing	-1.40

**Significant at 5% level of significance, **Significant at 1% level of significance, NS: Non-Significant*

4. SUMMARY AND CONCLUSION

Monthly rainfall (mm) data over the period of 60 years from 1960-2019 were collected and converted into seasonal and annual rainfall (mm) data was analyzed using non-parametric tests *viz.* M-K and MM-K tests to know the presence or absence of monotonic trend and Sen's slope estimator method to quantify the trend in rainfall data. The M-K test results revealed that all examined data sets have no monotonic trend indicating that there is the influence of serial correlation in the rainfall data. It is very clear from the above results by M-K test that the existence of either positive or negative autocorrelation in time series will interfere with proper identification of significant trends. Therefore, the MM-K test was applied to rainfall data of the NIK subdivision, the result of the test revealed that January, February, March and August months have monotonic increasing trend and April, May, July and September months have a monotonic decreasing trend whereas June, October, November and December have no monotonic trend in monthly rainfall data. The winter season has a monotonic increasing trend, the monsoon and the post-monsoon seasons have a monotonic decreasing trend, and the pre-monsoon season has no monotonic trend in seasonal rainfall data. Annual rainfall data have a monotonic decreasing trend.

Sen's slope value towards zero for monthly and seasonal rainfall data indicates that there is a negligible rate of increasing or decreasing change in rainfall data. The relatively higher value of Sen's slope values for annual rainfall data indicates that high rate of decreasing change in rainfall for annual data of the NIK subdivision.

To sum up, the study has analyzed the month-wise, seasonal and annual rainfall trend employing three non-parametric tests *viz.* Mann-Kendall (M-K), Modified Mann-Kendall (MM-K) tests and Sen's slope estimator for NIK subdivision of Karnataka using 60 years (1960-2019) rainfall data. The use of the M-K test showed a non-significant trend in all data sets. Whereas, the MM-K test showed a significant monotonic increasing and decreasing trend for the majority of data sets. Results of Sen's slope estimator revealed that the rate of increasing or decreasing change for any data set having a significant trend is negligible. Therefore, MM-K test was found to be more superior than the M-K test in the presence of serial correlation in the rainfall data for detecting trend most accurately, hence the Modified Mann-Kendall (MM-K) test and Sen's slope estimator are recommended instead of Mann-Kendall (M-K) and Sen's slope estimator for estimating monotonic trend in rainfall time-series data most accurately when there exist a serial correlation. The detection of trend in rainfall time series data most accurately using more improved statistical techniques provides valuable insights, instrumental for understanding historical patterns, assessing future risks, and essential for making informed decisions in various sectors impacted by climate variability and change, ranging from agriculture and water resource management to infrastructure planning and climate change adaptation. It helps stakeholders anticipate and respond to changing precipitation patterns, contributing to overall resilience and sustainability.

5. LIMITATION OF THE STUDY

This study is confined to the data obtained from NIK subdivision of Karnataka for the data under consideration over the period of 60 years from 1960 -2019 only with the assumption that serial correlation exists in the data.

FUTURE LINE OF WORK

The application of the MM-K test can be extended to find the trend in rainfall of other meteorological subdivisions of Karnataka like South Interior Karnataka, Coastal and Malnad subdivisions including whole Karnataka rainfall data as well as at All India level rainfall data.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Vignesh R, Jothiprakash V, Sivakumar B. Spatial rainfall variability in peninsular India: a nonlinear dynamic approach. Stoch Environ Res Risk Assess. 2019; 33:465-480.
2. Delitala A, Cesari D, Chesa P, Ward M. Precipitation over Sardinia (Italy) during the 1946–1993 rainy season and associated large scale climate variation. Int J Climatol. 2000;20(5):519-541.

3. Das J, Mandal T, Saha P, Bhattacharya SK. Variability and trends of rainfall using non-parametric approaches: A case study of semi-arid area. Mausam. 2020;71(1): 33-44.
4. Ghosh H, Paul RK, Prajneshu. Nonlinear time series modeling and forecasting for periodic and ARCH effects. J Stat Theory Pract. 2010;4:27-44.
5. Sanjeevaiah SH, Rudrappa KS, Lakshminarasappa MT, Huggi L, Hanumanthaiah MM, Venkatappa SD, Lingegowda N, Sreeman SM. Understanding the temporal variability of rainfall for estimating agro-climatic onset of cropping season over south interior Karnataka, India. Agronomy. 2021 ;11(6): 1135.
6. Mohan Kumar TL, Satishgowda CS, Darshan MB, Sheelarani S. Coffee production modelling in India using nonlinear statistical growth models. Agriculture Update. 2012;7(1&2):63-67.
7. Mohan Kumar TL, Satishgowda CS, Munirajappa R, Surendra, HS. Nonlinear statistical growth models for describing trends in area under coffee production in India. Mysore Journal of Agricultural Sciences. 2012;46(4):745-750.
8. Mohan Kumar TL, Darshan MB, Sathishgowda CS, Sheelarani S. Comparison of nonlinear statistical growth models for describing coffee export trends in India. Asian J Hort.. 2012;7(1) : 31-35.
9. Kumar V, Jain SK, Singh Y. Analysis of long-term rainfall trend in India. Hydrol Sci J. 2010;55:484-496.
10. Azam M, Maeng SJ, Kim HS, Lee SW, Lee JE. Spatial and temporal trend analysis of precipitation and drought in South Korea. Water. 2018; 10(6): 765-792.
11. Kulkarni A, Von Storch H. Monte Carlo experiments on the effect of serial correlation on the Mann-Kendall test of trend. Meteorologische Zeitschrift. 1995;4: 82-85.
12. Yue S, Pilon P, Phinney B, Cavadias G. The influence of autocorrelation on the ability to detect trend in hydrological series. Hydrol Process. 2002;16:1807-1829.
13. Bayazit M, Onoz B. To prewhiten or not to prewhiten in trend analysis?. Hydrol Sci J. 2007; 52: 611-624.
14. Hamed KH, Rao AR. A modified Mann-Kendall trend test for autocorrelated data. J Hydrol. 1998;204:182-196.
15. Yue S, Wang C. The Mann-Kendall test modified by effective sample size to detect trend in serially correlated hydrological series. Water Resour Manag. 2004;18: 201-218.
16. Mondal A, Kundu S, Mukhopadhyay A. Rainfall trend analysis by Mann-Kendall test: A case study of north-eastern part of Cuttack district, Orissa. Int J Geology Earth Environ Sci. 2012;2:70-78.
17. Bari SH, Rahman MTU, Hoque MA and Hussain MM. Analysis of seasonal and annual rainfall trend in the northern region of Bangladesh. A J Forecasting Pract Appl Trng Techniques Model. 2016;100:148-158.
18. Hu Z, Liu S, Zhong G, Lin H, Zhou Z. Modified Mann-Kendall trend test for hydrological time series under the scaling hypothesis and its application. Hydrol Sci J. 2020;7:1-20.
19. Srinivasareddy HS, Shivakumarnaiklal NG, Keerthy, Prasad Garag, Emily Prabha Jothi, Challa O. Drought vulnerability assessment in Karnataka: Through composite climatic index. Mausam. 2019; 70:159-170.
20. Mann HB. Non-parametric tests against trend, Econometrica. 1945;13:163-171.
21. Kendall MG. Rank Correlation Methods, 4th edition, Charles Griffin, London, 1975.
22. Lornezhad E, Ebrahimi H, Rabieifar HR. Analysis of precipitation and drought trends by a modified Mann–Kendall method: A case study of Lorestan province, Iran. Water Supply, 2023; 23(4): 1557.

    DOI:10.2166/ws.2023.068
23. Sonali P, Kumar DN. Review of trend detection methods and their application to detect temperature changes in India. J. Hydrol. 2013;476:212 -227.
24. Lettenmaier DP. Detection of trend in water quality data from records with dependent observations, Water Resour. Res. 1976:12(5):1037-1046.
25. Chakraborty S, Pandey RP, Chaube UC, Mishra SK. Trend and variability analysis of rainfall series at Seonath River Basin, Chhattisgarh (India). Int J Appl Sci Engr Res. 2013; 2:425-43.

26. Sharma S, Saha AK. Statistical analysis of rainfall trend over Damodar river basin, India. Arab J Geosci. 2017;10:319-331.

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