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Analysis of Rainfall Trend Series using Mann-Kendall and Sen's Slope Estimator Statistical Test in Mandya District, Karnataka

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Abstract - *Climatic variability particularly rainfall and temperature has received a greater attention throughout the world. Climate change and its variability in the climatic parameters may adversely affect the agriculture sector and water resources of agrarian country like India. The research on change of rainfall, occurrence and its allocation are the most significant way for sustainable water resource management and food security. Hence an understanding of rainfall patterns in the changing environment will help in better decision making and improving the adopting of the communities to sustain the extreme weather. The study is aimed at investigating Monotonic trends at local scale levels for different seasons, as the climate change is more pronounced at the local scale. In this study, trend analysis has been carried out for Mandya district, Karnataka by considering 21 stations spread across the district for a period 1991-2000. Mann-Kendall test and Sen's slope estimates were employed to detect the trend and trend magnitude respectively at a significance level of 5%. The paper showcases that, the annual and monsoon season trend depicts no trend at a significance level of 5%. However, significant positive trends were observed at stations Akkihebbalu, Basaralu, Hanakere, Kaudle, Mandya and V C Farm during pre-monsoon season indicating special attention to be addressed during land preparation and other operations before monsoon season commences in the selected study area.*

Key Words: Climate change, Trend Analysis, Mann-Kendall test, Sen's slope estimate, Significance level, etc.

1. INTRODUCTION

The trending topic of these modern days and the impact which has created on a holistic life culture is the climate change. Many of the consequences are already being observed throughout the world because of climate change. Recent studies from the IPCC (Intergovernmental Panel on Climate Change) shows that, the climate change is happening and is happening at a hasty rate which is far from our imagination. The impacts posed by this change is nearly doubled in the last few decades mainly because of the industrialization, release of CO2 emissions, etc., Even though many of the measures are being considered all over the world to reduce this rate, the effort is resulting in inevitable increase of climate change on a daily basis.

As per the IPCC 2013 report, the Global climate change is observed throughout the world by the warming created in the atmosphere, increased ocean temperature, melting of ice, increase of sea level, distortion of global water cycle, etc., contributed by the anthropogenic activities. The climate change has also resulted in the spatial and temporal distribution of rainfall. Rainfall variability and changes are predicted to have a major impact on the water and agricultural sectors in the Asia-Pacific region [4]. The deviations that are seen in the hydrological cycle has evidently affected the availability and quality of fresh water, which is a major environmental issue of the twenty-first century.

A country like India, having tropical climatic condition receives most of its precipitation during monsoon season whose management becomes crucial. Monsoon countries are likely to experience dramatic changes in land use patterns and population rise in the coming decades. There are strong lines of evidence of climate change and its impacts over the last century in India [6].

The Indian summer monsoon rainfall is very crucial by the economic development, disaster management, hydrological planning for the country. India ranks first in the world with highest net cropped area followed by U.S and China. As per 2018, agriculture employed more than 50% of the Indian workforce and contributed 17-18% to country's GDP. The worst consequences of climate change especially rain change has been experiencing by the agricultural sector of this country, consequently farmers who depend on agriculture have been devasted. During 1995-2014, 3 lakh farmers have committed suicide in India.

Adjusting to climate change involves taking the right actions to reduce the adversarial effects of climate change by building the suitable modifications (UNFCCC, 2007). Many of the farmers / cultivators are coming up with different alternative approach to acclimate themselves to the climate change which is resulting in their change of farming style, pattern, economics as well as emotional needs.

Assessment of the climate parameter is important because the hydrological cycle gets changed due to climate change in terms of occurrence of precipitation, distribution, time, intensity, quality, and quantity. Thus, there is a need to study the climate change at regional and local scale says National Action Plan on Climate Change (NAPCC, 2008) to assess its impacts on various sectors.

Understanding the spatial and temporal variability of precipitation is important not only to weather forecasters and climate scientists, but also to a large range of decision makers, including hydrologists, agriculturalists, and industrialists [3]. Many of the researchers have attempted to study seasonal and annual trends of precipitation throughout India [19]; [9]; [10]; [5]; [2];[11]; [8]; [22], but the research lack on regional basis.

However, in case of rainfall no particular increasing and decreasing trend was noticed in the average rainfall of whole India [16]. Pal and Al-Tabbaa (2011) used Mann-Kendall Test for trend analysis, they observed that there is great variation in seasonal rainfall among different geographical regions of India and no significance was noticed in seasonal and annual rainfall from 1871 to 2005. Work on Indian Summer Monsson (ISM) has been done with Mann-Kendall test by Duncan et al., 2012, who found that major parts of the country experienced quite significant rising trend in case of inter-annual variation in the rainfall.

In this regard, an attempt is being made to study the Rainfall trend considering micro-scale to assess the climate change at Mandya district, Karnataka by applying non-parametric statistical technique – Mann Kendall test, also Sen slope estimate to detect the trend magnitude which helps in better understanding of rainfall variability in the selected study area which also helps farmers in adopting suitable agricultural practices, soil and water conservation, and flood/drought management because climate change is more pronounced at the local scale.

2. STUDY AREA AND DATA USED

The trend analysis was conducted at Mandya district which lies in between 76° 19′ and 77° 20′ East Longitude and 12° 13′ and 13° 04′ North Latitude also popularly known as 'Land of Sugar' of Karnataka State. The district shares a border with surrounding districts of Mysore, Hassan, Tumakuru and Bengaluru. The topography of the district is relatively flat interspersed with hilly region and sparsely vegetated by thorns and bushes whose elevation vary from 762 to 914 meters from the mean sea level. On an average, Mandya receives an annual precipitation of 700 mm.

The district comprises of seven talukas with a total geographical area of 4,98,244 Hectares, out of which 2,48,825 Hectares forms the sown area. More than half of the total land area in the district is put to agricultural use. The total irrigated area is 1,16,901 Hectares. The soil groups that are found within the district are – red sandy loams, red clayey loams and Clayey loams. Agriculture is the main occupation in the district. The most commonly grown crops throughout the district are sugarcane, paddy, Ragi, Jowar, ground nuts, etc.,

For the present study, the monthly rainfall data series were collected from District Statistical department, Mandya for the period 1991 – 2020 (30 years) from 21 stations which is distributed spatially throughout the district and the locations have been illustrated in the Fig- 1.

The obtained data were averaged to get the annual as well as seasonal periods as follows: Pre monsoon (Mar-May), Monsoon (Jun-Sept), Post monsoon (Oct-Nov), Winter (Dec-Feb) and Annual (Jan-Dec).

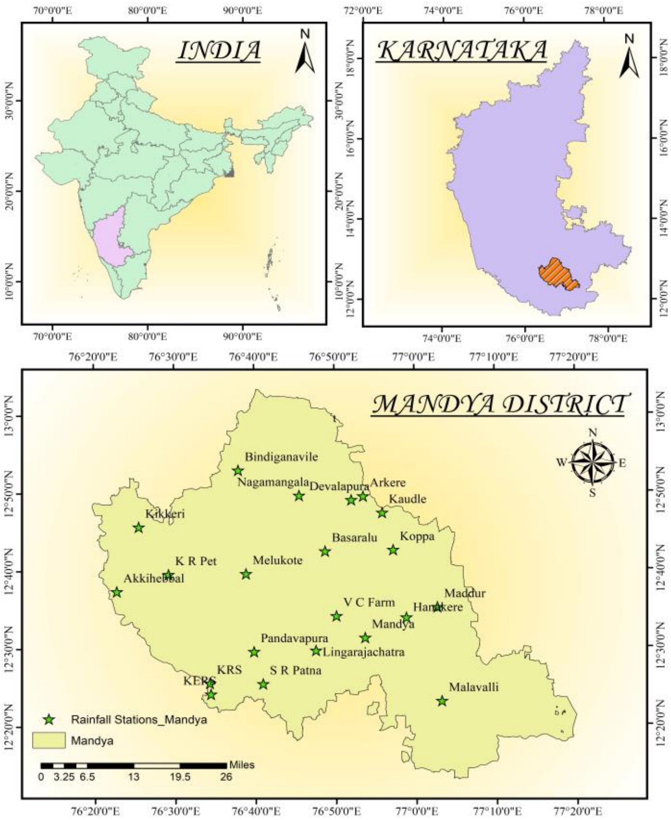

Fig -1: Location map of the study area along with rainfall stations

3. METHODOLOGY

The trend analysis has been done by taking historical and observed hydro-climatic data, which are normally used for planning of water resources management and canal designing, etc., subjecting the collected data to non-parametric test (MK test) to detect the trend and also Sen's slope estimate to detect the trend magnitude which is described as below:

3.1 Serial Correlation effect

In order to perform the Mann-Kendal test on any hydrological time series, the series considered needs to be serially independent. If the series is not made independent, there is a possibility of the null hypothesis of no trend is rejected too frequently, specifically if there is a positive serial correlation [7]. If randomness is found, or in other words if lag-1 serial correlation coefficients are statistically insignificant then, Mann-Kendall (MK) test is applied without altering the original data. The coefficient of serial correlation r_k for lag-k in a discrete time series is estimated as follows [23];

$$r_k = \frac{\sum_{t=1}^{n-k}(X_t - \bar{X}_t)(X_{t+k} - \bar{X}_{t+k})}{\left[\sum_{t=1}^{n-k}(X_t - \bar{X}_t)^2 (X_{t+k} - \bar{X}_{t+k})^2\right]^{0.5}} \quad (1)$$

Where, $\bar{X}_t$ and X_t are the mean sample and variance of first (n-k) terms, $\bar{X}_{t+k}$ and X_{t+k} are the mean sample and sample variance of the last (n-k) terms respectively. The hypothesis of serial independence is then tested by the lag-1 autocorrelation coefficient as $H_0 : r_1 = 0$ against $H_1 : |r_1| > 0$ using the test of significance of serial correlation [28] following Rai et al. 2010.

$$(r_k)_{tg} = \frac{-1 \pm 1.96\sqrt{n-2}}{n-1} \quad (2)$$

3.2 Pre-whitening

The method of pre-whitening is applied to eliminate the effect of serial correlation on the non-parametric test. The pre-whitening technique is not suggested when the trend exists within a time series. In such cases, the MK test is applied on the original data rather than subjecting to pre-whitening [29}. The pre-whitened time series may be obtained as ($X_2 - r_k X_1$, $X_3 - r_k X_2$,…….$X_n - r_k X_{n-1}$).

3.3 Non-parametric test

In order to detect the trend analysis, depending on the characteristics of the data being studied, either parametric or non-parametric method may be utilized for trend detection [30]. The assessment using Non-parametric techniques have many advantages over parametric tests as no assumptions about distribution are necessary, also the test has low sensitivity to abrupt breaks due to inhomogeneous time series. [24]; [25], [26].

Of the several methods of non-parametric test which are used to detect the trend in a hydrological time series, the Mann–Kendall (MK) test is the one which is widely used and preferred technique over other non-parametric tests to detect significant trends [18]; [24]; [25]. Hence, in the present study MK test is applied to detect the possibility of trend existence.

The Mann-Kendall statistic S is calculated as –

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \quad (3)$$

where, n is the number of data points, x_i and x_j are the data values in time series i and j (j>i), and sgn (x_i-x_j) is the sign function as:

$$sgn(x_i - x_j) = \begin{cases} +1, if\ x_j - x_i > 0 \\ 0, if x_j - x_i = 0 \\ -1, if\ x_j - x_i < 0 \end{cases} \quad (4)$$

The variance is computed as:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i-5)}{18} \quad (5)$$

where, n is the number of data points, m is the number of tied groups and t_i denotes the number of ties of extent. When the sample size n>10, the test statistic Z_s is computed as:

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, if\ S > 0 \\ 0, if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, if\ S < 0 \end{cases} \quad (6)$$

The positive values of Z_s represents the positive trend, while the negative values of Z_s represents the negative trend. The tests are done at a specific significance level. When $|Z_s| > Z_{1-\alpha/2}$, the null hypothesis is rejected and a significant trend exists in the time series. In the present study, a significance level of 5% is used, i.e., α = 0.05. At 5% significance level, the null hypothesis of no trend is rejected if $|Z_S|$>1.96.

3.4 Sen's slope estimate

The trend detection can be found using the MK test, but the trend magnitude in which it is varying can be found using Sens's lope estimates (Sen 1968). The slope (T_i) of all the data pairs is computed as:

$$T_i = \frac{x_j - x_k}{j-k} for\ i = 1, 2, 3, \dots\dots N \quad (7)$$

where x_j and x_k are the data values at times j and k (j>k) respectively. The median of these N values of T_i is considered as Sen's estimator of slope which is given as,

$$Q_{med} = \begin{cases} T_{\frac{N+1}{2}}\ N\ is\ odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right)\ N\ is\ even \end{cases} \quad (8)$$

Q_{med} sign reflects data trend reflection, while its value indicates the steepness of the trend. Q_{med} with a positive value indicates an upward or increasing trend and a negative value of Q_{med} signifies a downward or decreasing trend in the time series.

4. RESULTS AND DISCUSSIONS

Before applying MK test on the Rainfall data series, all the series were tested for serial correlation using lag-1 autocorrelation at 5% significance level to check the randomness of the data. The pre-whitening technique is applied to eliminate the effect of serial correlation.

4.1 Mann-Kendall & Sen's slope results

The results of lag-1 correlation coefficients after eliminating the influence of serial correlation are presented in the below table for all the stations considered for the period 1991-2020.

Table -1: Lag-1 serial co-efficients of Mandya rainfall stations

Stations	**Annual**	**Pre-monsoon**	**Monsoon**	**Post-monsoon**	**Winter**
Akkihebbal	0.144	-0.028	0.153	-0.129	-0.070
Arkere	0.146	-0.084	0.016	-0.152	-0.221
Basaralu	-0.083	0.063	-0.005	-0.193	-0.215
Bindiganavile	-0.036	0.059	-0.006	0.005	-0.211
Devalapura	0.106	-0.054	-0.055	-0.216	-0.178
Hanakere	-0.113	-0.087	0.191	-0.280	0.016
Kaudle	0.143	0.156	-0.055	-0.003	-0.173
Kikkeri	-0.037	0.146	-0.012	0.135	-0.139
Koppa	-0.188	-0.263	-0.047	-0.264	0.189
KERS	-0.072	-0.248	-0.078	-0.284	0.140
K R Pete	0.047	-0.085	-0.119	-0.145	-0.143
KRS	-0.028	-0.214	-0.073	-0.338	0.029
Lingarajachatra	-0.009	-0.027	0.045	-0.019	0.020
Maddur	0.070	0.179	0.124	0.006	-0.075
Malavalli	-0.084	-0.019	-0.077	-0.266	-0.227
Melukote	0.005	-0.135	0.177	-0.116	-0.141
Mandya	0.172	0.237	-0.006	0.102	-0.086
Nagamangala	-0.123	-0.313	0.072	-0.094	-0.048
Pandavapura	0.103	0.072	-0.021	-0.121	-0.044
S.R Patna	0.031	0.031	0.062	-0.016	-0.035
V.C Farm	0.164	0.217	0.123	0.096	-0.047

After the successful elimination of the effect of serial correlation, the MK test was conducted for all the 21 stations spread across the Mandya district, the trend detection using MK test- statistic Z along with trend Magnitude Q using Sen's slope estimate. The results of the statistical tests for seasonal and annual rainfall series over a period of 1991 – 2020 are presented in the below Table-2.

Table -2: Results of the statistical test Z & Q

Stations	**Test**	**Annual**	**Pre-monsoon**	**Monsoon**	**Post-monsoon**	**Winter**
Akkihebbal	Z	1.39	**2.00**	1.14	-0.79	-0.02
	Q	4.81	**3.44**	3.23	-1.80	0.00
Arkere	Z	-1.28	1.32	-0.89	-1.78	0.61
	Q	-7.27	2.70	-2.37	-4.50	0.00
Basaralu	Z	0.64	**2.73**	0.89	-1.48	0.22
	Q	1.95	**4.85**	1.69	-3.60	0.00
Bindiganavile	Z	-1.21	0.46	-0.29	**-2.46**	0.07
	Q	-5.37	0.92	-0.88	**-5.32**	0.00
Devalapura	Z	0.89	1.07	1.11	-1.11	1.60
	Q	4.93	1.59	2.39	-1.74	0.00
Hanakere	Z	1.53	**2.50**	1.28	-1.03	1.09
	Q	5.88	**4.95**	2.93	-2.29	0.00
Kaudle	Z	1.70	**2.39**	1.07	-0.36	**2.16**
	Q	8.04	**5.13**	4.31	-1.53	**0.44**
Kikkeri	Z	-0.50	1.89	-0.86	**-2.46**	0.82
	Q	-2.69	3.20	-2.75	**-4.47**	0.00
Koppa	Z	-0.04	1.50	0.29	-1.21	1.87
	Q	-0.23	1.39	1.44	-3.20	0.50
KERS	Z	-0.61	-0.18	-0.11	-0.50	-0.65
	Q	-4.07	-0.23	-0.50	-1.42	-0.16
K R Pete	Z	-0.68	-0.41	0.36	-1.07	0.72
	Q	-2.25	-0.68	1.19	-2.38	0.05
KRS	Z	-0.43	0.36	-0.82	-0.39	0.00
	Q	-2.36	0.62	-2.50	-1.35	0.00
Lingarajachatra	Z	-0.89	1.32	-0.23	-1.59	-0.47
	Q	-3.16	2.26	-0.41	-3.63	0.00
Maddur	Z	-1.00	1.36	0.75	-1.68	0.68
	Q	-2.92	1.94	2.61	-4.43	0.19
Malavalli	Z	0.82	0.46	0.77	-1.07	-0.07
	Q	1.62	0.40	2.51	-1.83	0.00
Melukote	Z	-1.71	0.43	-1.00	-1.87	-1.06
	Q	-7.68	0.60	-3.65	-4.89	0.00
Mandya	Z	-0.32	**2.00**	0.00	-1.68	-0.64
	Q	-1.61	**2.77**	-0.00	-4.57	-0.10
Nagamangala	Z	-1.21	1.02	0.00	-1.82	0.00
	Q	-7.98	1.37	0.06	-5.16	0.00
Pandavapura	Z	-1.18	0.59	-0.25	-1.14	0.40
	Q	-6.82	1.05	-0.65	-3.58	0.00
SR Patna	Z	0.54	1.64	0.68	-1.57	0.07
	Q	2.41	2.81	1.60	-4.18	0.00
VC Farm	Z	0.07	**2.16**	0.14	-0.30	-0.79
	Q	0.46	**3.82**	0.41	-1.61	-0.08

*Test: Z – Mann Kendall Statistic; Q – Sen's slope
Bold value indicates significant trend at the 95% confidence level.

From the above table it is evident that, the Mandya district shows a statistically insignificant negative trend in their annual rainfall for as many of the stations considered, indicating a fall in rainfall in the years to come. But there is no significant trend observed at any of the stations at a significance level of 5% for the annual rainfall series.

The stations such as- Akkihebbalu, Basaralu, Hanakere, Kaudle, Mandya and V C Farm shows a significant positive trend at 5% significance level during Pre-monsoon season with their increase magnitude as illustrated in the table. During Post-monsoon season, the stations- Bindiganavile and Kikkeri exhibits a negative significant trend.

The significant positive trend which are observed at stations Akkihebbalu, Basaralu, Hanakere, Kaudle, Mandya and V C Farm will have a positive trend magnitude of 3.44mm/yr, 2.73 mm/yr, 2.5 mm/yr, 5.13 mm/yr and 3.82 mm/yr respectively. During winter season, Kaudle station has a significant positive trend magnitude of 0.44 mm/yr. The significant negative trend at stations Bindiganavile and Kikkeri will have 5.32 mm/yr and 4.47 mm/yr respectively during post-monsoon season.

4.2 Spatial distribution of rainfall trends

Spatial distribution of weather stations with Statistically increasing, decreasing and no trends for the annual and seasonal data series during the period 1991–2020 for rainfall at 21 selected stations spread across the district is presented in the below figures.

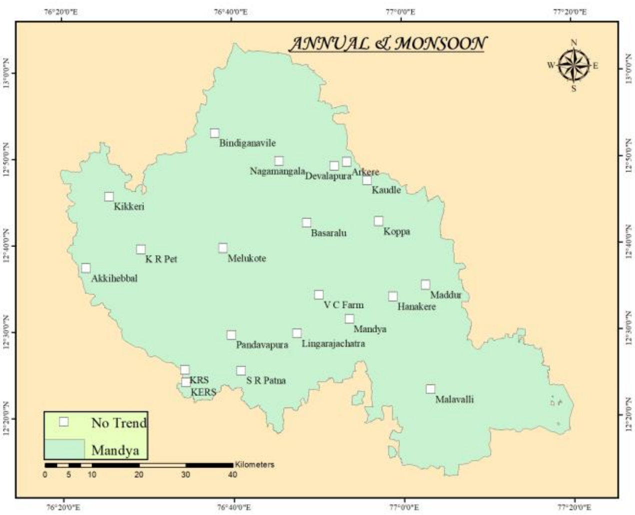

Fig -2: Spatial distribution of Annual & Monsoon data series

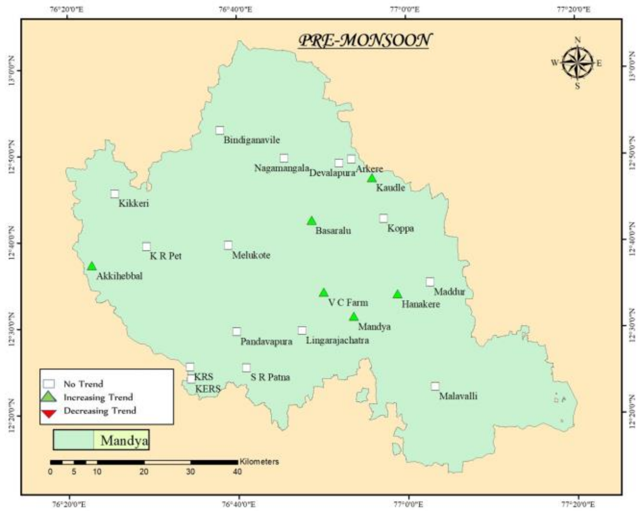

Fig -3: Spatial distribution of Pre-monsoon data series

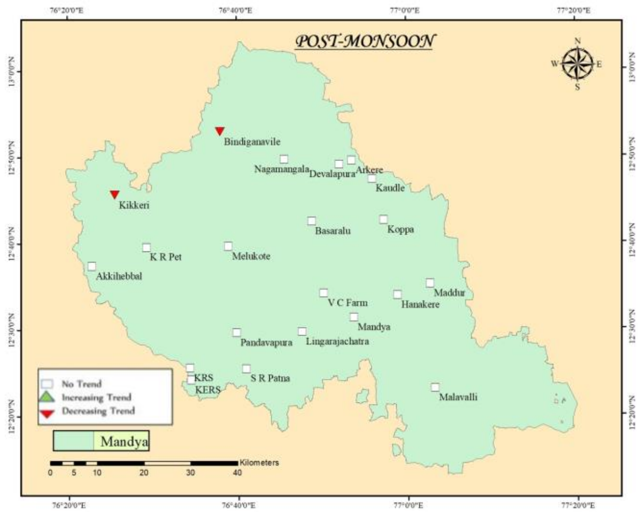

Fig -4: Spatial distribution of Post-monsoon data series

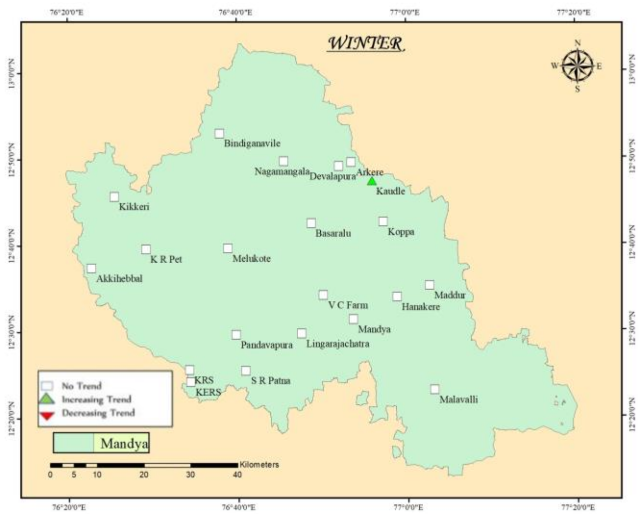

Fig -5: Spatial distribution of Winter data series

From the above figures it is evident that, no significant trends are observed for annual and monsoon rainfall series data throughout the Mandya district. The significant positive trends can be seen during pre-monsoon season at certain stations and a significant negative trend is observed at stations Bindiganavile and Kikkeri during post-monsoon season.

5. CONCLUSIONS

In the context of changing environment, rainfall and changing pattern in rainfall plays a crucial role for the planning and management of water resources. Mann Kendall test and Sen's slope estimate proves to be an ideal method for trend analysis for better decision making. From the studies it may be concluded that the rainfall over Mandya district (1991-2020) implies a non-significant decreasing trend during annual, monsoon and winter season for many of the stations considered. Significant positive trend is observed at pre-monsoon season except a significant negative trend at 2 stations of the 21 stations considered during post-monsoon season. The study findings help farmers in better understanding of the inevitable climate change with respect to rainfall to adopt themselves by taking suitable measures and strategies to combat the change.

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