TREND AND SHIFT ANALYSIS IN RAINFALL IN THE KBK REGION OF ODISHA, INDIA

[1]Prabhash Kumar Mishra, [2]Sharad Kumar Jain, [3]Sanjay Kumar Jain, and [4]Pradeep Kumar Bhunya

[1,2,3,4] *Scientist, National Institute of Hydrology (NIH), Roorkee, Roorkee (U.K.), India.*

E-mail: [1]*corresponding author: pkmishra@nih.ernet.in;*

Abstract

This study investigates annual and seasonal rainfall trend across KBK (Kalahandi-Bolangir-Koraput) region in the state of Odisha. KBK region, consisting of eight districts viz. Bolangir, Kalahandi, Koraput, Malkangiri, Nabarangpur, Nuapada, Rayagada and Sonepur, is one of the most backward areas in the country, as identified under BRGF (Backward Region Grant Fund) by Planning Commission, GoI, with water scarcity, malnourishment and poverty. This region is mainly dominated by tribal population. Annual average rainfall in the region varies from 1139.26 mm (Malkangiri) to 1429.31 mm (Nabarangpur) during the period 1901 to 2010 while standard deviation during the same period varies from 199.52 mm to 295.61 mm. In this study, Mann-Kendall test and Sen's slope estimator test are utilized to detect trend for rainfall for the period 1901 to 2010 (110 years). The year having considerable shift in rainfall pattern in the region has also been detected using Pettitt's test and Standard Normal Homogeneity Test (SNHT). The results indicate significant decreasing annual rainfall trend at 5% significant level in the district of Nuapada and increasing trend in Malkangiri district. The southern districts with dominant forest coverage viz. Koraput and Rayagada are showing increasing rainfall trend though non-significant, whereas Bolangir, Kalahandi, Nabarangpur and Sonepur districts are showing decreasing trend. Overall, amongst eight districts in the KBK region, three are showing increasing trend and five are showing decreasing trend in the annual rainfall. Trend analysis for seasonal rainfall has also been carried out. Monsoon rainfall shows decreasing trend in the districts of Nuapada, Kalahandi, Sonepur, Bolangir and Rayagada. The entire region is witnessing decrease in winter rainfall which plays a significant role for the rabi crops. The magnitude of the decreasing trends in the annual rainfall varies from 0.20 mm/ year (Kalahandi) to 0.85 mm/ year (Bolangir). Pettitt's test indicates 1961 as the shift year when considerable change occurred in the rainfall amount, whereas SNHT points to recent year (2005) when shifting in rainfall amount has occurred.

Keywords: *Rainfall, Trend, Mann-Kendall test, Sen's slope, Pettit's test, Standard Normal Homogeneity Test (SNHT) test, KBK region.*

1. Introduction:

In the recent few decades, importance of climate change has immensely increased due to increasing temperature and its effect on precipitation. Rainfall pattern is extremely varied both spatially and temporally and is also a manifest of temperature change. Any change in the rainfall magnitude and pattern will have considerable impact on the water resources. IPCC has reported that there was rise of about 0.74ºC in mean temperature in 100 years from 1906 to 2005 along with great variability in rainfall both spatially and temporally [1]. Constant occurrences of events like flood, drought, high intensity rainfall, hailstorm etc. are being reported throughout the world [2, 3, 4]. These increasing extreme incidents have led to the rising concern of climate change. Changes in the spatial and temporal distribution of precipitation is a major component in many studies.

In India, many studies have been done to understand climate change. A number of researches have been conducted on the precipitation pattern of India. But no particular increasing and decreasing trend was noticed in the average rainfall of whole India [5]. 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 [6]. The rainfall and temperature trend study carried out by Kothyari & Singh (1996) in the Ganga basin and also India as a whole, indicated a decreasing rainfall trend and increasing temperature trend [7]. Basistha et al. (2009) reported 1964 as the most probable year when a shift is detected in the annual and monsoon rainfall over Himalaya [8]. Rainfall trend was analysed in Kashmir valley where monsoon rainfall indicated decrease while increase is found in annual, pre-monsoon, post-monsoon and winter rainfall [9]. Kumar et. al (2010) carried out the regional trend analysis of long-term rainfall. The study showed no significant trend in the annual, seasonal and monthly rainfall in most of the months. For the whole of India no significant trend was detected for annual, seasonal, or monthly rainfall [10]. Work on Indian Summer Monsoon (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 [11]. Patra et al. (2012) analyzed rainfall trend over Orissa state for the period 1871-2006. The analysis revealed non-significant decreasing trend of annual and monsoon rainfall, whereas increasing trend in post-monsoon season over the state. However, rainfall during winter and summer seasons showed an increasing trend [12]. Jain and Kumar (2012) reviewed trend analysis of rainfall and temperature at basin level for India and indicated decreasing trends in sixteen basins and increasing trends in six basins [13].

Thus, wide variability in the precipitation trend has triggered the growing concern of climate change and its future impact on the environment. The present study involves monotonic trend analysis of rainfall in one of the most backward regions of India situated in the Western part of Odisha, famously known as KBK (Kalahandi-Bolangir-Koraput) region. Precipitation trend analysis has been done with Mann-Kendall (MK) test in 8 different districts *viz. Bolangir, Kalahandi, Koraput, Malkangiri, Nabarangpur, Nuapada, Rayagada and Sonepur*. Trend analysis for seasonal rainfall has also been carried out for the period 1901 to 2010 (110 years). This study will help the agricultural planners and managers dealing with the water resources of the area.

2. Study Area:

The Kalahandi-Koraput-Bolangir (KBK) is three individual district administrations in the state of Odisha. During 1992-93, the three districts were reorganized into eight districts viz. Malkangiri, Nabarangpur, Rayagada, Nuapada, Sonepur, Kalahandi, Koraput and Bolangir. These eight districts comprise of 14 Subdivisions, 37 Tehsils, 80 CD Blocks, 1,437 Gram Panchayats and 12,293 villages. The eight districts which form the KBK region account for 19.72% population occupy over 30.59% geographical area of the State (155820 Km^2). The KBK region is unfortunately famous for every poverty indices set forth by different study groups. The region though witnesses an annual rainfall of 956-1375 mm spread over four monsoon months viz. June, July, August and September, periodically facing drought in every 3-4 years. The climate in the area is sub-humid, dry with extreme summer and winter. The population in the region is a mixed group dominated by tribal. The area is endowed with mineral dominated natural resources and Non-Timber Forest Produce (NTFP) in the large encompasses of forest. Rain-fed agriculture is the principal occupation of the inhabitants. The location of the meteorological stations in the state of Madhya Pradesh has been shown in Figure 1.

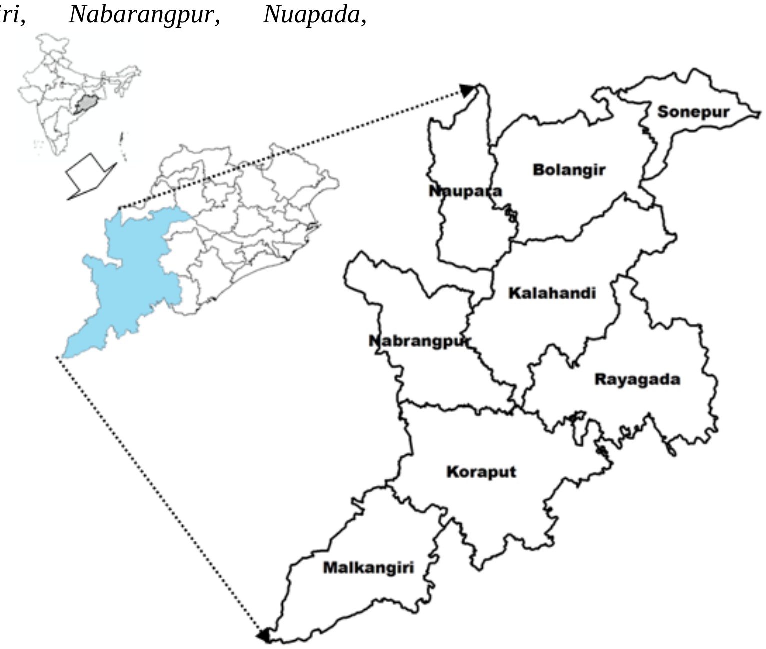

Fig.1. KBK districts in the state of Odisha

3. Materials and Methodology

Monthly rainfall of 110 years (1901-2010) has been considered for trend analysis in the study across eight KBK districts (source: www.indiawaterportal.org). Data was analysed on monthly (Jan-Dec), seasonal (pre-monsoon, monsoon, post-monsoon, winter) and annual basis. Homogeneity test was done on the series with Pettitt's test and Standard Normal Homogeneity Test (SNHT) at 5% significance level [14, 15]. The critical value of T_0 of SNHT for 110 samples of rainfall is 9.255 at 95% significant level [16]. The series is homogeneous if T_0 is less than critical values. Presence of any positive or negative autocorrelation may affect the trend detection [17]. The data was then tested for the serial correlation after which pre-whitening method was applied for removing the effect of correlation on MK Test [18, 19, 20, 21]. MK test was then applied on the pre-whitened series [22, 23, 24] together with the Theil-Sen's estimator [25, 26, 27] for obtaining the monotonic trend and magnitude of rainfall. Then Mann-Whitney-Pettitt (MWP) test was conducted to find the change or break point in the series [28].

3.1 Mann-Kendall Test and Theil-Sen's Estimator

To determine the presence of trend in the precipitation series, the non-parametric Mann-Kendall (MK) test has been employed.

The MK statistic is

$$Z_c = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} if, S>0 \\ 0 if, S=0 \\ \dfrac{S+1}{\sqrt{Var(S)}} if, S<0 \end{cases} \tag{1}$$

Where,

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(x_j - x_i) \tag{2}$$

Where,

$$\mathrm{sgn}(x_j - x_i) = \begin{Bmatrix} 1.......if\,(x_j - x_i) > 0 \\ 0.......if\,(x_j - x_i) = 0 \\ -1.......if\,(x_j - x_i) < 0 \end{Bmatrix} \tag{3}$$

Here x_j and x_i show the data values which are in sequence with n data, sgn (θ) is equivalent to 1, 0 and -1 in case θ is more than, equal to or less than 0 respectively. If Z_c found to be more than $Z_{\alpha/2}$ then the trend is believed to be significant where α is the level of significance [29].

The trend magnitude was calculated by Theil-Sen's estimator [25, 26].

$$\beta = median\left(X_i - X_j / i - j\right), \quad \forall j < i \tag{4}$$

Where $1<j<i<n$ and β estimator give the median of the entire data set of all combination of pairs and gives resistance to the effect of extreme values [29].

3.2 Mann-Whitney-Pettitt method (MWP)

The time series {X1, X2…, Xn} with length n is taken. t was taken as the time of the most expected change point. Two samples {X1, X2, …, Xt} and {Xt+1, Xt+2, …, *X*n} then can be obtained by dividing the time series at t time. The Ut index was obtained in the following way:

$$U_t = \sum_{i=1}^{t} \sum_{j=t+1}^{n} \mathrm{sgn}(X_i - X_j) \tag{5}$$

Where,

$$\mathrm{sgn}(x_j - x_i) = \begin{Bmatrix} 1.......if\,(x_j - x_i) > 0 \\ 0.......if\,(x_j - x_i) = 0 \\ -1.......if\,(x_j - x_i) < 0 \end{Bmatrix} \tag{6}$$

Plotting of Ut value against t in a time series will results in a continuously increasing value of |Ut| with no change point. Yet, if there is a change point (even a local change point), then $|Ut|$ will increase up to the change point level and then will begin to decrease. The major significant change point t gives the point where value of $|Ut|$ remains highest:

$$K_T = \max_{1 \le t \le T} |U_\tau| \tag{7}$$

The approximated significant probability $p(t)$ for a change point [28] is represented as:

$$p = 1 - \exp\left[\frac{-6K_T^2}{n^3 + n^2}\right] \tag{8}$$

When probability $p(t)$ surpasses $(1 - \alpha)$, then the change point becomes significant statistically at time t with the significance level of α.

4. Results and Discussion

The study investigates monthly, annual and seasonal trend of mean rainfall of KBK region for the period 1901 to 2010 (110 years). Seasonal analysis has been carried out for Pre-monsoon (Mar-May), Monsoon (Jun-Sept), Post-monsoon (Oct-Nov), Winter (Dec-Feb). The basic statistics of the annual series of rainfall is presented in Table 1. Annual average rainfall in the region varies from 1139.26 mm (Malkangiri) to 1429.31 mm (Nabarangpur) for the period 1901 to 2010. The standard deviation during the same period varies from 199.52 mm to 295.61 mm. The skewness in the annual average rainfall varied between 0.51 to 2.40, with an average positive skewness of 1.07 indicating a skewed asymmetric curve. The dispersion in the annual rainfall series is expressed through coefficient of variation varying between 15% (Bolangir) to 23% (Koraput). The average variation is 18% in the entire region. Figure 2 shows the temporal variation of annual rainfall with linear trend line for the eight KBK districts during the period 1901 to 2010. As seen from Figure 2, rainfall in the districts of Bolangir and Nuapada show a decreasing trend, Koraput and Malkangiri districts an increasing trend and others as no clear trend.

Before applying for MK test and Sen's Slope Estimate, all the series are tested for serial correlation using Lag-1 auto-correlation at 5% significance level (Table 2). Serially correlated series are made independent by pre-whitening to remove effects due to serial correlation. The results of MK test (z-statistics) are presented in Table 3. The test results indicate two districts with significant trend (Malkangiri with increasing and Nuapda with decreasing) in the annual rainfall (Fig.3). The magnitude of the decreasing trends in the annual rainfall varies from 0.204 mm/ year (Kalahandi) to 1.419 mm/ year (Nuapada). The analysis also indicates a non-significant increasing trends in the annual rainfall in the districts of Koraput (+0.935 mm/ year) and Rayagada (+0.382 mm/ year). The annual rainfall series for the districts of Bolangir, Nabarangpur and Sonepur indicates non-significant decreasing trend. Seasonal analysis of trend showed non-significant increasing as well as decreasing trend in pre-monsoon, monsoon and post monsoon rainfall in the study area. Koraput, Nabarangpur and Rayagada districts showed non-significant increasing trends and Bolangir, Kalahandi, Malkangiri, Nuapada and Sonepur districts showed non-significant decreasing trends in the summer rainfall (pre-monsoon). However, in case of seasonal monsoon rainfall, five districts (Bolangir, Kalahndi, Nuapada, Rayagada and Sonepur) showed non-significant decreasing trend and the remaining (Koraput, Malkangiri and Nabarangpur) showed increasing trends. Winter rainfall in the entire region showed decreasing rainfall trend which will considerably affect the rabi crops grown. When closely investigated the rainfall trend with respect to different districts, it has been found that districts with significant forest coverage (Koraput, Malkangiri) are receiving more rainfall in comparision to other districts such as Kalahandi, Nupada, Sonepur with less forest coverage.

Homogeneity test has been performed to find the shift year when a considerable change in the climate was witnessed in the region. Two widely used tests (Pettitt and SNHT) are employed to detect the change year for different series of rainfall and temperature. Table 5 presents change year for the annual series for different districts. Pettit test indicate shifting in annual rainfall mainly prior to 1961 and beyond, whereas SNHT test indicate to last decade (2005) as change year.

Table 1: Basic statistics of seasonal and annual mean rainfall series for KBK region

Rainfall series (mm)	Mean	Max	Min	Standard deviation	Coefficient of variation	Skewness	Kurtosis
Annual	1296.57	2123.48	928.28	205.49	0.16	0.88	1.80
Pre-monsoon	97.47	310.68	19.81	47.91	0.49	1.37	3.50
Monsoon	1063.36	1872.91	643.94	187.67	0.18	0.99	2.79
Post-monsoon	114.00	283.76	7.08	57.62	0.51	0.47	0.16
Winter	21.73	76.68	0.00	17.18	0.79	0.80	-0.04

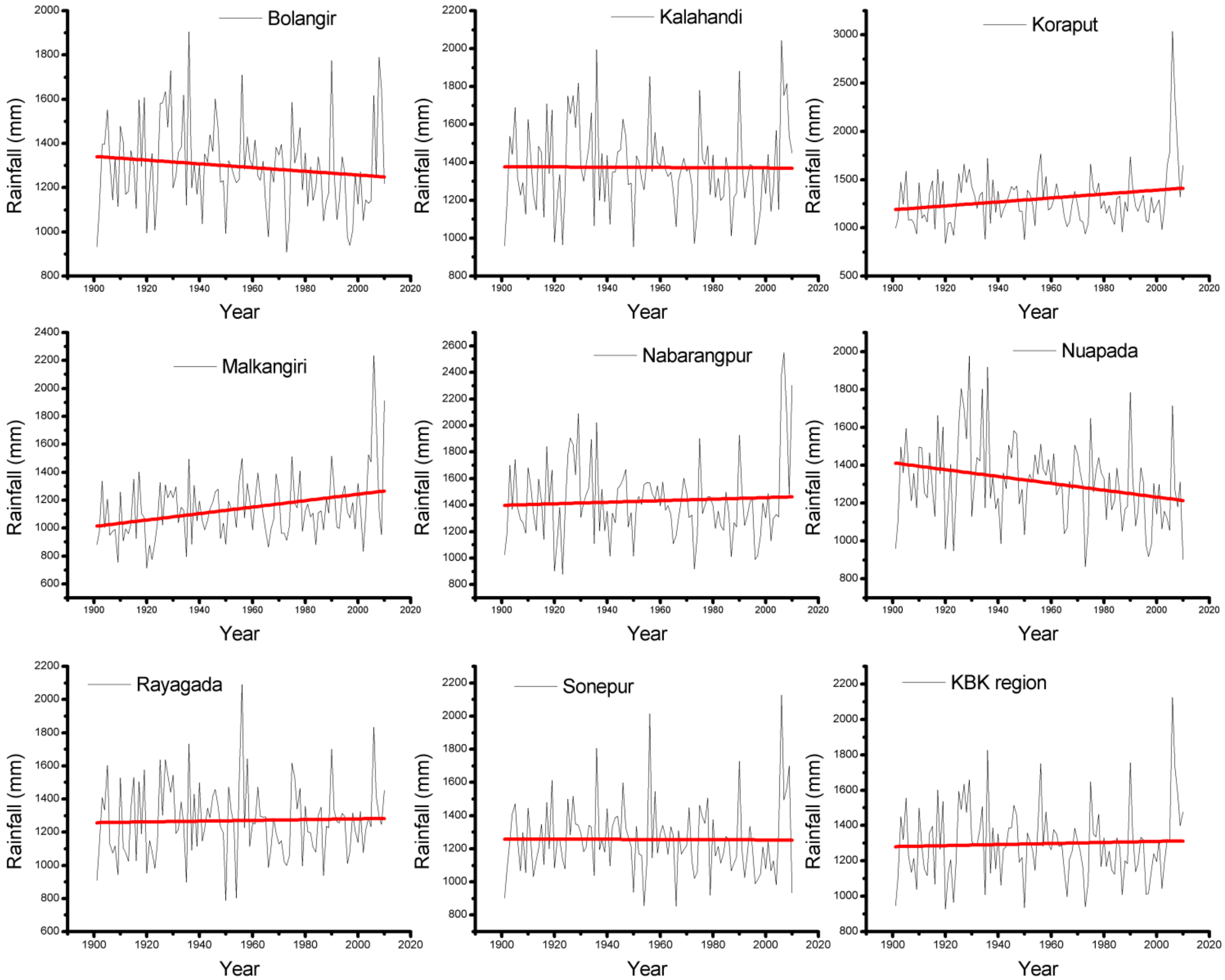

Fig.2. Temporal variation of annual rainfall for the KBK region during 1901 to 2010. Thick lines represent linear trend lines.

Table 2: Lag-1 serial autocorrelation

Districts	Rainfall				
	Annual	Pre-monsoon	Monsoon	Post-monsoon	Winter
Bolangir	0.129	-0.009	0.203	-0.038	-0.139
Kalahandi	0.118	0.004	0.231	-0.038	-0.060
Koraput	0.414	-0.115	0.486	0.020	0.030
Malkangiri	0.234	-0.061	0.226	0.117	-0.040
Nabarangpur	0.286	-0.061	0.401	-0.052	-0.006
Nuapada	0.161	-0.006	0.211	-0.041	-0.054
Rayagada	0.010	-0.014	-0.016	0.052	-0.042
Sonepur	0.010	0.062	0.071	0.027	-0.186
KBK region	0.183	-0.031	0.257	0.006	-0.069

Table 3: Mann-Kendall test statistics (Z value)

Districts	Rainfall				
	Annual	Pre-monsoon	Monsoon	Post-monsoon	Winter
Bolangir	-1.643	-0.305	-1.069	0.041	-0.625
Kalahandi	-0.279	-0.579	-0.015	-0.036	-1.348
Koraput	0.935	0.243	0.625	1.183	**-2.203**
Malkangiri	**2.041**	-0.641	1.715	1.860	-1.379
Nabarangpur	-0.398	0.858	0.031	0.439	-1.173
Nuapada	**-2.221**	-0.682	-1.555	-0.036	-0.863
Rayagada	0.382	1.137	-0.062	0.403	-1.193
Sonepur	-1.028	-0.517	-1.038	-0.212	-1.111
KBK region	0.062	-0.155	-0.098	0.465	-1.250

Table 4: Sen's slope (β-value)

Districts	Rainfall				
	Annual	Pre-monsoon	Monsoon	Post-monsoon	Winter
Bolangir	-0.852	-0.034	-0.661	0.003	-0.039
Kalahandi	-0.204	-0.099	-0.013	-0.007	-0.062
Koraput	0.673	0.038	0.428	0.278	-0.098
Malkangiri	1.312	-0.081	0.851	0.526	-0.046
Nabarangpur	-0.310	0.142	0.055	0.084	-0.048
Nuapada	-1.419	-0.077	-0.960	-0.006	-0.034
Rayagada	0.259	0.225	-0.027	0.098	-0.051
Sonepur	-0.599	-0.080	-0.538	-0.020	-0.069
KBK region	0.055	-0.026	-0.053	0.098	-0.057

Table 5: Homogeneity test

Districts	Pettitt's test				SNHT test			
	K	t	P value	Homogeneity	$T_0^{\#}$	t	P value	Homogeneity
Bolangir	815.0	1961	0.080	H_0 cannot be rejected.	5.744	2005	0.287	H_0 cannot be rejected.
Kalahandi	472.0	1962	0.610	H_0 cannot be rejected.	12.204	2005	0.014	H_a is true.
Koraput	642.0	1924	0.247	H_0 cannot be rejected.	35.723	2003	0.0002	H_a is true.
Malkangiri	920.0	1924	0.032	H_a is true.	26.635	2003	0.0003	H_a is true.
Nabarangpur	539.0	1961	0.449	H_0 cannot be rejected.	31.575	2005	0.0001	H_a is true.
Nuapada	1061.0	1961	0.008	H_a is true.	9.512	1961	0.047	H_a is true.
Rayagada	540.0	1924	0.450	H_0 cannot be rejected.	3.464	2005	0.642	H_0 cannot be rejected.
Sonepur	556.0	1978	0.417	H_0 cannot be rejected.	10.837	2005	0.066	H_0 cannot be rejected.
KBK region	471.0	2003	0.624	H_0 cannot be rejected.	16.553	2005	0.004	H_a is true.

H_0=null hypothesis i.e. series showing homogeneity; H_a=alternate hypothesis

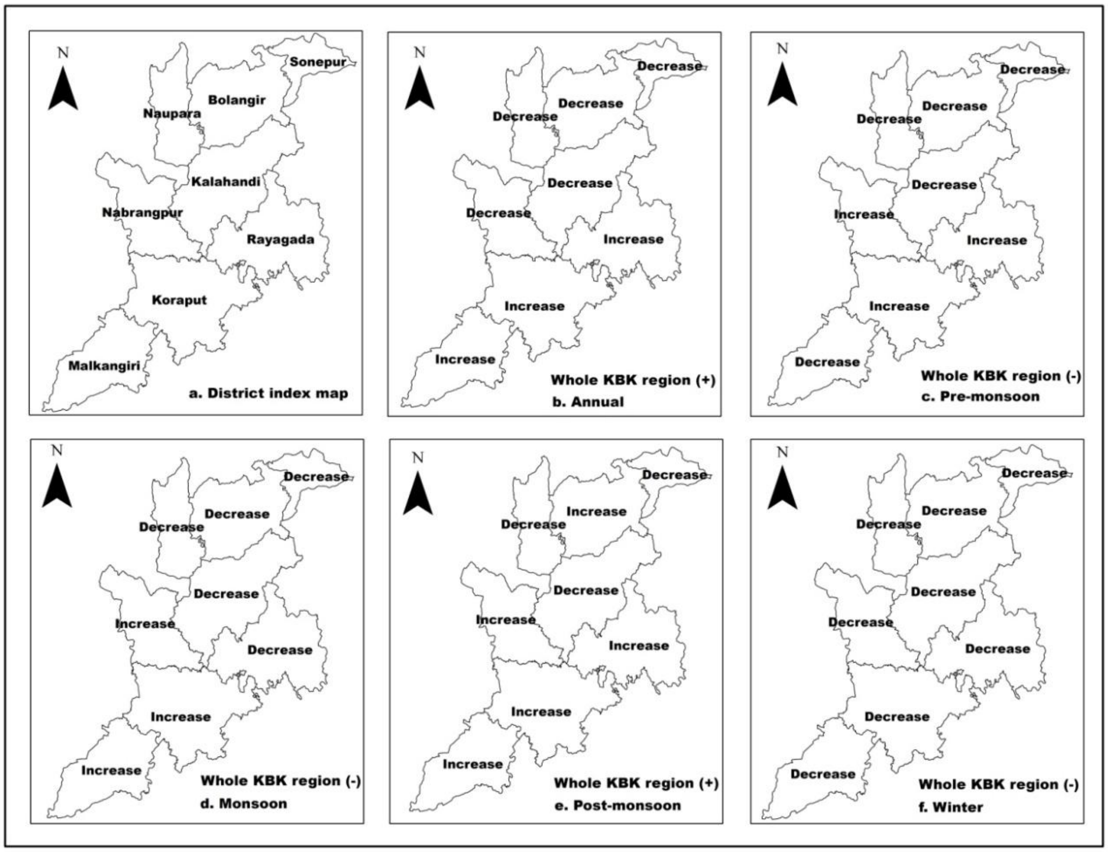

Fig.3. Map showing increasing or decreasing trend for the KBK districts

5. Conclusions

In the present study, trend analysis for long-term climatic data i.e. rainfall (110 years) has been investigated on monthly, seasonal and annual series in eight districts spread over in the KBK region in the western part of Odisha, India. The trends are generated using Mann-Kendall test and Sen's Slope estimates. The test results indicate two districts with significant trend (Malkangiri with increasing and Nuapada with decreasing) in the annual rainfall. The magnitude of the decreasing trends in the annual rainfall varies from 0.204 mm/ year (Kalahandi) to 1.419 mm/ year (Nuapada). The analysis also indicates a non-significant increasing trends in the annual rainfall in the districts of Koraput (+0.935 mm/ year) and Rayagada (+0.382 mm/ year). The annual rainfall series for the districts of Bolangir, Nabarangpur and Sonepur indicates non-significant decreasing trend. The winter series in the entire region showed a decreasing trend. Monsoon trend in the northern districts is showing decreasing trend in comparison to districts situated towards south of KBK region. The probable change years were mainly found prior to 1961 for annual rainfall series during the period 1901 to 2010 by Pettitt test, where as SNHT indicates to last decade (mainly the year 2005) when significant shift in rainfall pattern has been witnessed.

Overall, the study concludes based on the trend analysis that the region is witnessing significant decreasing trends in annual rainfall in the northern parts covering the districts of Kalahandi, Nuapada and Sonepur which are already facing water scarcity. Southern districts like Koraput and Malkangiri with considerable forest coverage in comparison to other districts in the KBK region are showing increasing rainfall trend. This mismatch in spatial as well as temporal rainfall magnitude and pattern has significant implications in overall water resources scenario in the region. How far these trends sustain in long-run requires further investigations using data simulated from different global climate models before finalizing water resources availability, distribution and utilization to meet current and future need.

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