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Mann-Kendall, and Sen's Slope Estimators for Precipitation Trend Analysis in North-Eastern States of India

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ABSTRACT
The cause of climate change detection is very tedious and complex phenomenon. For the purpose, the behaviour identification of climatic variable using long term historical database is very important. In present study, highlights the climatic variability has been identified using the non-parametric Mann-Kendall, and Sen's slope estimators over north-eastern region of India. In this study long term precipitation data has been considered during 1901-2015. The non-parametric tests have been tested at the 5% level of significance. The non-parametric tests were applied at eight north-eastern states i.e., Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and West-Bengal of India. This type of study is very necessary for long-term agricultural and water resources planning of the states.

Keywords
Mann-Kendall test, Sen's slope estimators, North-Eastern states, Climate Change

1. INTRODUCTION
For a developing country like India, which has agriculture based economy, the uncertainty and non-uniformity associated with rainfall characteristics could result in severe reduction in agricultural production and could adversely affect the water resources planning and management to meet demands for various purposes such as irrigation, domestic and hydropower. Among various hydro-climatic variables (rainfall, evapotranspiration, temperature, humidity), rainfall is the most important and most studied variable because of its significance for sustainable water, agriculture and ecological management (Chowdhury et al., 2014). The changing rainfall patterns and its impact on water resources is an important climatic problem facing society today. Associated with global warming, there are strong indications that rainfall changes are already taking place on both the global (Bradley et al., 1987) and regional scales (Maheras, 1988). Future climate changes may involve modifications in climatic variability as well as changes in averages (Rind et al., 1989).

Several researchers have investigated rainfall characteristics, variability and trends and have identified mechanisms for these changes, e.g., in United States (Alexander et al., 2006); Spain (De Luis et al., 2000); Australia (Hasan and Dunn, 2011), Upper Blue Nile river basin (Tabari et al., 2015); Malaysia (Loo et al., 2015); India (Lacombe and McCartney, 2014); and around the world (Rauch and DeToffol, 2006) and could be taken as the noteworthy works. Spatial and temporal trends in extreme precipitation intensity were also observed in Japan (Fujibe et al. 2005), India (Kumar et al., 2010), China (Wang and Zhou, 2005), and South Africa (Sen Roy and Rouault, 2013).

In Indian context, the studies done by Khan et al., (2000); Shrestha et al., (2000); Mirza, (2002); Goswami et al., (2006); Dash et al., (2007) found that, in general, the frequency of more intense rainfall events in many parts of Asia has increased, while the number of rainy days and total annual amount of precipitation has decreased. Goswami et al. (2006) used daily rainfall data to show the significant rising trends in the frequency and magnitude of extreme rain events, and a significant decreasing trend in the frequency of moderate events over central India during the monsoon seasons from 1951 to 2000. Mirza et al. (1998) carried out trend and persistence analysis for the Ganges, Brahmaputra and Meghna river basins. They showed that precipitation in the Ganges basin is, by and large, stable. Furthermore, one of three sub-divisions of the Brahmaputra basin shows a decreasing trend, while another shows an increasing trend. Singh et al. (2008) studied the changes in rainfall in nine river basins of northwest and central India and found an increasing trend in annual rainfall in the range of 2–19% of the mean per 100 years. Sinha Ray & De (2003) concluded that all-India rainfall and surface pressure shows no significant trend, except for some periodic behaviour. According to Sinha Ray & Srivastava (1999), the frequency of heavy rainfall events during the southwest monsoon has shown an increasing trend over certain parts of the country, whereas a decreasing trend has been observed during winter, pre-monsoon and post-monsoon seasons.

2. STUDY AREA
In the present study, North-East region of India is considered as a study area. In this region various states are considered i.e., Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and West-Bengal. The Location details and area description are shown in Table 1 as follows:

Table 1: Location details and area description of North-Eastern states

S. No.	North-Eastern States	Location Details	Area (km^2)
1	Arunachal Pradesh,	28.2180° N, 94.7278° E	83,743
2	Assam	26.2006° N, 92.9376° E	78,438
3	Manipur	24.6637° N,	22,327

		93.9063° E	
4	Meghalaya	25.4670° N, 91.3662° E	22,720
5	Mizoram	23.1645° N, 92.9376° E	21,081
6	Nagaland	26.1584° N, 94.5624° E	16,579
7	Tripura	23.9408° N, 91.9882° E	10,492
8	West-Bengal	22.9868° N, 87.8550° E	88,752

S Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and West-Bengal states are lies in North-Eastern part of India. As concern with climatic description of India, the highest average annual rainfall received about 11,873 mm in Mawsynram, Meghalaya which is also located in North-Eastern part of India. The monsoon season starts from June and end up to September in this region. The location map of study area is shown in Figure 1.

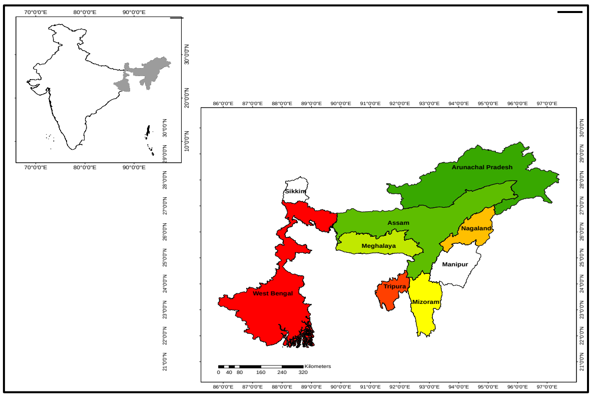

Figure1. Location map of study area

3. METHODOLOGY

3.1 Data Requirement and Availability

Present study requires long term (1901-2015) daily precipitation data, for the purpose fine India Meteorological Department (IMD) gridded (0.25deg x 0.25deg) data to be utilized. The gridded data base to be converted in to area weighted average rainfall for each state. Further data mining techniques has been utilized for further process viz. monthly and seasonal conversion. The entire data sets have been converted in to annual and seasonal time series. GIS administrative boundary of the entire districts shape files are downloaded from DIVA-GIS web-site.

3.2 Trend Analysis

To investigate the spatial and temporal changes in rainfall for different seasons, a year has been divided into four seasons: winter (December–February), pre-monsoon (March–May), monsoon (June–September), and post-monsoon (October–November). For the trend analysis, monthly rainfall series were used to form seasonal and annual series. Generally, rainfall data used in the studies of rainfall trends should only be affected by weather and climate conditions; however, other factors like location of the station, station environment, observing practices and instruments may also influence the homogeneity of rainfall time series (Chen et al., 2015). Further, as discussed above, the long term rainfall series may also have serial auto-correlations and therefore, before conducting further investigations, the rainfall series is tested for homogeneity using standard normal homogeneity test (SNHT) test and TFPW approach is used to make the series free from auto-correlations.

Long term trend analysis has been performed for each districts on the basis of monthly, seasonal and annual basis. SNHT has been for checking the homogeneity of long term data series at 5% significance level (Alexandersson 1986; Alexandersson; Moberg 1997). The critical values of SHNT statics T0 for various sample sizes (10 to 250) were originally developed from using relatively short Monte Carlo simulations with different critical percentage (Khaliqa and Ouardab, 2007). The series is homogeneous if the critical value of the SHNT statics T0 for 115 sample size at 95% critical level is less than 11.32.

In present study, long term rainfall trend analysis has been carried out using the Mann Kendall (MK) Test. However, MK test is most appropriate test for identification of monotonic trend in persistent data and is considered as better than other parametric tests (Mann, 1945). The MK test is one of the most commonly used non-parametric method, most of the literature significantly contains this approach for trend analysis (Buffoni et al. 1999; Déry; Wood 2005; Kumar; Jain 20210; Mondal et al. 2012a; Xu et al. 2003; Zhang et al. 2008). Magnitude of trend has been quantified by Theil-Sen's estimator (Duhan; Pandey 2013; Jhajharia et al. 2012) and positive and negative values of magnitude showed increasing and decreasing trend respectively. Results of trend has been shown in terms of positive significant, negative significant, positive non-significant and negative non-significant level of rainfall at 5% level of significance (Mondal et al. 2012b).

4. RESULTS AND DISCUSSIONS

4.1 Extraction of IMD daily fine resolution data (1901-2015) and processing

Extraction of IMD fine resolution data has been procured from Indian Meteorological Department, Pune. The daily gridded data are available in .txt format. The data has been extracted by using the MATLAB programming. In this study there are nine states are considered for detection of climatic variability using data mining technique. Initially daily rainfall data has been extracted for each of the fine resolution grids (0.25 deg. x 0.25 deg.). The total 98 grids lie over the entire nine states. Further, weighted average rainfall has been estimated by using the Thiessen polygon interpolation technique. The IMD grids arrangements over nine states are shown in Figure 2 below:

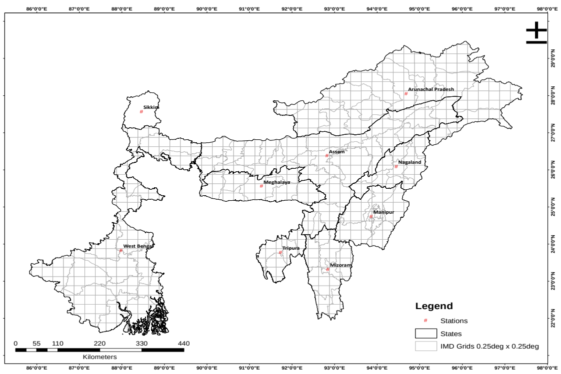

Figure 2: Location of stations and IMD fine resolution grid arrangements over NE state boundary

4.2 Preparation of GIS layers for study area

The GIS layers as well as maps have been prepared using the ArcMap 10.4. The administrative boundary of the state is downloaded from the DIVA-GIS site. The fine resolution grids are prepared using the add XY command in ArcMap 10.4. Stations are located in the centroid of the states using feature to point command in ArcMap 10.4. Further, applied the Thiessen Polygon commands over imported points, the grids are automatic generated shown in Figure 2.

4.3 Calculation of area weighted average rainfall and its statistics for each state

4.3.1 Preliminary data analysis

The weighted average of rainfall also calculated using the ArcMap 10.4. Initially, the two layers have been prepared state boundary and Thiessen grids. Further, intersect command has been used to super-impose the both layers and calculated the intersected area of each grids over the state. Thereafter, weighted average rainfall has been calculated for each of the state. General statistics of annual rainfall time series during 1901-2015 over North-East states shown in Table 2.

Table 2: General statistics of annual rainfall time series during 1901-2015 over North-East states

States	Observations	Minimum	Maximum	Mean	Std. deviation
Arunachal Pradesh	115	1227.1	4426.3	2634.6	622.2
Assam	115	1474.6	2744.3	2218.6	234.6
Manipur	115	857.3	2248.1	1515.6	246.5
Meghalaya	115	1300.3	6345.0	2781.5	821.2
Mizoram	115	1071.1	3089.7	1881.9	369.8
Nagaland	115	1162.4	2453.0	1929.5	270.1
Sikkim	115	1640.6	3814.0	2765.1	386.4
Tripura	115	1294.2	3508.2	2331.2	377.3
West Bengal	115	1348.3	2240.0	1775.0	193.5

General statistical parameters (Minimum, maximum, mean and standard deviation) of annual rainfall time series are calculated for each states of North-Eastern India. Annual rainfall varies between 857.3 mm (Manipur) to 6345 mm (Meghalaya) over the entire states. Weighted annual average rainfall of the entire state is calculated as 2203.67 mm. From the analysis, it has been observed that the standard deviation varies between 193.5 mm (West-Bengal) to 821.2 mm (Meghalaya) shown in Table 2. It can be concluded from the analysis that the zone of usually heavy rainfall shows complex variability and zone of low rainfall indicates less variability.

4.3.2 Conversion of data sets in to annual and seasonal time series using data mining technique

In this study, the entire daily gridded rainfall time series have been converted into monthly time series during 1901-2015. Before, applying the non-parametric trend analysis the monthly rainfall has been converted into annual and seasonal time series. The seasons are defined as per IMD i.e., pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-December) and winter (January-February). The entire analysis has been done on the basis of monthly, annual and seasonal basis. Weighted average time series has been prepared using the GIS analysis.

4.4 Rainfall trend analysis during 1901-2015

4.4.1 Results of Mann-Kendall (MK) Test

In this time series, MK test is analyzed on monthly, annual and seasonal basis. In monthly time step, the total values are 9x12=108, out of them most of the values (63 values) are showing negative trends and remaining (45 values) are positive. In annual time series, out of nine states five states showing negative trends and remaining are positive. However, out of nine states two states (Meghalaya and Mizoram) are showing significant positive and two states (Nagaland and Assam) showing significant negative trends at 5% significant level. Most of the significant trends have been shown in monsoon season. In monsoon season, two states (Meghalaya and Mizoram) showing significant positive and four states (Arunachal Pradesh, Assam, Nagaland and Sikkim) showing significant negative trends. In pre-monsoon season five states showing positive trend and four are negative. Whereas, one state (Nagaland) showing negative significant trend and two states (Meghalaya and Sikkim) showing positive significant trends. In post monsoon season, out of nine states five states are showing negative trends. However, two states (Meghalaya and Mizoram) are showing significant positive and one state (Nagaland) is showing significant negative trend. In winter season, most of the states are showing negative trend except two states (Arunachal Pradesh and Sikkim). Whereas, Assam and Nagaland are shows significant negative trends and Sikkim is showing significant positive trend. In totality, the states are falls under negative trends during 1901-2015.

4.4.2 Estimated magnitude of rainfall using Sen's slope estimator

Magnitude of monthly, annual and seasonal rainfall data is estimated by Sen's slope estimator and it has been represented in to box plots shown in Figure 3(a) and Figure 3(b). Figure 3(a) shows the box plots of different slope (in mm/day) values of different states at monthly time steps. Whereas the Figure 3(b) shows the box plots of different slope (in mm/day) values of different states at annual and seasonal time steps. In monthly time steps, the lowest value (Sikkim)for the slope of rainfall (-1.805 mm/year) trend line wasfound in August month during 1901–2015, and thehighest value (Meghalaya) for the slope of rainfall (2.408 mm/year) trend line was found in July month during 1901–2015 shown in Figure 3(a). In annual and seasonal time steps, the lowest value (Sikkim)for the slope of rainfall (-4.764 mm/year) trend line was found in the monsoon season during 1901-2015, and the highest value (Meghalaya) for the slope of rainfall (9.241 mm/year)trend line was found in the annual time scale during 1901–2015 shown in Figure 3(b). The entire MK/MMK and its magnitudes of rainfall over monthly, annual and seasonal time steps are shown in Table 4.

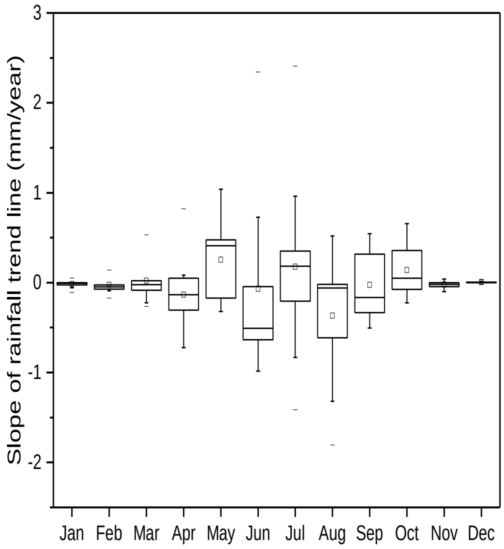

Figure 3(a): Box plot of the Theil-Sen's slopes in monthly time step

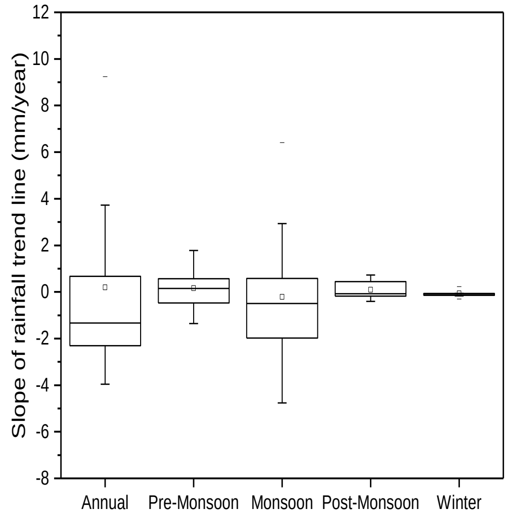

Figure 3(b): Box plot of the Theil-Sen's slopes in annual an d seasonal time step

Table 4: Results of Mann-Kendall test with Sen's slope estimator for different NE states of India during 1901-2015

MK	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter
Arunachal Pradesh	-0.435	1.267	1.849	0.169	-0.479	-2.086 a	-2.105 a	-3.075 a	-1.46	-0.655	-0.525	0.179	-1.281	1.027	-2.816 a	-0.861	0.972
Assam	-1.839	-1.165	-0.653	-1.603	-0.759	-2.180 a	-0.744	-2.872 a	-1.532	-0.527	-1.184	0.196	-3.423 a	-1.736	-3.360 a	-1.025	-2.391 a
Manipur	-0.743	-1.682	-0.706	-0.817	2.318 b	-0.331	0.863	-0.106	1.216	0.065	-1.540	0.254	0.024	0.515	-0.019	-0.452	-1.690
Meghalaya	0.111	-0.848	0.167	0.029	2.780 b	4.066 b	4.153 b	1.387	1.750	2.412 b	-0.321	2.149 b	4.165 b	2.175 b	3.657 b	2.490 b	-1.317
Mizoram	-0.885	-0.585	-0.184	-1.218	2.246 b	2.507 b	4.041 b	2.582 b	2.161 b	2.586 b	-0.094	1.176	3.867 b	0.742	4.544 b	2.151 b	-1.124
Nagaland	-2.707 a	-2.545 a	-1.994 a	-4.196 a	-1.769	-3.147 a	-0.981	-2.282 a	-1.929	-1.327	-2.071 a	-0.888	-5.383 a	-3.887 a	-3.846 a	-2.064 a	-3.72 a
Sikkim	1.429	1.939	3.785 b	4.249 b	1.905	-2.480 a	-2.891 a	-5.032 a	-1.421	1.912	1.354	2.629 b	-1.871	4.467 b	-4.641 a	1.830	2.407 b
Tripura	-1.561	-0.952	-1.472	-2.093 a	1.245	-1.697	1.199	-0.273	-0.764	0.249	-0.878	2.714 b	-1.148	-0.877	-0.887	-0.285	-1.806
West Bengal	-0.135	-1.346	-0.261	0.940	-0.425	-0.203	1.714	-0.338	1.702	0.788	0.534	1.454	1.037	-0.073	1.453	0.783	-1.172

Sen's Slope	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter
Arunachal Pradesh	-0.026	0.141	0.331	0.050	-0.173	-0.838	-0.830	-1.321	-0.477	-0.129	-0.022	0.004	-2.304	0.565	-3.225	-0.194	0.137
Assam	-0.056	-0.071	-0.085	-0.305	-0.184	-0.508	-0.162	-0.615	-0.302	-0.076	-0.045	0.003	-2.332	-0.564	-1.339	-0.176	-0.164
Manipur	-0.007	-0.090	-0.086	-0.133	0.477	-0.073	0.182	-0.020	0.200	0.016	-0.067	0.000	0.021	0.145	-0.011	-0.105	-0.124
Meghalaya	0.000	-0.037	0.023	0.008	1.039	2.344	2.408	0.519	0.544	0.656	-0.010	0.011	9.241	1.060	6.404	0.721	-0.085
Mizoram	-0.002	-0.025	-0.022	-0.300	0.630	0.728	0.961	0.494	0.499	0.467	0.000	0.000	3.732	0.314	2.932	0.443	-0.070
Nagaland	-0.110	-0.172	-0.264	-0.724	-0.321	-0.634	-0.206	-0.451	-0.334	-0.223	-0.100	-0.015	-3.956	-1.356	-1.973	-0.408	-0.303
Sikkim	0.053	0.118	0.531	0.821	0.411	-0.984	-1.414	-1.805	-0.506	0.357	0.041	0.031	-2.027	1.782	-4.764	0.445	0.232
Tripura	-0.007	-0.050	-0.223	-0.716	0.471	-0.621	0.350	-0.056	-0.165	0.051	-0.019	0.000	-1.333	-0.478	-0.494	-0.081	-0.142
West Bengal	-0.001	-0.047	-0.015	0.083	-0.053	-0.044	0.313	-0.061	0.317	0.146	0.012	0.004	0.672	-0.023	0.577	0.152	-0.068

Where, a Negative significant at the level of 5% and b Positive significant at the level of 5%

4.5 Rainfall variabilityin monthly, annual and seasonal rainfall over North-Eastern states

For agriculture, it is important to understand the seasonal variations of precipitation in order to obtain a precise assessment of supplemental water requirements (Gajbhiye et al. 2015).The analysis of the variability in rainfall patterns using CV for 1901–2015 for the different states of North-Eastern India indicates that theinter-annual and seasonal variability of rainfall shown in Figure 4(a-e). Variation is lowestfor annual and monsoon precipitation when minimum valuesof CV are 10.56 % and 29.52 %, respectively. In contrast, minimum values of CV for rainfall in the other seasons are36.36 % (post-monsoon), 48.35 % (winter) and 22 % (pre-monsoon). The seasonal precipitation variability is highest in Mizoram for three seasons: 91.92 % for winter, 34.31 %for monsoon and 73.54 % for post-monsoon, and 34.36 %, for the pre-monsoon season. The spatial presentation of the CV values is shown in Figure 4(a-e). Regions with higher inter-annual variability in rainfall are more susceptible to floods and droughts (Pandey and Ramasastri 2002; Turkes,1996)

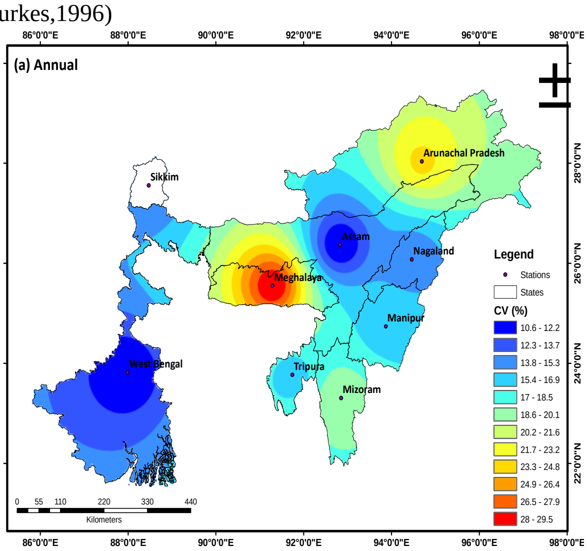

Figure 4(a): Rainfall variability (%CV) in annual time series during 1901-2015

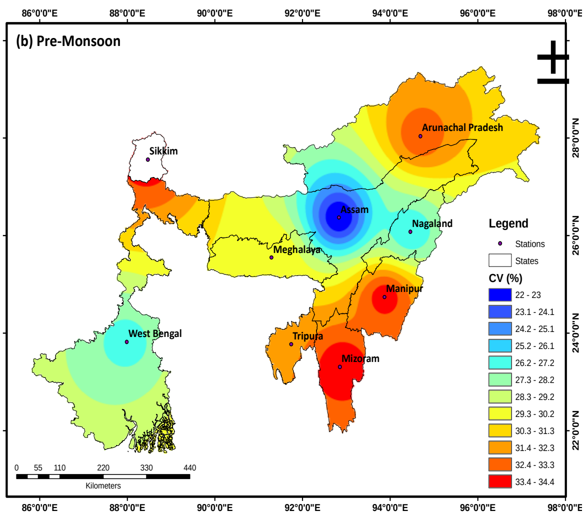

Figure 4(b): Rainfall variability (%CV) in pre-monsoon season during 1901-2015

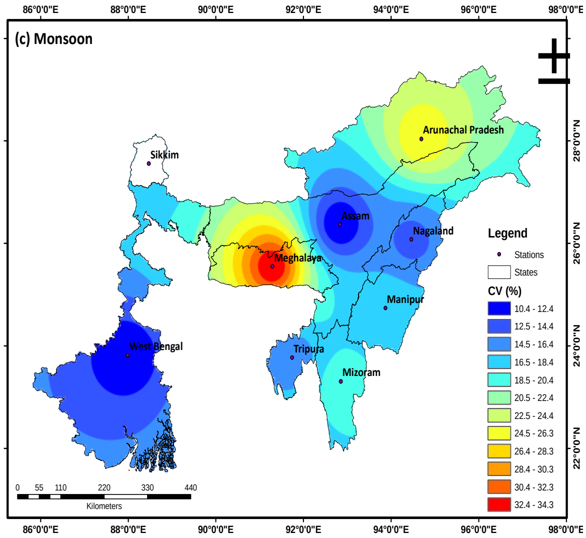

Figure 4(c): Rainfall variability (%CV) in monsoon season during 1901-2015

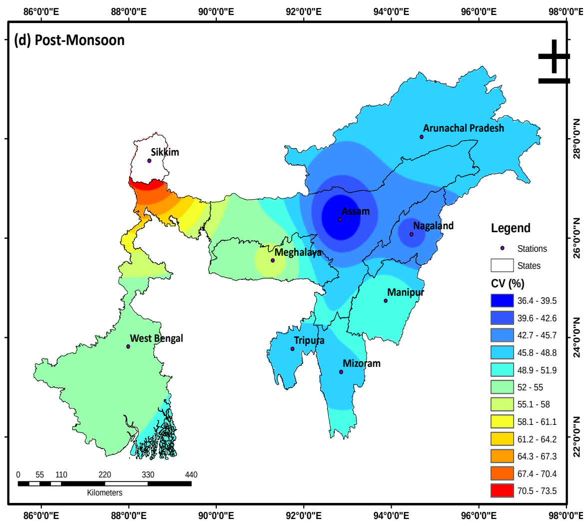

Figure 4(d): Rainfall variability (%CV) in post-monsoon season during 1901-2015

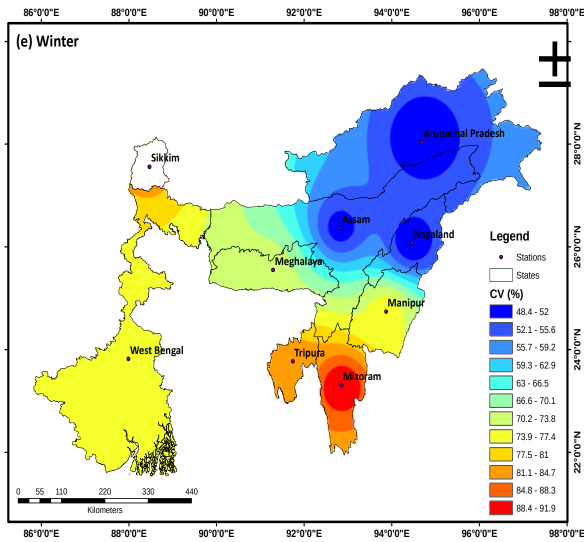

Figure 4(e): Rainfall variability (%CV) in winter season during

5. CONCLUSION

Trends and variability of monthly, annual and seasonal rainfall time series were analyzed for nine states of North-Eastern zone of India. The Mann–Kendall and Sen Slope estimation test were used to detect rainfall trends, and the Mann–Whitney–Pettitt and Standard Normal Homogeneity Test were used to identify possible change point's detection in rainfall time series during the 115-year period. From the results of the study, it is concluded that annual, monsoon and winter precipitation decreased in all the State during 1901–2015. The most probable year of change in the different state are different as shown in Table 3. During 1901–2015, the monthly time series are showed decreasing trends (significant or non-significant) except the December (positive trend) month. Overall, annual, monsoon and winter precipitation indicate declining trends whereas pre-monsoon rainfall shows most of the increasing trends at all stations during the whole period. In monthly time steps, the lowest value (Sikkim) for the slope of rainfall (-1.805 mm/year) trend line was found in August month during 1901–2015, and the highest value (Meghalaya) for the slope of rainfall (2.408 mm/year) trend line was found in July month during 1901–2015. In annual and seasonal time steps, the lowest value (Sikkim) for the slope of rainfall (-4.764 mm/year) trend line was found in the monsoon season during 1901-2015, and the highest value (Meghalaya) for the slope of rainfall (9.241 mm/year) trend line was found in the annual time scale during 1901– 2015. Thus decreasing rainfall in annual and seasonal basin indicates the possibility of drought condition or water scarcity. These will have an adverse effect on rain-fed agriculture as well as sustainable development of the state. For the study of weather phenomenon, the rainfall is an important factor which is responsible for climate change. However, climate change and its behavior is also complex phenomenon which depends upon natural and man-made factors. Evaluation of the long term trend of rainfall is very important for further climate studies. The results from the study can be useful for planning and managing the water resources, agriculture and sustainable development of the state and also important for any strategic planning for future adaptation and mitigation.

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