Applied Ecology and Environmental Sciences, 2022, Vol. 10, No. 6, 368-381
Available online at http://pubs.sciepub.com/aees/10/6/6
Published by Science and Education Publishing
DOI:10.12691/aees-10-6-6

Rainfall Trend of Imphal Watershed Using Innovative Trend Analysis

Rebati Sinam*

Centre for the Study of Regional Development, Jawaharlal Nehru University, New Delhi, India
*Corresponding author: rebatisinam0@gmail.com

Received April 10, 2022; Revised June 03, 2022; Accepted June 12, 2022

Abstract Rainfall is one of the most important meteorological elements that affects how living and non-living species exists on this planet. Innovative Trend Analysis (ITA) was developed by Zekai Sen as an alternative to conventional Mann Kendall test for trend analysis. Unlike the Mann-Kendall test, ITA is free from the problem of serial correlation and have no assumptions. Attempt has been made to analyse the rainfall trend of Imphal watershed using IMD 0.25° X 0.25° resolution gridded data. Imphal watershed has been divided into 24 grids named G1 to G24. Results show that there are cases of both negative and positive trend in annual rainfall. Winter rainfall has negative trend in all the grids. The southern part of the grid points experiences positive changes while the northern part has either no trend or negative trend. G2, G3 and G6 have significant positive trends during annual rainfall and pre-monsoon rainfall. The rainfall category wise analysis shows that high intensity rainfall in all the grids have positive tendency while the low and medium rainfall have negative or no trend behavior. There have been isolated cases of very high rainfall which affect the overall trend and the slope of change. As reiterated by other authors, ITA is a new and reliable tool for understanding the trend and unveiling the hidden trend of time series.

Keywords: *Imphal, innovative trend analysis, rainfall trend, rainfall gridded data*

Cite This Article: Rebati Sinam, "Rainfall Trend of Imphal Watershed Using Innovative Trend Analysis." *Applied Ecology and Environmental Sciences*, vol. 10, no. 6 (2022): 368-381. doi: 10.12691/aees-10-6-6.

1. Introduction

Rainfall is one of the most important meteorological phenomena that affects how human and other living and non-living species exists on the planet. It controls different facets of the biotic and abiotic ecological components of the Earth. It influences the volume and speed of hydrological flow and mass transport [1,2]. The study and analysis of rainfall characteristics of a basin is imperative for water resources management, mitigation of flood and drought scenarios, planning and design of hydraulic structures such as construction of reservoirs, barrages and dams, flood control, drainage network, flood routing, soil and water conservation [3]. With increasing population, industrialization and urbanization, the change in climate affects the local weather conditions which in turn, alter the hydrological response of the region. Therefore, understanding the nature and behavior of rainfall trends and variability is an essential requisite for any climate studies and to understand its impacts on regional economics.

Rainfall trend studies in India by different authors showed that there is no significant trend for the country as a whole but there are certainly regional variations from states to states, climatic zones to zones. Rainfall trend in India has been studied by [4] for the period 1901 to 1990 using Mann-Kendall statistics. They observed that India as a whole do not show any particular trend but the different rainfall stations have shown either a decreasing or increasing trend in terms of annual and seasonal rainfall. A rainfall trend analysis of Indian summer monsoon was conducted by [5] and their results were being compared to the study done by [6]. [5] concluded a contrasting result from that of [6] which observed an increasing trend of heavy rainfall and decreasing trend of moderate rainfall in India. [5] highlighted that there is 'spatially varying mixed responses of global warming toward rainfall occurrence and amounts all over India'. [7] discerned no significant trend in India during 1901 to 2000. Study on different river basins of India has been done by [8] using IMD gridded data from 1951 to 2004. [9] also found no significant trend in monthly, seasonal and annual rainfall in India. Using wavelet technique, [10] did not find any significant trend for India except for the regional variations.

Northeast India constitutes about 7.9 % of total geographical area of India consisting of the 8 states of Sikkim, Assam, Meghalaya, Mizoram, Tripura, Manipur, Nagaland and Arunachal Pradesh. The climatological and meteorological study on the Northeastern part of India is quite limited and, in most cases, literature, if at all available, are inaccessible. Regional studies on local or microshed level is limited as well. One of the earliest studies on rainfall and temperature has been done by [11]. As per the study, North East India did not show any clear trend for the period 1871 to 2008, although the authors had acknowledged the presence of seasonal trends for some hydro-meteorological sub-divisions. Earlier study by

[12] on North Assam subdivision and 4 meteorological stations in North East India, found no significant trend indicating that the monsoon rain in the region is trendless, rather random in nature with certain variations over time. However, a study by [13] witnessed steep decreasing trend in the normal Indian summer monsoon rainfall from 1871 to 2012 for north eastern region where 1960 to 1970 was considered to be the critical decade where there is reversal of trend. [14] observed no significant trend in annual and monsoon rainfall in North East India but they have witnessed seasonal variations for different stations in the region. For instance, Imphal showed significant increasing trend during pre-monsoon rain while Guwahati showed upward trend during post monsoon. Cherrapunji observed increased rainfall during winter. [15] noticed a decreasing trend in the annual, monsoon and winter rainfall, increasing trend in pre-monsoon rainfall for all north eastern states from 1901 to 2015.

Regional specific study by [16] on Assam indicated the average rainfall or rainy days in Assam during monsoon is about 1606 mm or 70 days. Trend analysis on 24 stations showed that 16 stations with decreasing trends during the months of June, July and December while 17 stations witnessed upward trends during September, 22 stations during February. In terms of annual and seasonal scale, there were both increasing and decreasing trends but were non-significant statistically. [17] analysed the rainfall pattern of Assam using 21 stations data for 102 years (1901 to 2002) and observed that there is no significant trend in the annual rainfall of Assam. 1959 was considered as the probable year of change in annual precipitation. [18] observed decline in the monthly rainfall in Assam from 1980 to 2014 in their forecast rainfall using SARIMA methodology. [19] observed non-significant upward trend in the total annual rainfall of Meghalaya with decline in monsoon rainfall and increase in pre-monsoon and post-monsoon rainfall. Rainfall study in Mizoram was done by [20] and observed significant reduction in the winter and post monsoon rainfall. Recent study on Meghalaya was done by [21] on two watersheds (Umiam and Umtru) to detect the trend using IMD gridded data. They used Innovative trend analysis to examine the trend in the watersheds and the results obtained from the study concluded that there is an increase in the high rainfall, decrease in low and medium rainfall during 1901 to 2018. [22] found increasing trend in the month of July, October, November rainfall of Meghalaya from 1872 to 2007 and decreasing trend in February-June, August and September. As for the world's rainiest station Cherrapunji, there was no trend in any month. Study on Pare watershed, Arunachal Pradesh by [23] indicated falling trends although statistically insignificant. With this in background, the paper attempt to analyse the rainfall trend of Imphal watershed using a new technique, other than the traditional Mann-Kendall Statistics. Mann-Kendall test has been traditionally used as the most common non-parametric tool for examining the trend in meteorological time series data. Over the years, new methods are being developed to overcome the shortcomings of MK test. One such method is Innovative Trend Analysis (ITA) which is being used in the present study. Moreover, the lack of inconsistent rain gauge station data has been one of the major difficulties of analyzing rainfall pattern. Attempt has been made in this study to use gridded data as an alternative to station data.

2. Material and Methods

2.1. Study Area

Imphal Watershed (Figure 2) is a lesser explored hydrological unit in the north eastern part of India. Imphal watershed has been extracted using Hydrology tools in spatial analyst of ArcGIS software. Imphal watershed is located between 25º27´N and 24º41´N latitude and 93º43´E and 94º19´E longitude. It is drained by two main rivers: Imphal and Iril. The watershed has an area of 2073.93 sq.km and is located in the state of Manipur. The region is very unique in the sense that while there is problem of excessive flooding every monsoon period, the state is reel with scarcity of water during the lean seasons despite receiving more than above average rainfall in India.

2.2. Data Sources

Gridded Rainfall data has been procured from Indian Meteorological Department (IMD), Pune. Gridded precipitation data with spatial resolution of 0.25º x 0.25º for the period 1901 to 2020 is obtained from National data Centre, IMD, Pune. The dataset is downloaded from the website https://www.imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html.

This gridded rainfall data has been prepared by a team of scientists led by [24] as an improvement over the 1º x 1º and 0.5º x 0.5º resolution data developed by [25,26]. The details for the data preparation are mentioned in [24].

2.3. Methodology

For examining the presence of monotonic increasing or decreasing trend, two methods are applied.

1. Mann Kendall test and Sen's estimator of slope
2. Innovative Trend Analysis developed by Zekai Sen (2012)

The analysis is carried out for five periods-Annual, Winter, Pre-Monsoon, Monsoon and Post-Monsoon. Seasonal division is based on IMD guidelines. Four seasons are categorized: Winter (January-February), Pre-Monsoon (March-May), Monsoon (June-September), Post-Monsoon (October-November).

The data are first tested for the presence of autocorrelation at lag 1 and accordingly pre-whitening test are applied to reduce the effect of serial correlation on trend analysis using Mann Kendall test. The data series for all the periods (annual and seasons) are tested for lag 1 autocorrelation both in excel and R studio for finding the presence of serial correlation. The details of MK test have been shortened and can be referred from [27].

The Mann-Kendall Test can be applied to cases when the data values 'x_i' of the time series can be assumed to obey the model

$$x_i = f(t_i) + \varepsilon_i \tag{1}$$

Where '$f(t_i)$' is a continuous monotonic increasing or decreasing function of time and the residuals 'ε_i' can be assumed to be from the same distribution with zero mean. The variance of the distribution is assumed to be constant in time. The null hypothesis of no trend, H_o, i.e., the observations 'x_i' are randomly ordered in time is to be tested against the alternative hypothesis, H_1, indicating the presence of an increasing or decreasing monotonic trend.

The Mann-Kendall Test statistic M is calculated using the formula

$$M = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_j - x_k\right) \tag{2}$$

Where, j>k. This is the number of positive differences minus the number of negative differences.

Firstly, the variance of M is computed by the following equation which account that the presence of a statistically significant trend is evaluated using the Z value.

$$VAR(M) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p \left(t_p - 1\right)\left(2t_p + 5\right) \right] \tag{3}$$

Where, q is the number of tied groups and t_p is the amount of data in the p^{th} group. Z is calculated using the formula below. A positive or negative value of Z indicates an increasing or decreasing trend.

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \tag{4}$$

The statistic Z has a normal distribution. To Test for either an upward or downward monotone trend (a two-tailed Test) at α level of significance, H_0 is rejected if the absolute value of Z is greater than Z_1-α/$_2$, where Z_1-α/$_2$ is obtained from the standard normal cumulative distribution tables. For instance, If the |Z|>2.575, then H_0 is rejected at 99% significance level, if |Z|>1.96, then H_0 is rejected at 95% significance level, if |Z|>1.645, H_0 is rejected at 90% significance level.

The Sen estimator of Slope's method is used in cases where the trend can be assumed to be linear. This means that f(t) is equal to

$$f(t) = Rt + C \tag{5}$$

Where R is the slope and C is a constant.

For estimating the slope estimate R, we first calculate the slopes of all data value pairs

$$R_i = \frac{x_j - x_k}{j - k} \tag{6}$$

Where j>k

If there is n values x_j in the time series, we will get as many as N = n(n-1)/2 slope estimates of $R_{i.}$

The slope is the median of these N values of R_i. The N values of R_i are ranked from the smallest to the largest and the Sen's estimator is

$$R = R_{\left[(N+1)/2\right]},\ if\ N\ is\ odd. \tag{7}$$

Or

$$R = \frac{1}{2}\left(R_{[N/2]} + R_{\left[(N+2)/2\right]}\right),\ if\ N\ is\ even. \tag{8}$$

In this paper, the Mann-Kendall statistics and Sen's Slope is directly calculated in R-Studio using the "Trend" package.

Innovative Trend Analysis (ITA):

ITA is not affected by serial correlation. Therefore, the procedure is not required for ITA. Innovative Trend Analysis (ITA) was developed by Zekai Sen as an alternative to conventional Mann Kendall test for trend analysis. Unlike the Mann-Kendall test and others, ITA is free from the problem of serial correlation in a time series and have no assumptions. It is solely based on the comparison of two ascendingly ordered halves from the original series [28,29]. The basis of the method conceptualized on the fact that if two similar time series are plotted on a 1:1 (45°) line on the Cartesian coordinate system, they will show a scatter plots [30]. Whether the time series is trend free or with trend, all the data points fall on the 1:1 upon plotting. This plot is not affected by the non-normality or normality of the distribution or small sample size or serial correlations. The only criterion is that the data points are sorted either in ascending or descending order along the 1:1 line.

The details of the ITA as proposed by [30] is given below:

1. The time series is divided into two equal halves arranged in ascending or descending order.
2. The first series and second series are positioned on the X-axis and Y-axis respectively.

Interpretation:

If the data are gathered or confined along the 1:1 ideal line, it indicates that the time series has no trend. If the data are positioned on the upward border of the ideal line, it indicates positive trend. If the data are consolidated on the downward triangular space of the ideal line, it represents a downward or negative trend in the time series [30]. In case, if the data points are scattered on both sides of the ideal (no trend) line, this means that the time series have both increasing and decreasing trends at different time scales (Figure 1). Accordingly, the interpretations must be done as many time series tends to depict both upward and downward trend along certain time scales. In this kind of cases, the scatter plots can be divided into three clusters as low, middle and high groups.

In the present study, the analysis is done using R Studio environment using the packages, "trendchange", "Kendall", "Trend". Analysis is executed for annual and seasonal (JF, MAM, JJAS and OND) period for each of the grid points.

Trend in different intensities of rainfall is also examined for low, medium and high rainfall intensity category. The division of these categories are done on the basis of percentile of data series: low <30th percentile, 30th percentile>medium>70th percentile, high>70th percentile. Most authors add a confidence limit interval (negative and positive at 90 per cent and 95 per cent) to represent the difference between each data points and the 1:1 (no trend) line. However, owing to the limitation of the ITA, there is “no single objective method to evaluate the limits on the ITA plots” [31]. Therefore, in this paper 0.5 and 1 bands are added only to help visualize the distance of the points from the no trend line, without attaching any statistical meaning to it. 0.5 and 1 band is the 5 per cent and 10 per cent value of the highest unit of the data series.

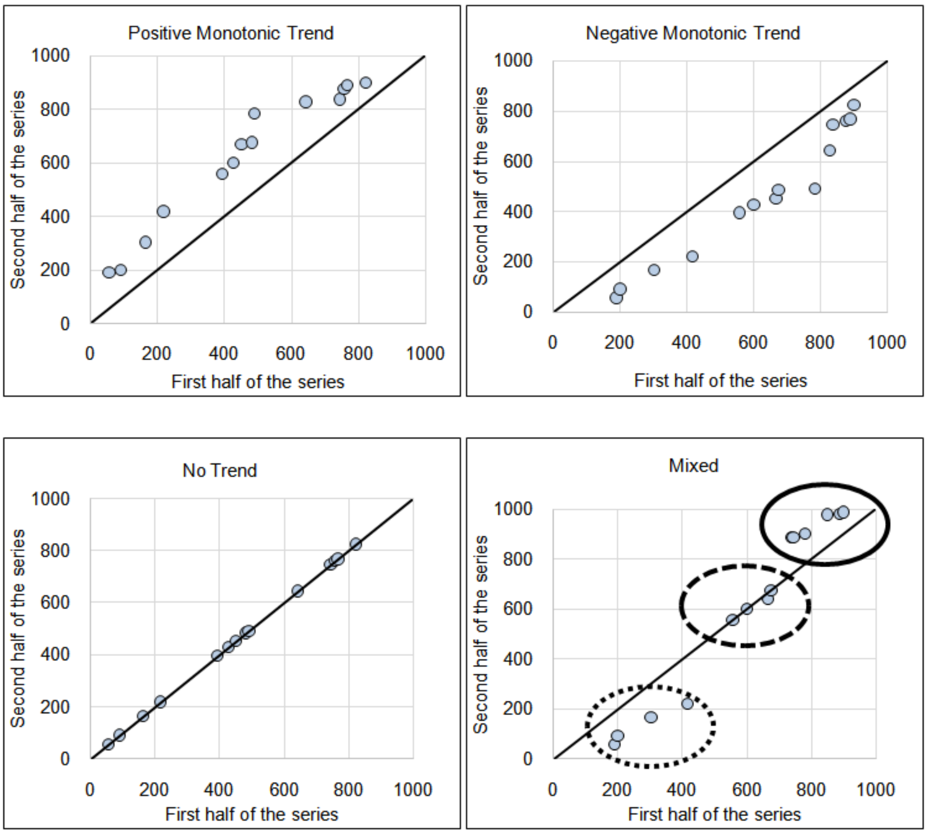


Figure 1. Type of Trend in ITA graph plot

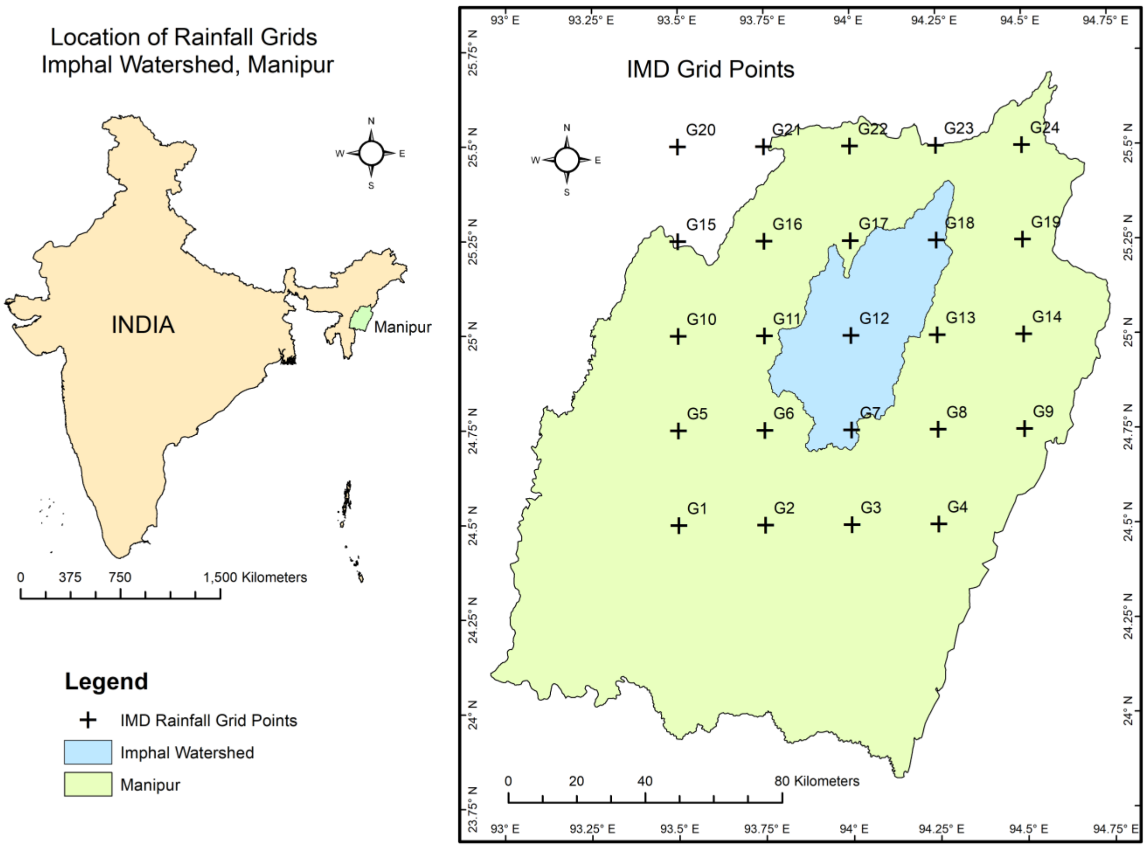


Figure 2. Study Area

The slope of the ITA trend line is given by the equation

$$X = \frac{2(\overline{S_j} - \overline{S_i})}{n} \quad (9)$$

Where, X is the ITA slope, $\overline{S_i}$ mean of first half series, $\overline{S_j}$ is the mean of second half series and n is the total number of data points.

X_α is the confidence limits of a standard normal distribution, with zero mean and standard deviation, σ_s. For 95 per cent and 90 per cent confidence limit, X_α corresponds to 1.96 and 1.645. If α is the level of significance, the confidence limit (CL) of the slope is given by

$$CL_{(1-\alpha)} = 0 \pm X_\alpha \sigma_s \quad (10)$$

Where σ_s is the slope standard deviation. The value of σ_s is calculated as

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}} \sigma \sqrt{1 - \rho_{\overline{S_i}\,\overline{S_j}}} \quad (11)$$

$\rho_{\overline{S_i}\,\overline{S_j}}$ is the cross correlation coefficient between the mean sorted S_i and S_j series.

If the slope lies between the upper (UL) and lower confidence (LL) limit, the time series is considered to have no trend [28].

3. Results and Discussion

There are total of 24 grid points named G1 to G24 taken into account for studying the rainfall characteristics of Imphal watershed (Figure 2). The overall mean annual rainfall of all the grids is 1573.67 mm with a standard deviation of 129.38 mm and a coefficient of variation of 8.22%. The seasonal mean rainfall of all the grids is 46.08 mm, 362.02 mm, 999.19 mm and 166.38 mm for JF, MAM, JJAS and OND respectively with a standard deviation of 1.83 mm, 46.81 mm, 82.35 mm and 4.68 mm (Table 1 and Figure 3). Pre-Monsoon season has the highest variation of 12.9% followed by Monsoon (8.24%) and Winter (3.98%).

Grid G1 has the highest annual mean rainfall of 1946.4 mm and G14 has the lowest annual mean rainfall of 1454.1 mm. G1 also have highest mean pre-monsoon rainfall (478.6 mm), mean monsoon rainfall (1239.4 mm) and mean post-monsoon rainfall (180.9 mm) among the 24 grids. G15 has the highest mean winter rainfall of 51.6 mm while G22 has the lowest mean winter rainfall. G11 has lowest mean monsoon rainfall (910 mm) and mean post-monsoon rainfall (159.1mm) while G23 has lowest mean pre-monsoon rainfall of 315.1 mm.

Table 1. Details on the Rainfall Grid Points, Imphal Watershed

Grid Points	Longitude	Latitude	Record Period	Mean annual Rainfall (mm)	Mean winter (mm)	Mean Pre-Monsoon (mm)	Mean Monsoon (mm)	Mean Post-Monsoon (mm)
					(JF)	(MAM)	(JJAS)	(OND)
G1	93.5	24.5	1901-2020	1946.4	47.57	478.57	1239.35	180.89
G2	93.75	24.5	1901-2020	1673.98	46.19	397.17	1062.34	168.28
G3	94	24.5	1901-2020	1590.61	46.19	368.9	1009.14	166.38
G4	94.25	24.5	1901-2020	1511.62	45.02	342.29	959.18	165.12
G5	93.5	24.75	1901-2020	1791.31	47.09	446.13	1125.58	172.52
G6	93.75	24.75	1901-2020	1591.44	46.84	383.78	995.84	164.98
G7	94	24.75	1901-2020	1552.39	45.83	360.36	981.3	164.9
G8	94.25	24.75	1901-2020	1531.7	45.99	348.35	971.41	165.94
G9	94.5	24.75	1901-2020	1461.99	45.49	326.94	923.69	165.87
G10	93.5	25	1901-2020	1747.07	49.53	433.15	1093.51	170.88
G11	93.75	25	1901-2020	1482.1	46.93	366.03	910	159.14
G12	94	25	1901-2020	1483.31	46.31	353.47	922.43	161.1
G13	94.25	25	1901-2020	1495.29	46.31	339.3	944.15	165.53
G14	94.5	25	1901-2020	1454.07	45.39	322.29	920.68	165.71
G15	93.5	25.25	1901-2020	1819.65	51.64	447.66	1147.36	172.99
G16	93.75	25.25	1901-2020	1479.4	46.03	355.09	918.27	160
G17	94	25.25	1901-2020	1489.61	45.91	334.57	944.05	165.08
G18	94.25	25.25	1901-2020	1506.73	45.91	325.72	967.34	167.77
G19	94.5	25.25	1901-2020	1497.06	45.3	321.43	963.62	166.71
G20	93.5	25.5	1901-2020	1586.31	46.23	364.93	1013.2	161.95
G21	93.75	25.5	1901-2020	1478.85	43.19	326.72	947.85	161.09
G22	94	25.5	1901-2020	1502.33	42.82	315.16	979.77	164.58
G23	94.25	25.5	1901-2020	1547.51	44.31	315.07	1020.35	167.79
G24	94.5	25.5	1901-2020	1547.24	43.85	315.42	1020.04	167.93
Mean (mm)				1573.67	46.08	362.02	999.19	166.38
Standard Deviation (mm)				129.38	1.83	46.81	82.35	4.68
Coefficient of Variation (%)				8.22	3.98	12.93	8.24	2.81

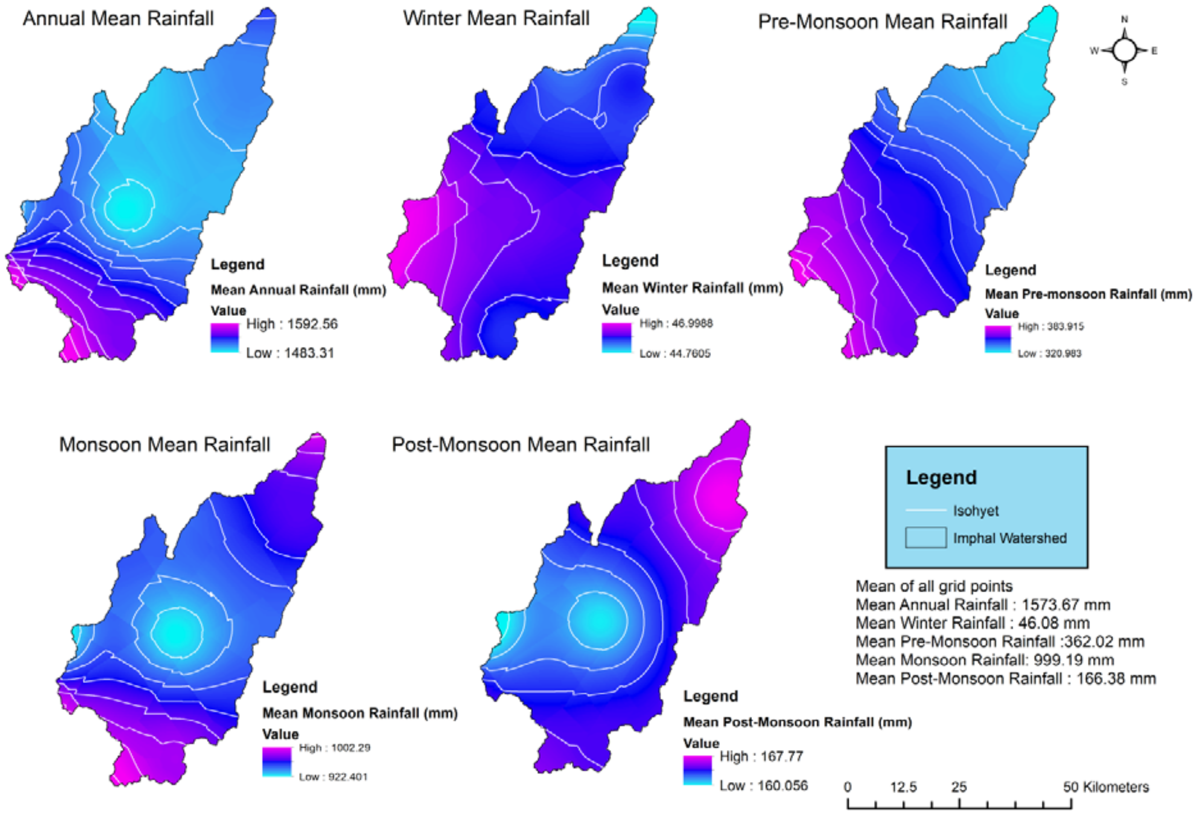
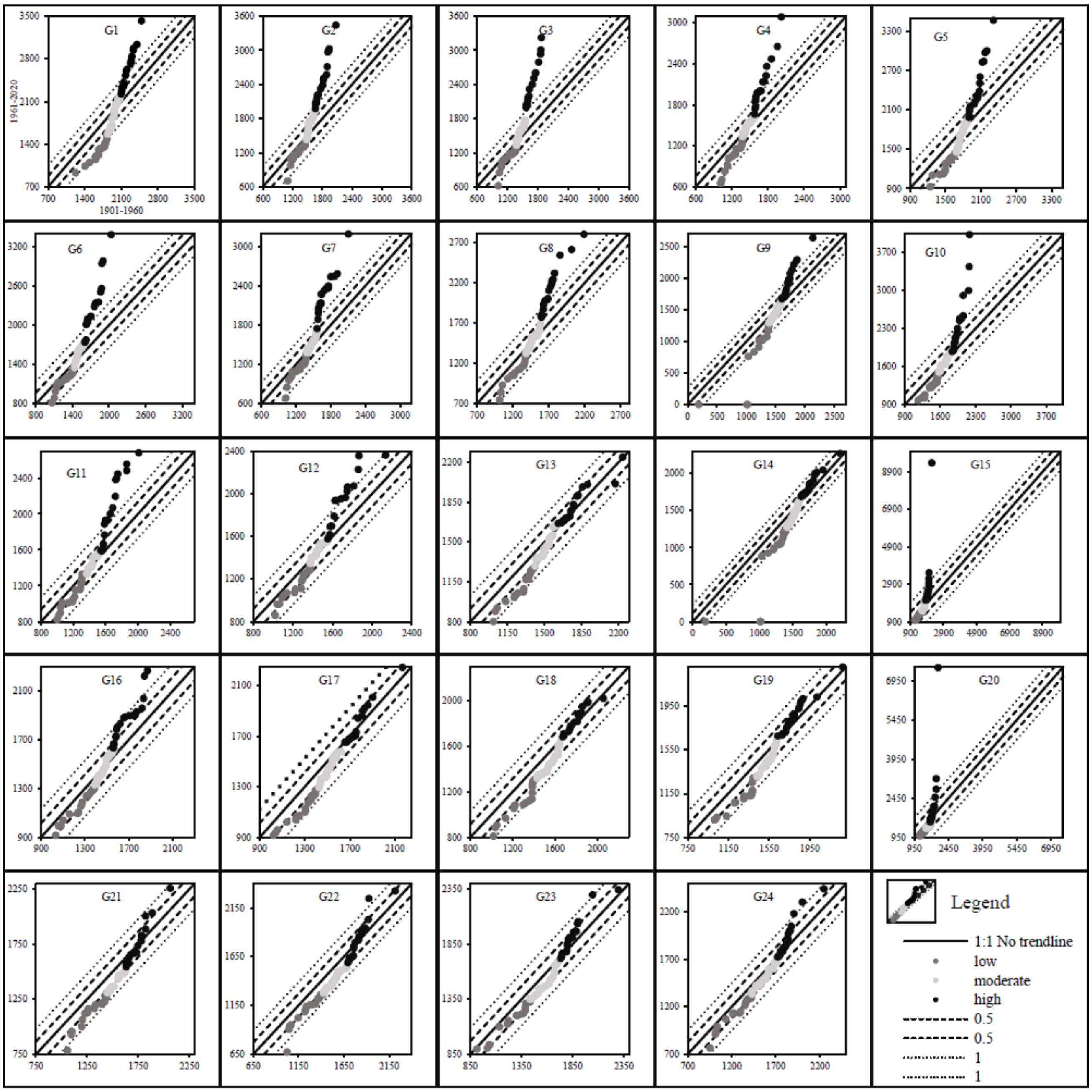


Figure 3. Annual and Seasonal Mean Rainfall of Imphal Watershed

Table 2. Result of ITA slope, MK test and Linear Regression for Annual Rainfall.

Grid	S	σ_s	LL	UL	Trend (ITA)	L	M	H	Sen's Slope	Z	p-value	b
G1	-0.41	0.16	-0.32	0.32	-	-21.6	-2.93	22.23	1.31	1.09	0.28	1.61
G2	3.68	0.15	-0.30	0.30	+	-6.85	6.21	36.74	2.84	2.95*	0.00	4.02*
G3	3.89	0.19	-0.37	0.37	+	-6.80	4.30	42.38	2.26	2.56*	0.01	3.80*
G4	1.17	0.11	-0.21	0.21	+	-10.2	0.80	21.84	0.72	1.00	0.32	1.09
G5	0.20	0.16	-0.31	0.31	No	-14.9	-2.59	21.84	0.99	1.05	0.30	2.02
G6	2.59	0.17	-0.34	0.34	+	-6.74	2.97	30.24	1.84	2.37*	0.02	3.26*
G7	2.48	0.16	-0.31	0.31	+	-6.95	1.78	31.35	1.42	1.79	0.07	2.52*
G8	1.25	0.12	-0.23	0.23	+	-8.06	0.25	21.56	0.85	1.03	0.30	1.50
G9	-0.66	0.21	-0.42	0.42	-	-17.2	-1.82	13.19	-0.43	-0.55	0.58	-1.23
G10	1.31	0.25	-0.50	0.50	+	-10.5	-0.52	26.04	0.74	0.84	0.40	1.91
G11	1.41	0.14	-0.28	0.28	+	-5.46	0.53	20.22	1.28	1.85	0.06	2.36*
G12	0.58	0.10	-0.19	0.19	+	-5.48	0.41	11.15	0.90	1.40	0.16	1.35
G13	-1.10	0.08	-0.16	0.16	-	-9.29	-2.24	1.09	-0.30	-0.40	0.69	-0.32
G14	-1.60	0.20	-0.39	0.39	-	-16.4	-3.14	4.23	-0.76	-0.91	0.36	-1.64
G15	3.28	0.98	-1.93	1.93	+	-10.4	-1.63	49.79	0.42	0.44	0.66	1.76
G16	0.41	0.08	-0.16	0.16	+	-5.24	-0.31	10.32	0.58	0.86	0.39	0.77
G17	-1.16	0.05	-0.11	0.11	-	-8.28	-3.01	0.76	-0.53	-0.85	0.40	-0.47
G18	-1.44	0.08	-0.15	0.15	-	-9.60	-4.36	1.34	-0.85	-1.10	0.27	-0.76
G19	-1.03	0.19	-0.37	0.37	-	-7.52	-3.74	2.68	-0.38	-0.50	0.62	-0.50
G20	0.08	0.78	-1.54	1.54	No	-11.8	-7.80	26.53	-2.16	-3.3*	0.00	-1.17
G21	-1.64	0.07	-0.14	0.14	-	-9.06	-5.40	0.46	-0.93	-1.26	0.21	-0.81
G22	-1.63	0.09	-0.18	0.18	-	-8.48	-5.70	0.45	-0.60	-0.71	0.48	-0.49
G23	-0.80	0.09	-0.17	0.17	-	-5.74	-3.72	3.48	0.23	0.29	0.77	0.18
G24	-0.57	0.08	-0.16	0.16	-	-6.38	-2.75	4.94	0.46	0.48	0.63	0.37

*Statistically significant at 95% CL; S = ITA's Slope; σ_s = Slope Standard Deviation; LL = Lower Limit at 95% CL; UL = Upper Limit at 95% CL; L = Low, M= Medium, H = High Rainfall category (Slope); Z = MK statistics; b = linear regression slope.



(G1-G24: X-Axis represents 1901 to 1960, Y-Axis represents 1961-2020)

Figure 4. ITA graphical plot, Annual Rainfall

Annual Rainfall:

The results for annual rainfall are given in Table 2 and Figure 4. The graphical plots divide the annual points into three different categories as mentioned in the methodology which can be differentiated by different shades. A visual examination of the graphical plots of the slope shows the presence of both positive and negative trend. G1 to G11 shows positive deviation from the 1:1 line in the high category rainfall while the low rainfall seems to deviate negatively from the 1:1 line. G16 and G21 have positive deviation from the no trend line but this seems to be influenced by one extreme value. G13, G14, G17, G18, G19, G21, G22, G23 and G24 have rainfall points within the confine of the 5% and 10% band in all the categories. All the Grids have the low and medium rainfall within the bands but the high rainfall falls out of the bands indicating marked increasing trends in this category. All the grids except G13,G14,G17,G18,G19, G21, G22 and G24 have high rainfall outside the two referenced bands.

Among the grids, ITA show a total of 11(45.8%) grids with positive trend, 11 (45.8%) grids with negative trend and two grids with no trend. MK test shows 15 (62.5%) grids with increasing out of which only three grids G2, G3 and G6 show statistically significant trend at 95 percent confidence level (CL), 9 grids have negative trends out of which only G20 has significant negative trend at 99 percent CL. Increasing tendency of G7 and G11 are significant at 90 percent CL.

Winter Rainfall:

All the 24 grids have negative deviation from the 1:1 line but there is one point (extreme value) having positive deviation from the 1:1 line in all the grids except G23 and G24 (Table 3 and Figure 5). This extreme deviation is due to the extreme rainfall events in the year 1993 during the month of February where there were cases of very high rainfall(17th and 18th february). The mean departure was much higher in these two isolated cases. For instance, the mean rainfall on 17th and 18th february for all the 120 years were 2.8 mm and 2.3 mm. But the rainfall on the same date in 1993 were 76.2 mm and 93.5 mm for G1. These exceptional cases are the reasons behind the unusually extreme positive deviation in the high rainfall category for Winter season. Low and Medium Rainfall falls within the two bands but the high rainfall have high negative distance from the no trend line in all the grids except G10. However, ITA analysis shows negative trends in all the 23 (88.5%) grids and no trend in one grid (G15). The result is similar to that obtained via MK test.

MK test show significant negative trend in G9, G14, G18, G19, G20, G21, G22, G23 and G24 with a Sen's slope of ranging between -0.16 to -0.19 mm/yr. Among the different category of rainfall intensities, all the grids shows negative trend in all the category except G15 that have no trend.

Pre-Monsoon Rainfall:

There are cases of extreme point positive deviation in G1, G2, G3, G4, G5 and G6. This extreme deviation is due to extreme rainfall event in the year 2004 during the pre-monsoon season. Low and Medium Rainfall are confined within the band and much closer to the 1:1 line indicating almost no trend tendency. However, high rainfall have shown positive deviation in case of G1, G2, G3, G5, H6, G7, G8, G11, G12, G15 and G20. All the other grids have the high rainfall within the bands. All the three categories shows increasing tendency. Among the grids, 14 (58.3%) grids show positive trend, 6 (25%) show negative trend and 4 grids (G1, G9, G18, G19) have no trend (Table 4 and Figure 6).

The ITA slope for the grids ranges between -0.01 to 1.05 mm/year. MK test show significant increasing tendency in five grids, G2, G3, G6, G7 and G11 with a Sen's slope of 1.01 mm/yr, 0.99 mm/yr, 0.92 mm/yr, 0.84 mm/yr, 0.80 mm/yr respectively.

Monsoon:

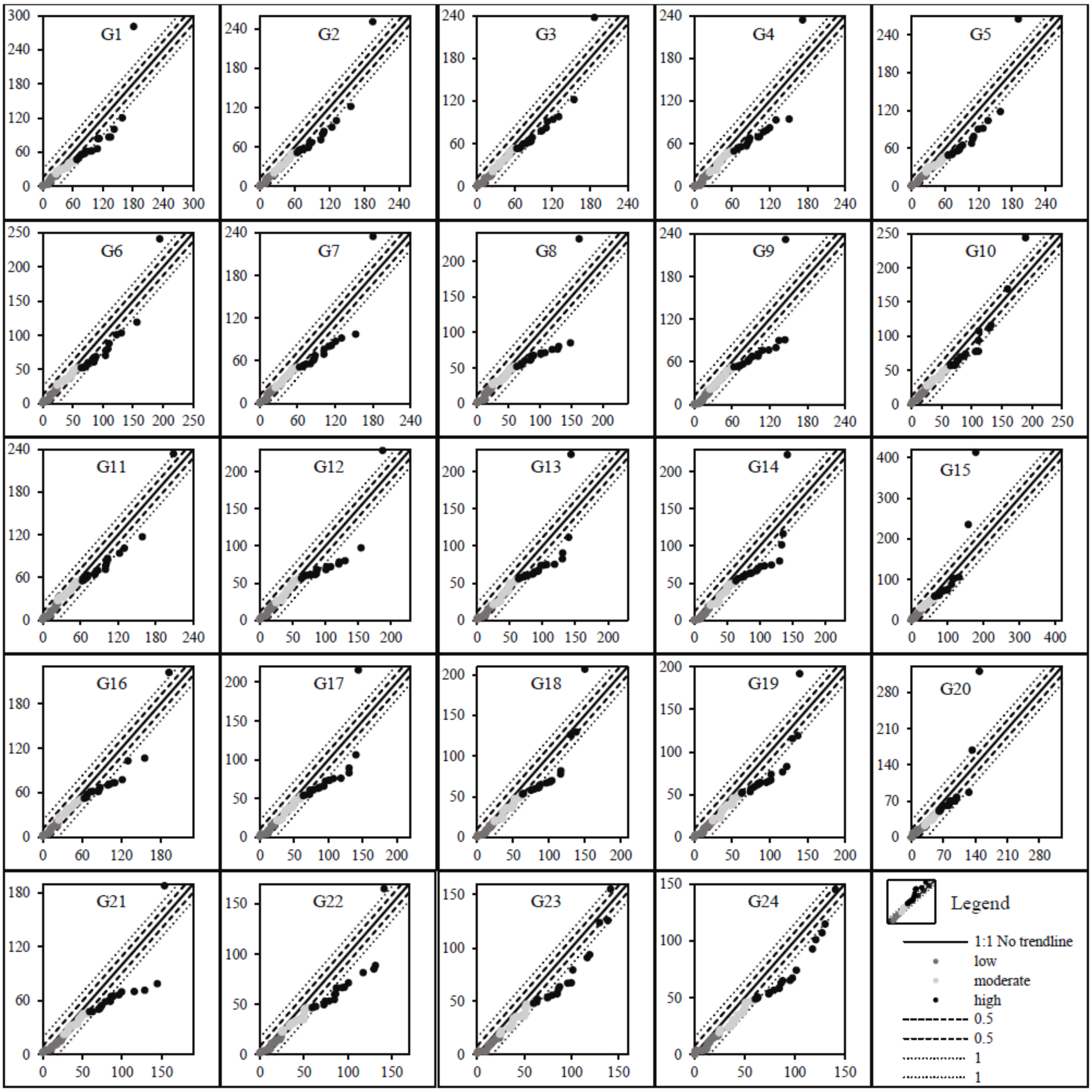
There is clear positive deviation in the high rainfall in G1 to G12. G15 and G20 have cases of extreme point deviation from 1:1 line which is influencing the overall trend line. Low and Medium category rainfall are showing negative deviation in all the grids but they are within the confine of the bands. Only the Grid G13 to G24 have prominent negative distance from the 1:1 line. High rainfall in G13, G14, G16 to G18, G21 to G24 are within the bands and almost along the no trend line. 37.5% of the grids (9 grids) shows positive trend, 41.7% (10 grids) shows negative trends while 20.83% shows no trend. G5 seems to have trend as per the graphical plot but according to the ITA slope calculation, it has no trend (Table 5 and Figure 7).

MK test shows 10 grids (41.7%) with increasing trend, 14 (58.3%) with negative trend while linear regression shows 15 (62.5%) with positive trend and 9 (37.5%) grids with negative trends. G2 and G20 is statistically significant at 95% CL while G3, G9, G14, G18 are significant at 90% CL.

Table 3. Result of ITA slope, MK test and Linear Regression for Winter Rainfall.

Grid	S	σ_s	LL	UL	Trend (ITA)	L	M	H	Sen's Slope	Z	P value	b
G1	-0.22	0.03	-0.06	0.06	-	-0.23	-0.48	-1.34	-0.13	-1.68	0.09	-0.16
G2	-0.16	0.02	-0.04	0.04	-	-0.16	-0.29	-1.10	-0.09	-1.15	0.25	-0.11
G3	-0.14	0.02	-0.03	0.03	-	-0.20	-0.22	-0.98	-0.09	-1.10	0.27	-0.11
G4	-0.18	0.02	-0.04	0.04	-	-0.24	-0.30	-1.28	-0.14	-1.74	0.08	-0.16
G5	-0.19	0.02	-0.05	0.05	-	-0.18	-0.37	-1.29	-0.12	-1.41	0.16	-0.14
G6	-0.13	0.02	-0.04	0.04	-	-0.09	-0.15	-1.06	-0.08	-1.03	0.30	-0.10
G7	-0.15	0.02	-0.04	0.04	-	-0.10	-0.22	-1.23	-0.10	-1.39	0.16	-0.13
G8	-0.16	0.03	-0.05	0.05	-	-0.07	-0.20	-1.34	-0.13	-1.61	0.11	-0.15
G9	-0.18	0.03	-0.05	0.05	-	-0.27	-0.27	-1.30	-0.17	-2.1*	0.03	-0.19
G10	-0.08	0.02	-0.03	0.03	-	-0.05	-0.17	-0.59	-0.10	-1.18	0.24	-0.11
G11	-0.09	0.01	-0.03	0.03	-	-0.09	-0.02	-0.92	-0.08	-1.07	0.29	-0.11
G12	-0.14	0.02	-0.04	0.04	-	-0.06	-0.12	-1.27	-0.11	-1.51	0.13	-0.14
G13	-0.15	0.02	-0.05	0.05	-	-0.16	-0.23	-1.10	-0.14	-1.59	0.11	-0.15
G14	-0.19	0.02	-0.05	0.05	-	-0.30	-0.36	-1.11	-0.19	-2.3*	0.02	-0.20
G15	-0.02	0.04	-0.08	0.08	No	-0.08	-0.14	0.12	-0.12	-1.50	0.13	-0.11
G16	-0.14	0.02	-0.03	0.03	-	-0.11	-0.13	-1.21	-0.12	-1.54	0.12	-0.15
G17	-0.16	0.02	-0.05	0.05	-	-0.16	-0.27	-1.15	-0.16	-1.86	0.06	-0.17
G18	-0.17	0.02	-0.04	0.04	-	-0.21	-0.33	-1.05	-0.16	-2.1*	0.03	-0.18
G19	-0.18	0.02	-0.04	0.04	-	-0.20	-0.35	-1.14	-0.17	-2.2*	0.03	-0.19
G20	-0.09	0.03	-0.07	0.07	-	-0.11	-0.35	-0.25	-0.16	-2.0*	0.04	-0.15
G21	-0.19	0.02	-0.04	0.04	-	-0.21	-0.29	-1.39	-0.17	-2.4*	0.02	-0.20
G22	-0.19	0.02	-0.03	0.03	-	-0.23	-0.34	-1.32	-0.18	-2.5*	0.01	-0.49
G23	-0.18	0.01	-0.02	0.02	-	-0.23	-0.37	-1.11	-0.17	-2.3*	0.02	0.18
G24	-0.18	0.01	-0.02	0.02	-	-0.23	-0.37	-1.16	-0.17	-2.2*	0.03	0.37

*Statistically significant at 95% CL; S = ITA's Slope; σ_s = Slope Standard Deviation; LL = Lower Limit at 95% CL; UL = Upper Limit at 95% CL; L = Low, M= Medium, H = High Rainfall category (Slope); Z = MK statistics; b = linear regression slope.



(G1-G24: X-Axis represents 1901 to 1960, Y-Axis represents 1961-2020)

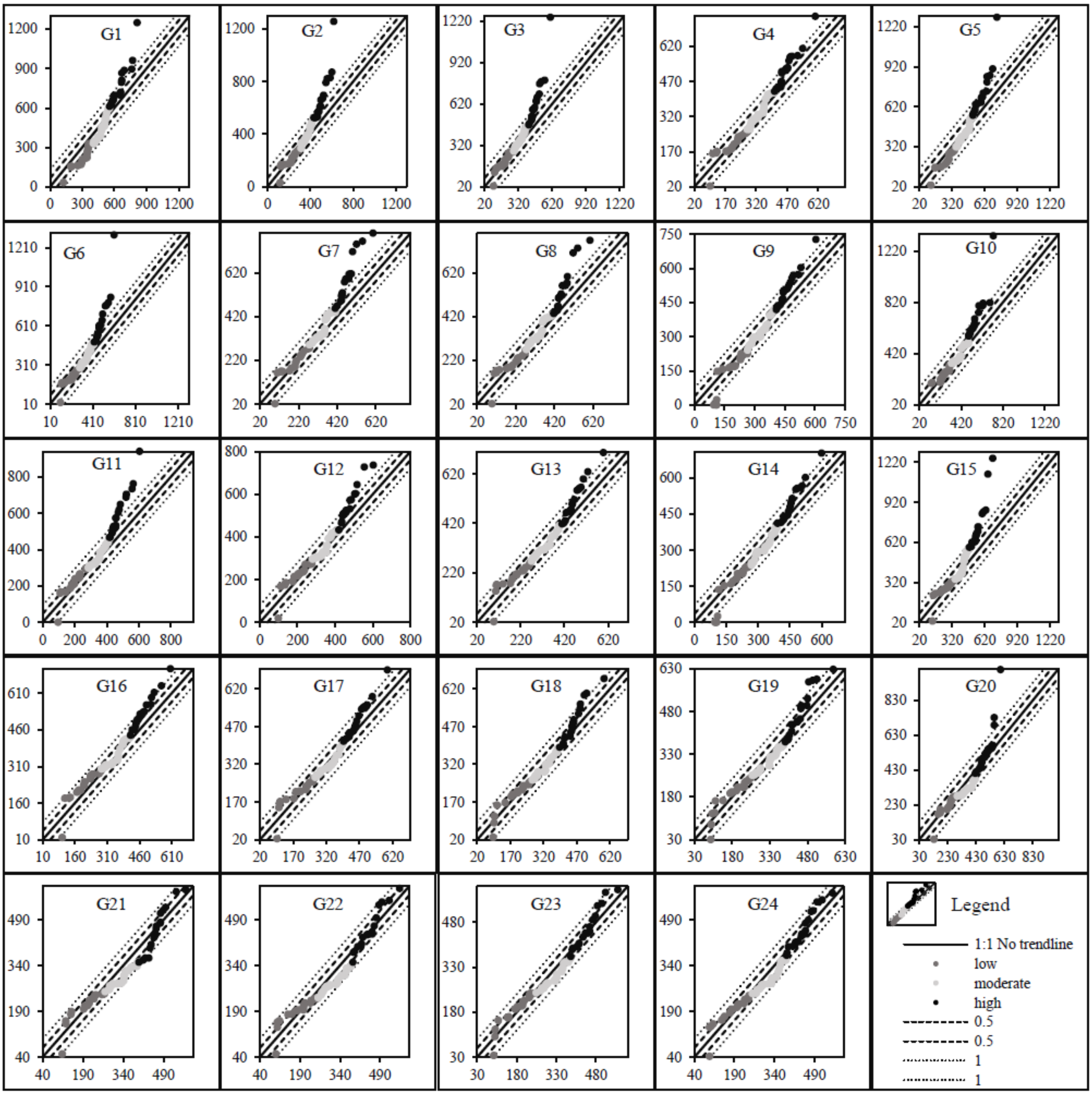
Figure 5. ITA graphical plot, Winter Rainfall, Imphal Watershed

Table 4. Result of ITA slope, MK test and Linear Regression for Pre-Monsoon Rainfall.

Grid	S	σ_s	LL	UL	Trend (ITA)	L	M	H	Sen Slope	Z	p-value	b
G1	-0.11	0.07	-0.14	0.14	No	-4.74	-1.64	6.40	0.41	0.80	0.43	0.72
G2	0.91	0.09	-0.17	0.17	+	-1.01	1.06	9.26	1.01	2.4*	0.02	1.41
G3	0.98	0.09	-0.17	0.17	+	0.05	1.04	9.02	0.99	2.3*	0.02	1.38
G4	0.26	0.04	-0.08	0.08	+	-0.27	0.02	3.08	0.42	1.07	0.28	0.53
G5	0.25	0.08	-0.16	0.16	+	-2.86	-0.79	7.06	0.63	1.24	0.22	0.95
G6	0.93	0.10	-0.19	0.19	+	-0.16	0.79	9.14	0.92	2.2*	0.03	1.36
G7	0.71	0.05	-0.10	0.10	+	0.27	0.77	6.30	0.84	2.0*	0.04	1.06
G8	0.43	0.05	-0.10	0.10	+	0.03	0.20	4.43	0.57	1.52	0.13	0.77
G9	-0.02	0.03	-0.06	0.06	No	-2.08	-0.40	2.62	0.12	0.34	0.73	0.13
G10	0.65	0.09	-0.18	0.18	+	-0.25	0.05	7.40	0.70	1.57	0.12	1.03
G11	0.80	0.06	-0.12	0.12	+	0.98	0.55	6.90	0.80	2.1*	0.03	1.09
G12	0.48	0.05	-0.09	0.09	+	0.82	0.23	4.13	0.63	1.67	0.09	0.78

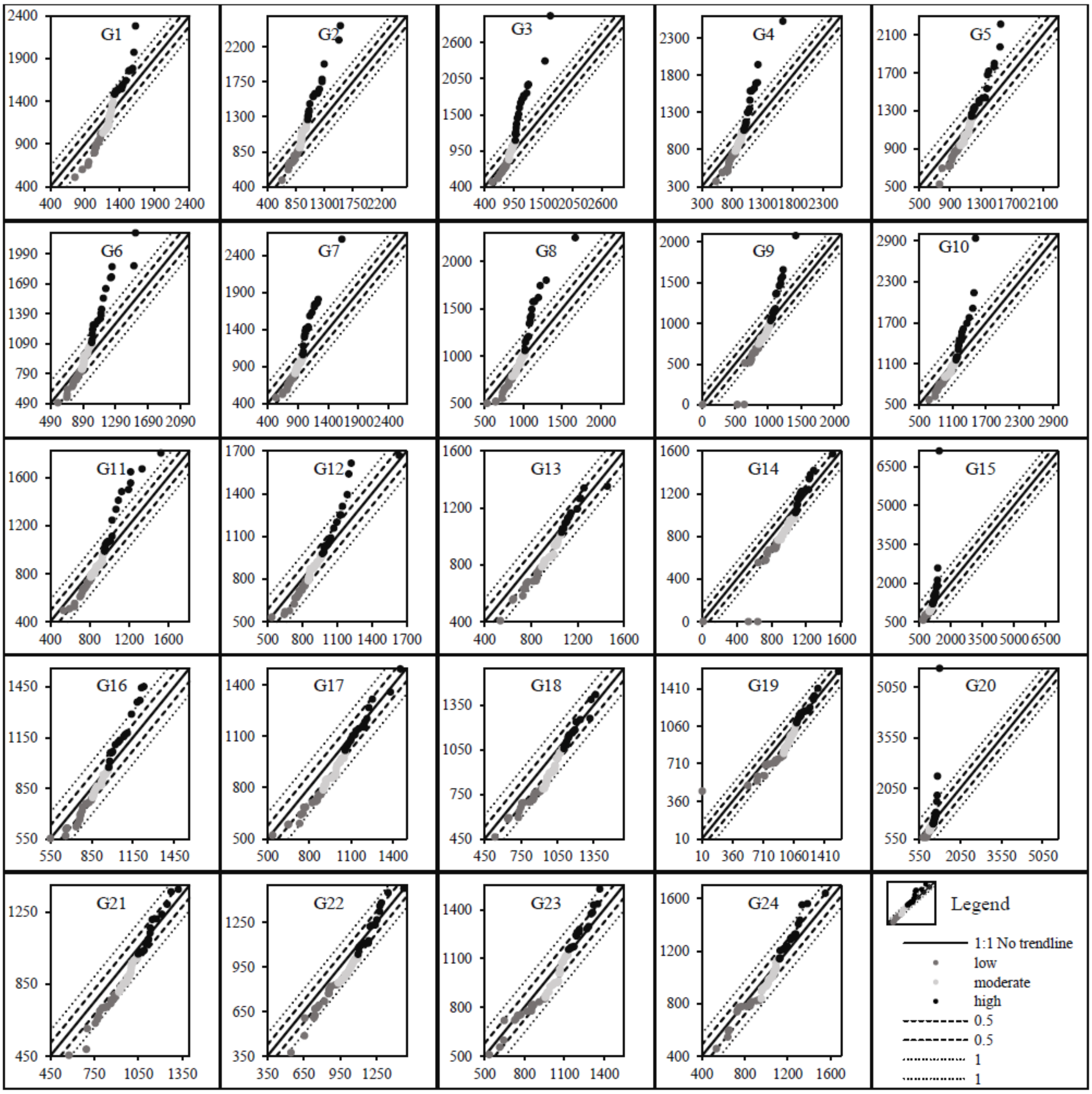
Grid	S	σ_s	LL	UL	Trend (ITA)	L	M	H	Sen Slope	Z	p-value	b
G13	0.24	0.04	-0.08	0.08	+	0.42	-0.22	2.61	0.46	1.23	0.22	0.53
G14	-0.09	0.03	-0.06	0.06	-	-1.80	-0.74	2.08	0.06	0.16	0.87	0.05
G15	1.05	0.10	-0.19	0.19	+	0.28	0.74	10.03	0.65	1.42	0.16	1.00
G16	0.42	0.04	-0.08	0.08	+	1.47	0.14	2.93	0.55	1.47	0.14	0.60
G17	0.12	0.04	-0.08	0.08	+	0.47	-0.50	1.79	0.32	0.90	0.37	0.40
G18	0.04	0.04	-0.07	0.07	No	0.01	-0.67	1.60	0.21	0.61	0.54	0.32
G19	-0.01	0.04	-0.08	0.08	No	0.07	-0.85	1.37	0.17	0.47	0.64	0.27
G20	-0.18	0.09	-0.17	0.17	-	-0.57	-2.10	2.30	-0.38	-1.18	0.24	-0.25
G21	-0.30	0.04	-0.09	0.09	-	0.12	-1.53	-0.70	-0.13	-0.42	0.67	-0.07
G22	-0.22	0.04	-0.08	0.08	-	0.14	-1.51	0.11	-0.06	-0.22	0.83	0.00
G23	-0.11	0.03	-0.07	0.07	-	0.26	-1.10	0.47	0.06	0.15	0.88	0.12
G24	-0.12	0.04	-0.07	0.07	-	0.28	-1.16	0.44	0.03	0.07	0.94	0.11

*Statistically significant at 95% CL; S = ITA's Slope; σ_s = Slope Standard Deviation; LL = Lower Limit at 95% CL; UL = Upper Limit at 95% CL; L = Low, M= Medium, H = High Rainfall category (Slope); Z = MK statistics; b = linear regression slope.



(G1-G24: X-Axis represents 1901 to 1960, Y-Axis represents 1961-2020)

Figure 6. ITA graphical plot, Pre-Monsoon Rainfall, Imphal Watershed



(G1-G24: X-Axis represents 1901 to 1960, Y-Axis represents 1961-2020)

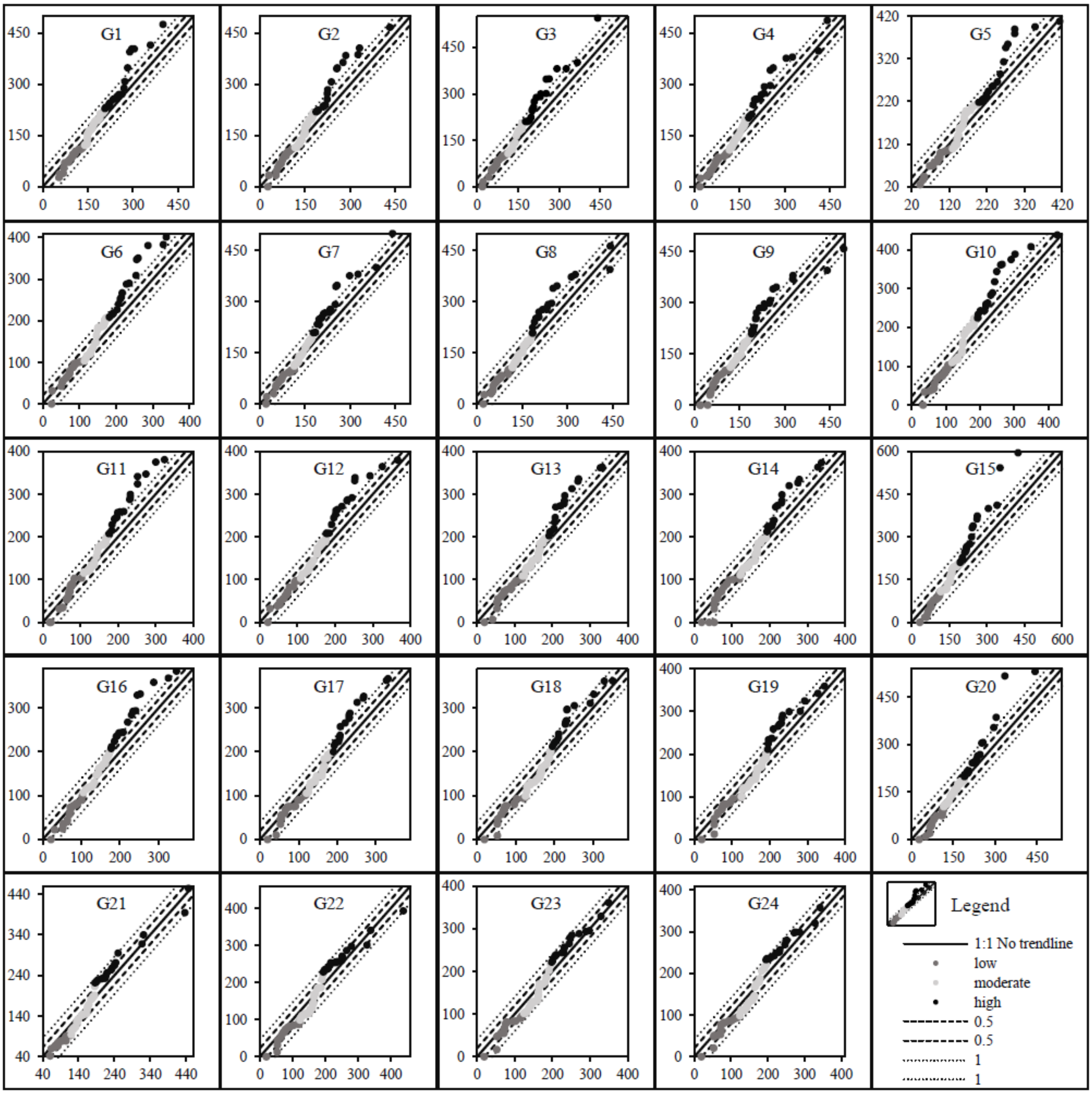
Figure 7. ITA graphical plot, Monsoon Rainfall, Imphal Watershed

Table 5. Result of ITA slope, MK test and Linear Regression for Monsoon Rainfall

Grid	S	σ_s	LL	UL	Trend (ITA)	L	M	H	Sen's Slope	z	p-value	b
G1	-0.25	0.09	-0.18	0.18	-	-10.77	-1.85	11.29	0.67	0.79	0.43	0.88
G2	2.57	0.07	-0.14	0.14	+	-3.51	4.25	24.53	1.60	2.4*	0.02	2.49*
G3	2.66	0.13	-0.26	0.26	+	-4.44	1.95	30.51	1.04	1.72	0.09	2.30*
G4	0.85	0.10	-0.20	0.20	+	-7.02	-0.97	18.14	-0.08	-0.12	0.90	0.61
G5	-0.05	0.08	-0.15	0.15	No	-7.25	-2.29	10.81	0.24	0.37	0.71	1.04
G6	1.46	0.09	-0.19	0.19	+	-4.34	1.24	18.33	0.93	1.50	0.13	1.80
G7	1.61	0.11	-0.22	0.22	+	-4.59	-0.16	22.80	0.43	0.74	0.46	1.44
G8	0.74	0.12	-0.24	0.24	+	-5.71	-1.66	16.89	-0.07	-0.10	0.92	0.78
G9	-0.61	0.18	-0.34	0.34	-	-10.83	-3.59	10.47	-1.06	-1.71	0.09	-1.20
G10	0.45	0.18	-0.36	0.36	+	-5.73	-2.68	15.53	-0.11	-0.18	0.85	0.83
G11	0.39	0.08	-0.16	0.16	+	-4.09	-1.14	10.47	0.35	0.66	0.51	1.17
G12	-0.01	0.09	-0.17	0.17	No	-3.97	-0.92	5.46	0.18	0.42	0.68	0.59

Grid	S	σ_s	LL	UL	Trend (ITA)	L	M	H	Sen's Slope	z	p-value	b
G13	-1.25	0.06	-0.13	0.13	-	-6.52	-3.88	-0.45	-0.88	-1.51	0.13	-0.67
G14	-1.37	0.13	-0.26	0.26	-	-9.74	-4.19	1.95	-1.19	-1.92	0.05	-1.45
G15	2.00	0.78	-1.54	1.54	+	-6.10	-2.86	33.37	-0.31	-0.55	0.58	0.83
G16	-0.10	0.05	-0.10	0.10	No	-3.96	-1.58	5.61	-0.07	-0.16	0.88	0.21
G17	-1.17	0.05	-0.10	0.10	-	-5.82	-3.72	-0.57	-0.85	-1.60	0.11	-0.66
G18	-1.26	0.06	-0.12	0.12	-	-6.05	-4.12	-0.61	-0.95	-1.65	0.10	-0.79
G19	-0.82	0.13	-0.26	0.26	-	-3.85	-3.41	0.78	-0.57	-0.96	0.34	-0.50
G20	0.32	0.61	-1.19	1.19	No	-9.36	-4.39	20.72	-1.26	-2.7*	0.01	-0.62
G21	-1.12	0.04	-0.07	0.07	-	-6.48	-3.28	-0.09	-0.39	-0.79	0.43	-0.41
G22	-1.09	0.05	-0.10	0.10	-	-5.29	-3.83	-0.04	-0.11	-0.21	0.84	-0.12
G23	-0.37	0.08	-0.15	0.15	-	-2.30	-2.29	2.21	0.49	0.71	0.48	0.39
G24	-0.19	0.07	-0.14	0.14	-	-2.83	-1.76	3.86	0.64	1.01	0.31	0.55

*Statistically significant at 95% CL; S = ITA's Slope; σ_s = Slope Standard Deviation; LL = Lower Limit at 95% CL; UL = Upper Limit at 95% CL; L = Low, M= Medium, H = High Rainfall category (Slope); Z = MK statistics; b = linear regression slope.



(G1-G24: X-Axis represents 1901 to 1960, Y-Axis represents 1961-2020)

Figure 8. ITA graphical plot, Post-Monsoon Rainfall, Imphal Watershed

Table 6. Result of ITA slope, MK test and Linear Regression for Post-Monsoon Rainfall

Grid	S	σ_s	LL	UL	Trend (ITA)	L	M	H	Sen's Slope	z	p-value	b
G1	0.17	0.02	-0.04	0.04	+	-0.75	0.20	2.28	0.04	0.17	0.86	0.18
G2	0.36	0.02	-0.04	0.04	+	0.00	0.62	2.90	0.14	0.66	0.51	0.23
G3	0.39	0.02	-0.04	0.04	+	-0.04	0.70	3.12	0.16	0.75	0.46	0.23
G4	0.26	0.03	-0.05	0.05	+	-0.34	0.35	2.57	0.07	0.30	0.77	0.12
G5	0.19	0.03	-0.05	0.05	+	-0.38	0.35	1.88	0.08	0.37	0.71	0.18
G6	0.33	0.03	-0.06	0.06	+	0.03	0.59	2.53	0.17	0.70	0.48	0.21
G7	0.31	0.02	-0.04	0.04	+	-0.18	0.48	2.74	0.11	0.50	0.62	0.16
G8	0.24	0.03	-0.06	0.06	+	-0.26	0.24	2.49	0.05	0.25	0.80	0.10
G9	0.15	0.04	-0.07	0.07	+	-0.60	0.08	2.13	0.00	-0.01	0.99	0.02
G10	0.29	0.03	-0.05	0.05	+	-0.73	0.50	3.09	0.06	0.29	0.77	0.15
G11	0.32	0.03	-0.06	0.06	+	-0.22	0.54	2.79	0.15	0.71	0.48	0.21
G12	0.24	0.03	-0.06	0.06	+	-0.30	0.37	2.35	0.10	0.43	0.67	0.13
G13	0.06	0.05	-0.09	0.09	No	-0.54	-0.07	1.38	-0.03	-0.08	0.93	-0.03
G14	0.05	0.05	-0.10	0.10	No	-0.54	-0.13	1.33	-0.04	-0.20	0.84	-0.05
G15	0.26	0.02	-0.04	0.04	+	-1.21	0.09	3.96	-0.08	-0.36	0.72	0.05
G16	0.23	0.03	-0.06	0.06	+	-0.62	0.44	2.41	0.06	0.31	0.76	0.10
G17	0.05	0.05	-0.09	0.09	No	-0.56	-0.10	1.28	-0.03	-0.17	0.86	-0.04
G18	-0.05	0.05	-0.10	0.10	No	-0.61	-0.41	0.74	-0.08	-0.41	0.68	-0.12
G19	-0.03	0.05	-0.10	0.10	No	-0.46	-0.44	0.92	-0.06	-0.32	0.75	-0.08
G20	0.03	0.02	-0.04	0.04	No	-1.49	-0.22	2.17	-0.19	-0.92	0.36	-0.15
G21	-0.03	0.03	-0.05	0.05	No	-0.98	-0.30	1.13	-0.14	-0.65	0.52	-0.13
G22	-0.13	0.04	-0.07	0.07	-	-0.95	-0.59	0.56	-0.19	-0.84	0.40	-0.17
G23	-0.13	0.04	-0.09	0.09	-	-0.74	-0.52	0.18	-0.12	-0.48	0.63	-0.14
G24	-0.07	0.04	-0.08	0.08	No	-0.70	-0.37	0.53	-0.08	-0.30	0.76	-0.09

S = ITA's Slope; σ_s = Slope Standard Deviation; LL = Lower Limit at 95% CL; UL = Upper Limit at 95% CL; L = Low, M= Medium, H = High Rainfall category (Slope); Z = MK statistics; b = linear regression slope.

Post-Monsoon Rainfall:

The high intensity rainfall in G1 to G3, G5 to G8, G10 to G12, G15 and G16 have positive deviation slightly outside the bands. The rest of the grids have points within the bands where low and medium rainfall have values along the 1:1 line in most grids. Only G22 and G23 have slight negative deviation from the 1:1 line in the low and medium category. Both low and high rainfall have no clear tendency. 58.3% (14 grids) of the grids show positive tendency, 8.3% show negative trends, 33.33% grids have no trend (Table 6 and Figure 8). 95.8% grids have negative trend in low rainfall while 100% of the grids have positive trend in high category post-monsoon rainfall. 58.3% of the grid have increasing trend in medium category rainfall while the remaining grids have negative trend in the said category. MK test shows 50% of the grids with positive and other 50% with negative trend but none of them significant.

The study was mainly to evaluate the Innovative Trend Analysis (ITA) technique as a tool for analysing the trend in any time series, in this case, Rainfall. Imphal watershed has only one working station where there is issue for data inconsistency. This data gap was filled by the use of gridded data as developed by Indian Meteorological Department. From the above study, it is apparent that the technique was able to diagnose the behaviour of the rainfall in each of the grid points covering the Imphal watershed. It was able to categorise the rainfall into three different classes (low, medium, high) and examined the pattern. For instance, it was observed that high intensity rainfall has a increasing tendency while the low and medium intensity rainfall tends to have no trend or negative trend. At the same time, it was also observed that winter rainfall have consistent negative trend in all the grid points. A general observation of the grid points showed that the grid points located in the northern part has no trend or negative trend while the grid points on the southern part of the watershed shows mostly positive tendency in the rainfall pattern.

4. Conclusion

The study deals with the rainfall characteristics of Imphal watershed. The IMD gridded data was used to understand the overall rainfall trend behavior of the watershed. Annual Rainfall have both negative and positive trend in the grid points. Winter rainfall has negative trend in all the grids. The southern part of the grid points experiences positive changes while the northern part has either no trend or negative trend. G2, G3 and G6 have significant positive trends during annual rainfall and pre-monsoon rainfall. The study was conducted using ITA in comparison to MK test. The category wise analysis shows that high rainfall in all the grids have positive tendency while the low and medium rainfall have negative or no trend behavior. As reiterated by other authors, ITA is a reliable tool for understanding the trend and unveiling the hidden trend of time series. However, it is also observed that there are varying results obtained by the two methods. There have been cases of very high rainfall which seems to affect the overall trend and the slope of change. These cases should be treated with exception and cannot be considered in the overall trend of the series significantly. The lack of sufficient number of station data is a drawback. But gridded data can be used as an alternative to tackle this problem.

Acknowledgements

The author would like to thank Indian Meteorological Department for providing the rainfall data. Much gratitude is owed to Prof. Milap Chand Sharma for his mentorship and moral support. The author also like to thank Mr. Sachidanand Kumar of IIT (ISM) Dhanbad for his valuable technical support in handling of gridded data.

References

[1] Chaubey, I., Haan, C. T., Salisbury, J. M., and Grunwald, S., "Quantifying model output uncertainty due to spatial variability of rainfall," *Journal of the American Water Resources Association*, 35(5). 1113-1123. May 1999.

[2] Sangati, M. and Borga, M., "Influence of rainfall spatial resolution on flash flood modelling," *Natural Hazards and Earth System Science*, 9(2). 575-584. February 2009.

[3] Lee, H., Mcintyre, N., Wheater, H., and Young, A., "Selection of conceptual models for regionalisation of the rainfall-runoff relationship," *Journal of Hydrology*, 3(12). 125-147. December 2005.

[4] Srivastava, H. N., Ray, K. C. S., Dikshit, S. K., and Mukhopadhyay, R. K., "Trends in rainfall and radiation over India," *Vayu Mandal*, 22(6). 41-45. June 1998.

[5] Bhaskar Rao, Srinivas, D., and Ratna, S. B., "Development of a high resolution daily gridded temperature data set (1969-2005) for the Indian region," *Atmospheric Science Letters*, 10(10). 249-254. October 2009.

[6] Goswami, B. N., Venugopal, V., Sangupta, D., Madhusoodanan, M. S., and Xavier, P. K., "Increasing trend of extreme rain events over India in a warming environment," *Science*, 314(5804). 1442-1445. December 2006.

[7] Joshi, M. K. and Pandey, A. C., "Trend and spectral analysis of rainfall over India during 1901 - 2000," *Journal of Geophysical Research*, 116(12). 1-13. December 2011.

[8] Kumar, V. and Jain, S. K., "Trends in rainfall amount and number of rainy days in river basins of India (1951 - 2004)," *Hydrology Research*, 42(4). 290-306. April 2011.

[9] Subash, N. and Sikka, A. K., "Trend analysis of rainfall and temperature and its relationship over India," *Theoretical and Applied Climatology*, 117(19). 449-462. October 2014.

[10] Paul, R. K. and Birthal, P. S., "Investigating rainfall trend over India using the wavelet technique," *Journal of Water and Climate Change*, 7(2). 353-364. February 2016.

[11] Jain, S. K., Kumar, V., and Saharia, M., "Analysis of rainfall and temperature trends in northeast India," *International Journal of Climatology*, 33(4). 968-978. April 2013.

[12] Prokop, P. and Walanus, A., "Trends and Periodoicity in the longest instrumental rainfall series for the area of most extreme rainfall in the world, northeast India," *Geographica Polonica*, 76(2). 25-35. February 2003.

[13] Oza, M. and Kishtawal, C. M., "Trends in Rainfall and Temperature Patterns over North East India," *Earth Science India*, 7(4). 90-105. April 2014.

[14] Das, S., Tomar, C. S., Saha, D., Shaw, S. O., and Singh, C., "Trends in Rainfall Patterns over North-East India during 1961-2010," *International Journal of Earth and Atmospheric Science*, 2(2). 37-48. February 2015.

[15] Tiwari, A., Shoab, M., Chandniha, S. K., Pal, L., Prabhakar, A. K., and Kumar, A., "Application of non-parametric tests for long-term trend analysis of rainfall over northeastern region of India," *Journal of Agrometeorology*, 21(3). 379-381. March 2019.

[16] Jhajharia, D., Yadav, B. K., Maske, S., Chattopadhyay, S., and Kar, A. K., "Identification of trends in rainfall, rainy days and 24 h maximum rainfall over subtropical Assam in Northeast India," *Geoscience*, 344(1). 1-13. 2012.

[17] Goyal, M. K., "Statistical Analysis of Long-Term Trends of Rainfall During 1901 - 2002 at Assam, India," *Water Resources Management*, 28(3). 1501-1515. March 2014.

[18] Hazarika, J., Pathak, B., and Patowary, A. N., "Studying monthly rainfall over Dibrugarh, Assam: Use of SARIMA approach," *Mausam*, 68(2). 349-356. February 2017.

[19] Choudhury, B. U., Das, A., Ngachan, S. V, Slong, A., Bordoloi, L. J., and Chowdhury, P., "Trend Analysis of Long-Term Weather Variables in Mid Altitude Meghalaya, North-East India," *Journal of Agricultural Physics*, 12(1). 12-22. January 2012.

[20] Saha, S. *et al.*, "Spatial variability in temporal trends of precipitation and its impact on the agricultural scenario of Mizoram," *Current Science*, 109(12). 2278-2282. December 2015.

[21] Marak, J. D. K., "Innovative trend analysis of spatial and temporal rainfall variations in Umiam and Umtru watersheds in Meghalaya, India," *Theoretical and Applied Climatology*, 14(2). 1397-1412. February 2020.

[22] Deka, S., "Statistical analysis of long-term rainfall trends in Cherrapunji, Meghalaya, India," *Journal of Applied and Natural Science*, 13(1). 170-177. January 2021.

[23] Singh, A., Thakur, S., and Adhikary, N. C., "Analysis of spatial and temporal rainfall characteristics of the North East region of India," *Arabian Journal of Geosciences*, 14(885). 1-16. May 2021.

[24] Pai, D. S., Sridhar, L., Badwaik, M. R., and Rajeevan, M., "Analysis of the daily rainfall events over India using a new long period (1901-2010) high resolution (0.25° × 0.25°) gridded rainfall data set," *Climate Dynamics*, 4(5). 755-776. May 2015.

[25] Rajeevan, M., Bhate, J., Kale, J. D., and Lal, B., "High resolution daily gridded rainfall data for the Indian region: Analysis of break and active monsoon spells," *Current Science*, 91(3). 296-306. March 2006.

[26] Guhathakurta, P. and Rajeevan, M., "Trends in the rainfall pattern over India," 1469(11). 1453-1469. November 2008.

[27] Salmi, T., Määttä, A., Anttila, P., Ruoho-Airola, T., and Amnell, T., "Detecting Trends of Annual Values of Atmospheric pollutants by the Mann-Kendall Test and Sen's Slope Estimates-The excel Template application Makesens," Finnish Meteorological Institute, Finland, 2002.

[28] Şen, Z., "Innovative trend significance test and applications," *Theoretical and Applied Climatology*, (11). 1-9. November 2015.

[29] Öztopal, A. and Şen, Z., "Innovative Trend Methodology Applications to Precipitation Records in Turkey," *Water Resources Management*, 31(3). 727-737. March 2017.

[30] Şen, Z., "Innovative Trend Analysis Methodology," *Journal of Hydrologic Engineering*, 17(9). 1042-1046. October 2012.

[31] Caloiero, T., "Evaluation of rainfall trends in the South Island of New Zealand through the innovative trend analysis (ITA)," *Theoretical and Applied Climatology*, (9). 1-12. August 2019.