Climate Change in Bangladesh: On Evidence of Spatio-Temporal Analysis of Rainfall and Temperature

B.Sc. Engineering THESIS

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The thesis titled "Climate Change in Bangladesh: On Evidence of Spatio-Temporal Analysis of Rainfall and Temperature" submitted by
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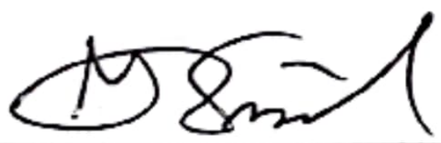

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DECLARATION OF CANDIDATE

We hereby declare that the undergraduate research work reported in this thesis has been performed by us under the supervision of Professor Dr. Md Rezaul Karim and this work has not been submitted elsewhere for any purpose (except for publication).

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Abstract:

The regular influence of an area's climatic factors that indicate the usual pattern is referred to as climate change. Bangladesh, like every other country, is undergoing rapid climatic change. Bangladesh has six distinct seasons once upon a time. Unfortunately, there are now only four. Summer days are becoming unbearably hot, and monsoon rains are diminishing. These changes are a result of climate change. Cyclones, floods, droughts, and other natural calamities are become more common in recent years. As a result, concerns such as food scarcity, ecological imbalance, and other issues are becoming more likely.

Climate change is a key concern in the subject of Environmental Engineering. A thorough and thorough examination of this update is necessary to determine the best countermeasures to the vulnerabilities. Temperature, relative humidity, wind speed, daylight length, and rainfall all contribute to climate, and any change in these characteristics will affect the elements and patterns of the environment. Temperature and rainfall, in particular, have a significant influence on climate. Significant fluctuation in rainfall and temperature patterns puts agriculture output at risk in many parts of the world. Irrigation, fisheries, water resources, and other industries are all affected.

The goal of the study is to develop a complete overview of climate change in Bangladesh. The impact will be investigated using a spatiotemporal assessment of rainfall and temperature trends. The assessment took into account 26 meteorological stations in Bangladesh. This study spans the years 1975 through 2019.

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Chapter 1: Introduction

1.1 General

Climate change is the regular influence of an area's climatic parameters that represent the usual pattern. Bangladesh, like every other country, is experiencing highly delicate climatic change. There was a time when Bangladesh had six distinct seasons. Unfortunately, it now only has four. Summer days are getting extremely hot, and monsoon rainfall is decreasing. Climate change is causing these kinds of changes. Climatic disasters such as cyclones, floods, droughts, and other natural disasters are becoming more common. As a result, the risk of challenges such as food scarcity, ecological imbalance, and so on is increasing.

In the field of Environmental Engineering, climate change is a major concern. A proper and comprehensive study of this change is effective to find out the precautionary measures against the vulnerabilities. Climate is defined by temperature, relative humidity, wind speed, sunshine length, and rainfall, and any change in these factors will have an impact on the elements and pattern of the environment. Temperature and rainfall, in particular, have a considerable impact on the climate. In many parts of the world, significant variability in rainfall and temperature patterns puts agriculture production at risk. Other sectors, like irrigation, fisheries, water resources, etc. are also being impacted.

The purpose of the research is to create a detailed representation of climate change in Bangladesh. A spatiotemporal study of rainfall and temperature patterns will be used to investigate the impact. A total of 26 meteorological stations in Bangladesh were considered for the assessment. This research covers the years 1975 to 2019.

1.2 Objectives of the Study

1. To perform a trend analysis of Bangladesh's rainfall and temperature patterns.

2. To identify the most vulnerable areas by comparing climate variables. (Temperature and Rainfall)

3. To evaluate the variation in climate change across Bangladesh.

1.3 Scopes of the Study

1. This research will provide a comprehensive picture of Bangladesh's climate change.

2. Various trend analysis approaches have been applied to portray the trend for various regions.

3. Innovative trend analysis approach was applied to provide insight into the sub-trend.

4. To increase the correctness of the work, missing data were modified using the Random Forest algorithm.

5. Because of using different graphical representations, extremely affected areas can be identified easily.

Chapter 2: Literature Review

2.1 General

Bari et al. analyzed the monthly precipitation data for Bangladesh's northern area for the time frame 1964 to 2013. Their goal was to depict the pattern of rainfall variability and seasonality index variations. When compared to inter-seasonal variability, annual precipitation variability was found to be modest and fairly similar to that of the monsoon season.

Karim et al. used the statistical study of rainfall data to determine the rainfall trend and variability that reflect Bangladesh's climate change. To demonstrate and analyze the results, methods or parameters such as modified Mann Kendal statistic, standard anomaly index, and variance were applied. When compared to inter-seasonal variability, annual rainfall variation was found to be modest and fairly similar to that of the monsoon season.

Khan et el. approached to detect climate variable fluctuation in Bangladesh. They used meteorological data from 35 distinct regions of Bangladesh, including monthly maximum and minimum temperatures, daily average temperatures, humidity, total precipitation, and wind speed. The climate change study (M-K, Sen's Slope, and Spearman Rho) indicates variations in climactic variable time set in Bangladesh from 1988 to 2017.

D. Bhuiyan et al. attempted to forecast as well as analyze temperature and rainfall changes in Bangladesh's northwestern region. According to the study, the highest average temperature was found during pre-monsoon and gradually declined to winter, whereas the

most normal rainfall was found during monsoon season and subsequently declined to winter before increasing from pre-monsoon to winter.

Das et al. carried out a study to characterize rainfall in Bangladesh from a spatiotemporal perspective. Innovative trends and discontinuous wavelet transformation are among the techniques used in the research. They used seasonal fluctuation to illustrate the outcome. For this reason, post-monsoon rainfall has a major increasing tendency, but winter rainfall has a significant declining trend; pre-monsoon and monsoon rainfall have both declining and rising tendencies.

2.2 Summary

Recent research studies on Bangladesh have been used as a motive for this study. Researchers tried to establish their findings for different regions of Bangladesh; some worked with the data of the whole of Bangladesh. But, both the idea of missing values imputation and sub-trend was vague. Very few studies have been found for temperature whereas it is also a significant variable like rainfall for climate change. The use of updated software like RStudio was found rarely. Besides these, graphical representation with a comprehensive explanation was missing. Other than that, trend analysis approaches have efficiently been used for the evaluation process.

Chapter 3: Methodology

3.1 Data Collection &Missing Data Imputation

3.1.1 General

Daily rainfall records, as well as daily maximum, minimum, and average temperature records, were collected from the Meteorological Department of Bangladesh. However, some data were missing prone to creating inconsistency in the analysis process.
Analyzing any inconsistent records will not assist to project the real circumstance or outcome. Because of that, the Random Forest method was utilized to eliminate the discrepancy. RStudio's MICE algorithm package was used for approaching the random forest method.

3.1.2 Study Area

The analysis was conducted for 26 meteorological stations all over Bangladesh that would significantly represent the whole of Bangladesh.

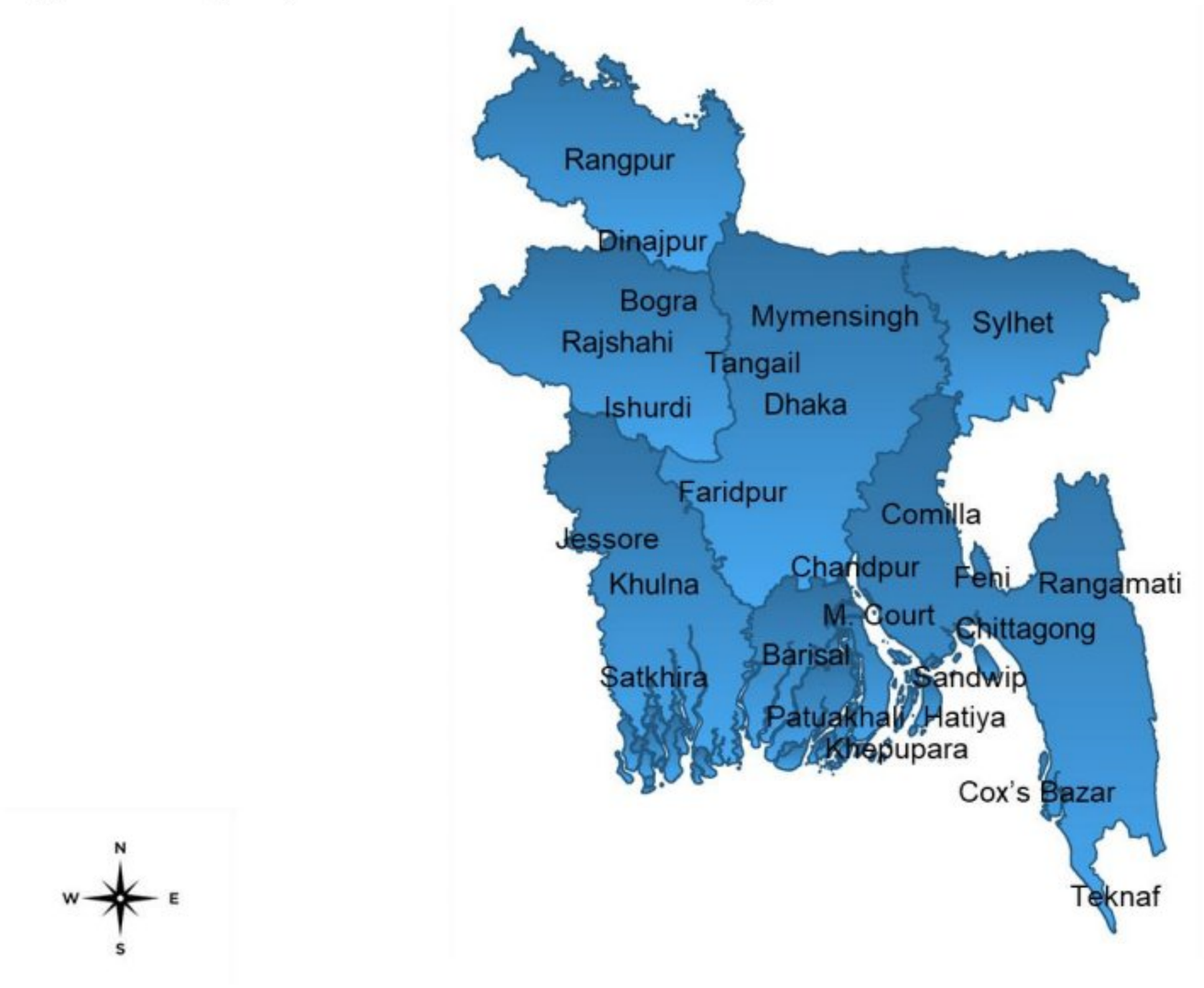


Figure 1. Study Area

3.1.3 Random Forest and MICE Approach

The random forest method is a very effective method for finding out missing values of a large data set. This approach extracts the missing data by combining random decision trees. Initially, after getting all possible values from decision trees a proximity matrix is created. Later from that matrix, data is predicted in such a way that it does not impact the total average of the data set. However, the analysis can be done considering the dataset to be univariate or multivariate. But, as climatic events are uncertain, data was considered to be multivariate. For that, the MICE (Multivariate Imputation using Chained Equation) algorithm has been utilized.

3.2 Trend Analysis & Graphical Representation

3.2.1 General

Trend Analysis is a very well-known and reliable approach for identifying the behavioral pattern of climate. Traditionally, the Mann Kendal test is being used to identify the trend. But there are also some other well-known methods like Sen's Slope Method and Modified Mann Kendal Method. All of the mentioned three methods have been used for trend analysis and for overviewing the sub-trend of Innovative Trend Analysis have been operated. Other than these methods, graphical representations have been done that actually reflect the actual scenario more precisely.

GIS map represents climate patterns of Bangladesh altogether whereas the Whisker plot helps to understand the data distribution per station.

3.2.2 Mann Kendal Method

The M-K Trend Test is used to look for consistently growing or decreasing patterns of data gathered over time. It's a non-parametric test, which means it may be used with any distribution but it must be free of serial correlation.

The null hypothesis for the test is that the series does not have a monotonic trend. Another hypothesis is that there is a trend. It can be neutral, good, or negative. The test looks at how the signs of previous and subsequent data points differ.

The idea of this assumption is that if a pattern exists, the symbol values should tend to increase or decrease on a regular basis. Every value in the time-series data is compared with every value before it, yielding n (n – 1) / 2 sets of data, where "n" is indeed the number of records in the set.

$$S = \sum_{j=1}^{n-1} \sum_{k=j+1}^{n} \operatorname{sign}\left(y_k - y_j\right)$$

$$\mathrm{VAR}(S) = \frac{1}{18}\left\{n(n-1)(2n+5) - \sum_{j=1}^{g} t_j\left(t_j-1\right)\left(2t_j+5\right)\right\}$$

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

Figure 2 Mann Kendall Formula

Here, n is the number of records, and y_k and y_j are the record points of time k and j. The Z is the actual indicator of the trend.

3.2.3 Sens Slope Estimator

Sen's slope estimator was used to calculate the magnitudes of the rainfall trend (slope Q). The slope Q could be calculated with N sets of data as follows:

$$Q_i = \frac{x_k - x_j}{k-j}, i = 1, 2, 3, \cdots\cdots N, k > j$$

Figure 3 Sens Slope Formula

3.2.4 Modified Mann Kendal Method

Modified Mann Kendal method is basically the updated formation of or traditional MK method. The traditional one sometimes may have some false positive error due to the auto correlation function. That is why modified MK approach have been invented that actually uses a coefficient that eliminates the error.

$$\mathrm{VAR}(S) = \left(\frac{n\,(n-1)(2n+5)}{18}\right).\left(\frac{n}{n_e^*}\right)$$

Figure 4 Modified Mann Kendal Folrmula

3.2.5 Innovative Trend Analysis

Sen was the first to suggest the visual non-parametric ITA approach. By inspecting the ITA graph, it is capable of detecting the periodic pattern as well as semi trend in the time series dataset, as well as identifying different combination of patterns in different spans of time series data. It can also deal with autocorrelation and outliers. The following equation is used to compute ITA's slope:

$$B = \frac{1}{n}\sum_{i=1}^{n} \frac{10\left(x_j - x_k\right)}{\overline{x}}$$

Figure 5 ITA Fornula

3.2.6 GIS Mapping and Whisker Plot

GIS integrates location data (where things are) with all forms of descriptive information to create a map (what things are like there). GIS is the initials for geographic information system. It's a form of mapping feature that enables layer data linked to specific locations. GIS mapping allows to explore customized pairings of data layers in a conceptual tool,

rather than just a few important elements on a static map.
When the data pieces are in table format, GIS mapping helps to analyze and recognize trends that are tough to perceive. It also aids in the detection of patterns that arise when two or more datasets are viewed together.

A Whisker Plot (also called a Box Plot) is a quartile-based visual depiction of data distribution. Outside the top and bottom quartiles, the "whiskers," which are parallel projecting from the boxes, are used to show variability.

The two styles of graphical representations were employed to better clearly convey the results.

Chapter 4 : Result And Discussion

The results of analysis of Climatic parameter (rainfall and temperature) and extreme events based on it for 26 stations all over Bangladesh using Mann-Kendall, Sen's Slope estimator, Modified Mann-Kendall and Innovative Trend Analysis (ITA) over a time frame of 45 years are represented below.

4.1 Rainfall Scenario:

The descriptive statistics show that Bangladesh's mean annual rainfall ranged from 6095 mm to 495 mm from 1975 to 2019, with an average of 2491.88 mm. the overall rainfall variability across the country indicates lower to medium variability of distribution of rainfall, which basically indicates a decreasing rainfall trend all over the country excluding some specific regions. According to the analysis, for all 4 types of approaches, a similar result is found all over the country indicating significantly large amount of rainfall at the South Eastern region of the country, where as the opposite scenario has been observed at the Central and Western belt of the country with significantly lower amount of rainfall along with a decreasing trend over time.

According to the ITA analysis result, 26.92% among the 26 stations of the study are shows the positive increasing trend i.e. 73.08% area or 7/19 of the total study are has a negative decreasing trend of rainfall in Annual scale, as represented in the GIS Mapping

4.1.1 Pre-Monsoon:

The MK, Modified MK, Sen's Slope and ITA in the Pre-Monsoon season value has been shown using particular graphs of the analyzed data. So based on the analysis data the value has seen to be varying below zero ranging Z= -3.1892 to Z= 1.0666 all around the country where Faridpur is seen to be having the mostly negative decreasing value which indicates a decreasing pattern of rainfall at the central portion of the country over the time period and Rajshahi which is the North Western region with a significant positive result. The consecutive decrease in trend has been observed all over the country except the South Eastern zone of Chottogram division which bears a significant positive increasing trend. For Sen's Slope a similar type or result is also found indicating Dhaka (S= -1.7209) and Teknaf (S= 1.041667) as the Most positively increasing. Whereas ITA shows more précised value where it is shown that 57.69 % of the total study area contains a negatively decreasing trend while the rest 42.31% with a positively increasing trend along with Faridpur (ITA slope =-2.144) and Teknaf (ITA slope =1.59). Although there is a variation among the stations but these stations are actually located to a nearer regions.

Table 1 Rainfall Trend - Pre-Monsoon

Station	Z	Sen's Slope	Tau	IT-Slope	Trend
Barisal	-0.880451	-0.3939394	-0.0919	-0.4087542	↓
Bogra	-0.54784	-0.3838384	-0.0576	-0.0262626	↓
Chandpur	-0.95871	-0.7600733	-0.1	-1.8707071	↓
Chittagong	-0.948885	-0.8333333	-0.099	-0.6181818	↓
Comilla	-0.47933	-0.4371212	-0.0505	-0.7306397	↓
Cox's Bazar	0.4500082	0.6111111	0.04747	1.0464646	↑
Dhaka	-2.1232	-1.729048	-0.2202	-1.6289562	↓
Dinajpur	-0.058697	-0.05	-0.0071	0.07272727	↓
Faridpur	-3.1892	-1.721326	-0.3303	-2.1441077	↓
Feni	-0.929409	-0.974359	-0.097	-1.2814815	↓
Hatiya	-0.01957	0.06862745	-0.003	-0.003367	↓
Ishurdi	-2.0348	-1.134183	-0.2111	-0.9252525	↓

Jessore	-0.185882	-0.2	-0.0202	-0.183165	↓
Khepupara	-0.645664	-0.5333333	-0.0677	-0.0484849	↓
Khulna	-1.173935	-0.7	-0.1222	-0.5824916	↓
M. Court	-0.361981	-0.1555556	-0.0384	-0.5602694	↓
Mymensingh	-1.3696	-1.105045	-0.1424	-0.5771044	↓
Patuakhali	-0.978279	-0.6231884	-0.102	-1.0929293	↓
Rajshahi	1.0666	0.468254	0.11111	0.1447811	↑
Rangamati	0.2543525	0.1818182	0.02727	0.05521886	↑
Rangpur	0.50875	0.3333333	0.05354	0.76902357	↑
Sandwip	-0.714109	-0.5614035	-0.0747	0.5979798	↓
Satkhira	-0.234809	-0.1851852	-0.0253	0.38922559	↓
Srimangal	0.45005	0.3207071	0.04747	0.5717172	↑
Sylhet	0.34238	0.5981681	0.03636	0.1848485	↑
Teknaf	0.9195821	1.041667	0.09596	1.593266	↑

4.1.2 Monsoon:

A variable result has been reached during the monsoon season, when rainfall is projected to be at its peak. According to the MK and Modified MK tests, 50 percent of the overall study area has a positive trend, whilst the other has a strong negative trend, indicating that the amount of rainfall expected during the monsoon season has altered dramatically. Because Bangladesh is an agricultural country, not all region of the country receives the appropriate amount of precipitation. As a result, it is apparent that the intensity of rainfall across the country has shifted to a different timetable or has diminished from its prior shape.

According to Sen's slope, the variation of rainfall among the stations are 69% of the stations receives precipitation whereas the other 30.7 % of it being deprived from the monsoon rainfall. ITA testing shows quite a different result from tradition trend analysis result, stating 69% of the total study area is deprived from required amount of rainfall as per demand of the season and the rest 31% has a positive increasing trend of rainfall. Account to the analysis, Rajshahi (-3. 0522 mm/yr), Patuakhali (-1.980 mm/yr) and Dinajpur (-1.902439) stations has dominating negative decreasing trend where as Khepupara (+1.839 mm/yr), Sandwip (+3.0425 mm/yr) and Hatiya (+1.9024mm/yr) has a significant positively increasing trend|.

Table 2 Rainfall Trend - Monsoon

Station	Z	Sen's Slope	Tau	IT-Slope	Trend
Barisal	-0.52827	-0.63825	-0.05556	0.262121	↓
Bogra	-1.3207	-1.50819	-0.13737	-1.93535	↓
Chandpur	-1.4576	-1.26316	-0.15152	-2.5303	↓
Chittagong	-1.6338	-1.36546	-0.1697	-1.79697	↓
Comilla	-0.58697	-0.58426	-0.06162	-0.8399	↓
Cox's Bazar	-3.0522	-2.23438	-0.31616	-0.70404	↓
Dhaka	-1.7119	-1.65727	-0.17778	-1.31061	↓
Dinajpur	-1.1152	-1.8817	-0.11616	-2.06364	↓
Faridpur	0.11739	0.130595	0.013131	0.482323	↑
Feni	-1.301	-0.99621	-0.13535	-0.60707	↓
Hatiya	0.068483	0.034903	0.008081	1.41936	↑
Ishurdi	0.019566	0.026389	0.00303	-0.38485	↑
Jessore	0.215221	0.217105	0.023232	0.726768	↑
Khepupara	-0.98801	-0.80769	-0.10303	-0.45152	↓
Khulna	0.313079	0.2	0.033333	1.048485	↑
M. Court	-0.78262	-0.71429	-0.08182	-0.39293	↓
Mymensingh	-1.58481	-1.98026	-0.16465	-1.49293	↓
Patuakhali	1.839164	1.697917	0.190909	2.117677	↑
Rajshahi	0.039131	-0.375	0.005051	0.865657	↑
Rangamati	1.281484	2.142857	0.133333	4.924242	↑
Rangpur	1.653212	3.425926	0.171717	6.793434	↑
Sandwip	0.303252	0.25641	0.032323	1.210606	↑
Satkhira	1.085837	2.047619	0.113131	2.239394	↑
Srimangal	1.310894	2.846154	0.136364	3.632323	↑
Sylhet	-1.04671	-0.88889	-0.10909	-1.56566	↓
Teknaf	1.036976	1.625	0.108081	3.118182	↑

4.1.3 Post Monsoon:

One of the major turning point of the rainfall variation has been witnessed in the Post Monsoon Period. According the MK and Modified MK tests result 73.07% and 69.23% of the total study area all over Bangladesh respectively has experienced with a positive increasing trend of precipitation whereas rest 23% to 30% has a negative decreasing trend where the range of negativity is very low. In case of Sen's Slope estimator the result is almost similar to MK test with exactly the same scenario of rainfall. For ITA the result is a bit ahead indicating 76.9% of the total study area received precipitation in an increasing pattern and the rest 23.07 % has a negative trend with a range of within -0.8 to -0.3 mm/yr. The central portion of the country mainly Dhaka has seen to be having a significant negative trend (-1.2718 mm/yr) according to MK and so as for Modified Mk, Sen's Slope, but according ITA slope the result was for Sylhet region (-0.867) but for all the 4 approaches show dominating positive trend in Hatiya (+1.624 mm/yr) at the South Eastern Zone of Bangladesh.

The most significant result from this section of the result analysis is that all of the above-mentioned data and explanations clearly demonstrate that the likely shift of the rainfall period has shifted from Monsoon to Post Monsoon, which is actually an indication of a change in Bangladesh's climate.

Table 3 Rainfall Trend - Post- Monsoon

Station	Z	Sen's Slope	Tau	IT-Slope	Trend
Barisal	-1.2718	-0.672619	-0.1323	-0.8131313	↓
Bogra	-0.59695	-0.3973684	-0.0626	0.7555556	↓
Chandpur	0.29348	0.29348	0.03131	1.3575758	↑
Chittagong	0.90996	0.5069444	0.09495	0.31818182	↑
Comilla	-0.39135	-0.2272727	-0.0414	-0.6575758	↓
Cox's Bazar	-0.35221	-0.3514706	-0.0374	-0.1474747	↓
Dhaka	-0.058715	-0.01785714	-0.0071	0.6070707	↓
Dinajpur	-0.49895	-0.4288721	-0.0525	-0.8676768	↓
Faridpur	1.0761	0.5989279	0.11212	0.4454545	↑
Feni	-0.55765	-0.3238095	-0.0586	-0.2292929	↓
Hatiya	-0.50875	-0.3037281	-0.0535	-0.3313131	↓
Ishurdi	0.89039	0.6354167	0.09293	0.6424242	↑

Jessore	0.6555409	0.3589744	0.06869	0.4393939	↑
Khepupara	1.242355	0.7205882	0.12929	0.8151515	↑
Khulna	1.26204	0.7083333	0.13131	0.6727273	↑
M. Court	0.5870235	0.3382353	0.06162	0.06565657	↑
Mymensingh	1.350025	1.47619	0.1404	0.8555556	↑
Patuakhali	1.330459	1.607143	0.13838	0.7878788	↑
Rajshahi	0.5869673	0.6875	0.06162	0.469697	↑
Rangamati	1.624098	1.902439	0.16869	2.369697	↑
Rangpur	1.164096	1.388889	0.12121	1.6222222	↑
Sandwip	1.164319	0.76	0.12121	0.05252525	↑
Satkhira	0.0782623	0.2083333	0.00909	0.04040404	↑
Srimangal	0.7436342	0.9772727	0.07778	-0.3030303	↑
Sylhet	1.07621	1.2	0.11212	0.8333333	↑
Teknaf	1.115238	1.413043	0.11616	1.0808081	↑

4.1.4 Dry:

The scenario for Dry season according to the analysis result is quite similar to the expectations. About 95% of the study area has a decreasing or close to stable pattern of rainfall indication very less precipitation whereas a little amount of variation is seen in case of Teknaf (+ 0.287 mm/yr) in rainfall which may be due to consecutive lower pressures at the sea levels and due to storms and cyclone.

Table 4 Raifall Trend - Dry

Station	Z	Sen's Slope	Tau	IT-Slope	Trend
Barisal	-1.0279	-0.1262815	-0.1071	-0.2707071	↓
Bogra	-2.0761	-0.1642857	-0.2152	-0.2107744	↓
Chandpur	-0.88121	-0.07961973	-0.0919	-0.1548822	↓
Chittagong	-0.39181	-0.03703704	-0.0414	-0.1737374	↓
Comilla	0.20573	0.006410256	0.02222	-0.2734007	↑
Cox's Bazar	-0.99877	-0.07671958	-0.104	-0.3003367	↓
Dhaka	0.088156	0	0.0101	-0.1939394	↑
Dinajpur	-0.43053	-0.05157308	-0.0455	-0.1808081	↓
Faridpur	-0.137	-0.02191092	-0.0152	-0.0740741	↓
Feni	-0.73424	-0.06156595	-0.0768	-0.1986532	↓
Hatiya	-0.93009	-0.08333333	-0.097	-0.1225589	↓
Ishurdi	-0.29369	-0.0327957	-0.0313	-0.0861953	↓
Jessore	-1.06692	-0.2	-0.1111	-0.43367	↓
Khepupara	-0.88107	-0.1764706	-0.0919	-0.2484849	↓
Khulna	-0.783198	-0.1403509	-0.0818	-0.3542088	↓
M. Court	-0.734283	-0.1111111	-0.0768	-0.1111111	↓
Mymensingh	-0.822831	-0.1111111	-0.0859	-0.1717172	↓
Patuakhali	-0.195818	-0.03333333	-0.0212	-0.1097643	↓
Rajshahi	-2.202357	-0.2272727	-0.2283	-0.3313131	↓
Rangamati	-0.362397	-0.04	-0.0384	-0.1468014	↓
Rangpur	-1.578887	-0.1777778	-0.1636	-0.2255892	↓

Sandwip	-0.117811	-0.01851852	-0.0131	-0.1010101	↓
Satkhira	-0.812893	-0.05333333	-0.0848	-0.0989899	↓
Srimangal	-0.452104	-0.01666667	-0.0475	-0.1589226	↓
Sylhet	-1.243983	-0.1794872	-0.1293	-0.3319865	↓
Teknaf	0.2875754	0	0.0303	0.01481481	↑

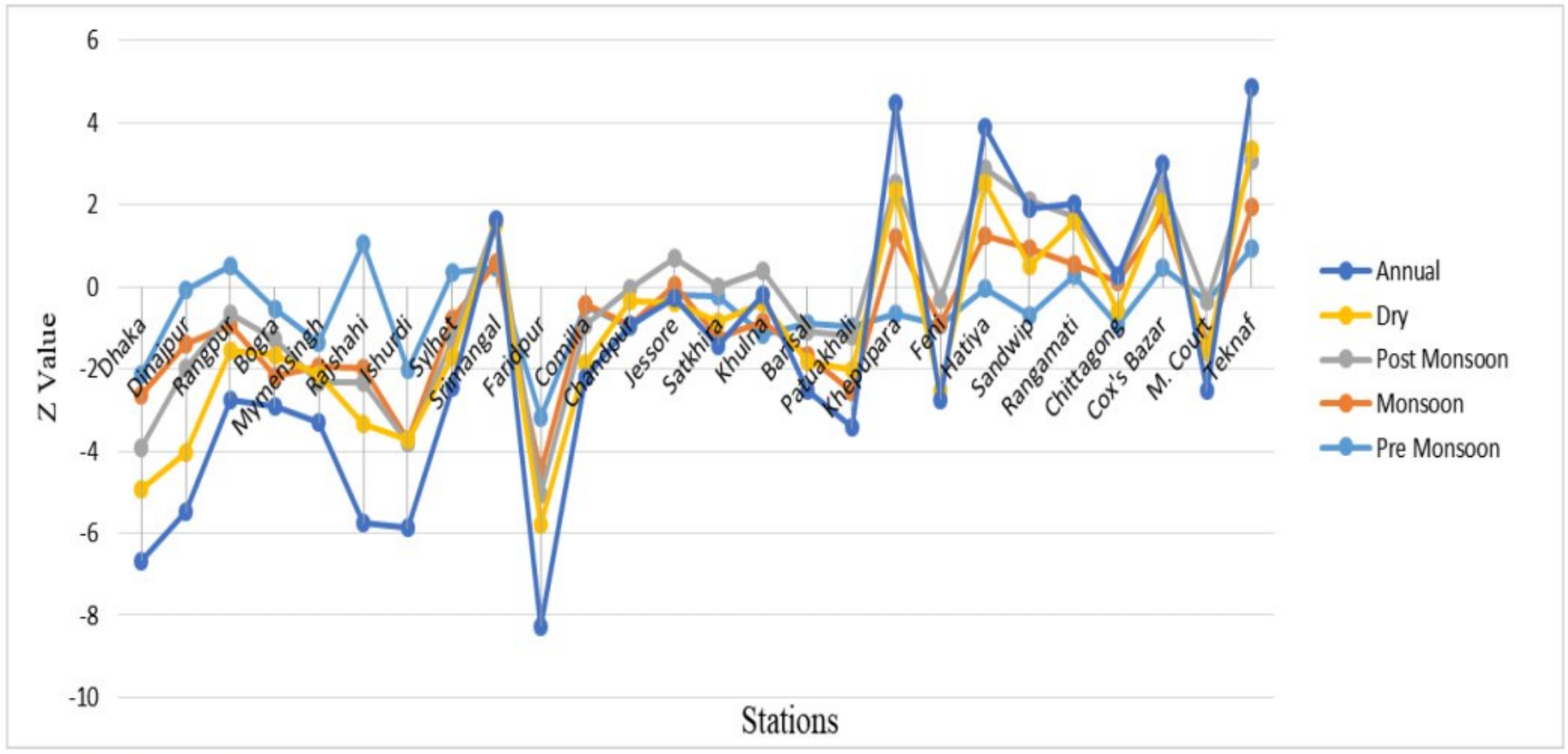


Figure 6 MK Test Result.

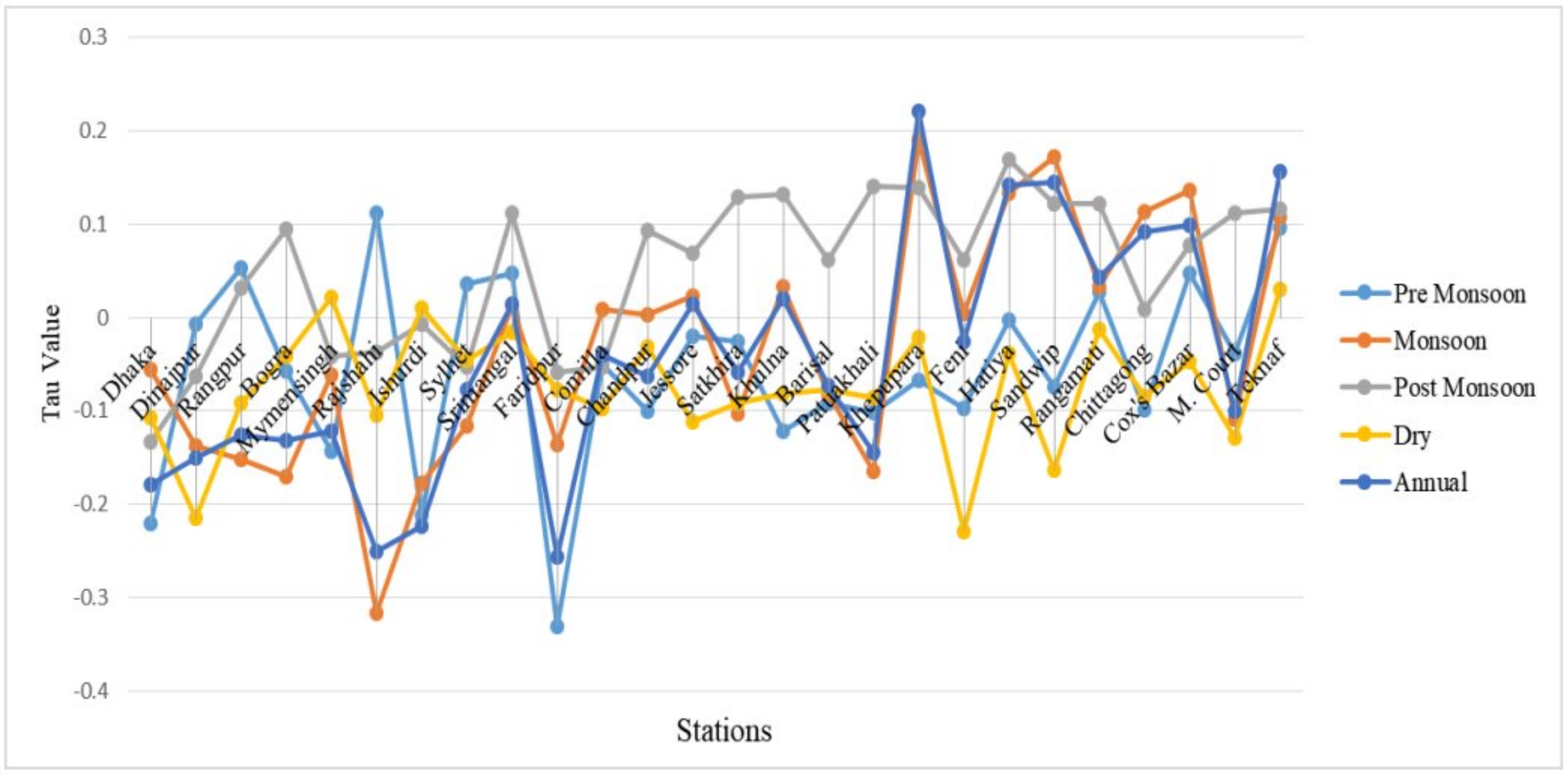


Figure 7 Modified MK Result

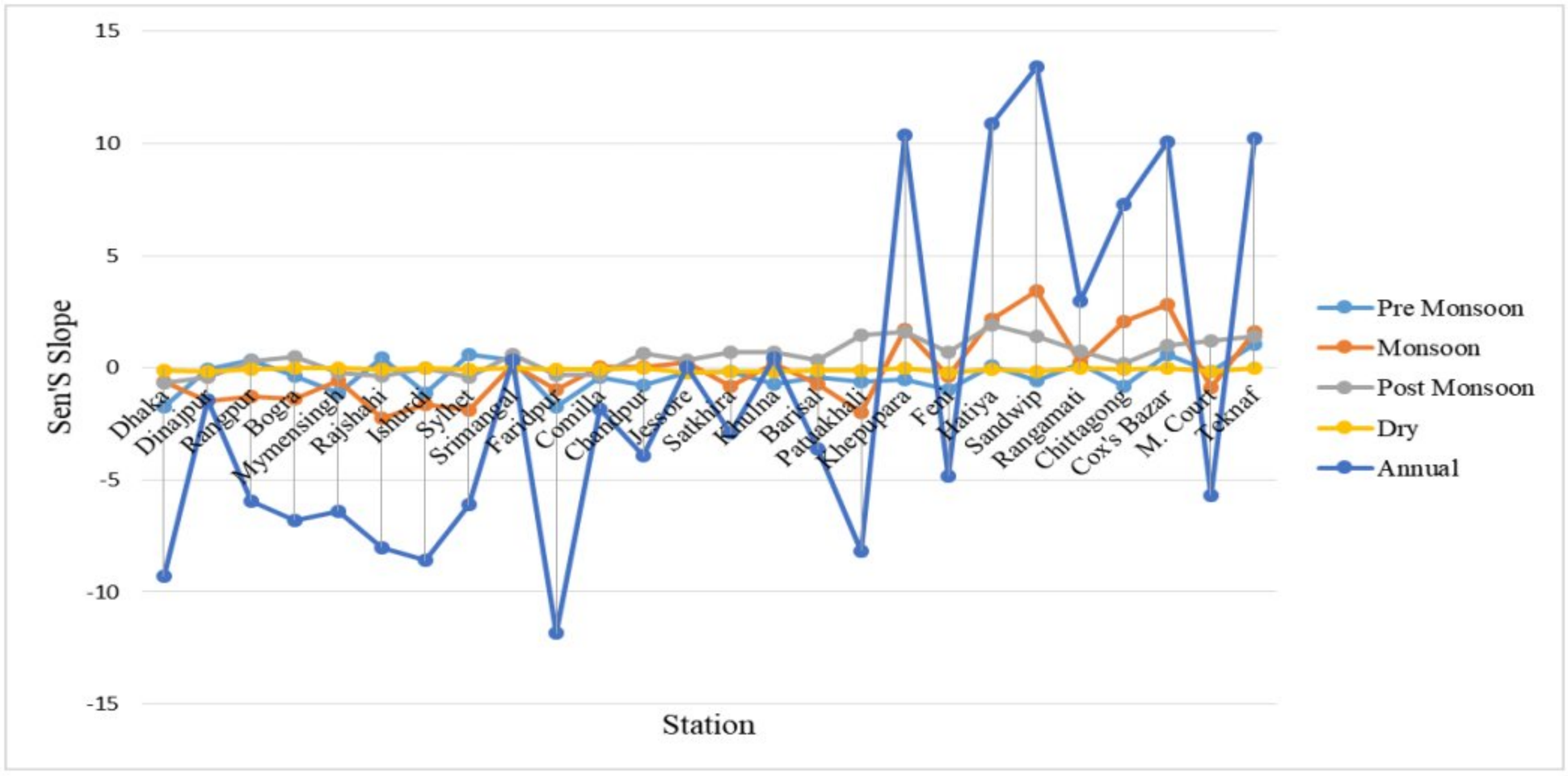


Figure 8 Sen's Slope Result

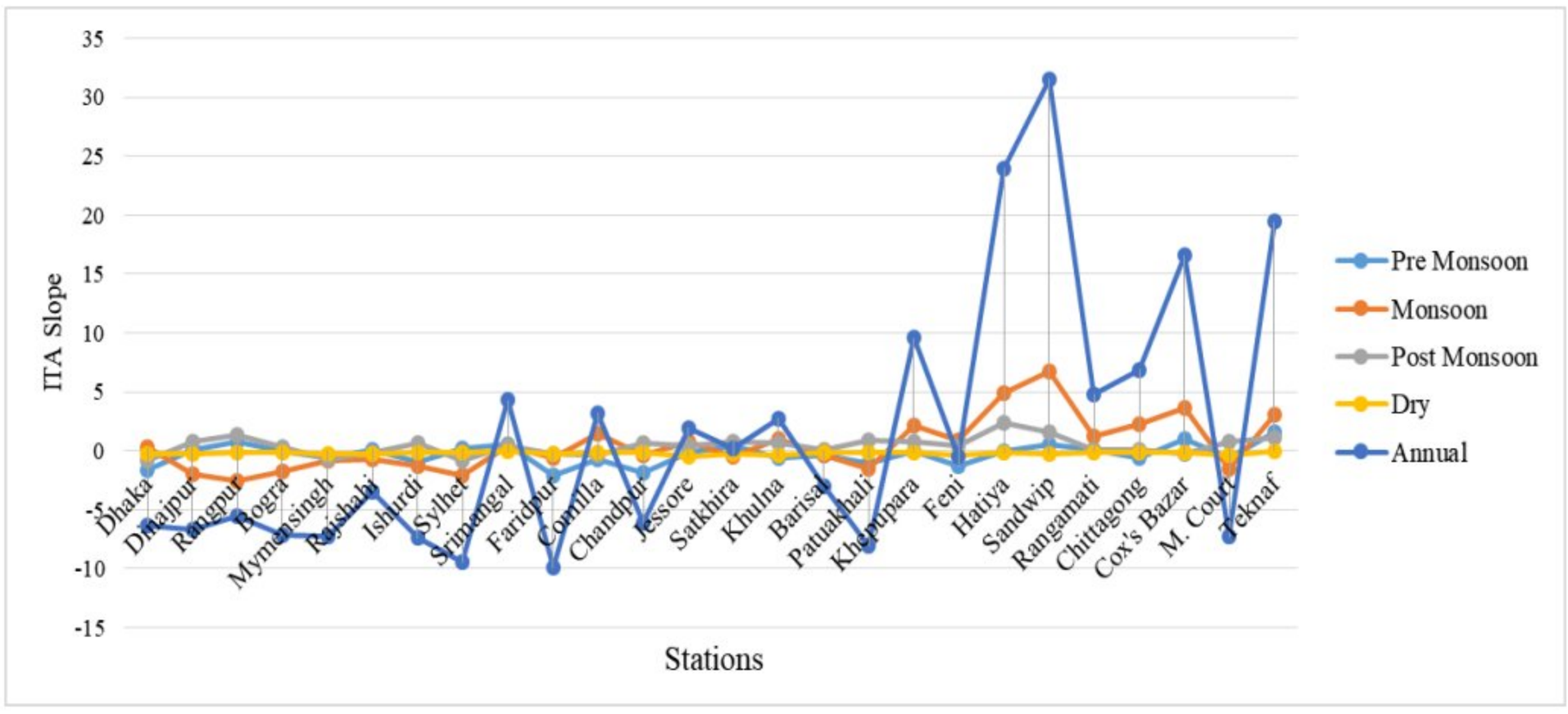


Figure 9 ITA result

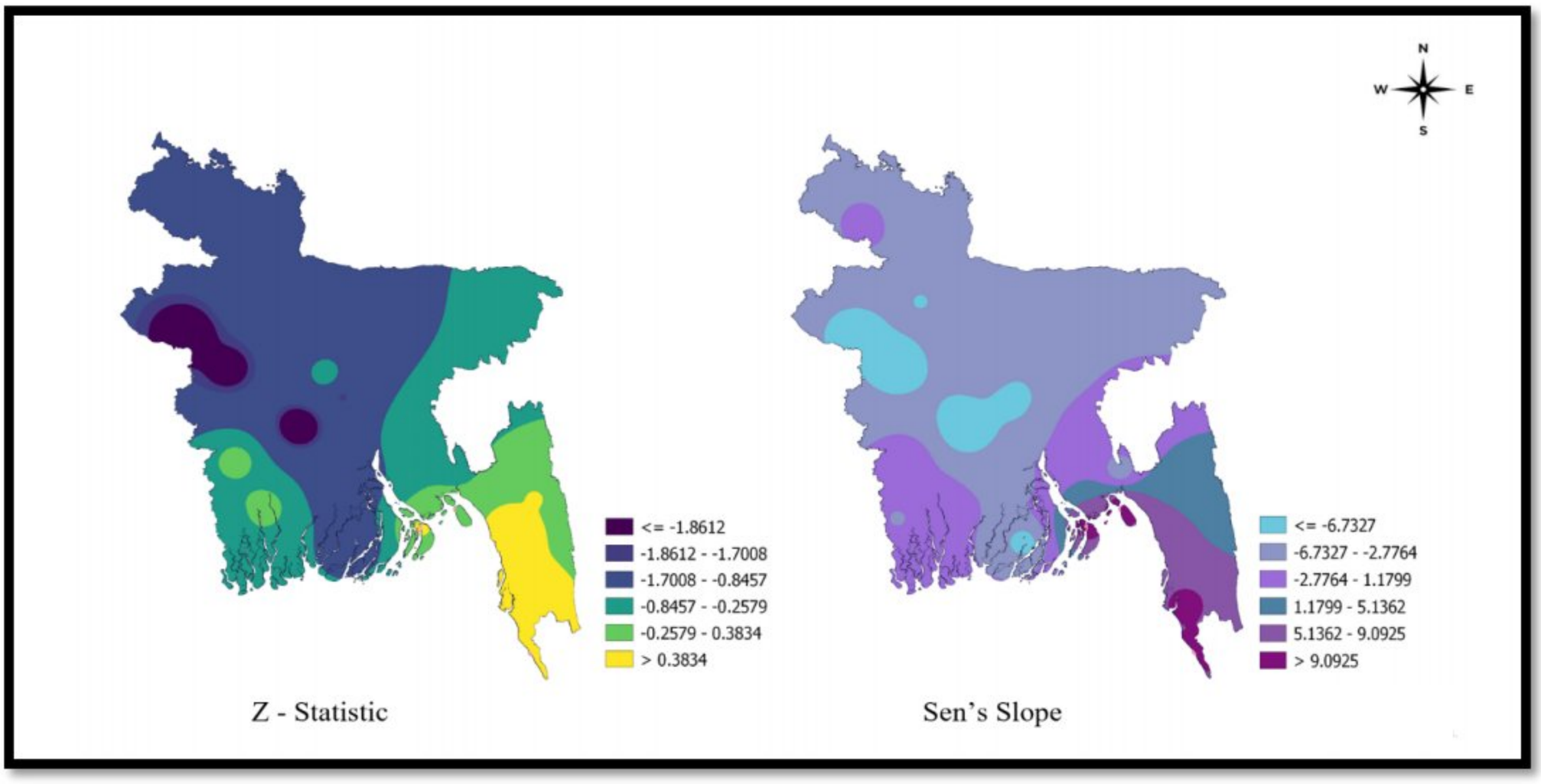


Figure 10 GIS mapping MK test and Sen's Slope test (Annual)

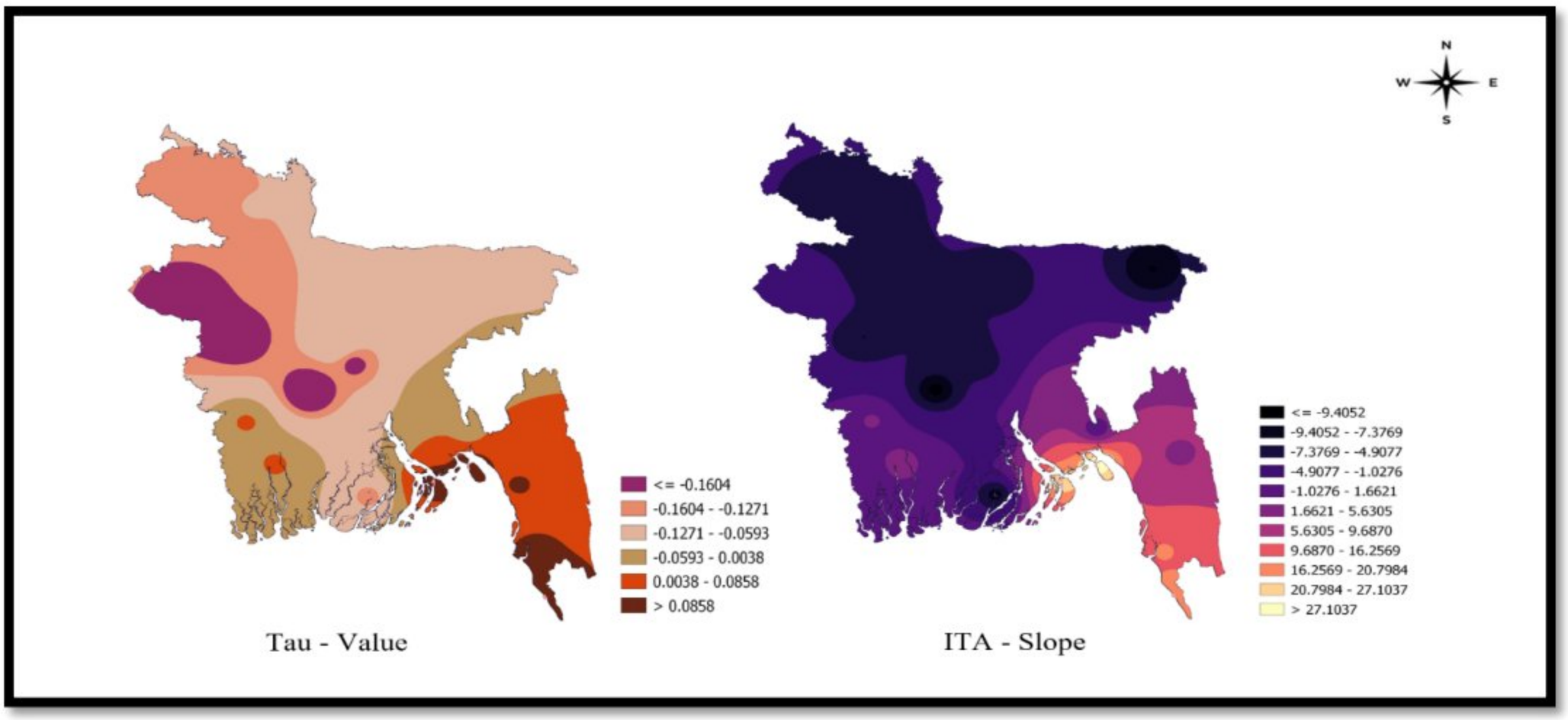


Figure 11 GIS Mapping of Modified MK & ITA result (Annual)

4.2 Temperature Scenario:

The analysis also includes a detailed description of the temperature pattern, including maximum, minimum, and average temperatures, as well as variations from 1975 to 2019. Bangladesh's historical climate has experienced average temperatures around 26ºC, but range between 15ºC and 34ºC throughout the year. However, extreme weather was also observed, with a maximum temperature of 42.9°C and a low temperature of 4.0°C shattering all previous temperature records across the country. According to the analysis, a similar result is obtained across the country for all four types of methods, demonstrating a growing trend in temperature combined with medium to larger variability in temperature, with the exception of a few specific places with the opposite result. The North Eastern zone shows a significantly increasing trend over the time where as a particular portion of Southern (Khepupara) and Southern Eastern region (Rangamati) shows the negatively decreasing trend.

4.2.1 Pre-Monsoon:

The Pre-Monsoon season value of the MK, Modified MK, Sen's Slope, and ITA has been demonstrated using specific graphs of the examined data. So based on the analysis data the value has seen to be varying below zero ranging Z= -2.807 ºC/ yr to Z= 3.159 ºC/ yr all around the country with Mymensingh having the mostly negative decreasing value, indicating a decreasing pattern of temperature in the central portion of the country over the time period, and Chittagong, the South Eastern region, having a significant positive result. With the exception of some portions of the North Eastern zone and a tiny portion of the country's Southern belt, the tendency has been increasing steadily. For Sen's Slope a similar type or result is also found indicating Mymensingh (S= -0.2909) and Chittagong (S= +0.32727) as the Most positively increasing. Whereas ITA shows more précised value where it is shown that 73.07 % of the total study area contains a positively increasing trend while the rest 26.93% with a negatively decreasing trend along with Khulna (ITA slope = + 0.018) and Satkhira (ITA slope = -0.0326). . Maximum positive increasing trend for Maximum temperature was observed in Sandwip whereas Minimum decreasing negative trend for Maximum temperature was observed around Bogra.

One of the significant results in this section is that during the Pre-Monsoon period, when the temperature is substantially higher, several sections of the country, particularly the North Eastern and Southern regions near the Bay of Bengal, have a positive growing tendency in rainfall. This could be due to the cyclone and Kalboishakhi influence in some areas, which is the main cause of the rain.

Table 5 Average Temperature - Pre-Monsoon

Station	Z	Sen's Slope	Tau	IT-Slope	Trend
Barisal	-0.880451	-0.3939394	-0.0919192	-0.4087542	↓
Bogra	-0.54784	-0.3838384	-0.0575758	-0.0262626	↓
Chandpur	-0.95871	-0.7600733	-0.1	-1.8707071	↓
Chittagong	-0.948885	-0.8333333	-0.0989899	-0.6181818	↓
Comilla	-0.47933	-0.4371212	-0.0505051	-0.7306397	↓
Cox's Bazar	0.450008	0.6111111	0.04747475	1.0464646	↑
Dhaka	-2.1232	-1.729048	-0.220202	-1.6289562	↓
Dinajpur	-0.058697	-0.05	-0.0070707	0.0727273	↓
Faridpur	-3.1892	-1.721326	-0.330303	-2.1441077	↓
Feni	-0.929409	-0.974359	-0.0969697	-1.2814815	↓
Hatiya	-0.01957	0.06862745	-0.0030303	-0.003367	↓
Ishurdi	-2.0348	-1.134183	-0.2111111	-0.9252525	↓
Jessore	-0.185882	-0.2	-0.020202	-0.183165	↓
Khepupara	-0.645664	-0.5333333	-0.0676768	-0.0484849	↓
Khulna	-1.173935	-0.7	-0.1222222	-0.5824916	↓
M. Court	-0.361981	-0.1555556	-0.0383838	-0.5602694	↓
Mymensingh	-1.3696	-1.105045	-0.1424242	-0.5771044	↓
Patuakhali	-0.978279	-0.6231884	-0.1020202	-1.0929293	↓
Rajshahi	1.0666	0.468254	0.1111111	0.1447811	↑
Rangamati	0.254353	0.1818182	0.02727273	0.0552189	↑
Rangpur	0.50875	0.3333333	0.05353535	0.7690236	↑
Sandwip	-0.714109	-0.5614035	-0.0747475	0.5979798	↓
Satkhira	-0.234809	-0.1851852	-0.0252525	0.3892256	↓
Srimangal	0.45005	0.3207071	0.04747475	0.5717172	↑
Sylhet	0.34238	0.5981681	0.03636364	0.1848485	↑
Teknaf	0.919582	1.041667	0.0959596	1.593266	↑

4.2.2 Monsoon:

One of the major turning point of the rainfall variation has been witnessed in the Monsoon Period. According the MK and Modified MK tests result 100 % of the total study area all over Bangladesh respectively has experienced with a positive increasing trend of temperature ranging from 2.123°C to5.82°C. In case of Sen's Slope estimator the result is almost similar to MK test with exactly the same scenario of temperature. For ITA the result shows all positive increasing trend especially maximum at Rangpur (ITA slope= + 0.0412) as the maximum.

The Observation that is to be focused solely is that Monsoon is considered to be the season with a significant amount of precipitation all over the country for which it is expected that the temperature will be at a handy form. However, according to the previously mentioned result analysis of temperature and rainfall, a completely different scene is observed, with a drastic decrease in rainfall pattern and a rapid and dominating increase in temperature trend across the country, clearly demonstrating that a permanent change in climate has already occurred. Moreover the increase in maximum temperature within the time frame is observed to be ranging from 27.3 °C to 39.3 °C

Table 6 Average Temperature - Monsoon

Station	Z	Sen's Slope	Tau	IT-Slope	Trend
Barisal	-0.52827	-0.63825	-0.05556	0.262121	↓
Bogra	-1.3207	-1.50819	-0.13737	-1.93535	↓
Chandpur	-1.4576	-1.26316	-0.15152	-2.5303	↓
Chittagong	-1.6338	-1.36546	-0.1697	-1.79697	↓
Comilla	-0.58697	-0.58426	-0.06162	-0.8399	↓
Cox's Bazar	-3.0522	-2.23438	-0.31616	-0.70404	↓
Dhaka	-1.7119	-1.65727	-0.17778	-1.31061	↓
Dinajpur	-1.1152	-1.8817	-0.11616	-2.06364	↓
Faridpur	0.11739	0.130595	0.013131	0.482323	↑
Feni	-1.301	-0.99621	-0.13535	-0.60707	↓
Hatiya	0.068483	0.034903	0.008081	1.41936	↑
Ishurdi	0.019566	0.026389	0.00303	-0.38485	↑
Jessore	0.215221	0.217105	0.023232	0.726768	↑
Khepupara	-0.98801	-0.80769	-0.10303	-0.45152	↓
Khulna	0.313079	0.2	0.033333	1.048485	↑
M. Court	-0.78262	-0.71429	-0.08182	-0.39293	↓
Mymensingh	-1.58481	-1.98026	-0.16465	-1.49293	↓
Patuakhali	1.839164	1.697917	0.190909	2.117677	↑
Rajshahi	0.039131	-0.375	0.005051	0.865657	↑
Rangamati	1.281484	2.142857	0.133333	4.924242	↑
Rangpur	1.653212	3.425926	0.171717	6.793434	↑
Sandwip	0.303252	0.25641	0.032323	1.210606	↑
Satkhira	1.085837	2.047619	0.113131	2.239394	↑
Srimangal	1.310894	2.846154	0.136364	3.632323	↑
Sylhet	-1.04671	-0.88889	-0.10909	-1.56566	↓
Teknaf	1.036976	1.625	0.108081	3.118182	↑

4.2.3 Post Monsoon:

According the MK and Modified MK tests result shows a 50/50 result in the increase and decreasing trend pattern of temperature of the total study area all over Bangladesh. For MK AND Modified MK, positive increasing trend was observed at North Eastern zone, Sylhet (3.511°C/yr) and negatively decreasing trend was observed in Khepupara (-3.922 °C) i.e. the Southern zone. In case of Sen's Slope estimator the result shows positive increasing trend in Rangpur and negative decreasing trend in Mymensingh whereas for ITA, the result interpretation is a bit different from the other tradition tests where it has been deduced that 65.38 % of the total study area has been under positive increasing trend of temperature and the rest 34.6 % is negative decreasing, and Sylhet, Rangpur Rangamati stations are to be observed with maximum positive trend and Khepurara Satkhira and Mymensingh Stations are of negatively decreasing.

Table 7 Average Temperature - Post Monsoon

Station	Z	Sen's Slope	Tau	IT-Slope	Trend
Barisal	-1.2718	-0.672619	-0.1323	-0.8131	↓
Bogra	-0.59695	-0.397368	-0.0626	0.75556	↓
Chandpur	0.29348	0.29348	0.03131	1.35758	↑
Chittagong	0.90996	0.5069444	0.09495	0.31818	↑
Comilla	-0.39135	-0.227273	-0.0414	-0.6576	↓
Cox's Bazar	-0.35221	-0.351471	-0.0374	-0.1475	↓
Dhaka	-0.058715	-0.017857	-0.0071	0.60707	↓
Dinajpur	-0.49895	-0.428872	-0.0525	-0.8677	↓
Faridpur	1.0761	0.5989279	0.11212	0.44545	↑
Feni	-0.55765	-0.32381	-0.0586	-0.2293	↓
Hatiya	-0.50875	-0.303728	-0.0535	-0.3313	↓
Ishurdi	0.89039	0.6354167	0.09293	0.64242	↑
Jessore	0.6555409	0.3589744	0.06869	0.43939	↑
Khepupara	1.242355	0.7205882	0.12929	0.81515	↑
Khulna	1.26204	0.7083333	0.13131	0.67273	↑
M. Court	0.5870235	0.3382353	0.06162	0.06566	↑
Mymensingh	1.350025	1.47619	0.1404	0.85556	↑
Patuakhali	1.330459	1.607143	0.13838	0.78788	↑
Rajshahi	0.5869673	0.6875	0.06162	0.4697	↑
Rangamati	1.624098	1.902439	0.16869	2.3697	↑
Rangpur	1.164096	1.388889	0.12121	1.62222	↑
Sandwip	1.164319	0.76	0.12121	0.05253	↑
Satkhira	0.0782623	0.2083333	0.00909	0.0404	↑
Srimangal	0.7436342	0.9772727	0.07778	-0.303	↑
Sylhet	1.07621	1.2	0.11212	0.83333	↑
Teknaf	1.115238	1.413043	0.11616	1.08081	↑

4.2.4 Dry:

The scenario for Dry season according to the analysis result is not quite similar to the expectations. About 69.23% to 73.07% of the study area has a decreasing pattern of temperature indicating lesser temperature 27-30% of the study area has a temperature with an increasing trend over the time period which is not supposed to be as dry season is considered to be winter and the range of minimum temperature varies all around the country with extreme events at Srimongal, Jessore, Khulna, Rajshahi region with minimum temperature ranging from 7.7-3.9°C. MK, Modified Mk, Sen's Slope estimator showed quite same result whereas for the ITA, the result was more precise showing 57.69 % are with negative decreasing trend and the rest as positive increasing trend of temperature. With actually means that there is increase in temperature in gradual over the time period taken and it is still increasing even during winter.

Table 8 Average Temperature - Dry

Station	Z	Sen's Slope	Tau	IT-Slope	Trend
Barisal	-1.0279	-0.126282	-0.1071	-0.2707	↓
Bogra	-2.0761	-0.164286	-0.2152	-0.2108	↓
Chandpur	-0.88121	-0.07962	-0.0919	-0.1549	↓
Chittagong	-0.39181	-0.037037	-0.0414	-0.1737	↓
Comilla	0.20573	0.0064103	0.02222	-0.2734	↑
Cox's Bazar	-0.99877	-0.07672	-0.104	-0.3003	↓
Dhaka	0.088156	0	0.0101	-0.1939	↑
Dinajpur	-0.43053	-0.051573	-0.0455	-0.1808	↓
Faridpur	-0.137	-0.021911	-0.0152	-0.0741	↓
Feni	-0.73424	-0.061566	-0.0768	-0.1987	↓
Hatiya	-0.93009	-0.083333	-0.097	-0.1226	↓
Ishurdi	-0.29369	-0.032796	-0.0313	-0.0862	↓
Jessore	-1.06692	-0.2	-0.1111	-0.4337	↓
Khepupara	-0.88107	-0.176471	-0.0919	-0.2485	↓
Khulna	-0.783198	-0.140351	-0.0818	-0.3542	↓
M. Court	-0.734283	-0.111111	-0.0768	-0.1111	↓
Mymensingh	-0.822831	-0.111111	-0.0859	-0.1717	↓
Patuakhali	-0.195818	-0.033333	-0.0212	-0.1098	↓
Rajshahi	-2.202357	-0.227273	-0.2283	-0.3313	↓
Rangamati	-0.362397	-0.04	-0.0384	-0.1468	↓
Rangpur	-1.578887	-0.177778	-0.1636	-0.2256	↓
Sandwip	-0.117811	-0.018519	-0.0131	-0.101	↓
Satkhira	-0.812893	-0.053333	-0.0848	-0.099	↓
Srimangal	-0.452104	-0.016667	-0.0475	-0.1589	↓
Sylhet	-1.243983	-0.179487	-0.1293	-0.332	↓
Teknaf	0.2875754	0	0.0303	0.01481	↑

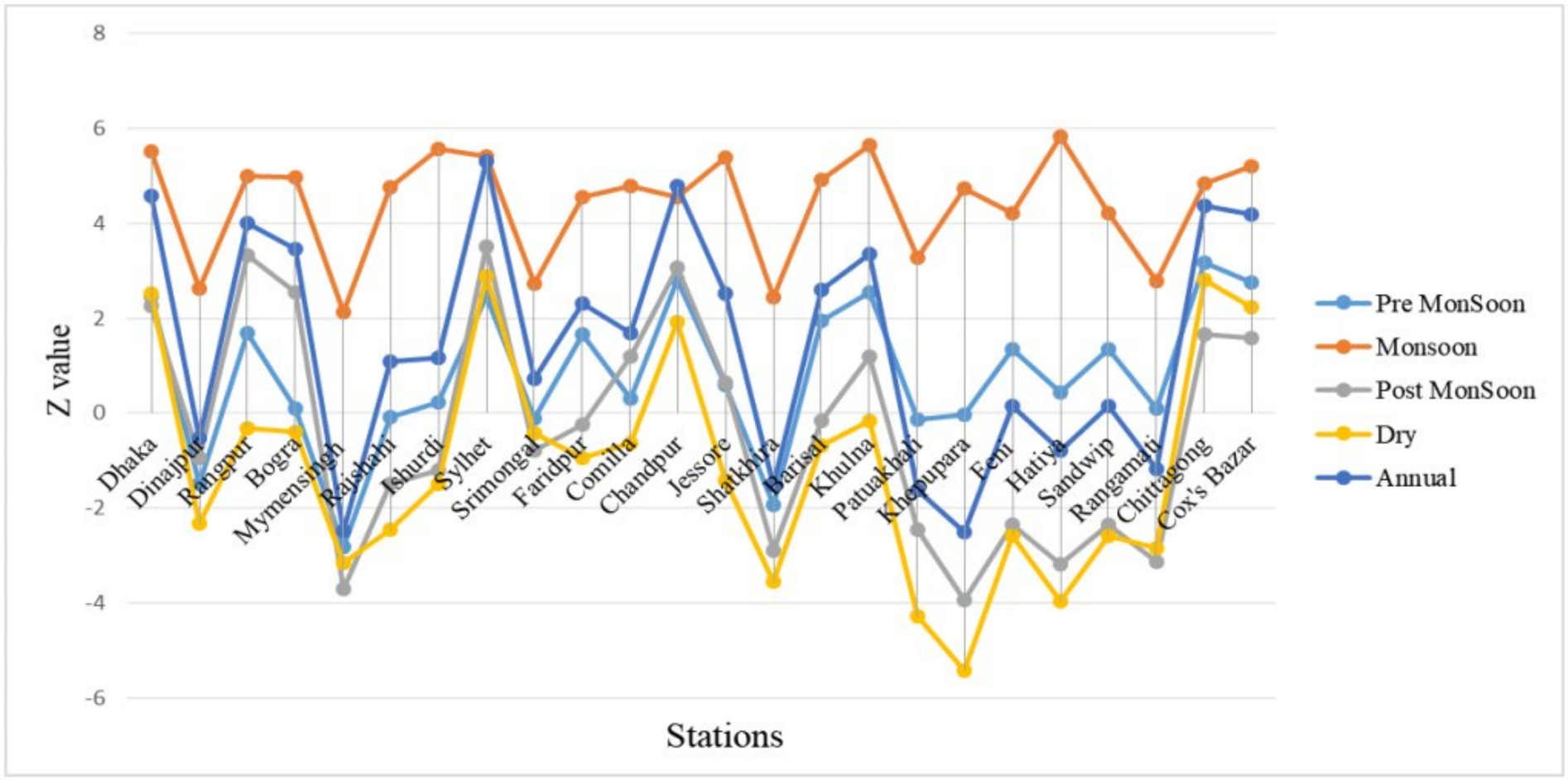


Figure 12 MK test result Average Tempareture.

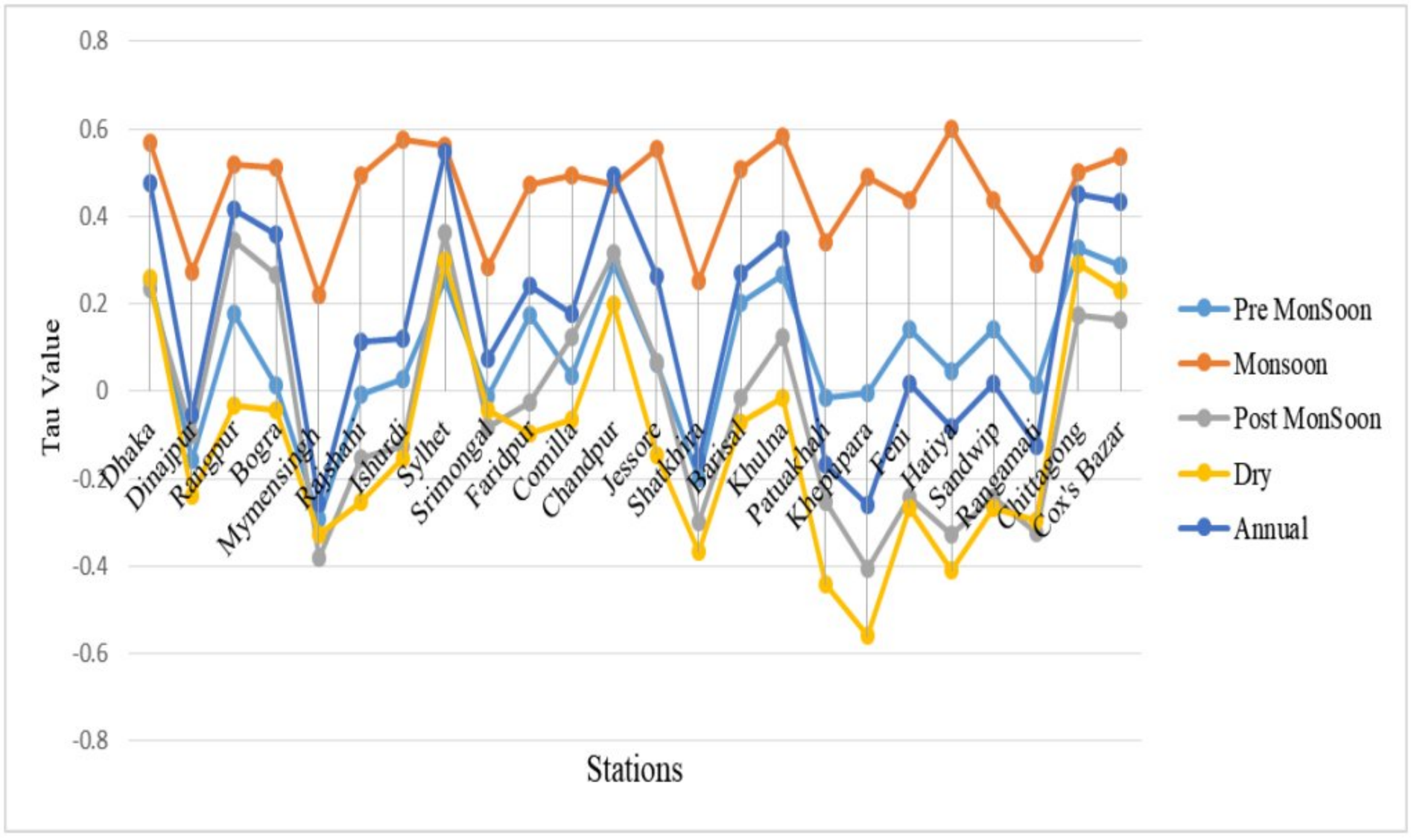


Figure 13 Modified Mk test result Average Temperature.

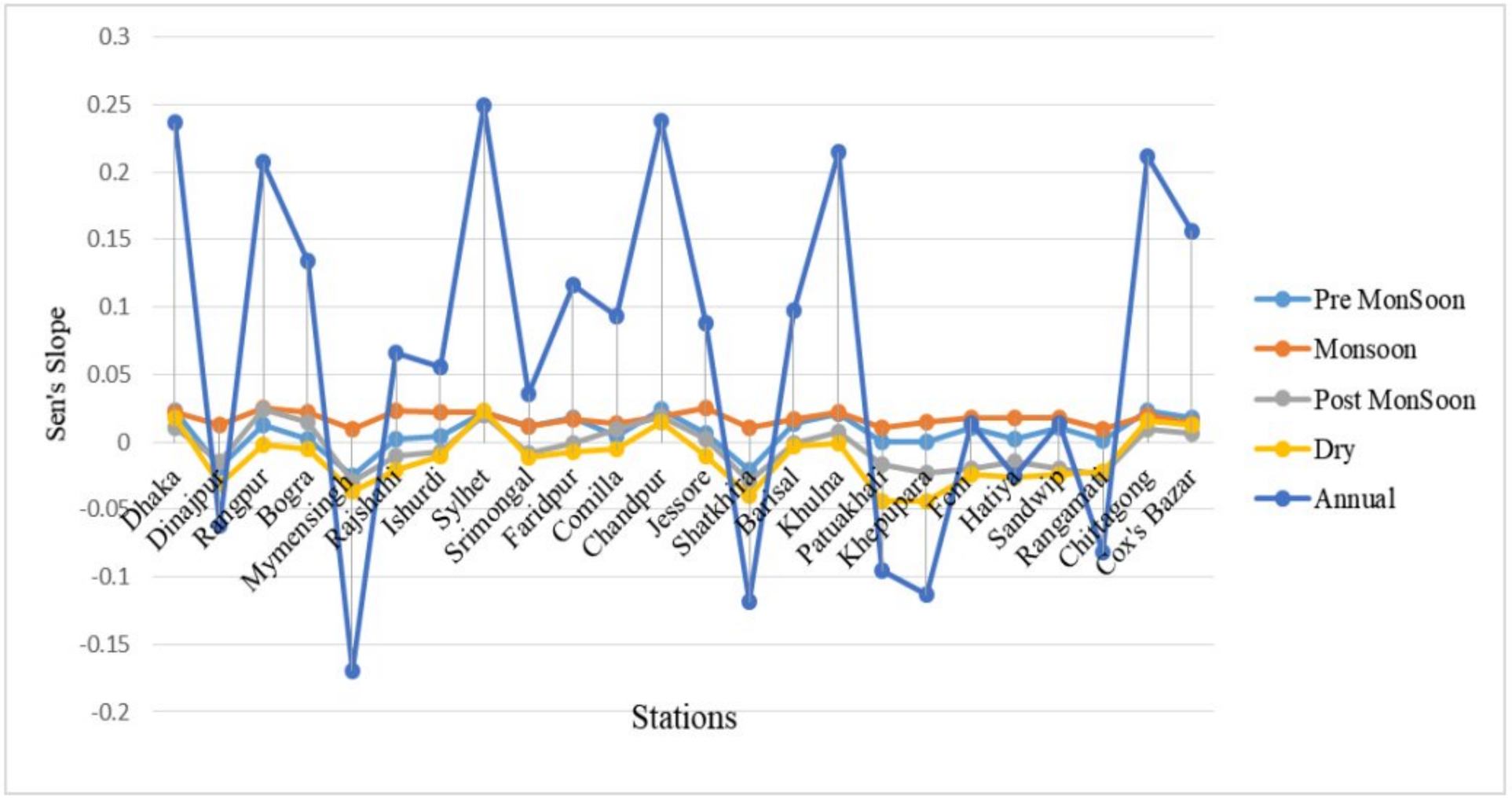


Figure 14 Sen's Slope result Average Temperature

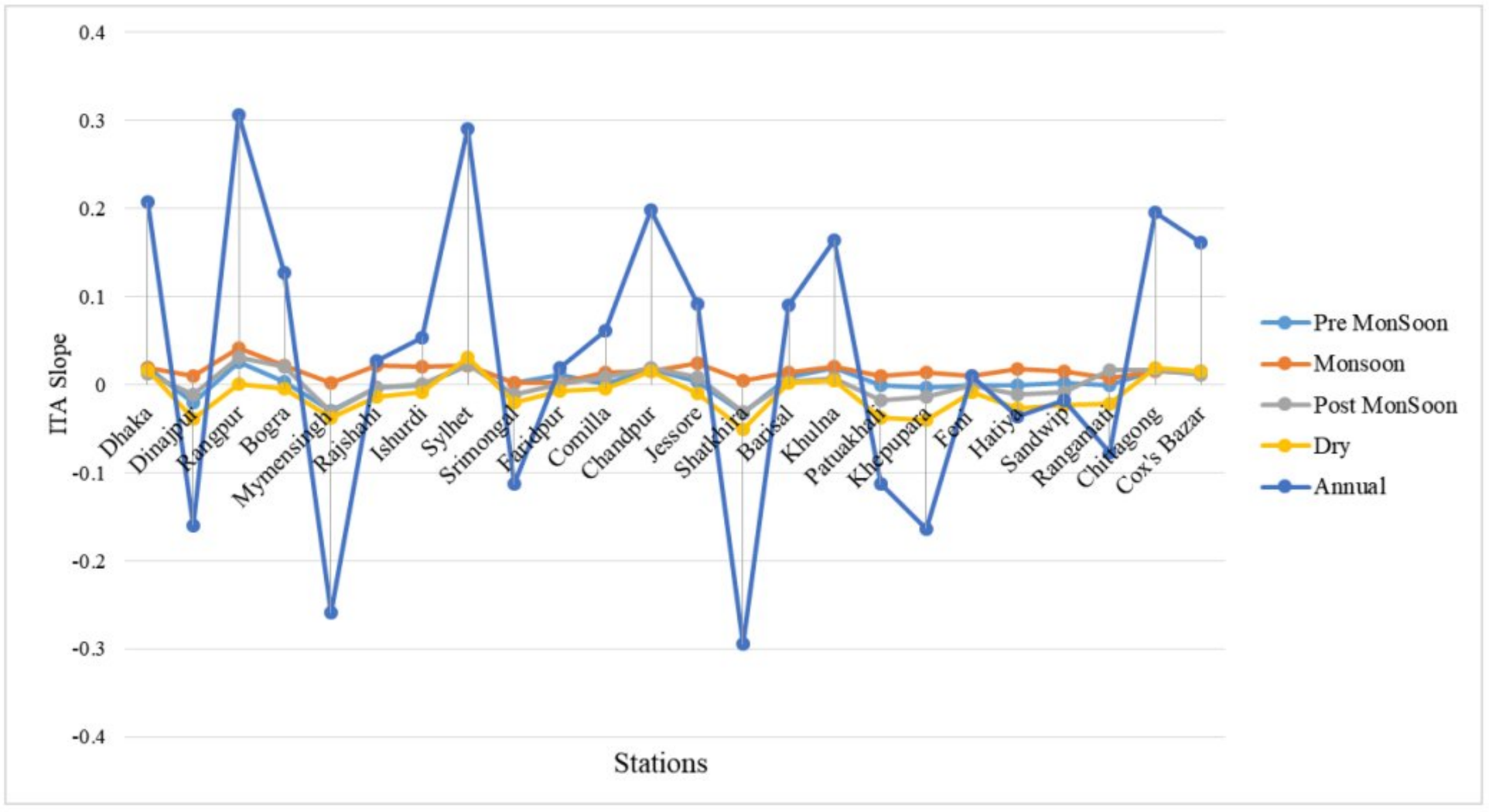


Figure 15 ITA Slope result Average Temperature.

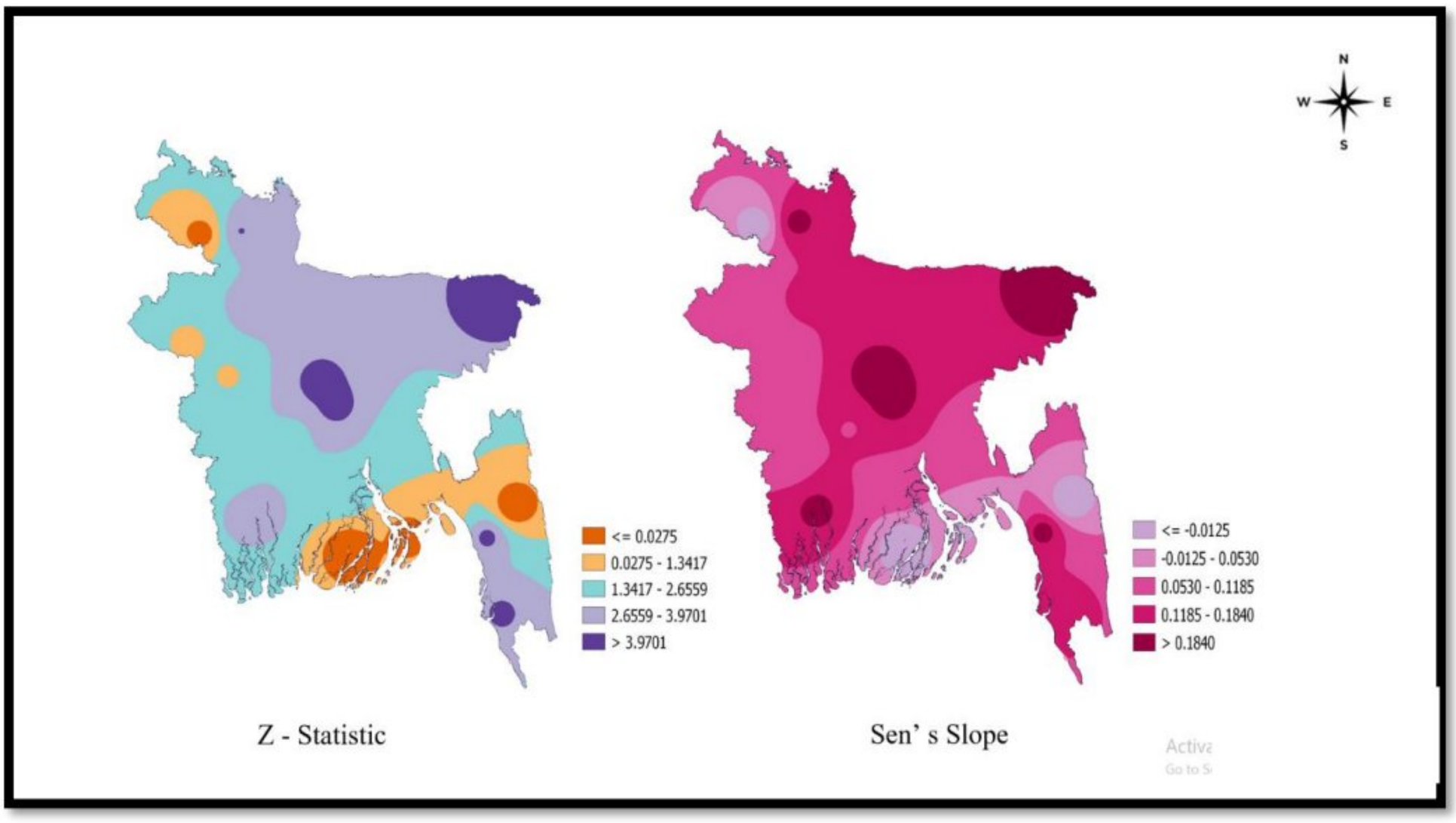


Figure 16 GIS MAPPING for MK and Sen's Slope testing for Average Annual temperature.

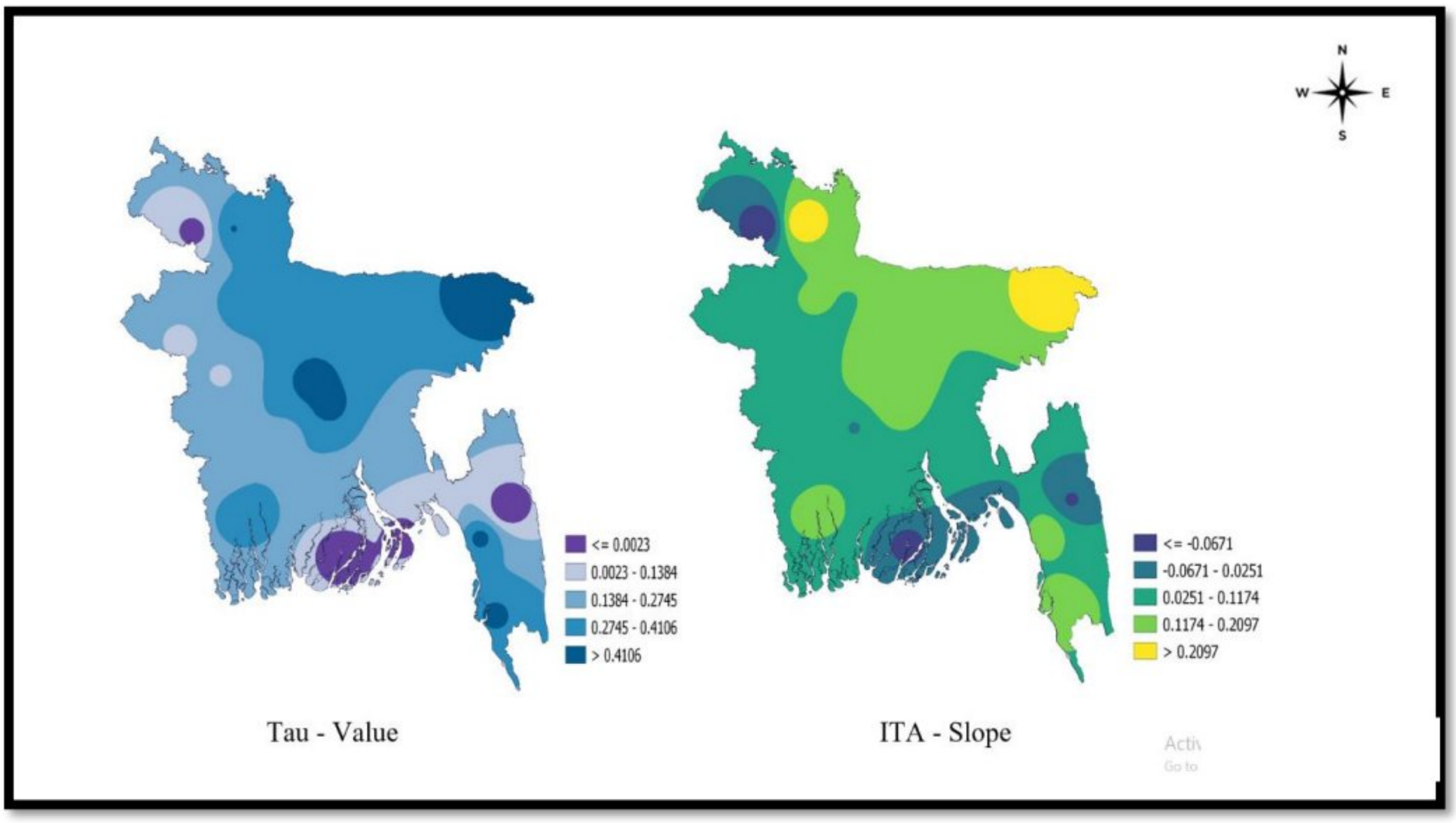


Figure 17 GIS MAPPING for Modified MK and ITA testing for Average Annual temperature.

4.3 Relation between Rainfall and Temperature variation:

Based on all the above mentioned Historical Data Analysis for Rainfall and Temperature, some relations can be developed based on the regular pattern of rainfall and temperature.

As we can see according to the above mention result 2 extreme events for rainfall and 2 extreme events for temperature has been taken under to develop a relation between the tradition temperature and rainfall patterns. So for Faridpur Station, being a negatively decreasing trend, most of the rainfall prevailed in the month of Jun July i.e. the Monsoon period. Also a significant amount of rainfall is also observed during the April, May, August and September period. Precipitation level is although seen in the other period of time but the amount cannot be consider significant.

But in case of Sandwip, a maximum Positively Increasing Station, the maximum amount of precipitation has been observed at a very high frequency from June to August its Monsoon to Post Monsoon, which clearly defines about the shift of rainfall trend from Monsoon to Post Monsoon period. Also there were rainfall in September and October which was larger than that of the frequency of Faridpur.

Now for the temperature pattern, the Whisker Plot plot shows an increasing pattern during the end of Dry and Pre-Monsoon period, afterwards from Pre-Monsoon till Post Monsoon, the temperature remains quite stable without any major variation. But in real scenario, the actual pattern should be like a normal distribution curve, and also for decreasing temperature of Khepupara, exactly similar pattern is observed.

As a result of the above explanation, it is clear that the rainfall period has shifted to Post Monsoon, and the temperature pattern has distorted Bangladesh's normal temperature pattern. Furthermore, there is no regular co-relation between the decrease in temperature and the increase in rainfall, indicating that Bangladesh's climate has been greatly impacted and a permanent deformation has occurred.

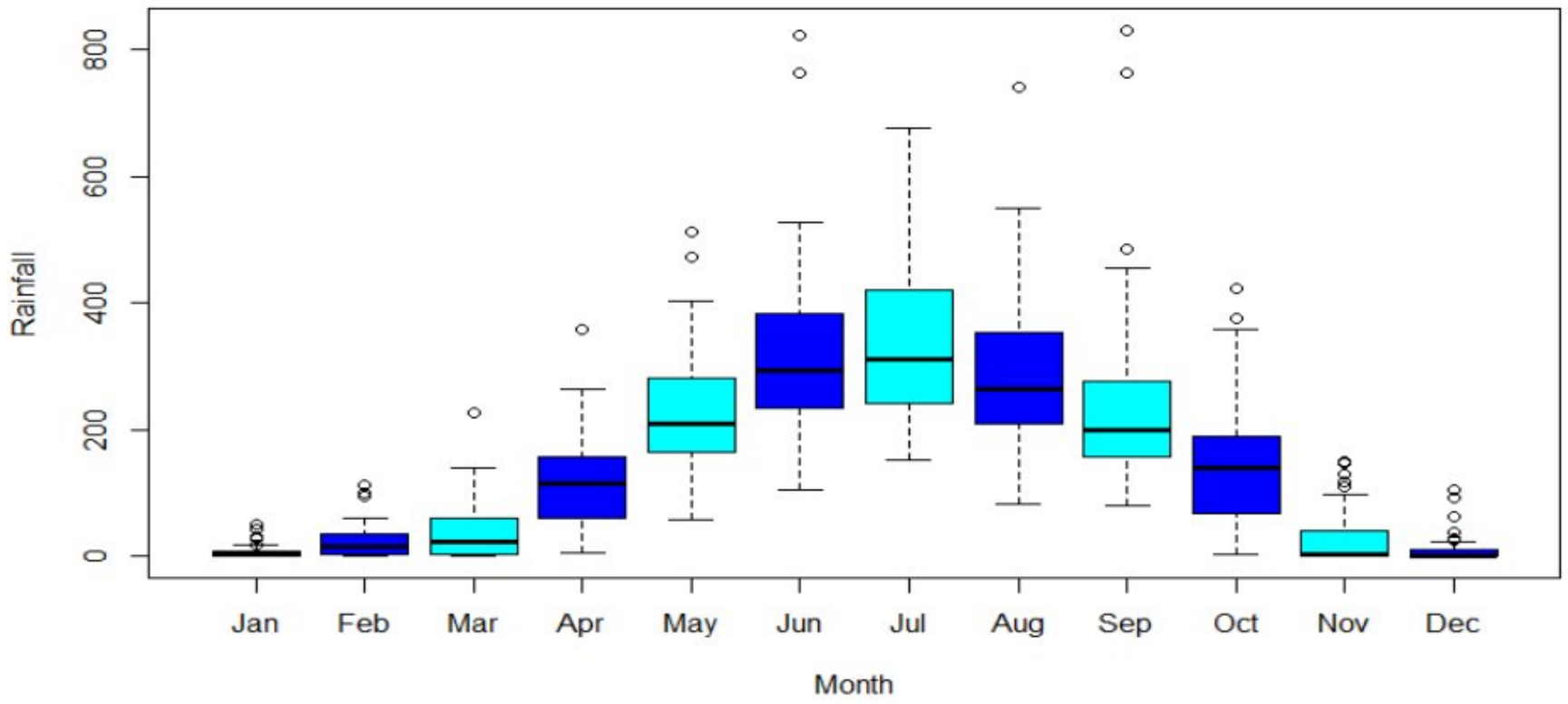


Figure 18 Faridpur Annual Rainfall Pattern

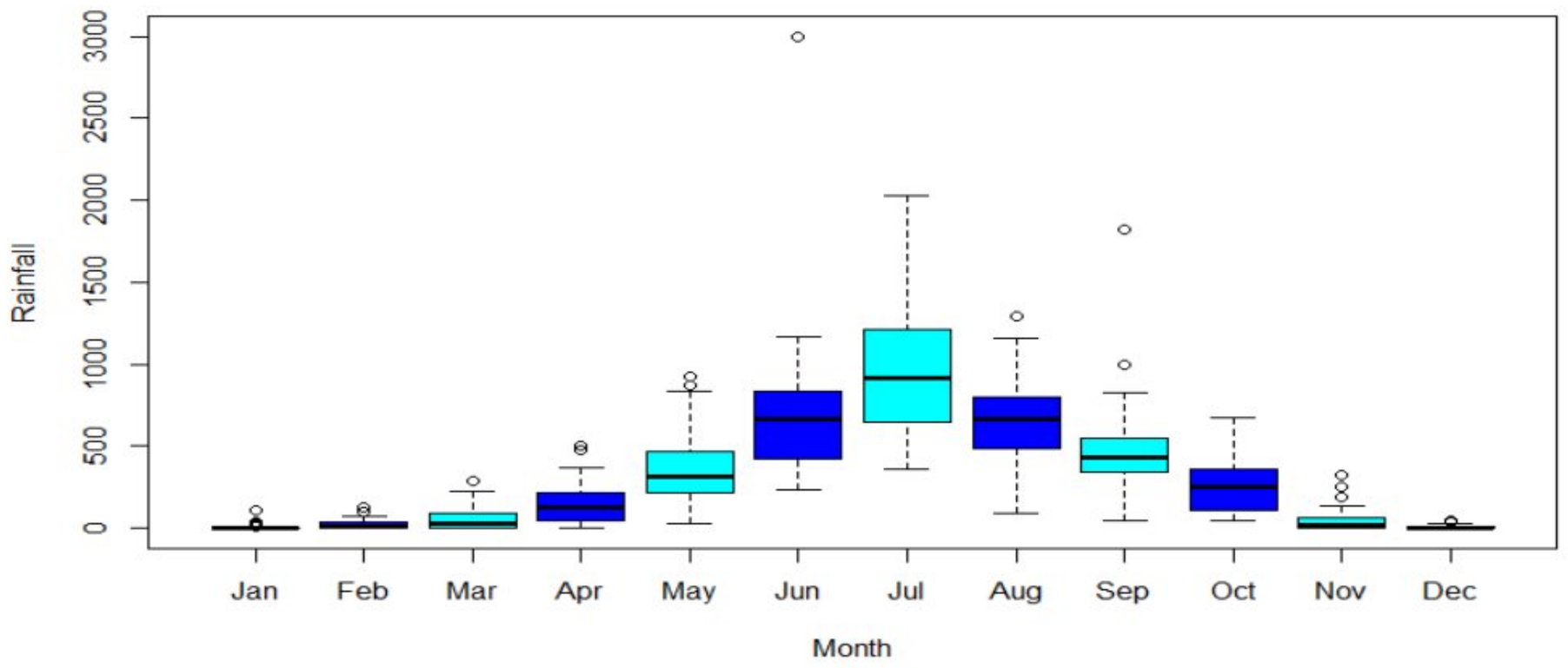


Figure 19 Sandwip Annual Rainfall Pattern

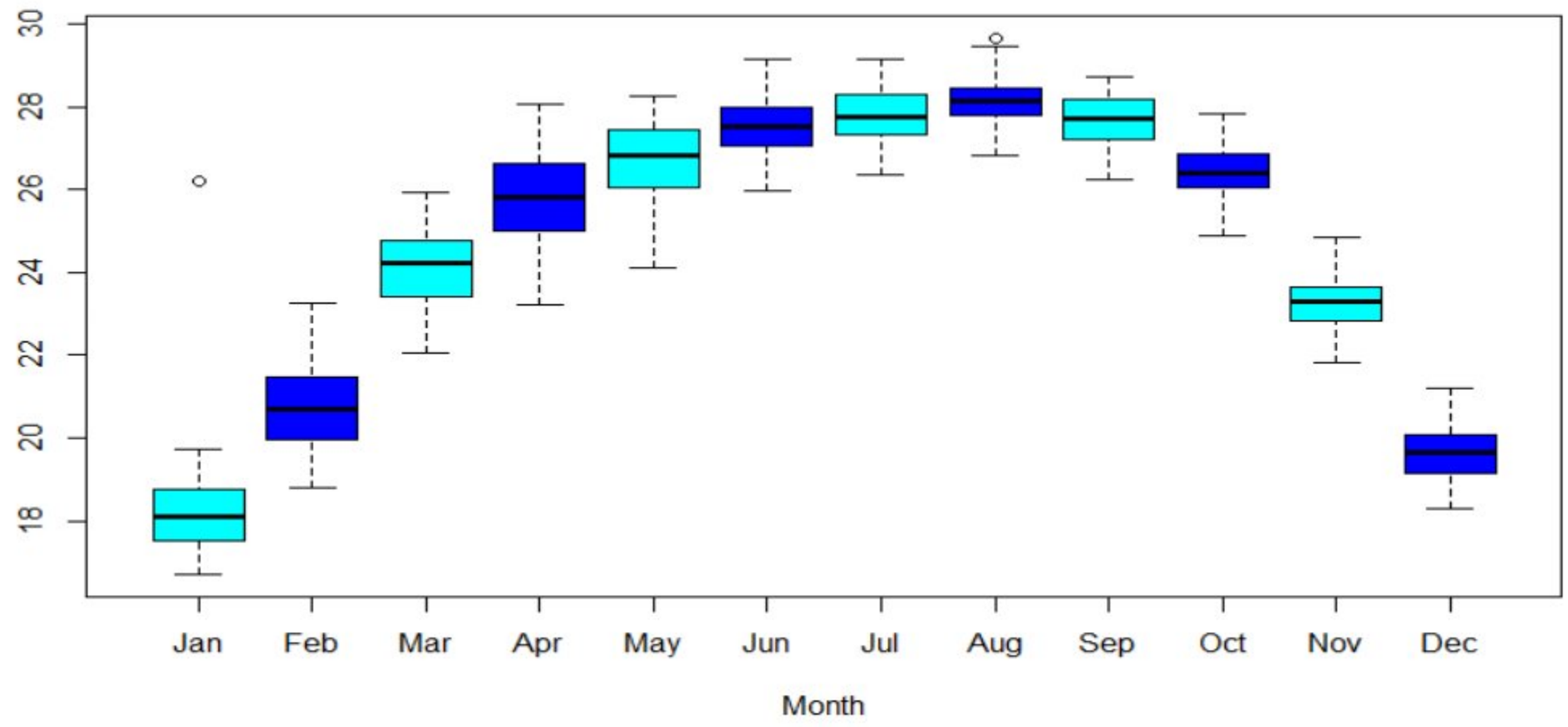


Figure 20 Sylhet Annual Temperature Pattern

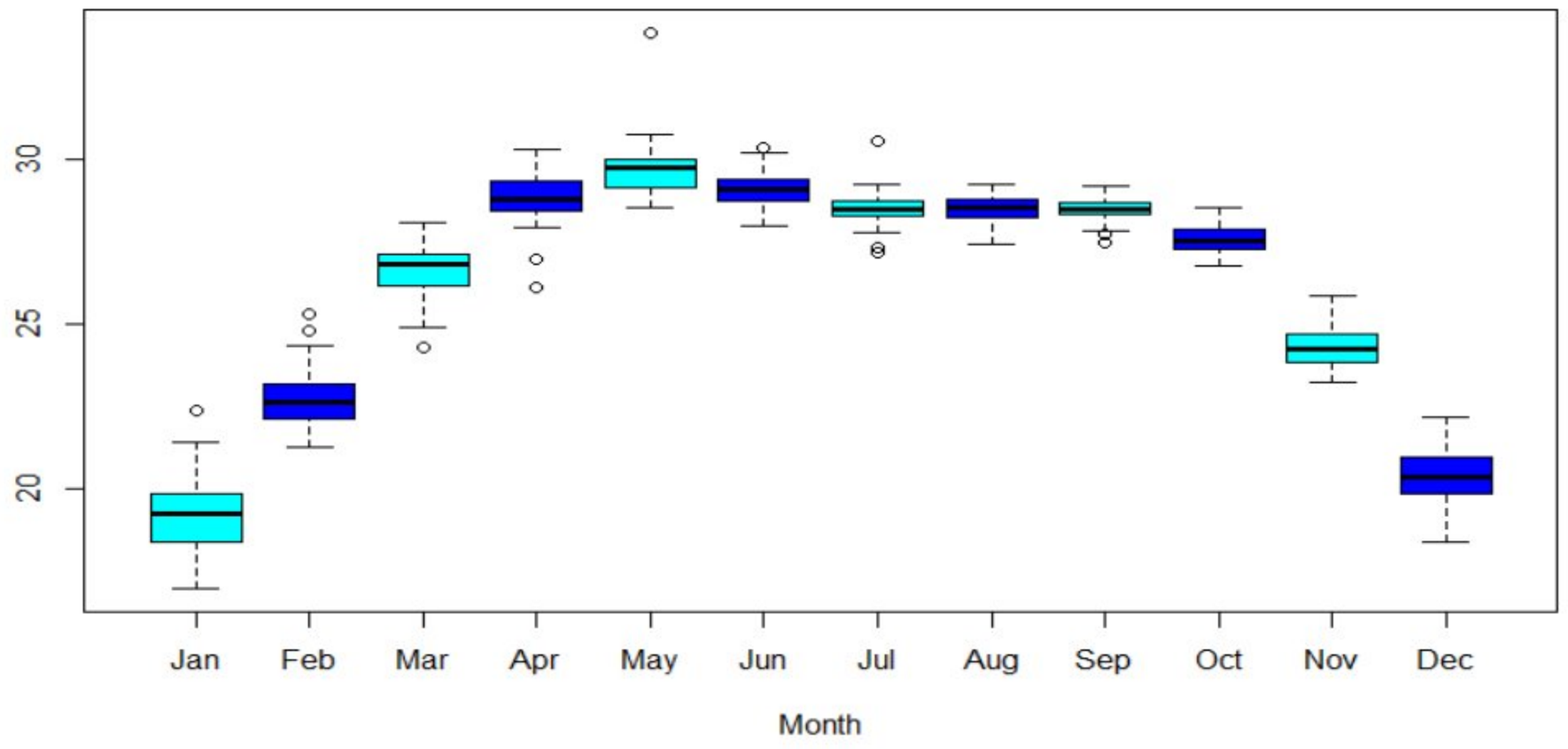


Figure 21 Khepupara Annual Temperature

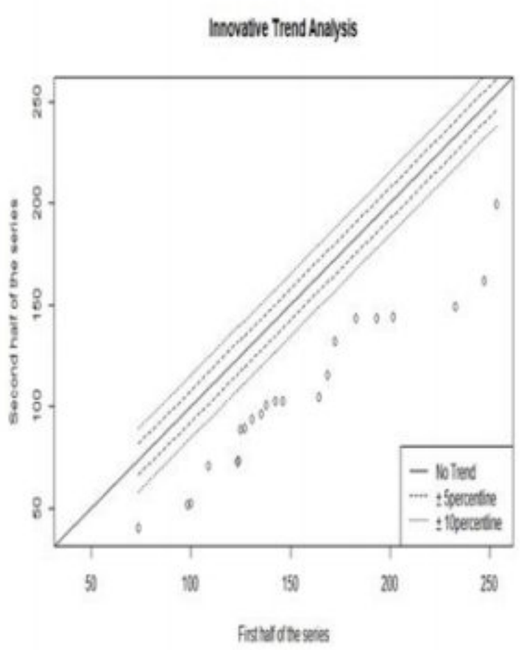
4.4 Concept of Sub Trend Analysis for ITA:

Sub trend analysis of Innovative trend analysis result is one of the latest inclusion in the field of trend analysis, which actually aims to investigate the result at its scratch to discover the actual scenario which is often hindered due to regular pattern of representation.

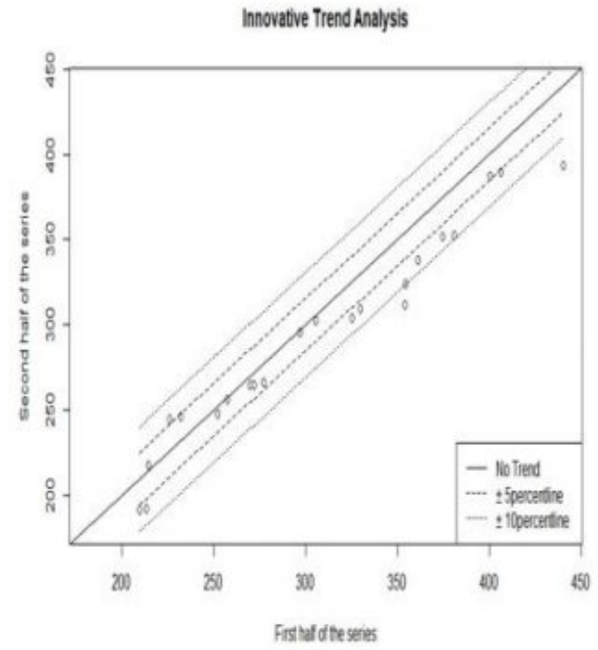
In figure 19 the explanation of the ITA slope for all 5 seasonal period has been explained for the Faridpur Station where a negatively decreasing trend has been observed during all 5 seasonal variations. Although according to the traditional and overall review the result has been deduced to be negatively decreasing, but if the values are discussed considering the 95 percent confidence interval i.e. for ± 5 percentile and ± 10 percentile values. There are some events which actually has crossed the Neutral trend line showing some positive increasing value with in the ± 5 percentile range. But since in broader sense this didn't get that much privilege due to the presence of sufficient negative decreasing trend, the overall value were as per the majority .

So the subtrend analysis can be done in future in a rigorous manner to determine the root cause of the variation and to differentiate the real situation over the traditional test values.

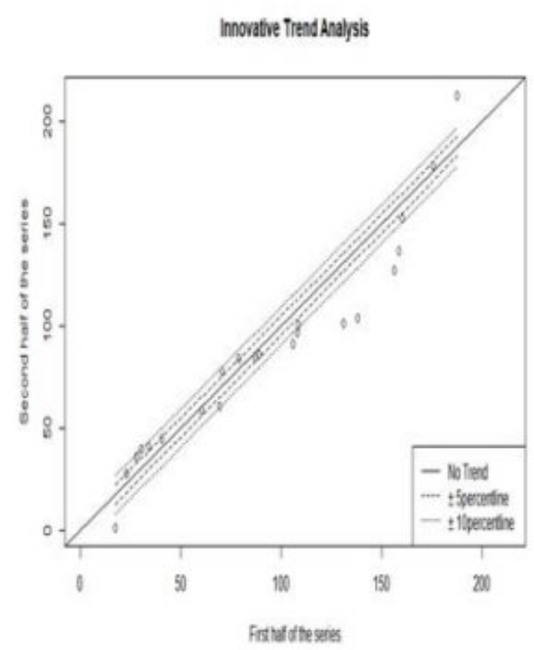
Using the same method all the ITA reports can be explained and the sub trend can be found out which can actually bring a revolutionary change in the so called pattern of Historical trend Analysis.



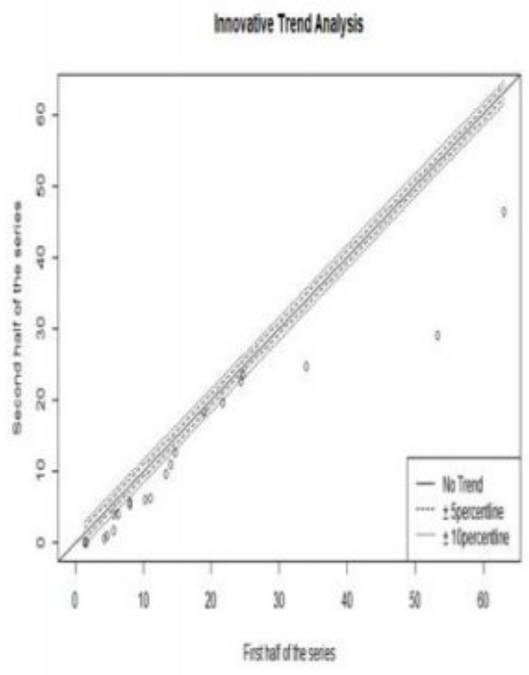
Faridpur Pre Monsoon (-2.144)



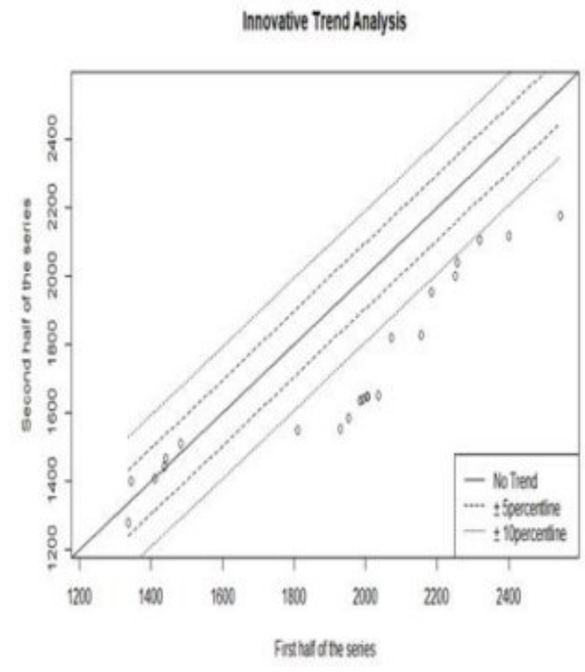
Faridpur Monsoon(-0.607)



Faridpur Post Monsoon (-0.23)



Faridpur Dry (-0.19865)



Faridpur Annual (-9.89)

Figure 22 ITA Slope Plot

Chapter 5: Conclusion

The present study explored the detailed spatio-temporal characteristics of precipitation and temperature in Bangladesh. By analyzing the trend of precipitation and temperature, it could be assumed that the result of ITA showed a more or less similar trend for all the stations and time scales, and *Z* statistic , Modified MK and Sen's slope confirmed its reliability. The results show a severe shift in precipitation, Maximum, Minimum, and Average temperature conditions over the whole study area, save for a few pocket locations, indicating that the climate has altered adequately during the study period (1975–2019). Such changes in most stations make the region the most vulnerable, and this practice continues at a medium to high rate, potentially affecting crop cycles, crop rotation, and the country's overall agricultural system. Furthermore, the relationship between the meteorological parameters Temperature and Rainfall has yet to be established, which is concerning.

However, other climatic parameters especially air pressure, humidity, wind pattern, sunshine and other important parameters were not included within this study, which can make a future scope towards a rigorous work and modeling of environment. The outcomes and findings of our study will be helpful for future works to estimate different environmental and climatic parameters as well as to find out sustainable water sources. Furthermore, it may help the policymakers and scientists to focus on the worldly concern of Global Warming and to take preventive measures regarding extreme environmental impacts, droughts and flood condition of the country so that it can help the agricultural sectors of Bangladesh.

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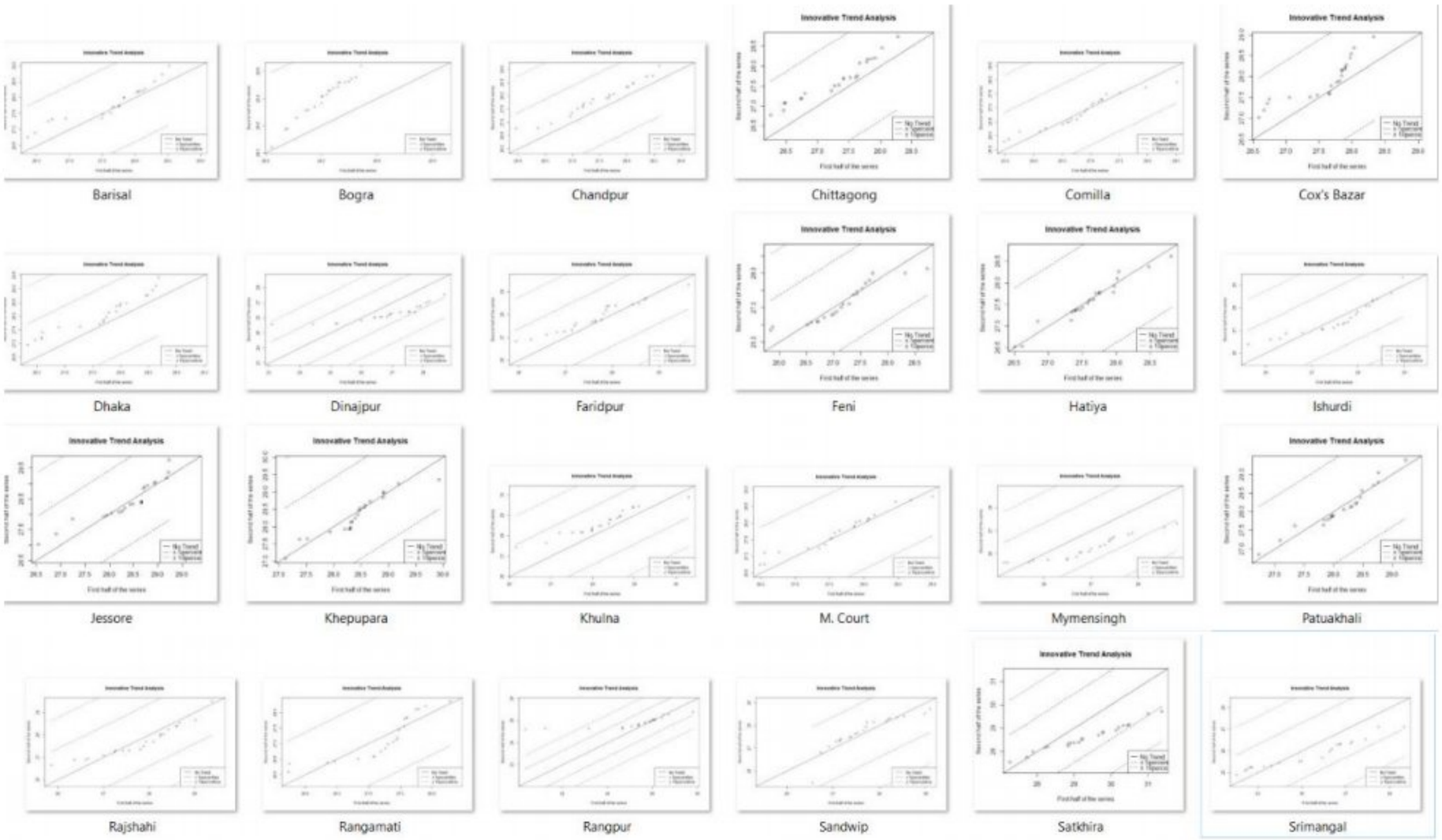
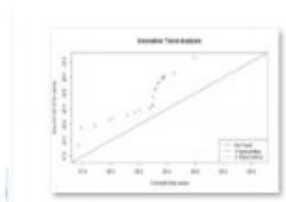
Appendix

Remaining graphical representation of Sub Trend are attached below:

Average Temperature- Pre-Monsoon



Average Temperature- Monsoon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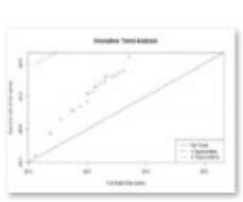
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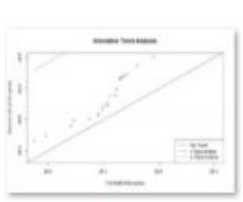
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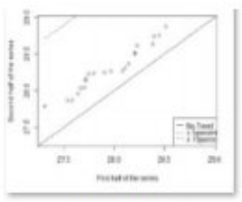
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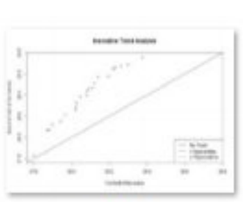
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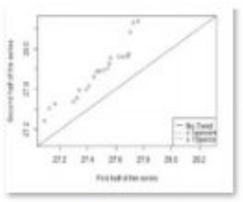
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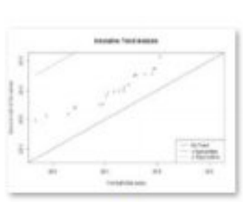
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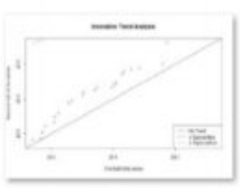
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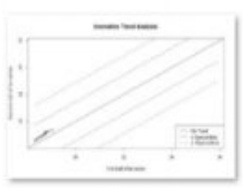
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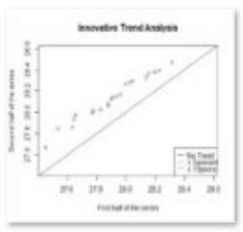
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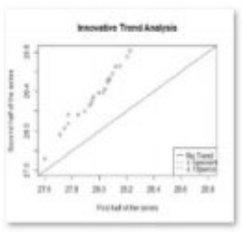
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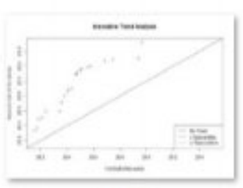
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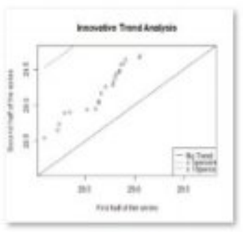
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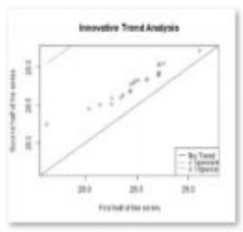
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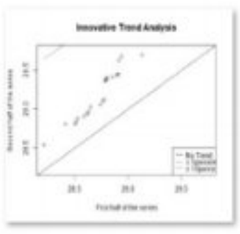
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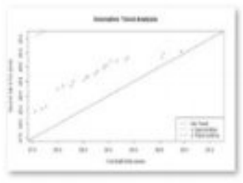
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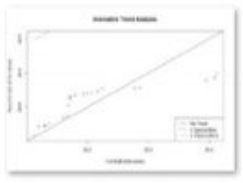
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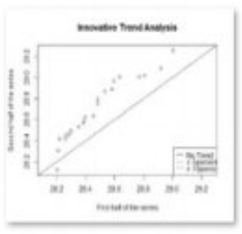
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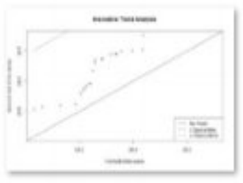
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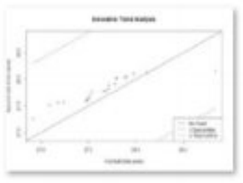
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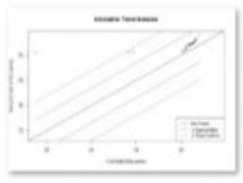
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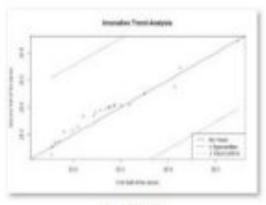
Average Temperature - Post-Monsoon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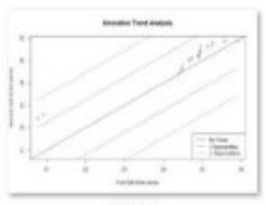
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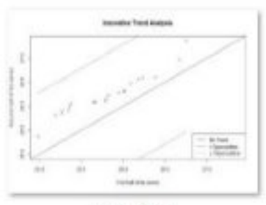
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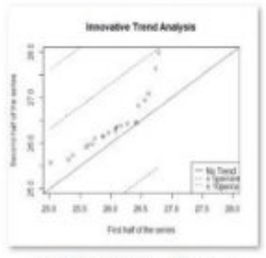
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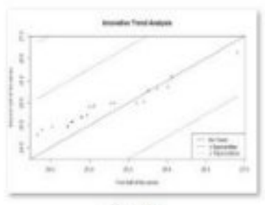
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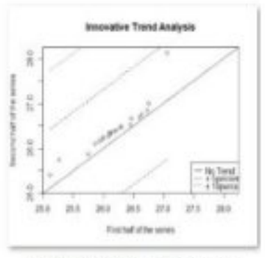
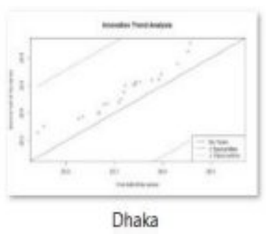

COX BAZAR Post Moonsoon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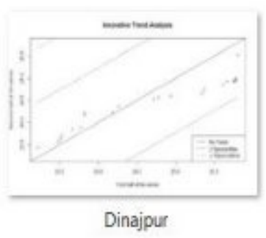
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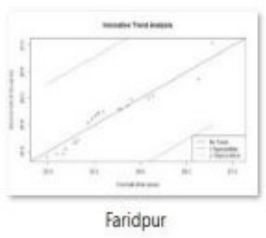
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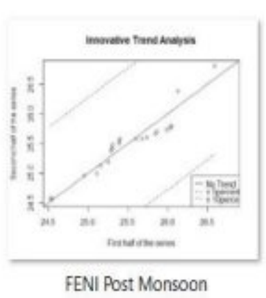
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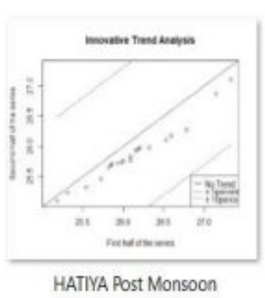
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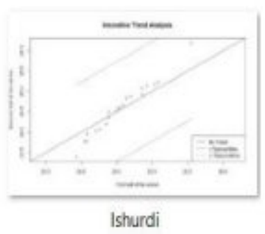
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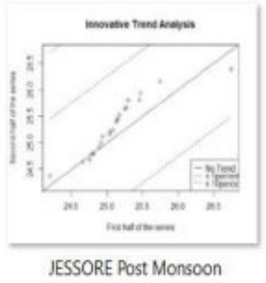
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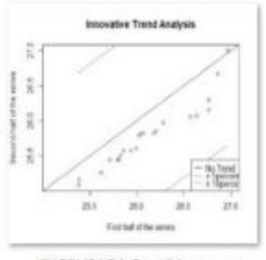
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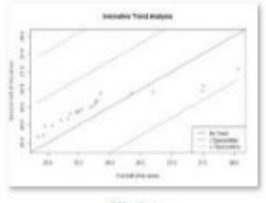
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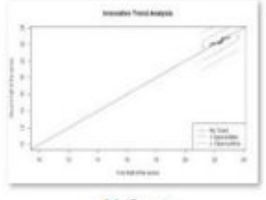
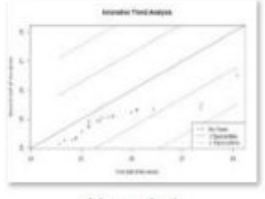

M. Court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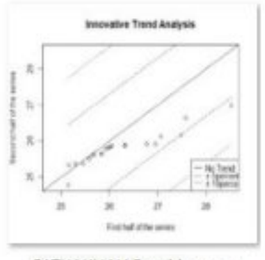
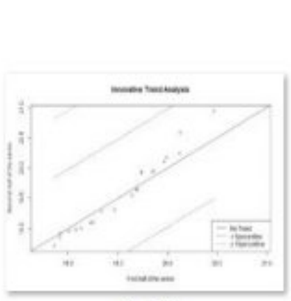

PATUAKHALI Post Monsoon

Average Temperature – Dry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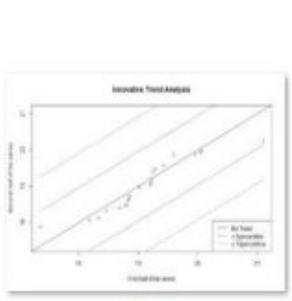
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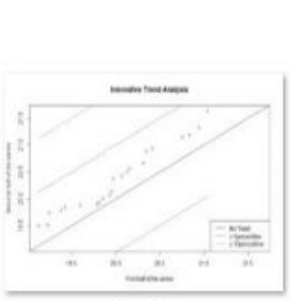
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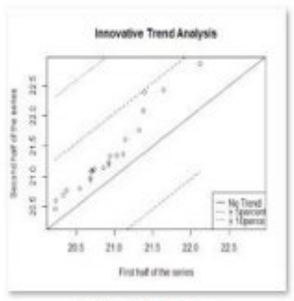

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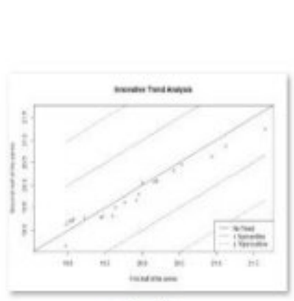
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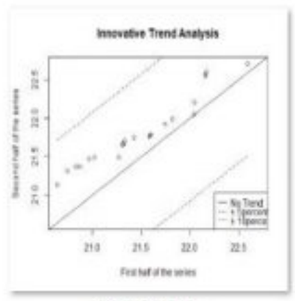

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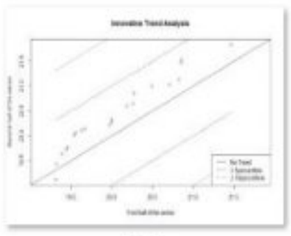
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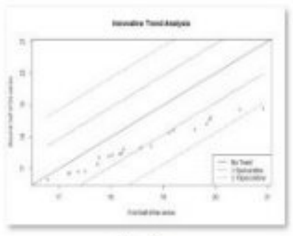
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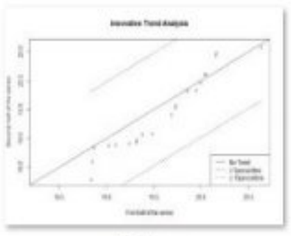
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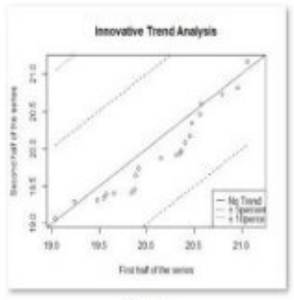

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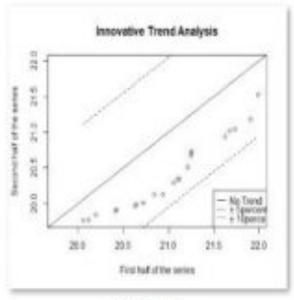

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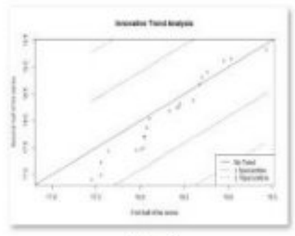
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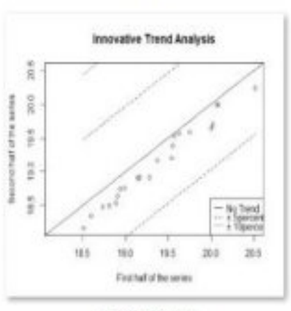

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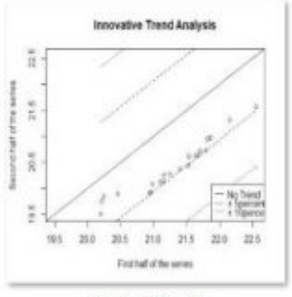

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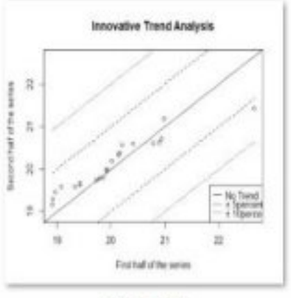

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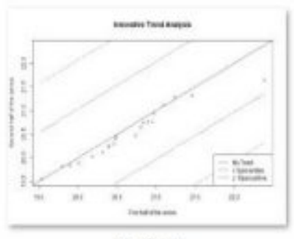
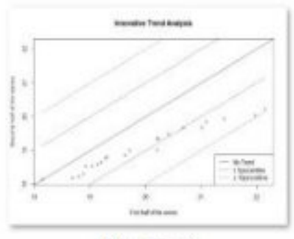

M. Court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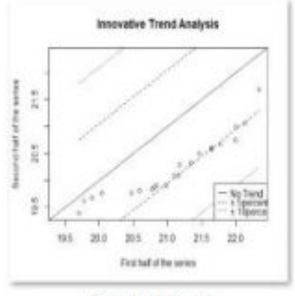
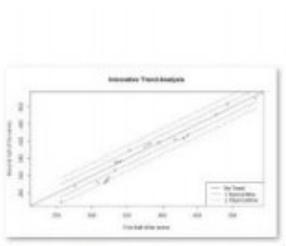


PATUAKHALI Dry

Rainfall – Monsoon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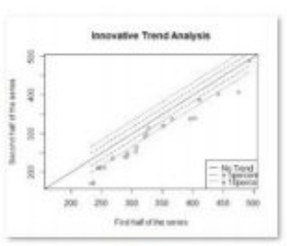
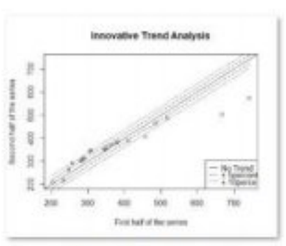
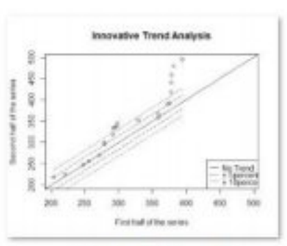


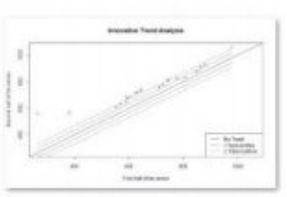
BOGRA MONSOON

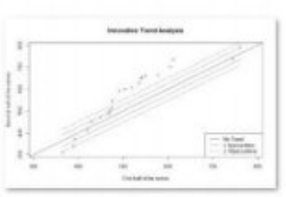


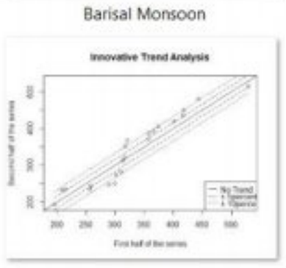
CHNADPUR MONSOON

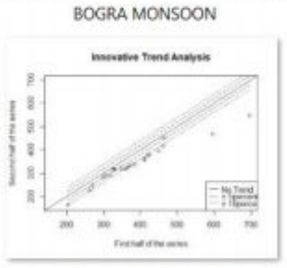


COMILLA MONSOON

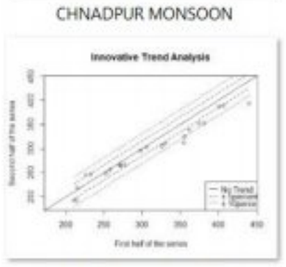

Coxs Bazar Monsoon


Ctg Monsoon


DHAKA Monsoon



DINAJPUR MONSOON



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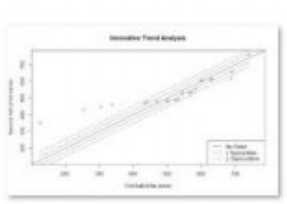
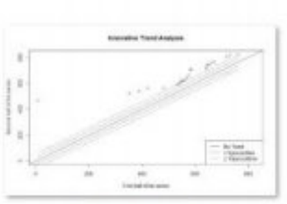
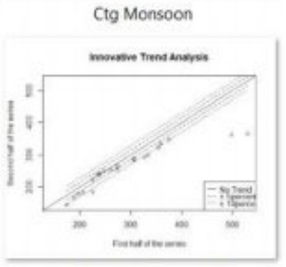
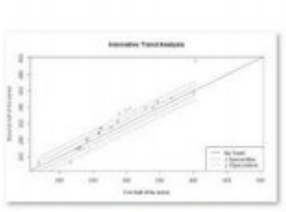
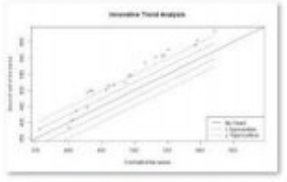

Feni Monsoon

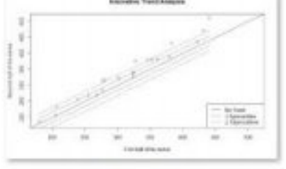

Hatiya Monsoon



ISHURDI MONSOON


Jessore Monsoon


Khepupara Monsoon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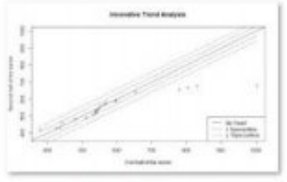
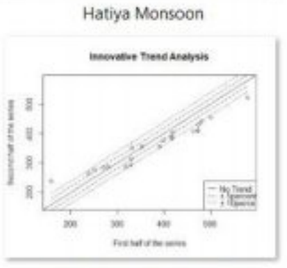
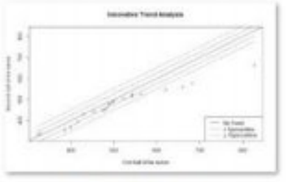

M. Court Monsoon

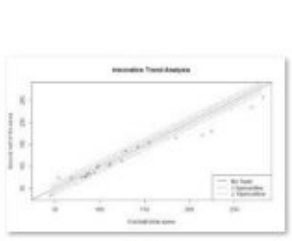


MYMENSINGH MONSOON



Patuakhali Monsoon

Rainfall –Pre- Monsoon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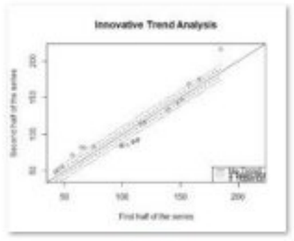
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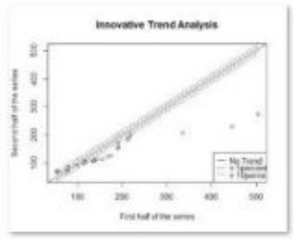
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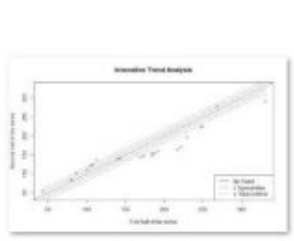
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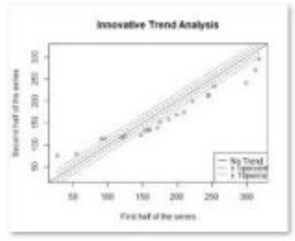
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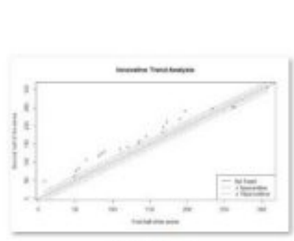
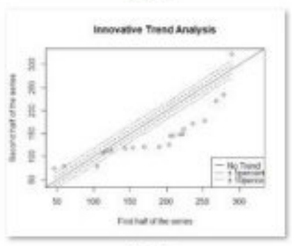
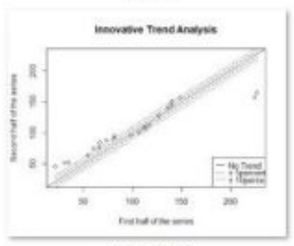
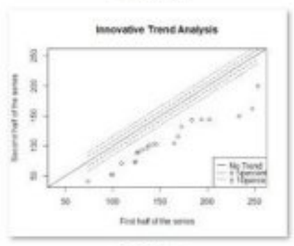
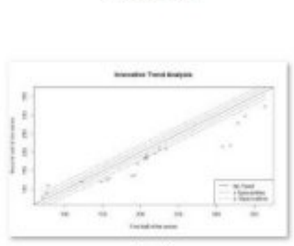
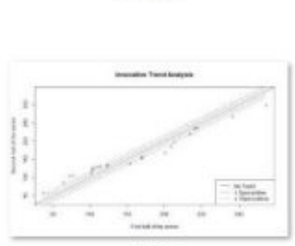

Cox's Bazar


Dhaka


DINAJPUR


Faridpur


Feni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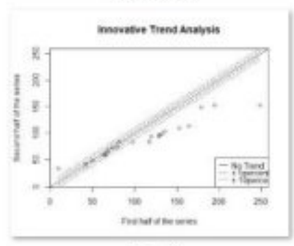
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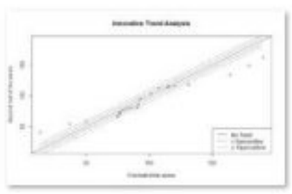
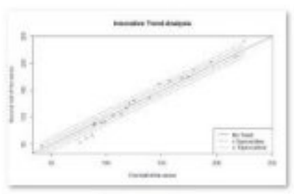
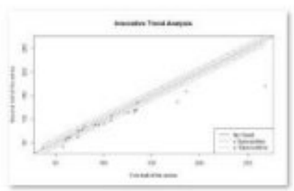

Jessore


Khepupara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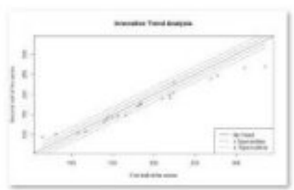
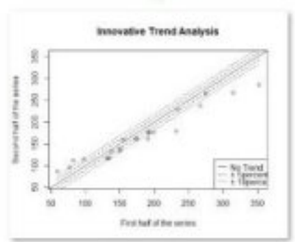
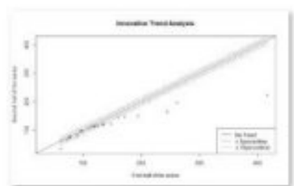
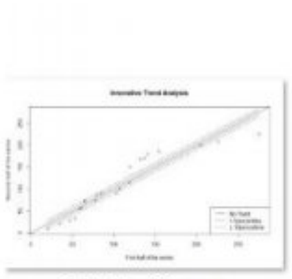
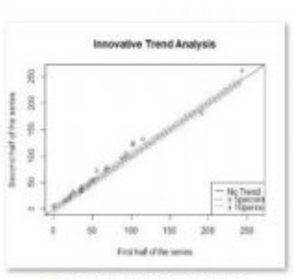

M. Court

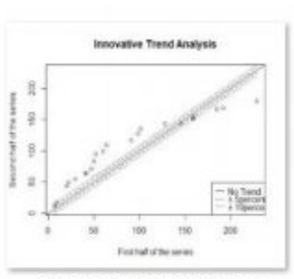

Mymensingh

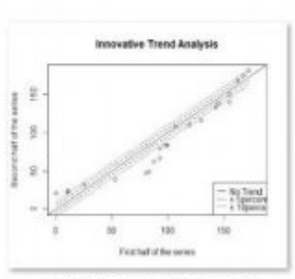

Patuakhali

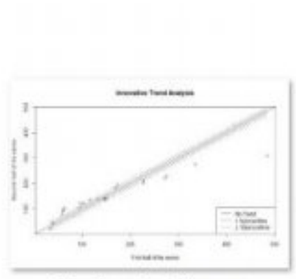
Rainfall –Post- Monsoon

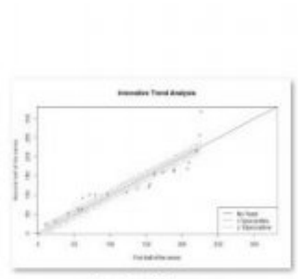

Barisal PostMonsoon

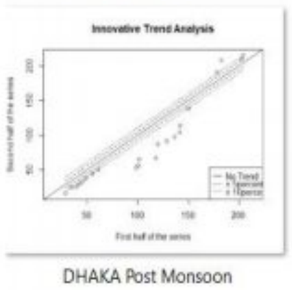

BOGRA POST MONSOON

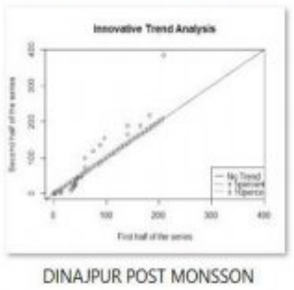

CHANDPUR POST MONSOON


COMILLA POST MONSOON

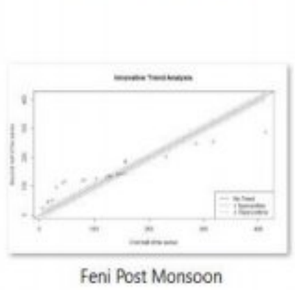

Coxs Bazar Post Monsoon


Ctg Post Monsoon


DHAKA Post Monsoon


DINAJPUR POST MONSSON


FARIDPUR POST MONSOON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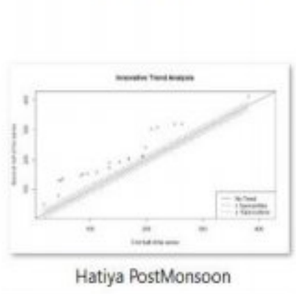
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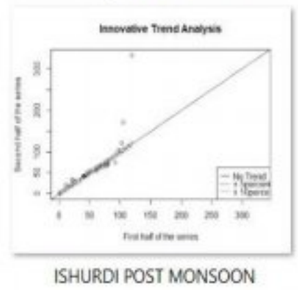
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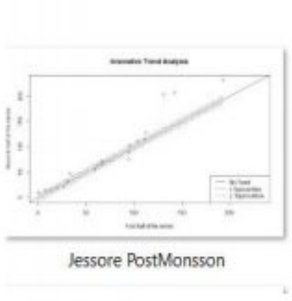
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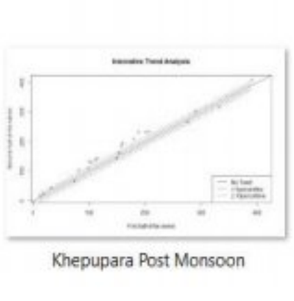
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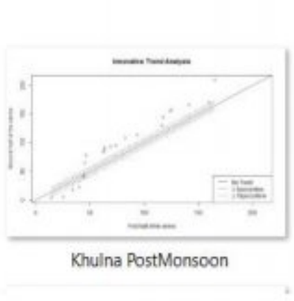
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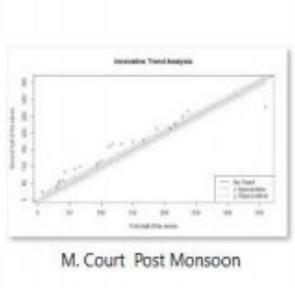
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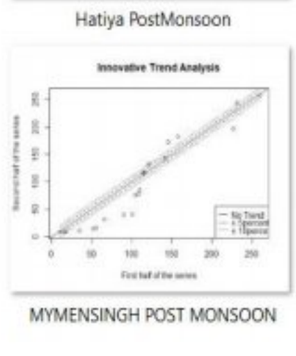
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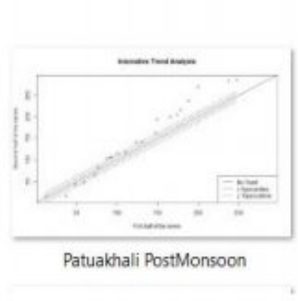
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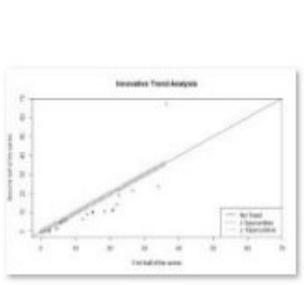
Rainfall –Dry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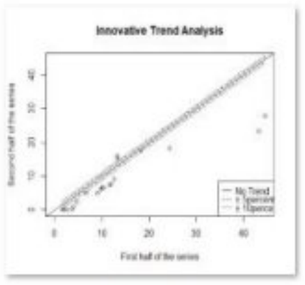

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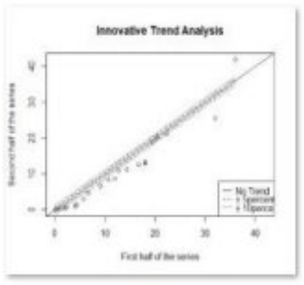

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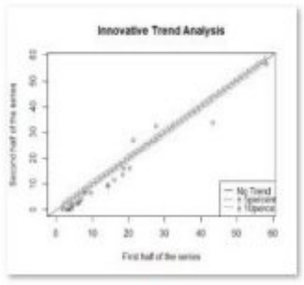

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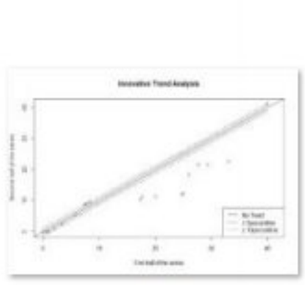
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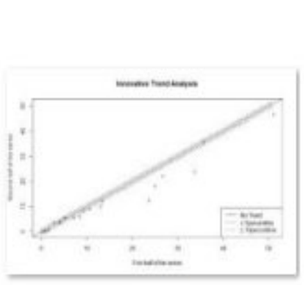
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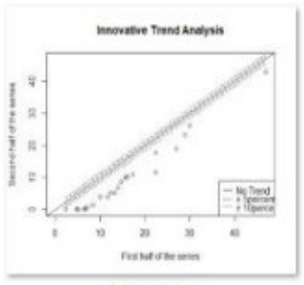
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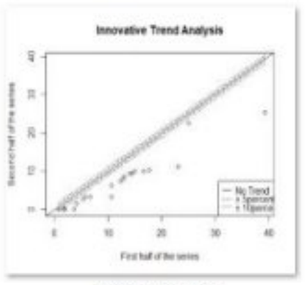
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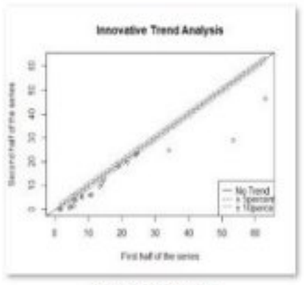
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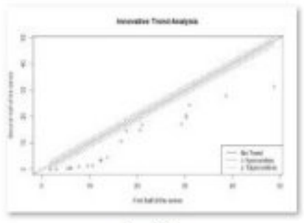
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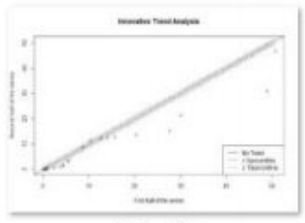
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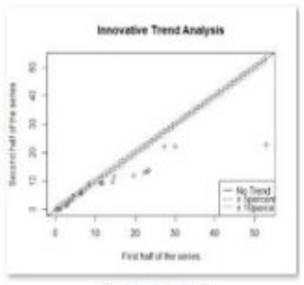

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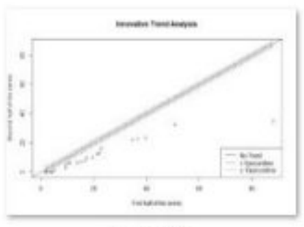
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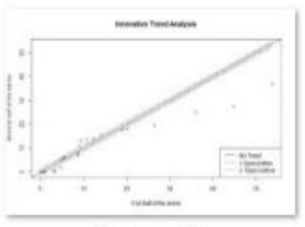
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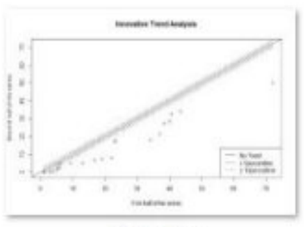
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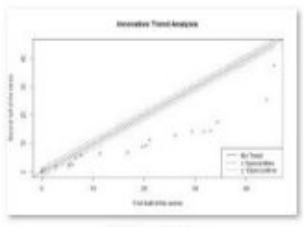
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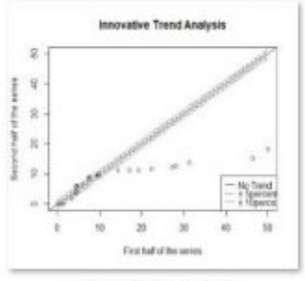

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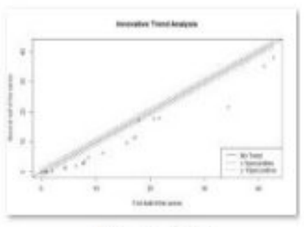
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