MASTER OF SCIENCE IN CIVIL ENGINEERING

Evaluation of Climate Change Variables based on Historical Data of Bangladesh

by

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Islamic University of Technology

Gazipur, Bangladesh

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A Thesis

by

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Recommendation of the Board of Examiners

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Dedication

This study is wholeheartedly dedicated to my beloved parents, who have been my source of inspiration and gave me strength when I thought of giving up, who continually provide their moral, spiritual, emotional, and financial support.

I would like to dedicate this thesis to all my teachers who brought me up to this moment.

And lastly, I dedicate this book to the Almighty God, thank you for the guidance, strength, power of mind, protection and skills and for giving me a healthy life.

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ABSTRACT

Bangladesh is considered as one of the most vulnerable countries to be impacted by climate change. In recent times, Bangladesh is experiencing less rainfall in rainy season, warmer dry season, dominance of warm years, abnormal seasonal variation, drought conditions during pre-monsoon and post-monsoon season which is leaving the country to be more prone to climate change effects. Analysis of extreme climatic events, indices and trends is crucial to understand the climatic change pattern of a country. Though several studies have been undertaken but to the best of my information, none of them covered trend, sub trend, extreme events and indices analysis altogether to get a complete picture of the climate change pattern of entire Bangladesh.

Therefore, extensive statistical analysis was performed using meteorological data, to explore the coherent trend and sub trend to explain their changes in the time series and identify the pattern of occurrence of extreme events as well as the extreme indices and represent them using GIS mapping. For Climate change analysis, daily average rainfall and daily average, maximum and minimum temperature data of 26 stations has been collected from Bangladesh Meteorological Department (BMD) from the year 1975 to 2019 for this study.

For this study, ITA method has been used to identify trends along with sub-trend analysis of rainfall and temperature data and the reliability of ITA method has been checked with the traditional approach like MK, mMK. Sen’s slope estimator. Standard Anomaly Index (SAI) have been used to identify frequency, severity and occurrence of extreme natural events i.e., drought and flood in Bangladesh. At last, ClimPACT2 software has been used to check homogeneity and calculate extremes of temperature and rainfall using daily observed data. Arc GIS 10.3 and R 4.0.2 software has been used for mapping and data analyzing.

The analysis shows that during the last four decades climate variables changed its pattern and trend heterogeneously. Both increasing and decreasing trend of annual rainfall was observed but majority stations showed decreasing trend. The central part of the country showed significant decreasing trend for rainfall. Northern and central part of the country showed significant increasing trend for annual average temperature. Increase in maximum temperature is more prominent than in minimum temperature. The rainfall and maximum temperature are

inversely related during monsoon and dry season as rainfall follows decreasing trend (0.65mm/year) and temperature shows increasing trend (0.017^{o}C/year).

The sub-trend analysis shows that the stations which show overall positive trend, shows decreasing sub trend for medium to high intensity rainfall. For temperature the sub trend analysis shows that lower maximum and minimum temperature is increasing which is minimizing the seasonal variation of temperature and causing a warming weather throughout the whole year.

The Standard Anomaly Index analysis shows that, the occurrence of drought and wet year is alternating in nature in almost all the stations. In the past 20 years, the country's western region experienced more drought years while the coastal region experienced more wet years.

The overall result of extreme indices analysis suggests that, Sylhet is vulnerable to temperature rise. Where all the stations experience negative trends in rainfall indices, Barisal and Rajshahi is susceptible to significant drought condition.

This study is anticipated to aid in understanding regional climate change in the South Asian region as well as in defining appropriate policies and plans to mitigate the adverse effects of climate change in Bangladesh.

LIST OF ABBREVIATIONS

ARIMA	Auto Regressive integrated moving average
BMD	Bangladesh Meteorological Department
CDD	Consecutive Dry Days
CMIP5	Coupled Model Intercomparison Project 5
CSDI	Cold Spell Duration Indicator
CV	Coefficient of Variation
CWD	Consecutive Wet Days
DTR	Diurnal Temperature
ETCCDI	Expert Team on Climate Change Detection and Indices
ET-SCI	Expert Team on Sector-Specific Climate Indices
GIS	Geographic Information System
GSL	Growing Season Length
IPCC	Intergovernmental Panel on Climate Change
ITA	Innovative Trend Analysis
MK	Mann–Kendall
mMK	modified Mann–Kendall
PCI	Precipitation Concentration Index
RAI	Rainfall anomaly Index
SAI	Standardized Anomaly Index
SPI	Standardized Precipitation Index
TN	Minimum Temperature
TR	Tropical Nights
TX	Maximum Temperature
WSDI	Warm Spell Duration Indicator

LIST OF NOTATIONS

Z	Indicator of the trend from MK analysis
τ	Indicator of the trend from mMK analysis

CHAPTER 1 INTRODUCTION

1.1 Background

Bangladesh is considered as one of the most exposed countries to be impacted by climate change and has long been exposed to various climatological (e.g., drought), hydrometeorological (e.g., cyclones, storm surge, flood) hazards. In recent times, Bangladesh is facing less rainfall in rainy season, warmer dry season, dominance of warm years, abnormal seasonal variation, drought conditions during pre-monsoon and post-monsoon season which is leaving the country to be more prone to climate change effects.

IPCC also recognized Bangladesh as one of the most threatened countries in the world to the unfortunate impacts of the climate change (Solomon et al., 2007). As per IPCC 2007, there will be an increase in the intensity of heavy rainfall events in the future but an overall decrease by up to 15 days in the annual number of rainy days and an increase of 3.3°C in annual mean temperature over a large part of South Asia by the end of the 21^{st} century (Solomon et al., 2007).

Recently, Ministry of Environment, Forest and Climate Change, Government of the People's Republic of Bangladesh has prepared National Adaptation Plan of Bangladesh (2023-2050) considering exacerbating stresses on socioeconomic progress and human well-being due to climate change. Thus, micro level analysis of detailed characteristics of crucial climatic variables i.e., rainfall and temperature to identify the impact of climate change and occurrence of extreme events would have a significant impact on the management of water resources, crop production and the life of the general public (Das et al., 2021).

Statistical models are typically utilized to comprehend the pattern of climate change and the occurrence of extreme events. These models are a useful tool for analyzing temperature and rainfall trends (Das et al., 2021; Zannat et al., 2019). Until now, different statistical nonparametric models, e.g., Mann-Kendall (Kendall, 1955; Mann, 1945), Spearman’s rho (Spearman, 1904), Pettitt test (Pettitt, 1979), Sen’s slope estimator (Sen, 1968) have been applied for the assessment and changes in trend in the rainfall and temperature.

Several studies (Alifujiang et al., 2020; Bavil et al., 2018; Cui et al., 2017; Fathian et al., 2016; Girma et al., 2020; Koudahe et al., 2017; Naqi et al., 2021; Sa'adi et al., 2019; Sonali and Kumar, 2013; Wu et al., 2019; Yacoub and Tayfur, 2019) have been carried out to identify the trend in rainfall and temperature data for different parts of the world.

A novel trend method to find any hidden trends in a time series dataset was recently proposed by (Şen, 2012) and it has received significant attention in various regions of the world (Güçlü, 2018; Sonali and Kumar, 2013; Wu and Qian, 2017; Yacoub and Tayfur, 2019). This method enables more in-depth interpretations of trend identification, which is advantageous for identifying hidden sub-trends and the graphical representation of the trend variability of extreme events, such as "high" and "low" values of climatic variables (Alifujiang et al., 2020).

Standardized anomaly index (SAI) is another important statistical analysis to determine the drought and wet years, cold and warm years. It can measure the frequency and severity of extreme events.

In addition to this, the WMO expert team on climate change has defined several indices for climate change analysis (Tank et al., 2009). Several studies (Encinas et al., 2013; Kim et al., 2011; Marigi et al., 2016; Naqi et al., 2021; Razavi et al., 2016) have been undertaken at different study areas to understand the changes of climatic indices for the adaptation plan. The indices are diagnostic tools used to describe the state of a climate system (Marigi et al., 2016).

In recent years, several studies (Bari et al., 2017; Bhuyan et al., 2018; Hasan et al., 2014; Islam et al., 2020; Khan et al., 2019; Mehzabin and Mondal, 2021; Noorunnahar and Hossain, 2019; Rahman et al., 2017; Rahman and Lateh, 2017; Shahid, 2010a, 2010b) have been undertaken to identify trend analysis of rainfall and temperature using parametric (i.e., linear regression) and non-parametric methods i.e., Mann–Kendal (MK) or modified Mann–Kendall (mMK) test in Bangladesh.

Among them, Das et al. (2021) and Islam et al. (2020) have applied ITA method but none of them have applied ITA method for both rainfall and temperature data and analyzed sub-trend of them which is essential to understand the detail pattern and inter relationship of the two climatic variables. Das et al. (2021) used MK, modified MK, ITA method to identify trend, sequential MK to identify changing point , Sen's slope for magnitude of change and Discrete wavelet transform to identify the periodicity of annual and seasonal rainfall.

Islam et al. (2020) applied MK, Spearman's rho, ITA to identify trend of daily rainfall data, Sen's slope for magnitude and probability distribution function for obtain more information about the frequency of daily rainfall ranges with some forthcoming periods (in years).

Though several studies have been undertaken but to the best of my information, none of them covered trend, sub trend, extreme event and indices analysis altogether to get a complete picture of the climate change pattern of entire Bangladesh.

Therefore, extensive statistical analysis was performed using meteorological data, to explore the coherent trend and sub trend of related climatic variables in order to explain their changes in the time series and identify the pattern of occurrence of extreme events as well as the extreme indices and represent them using GIS mapping. In addition to that, it will be intriguing to compare the results of different statistical models to check their reliability.

1.2 Objectives

The objectives of this study were as follows:

i. To evaluate and quantify the variables of climate change in Bangladesh using the historical rainfall and temperature data.
ii. To analyze the occurrence of extreme events by calculating extreme indices of temperature and precipitation.

1.3 Outline of Methodology

For this study, rainfall and temperature time-series data (i.e., daily rainfall, maximum, minimum and average temperature) has been collected from BMD for 26 stations from the year 1975 to 2019 which covers almost entire Bangladesh.

The time series data has been pre-whitened to eliminate serial correlation. Trend and sub-trend analysis of seasonal and annual rainfall and temperature has been carried out using the Sen's Innovative Trend Analysis (ITA) (Şen, 2012) method which has advantages of visual-graphical illustrations along with the identification of sub-trends (Alifujiang et al., 2020, Wu et al., 2019) and reliability of it has been checked with conventional tests i.e. Mann-Kendall, Modified Mann-Kendall and Sen's slope estimator. Arc GIS 10.3 and R 4.0.2 software has been used for mapping and data analysis.

Standardized Anomaly Index (SAI) of rainfall and temperature has been used to determine the frequency and severity of dry or wet years and cold or warm years accordingly.

The extreme indices of temperature and precipitation i.e., consecutive warm or cold days, consecutive dry and wet days, annual number of days when precipitation or temperature is higher or lower than average precipitation or temperature respectively, frequency and severity of dry and wet years etc. has been calculated using ClimPACT2 software.

1.4 Organization of the Thesis

The thesis has been presented in five chapters.

Chapter One presents the background of the study, objective, and outline of methodology in brief.

Chapter Two presents a review of the statistical methods those have been used so far for the evaluation of climate change variables in recent papers of different study areas worldwide. This chapter describes related works which have been performed previously.

Chapter Three presents the methodology followed in this research. It includes details of the statistical methods and analysis of climatic variables, and it describes in details of the parameters that have been checked during the study.

Chapter Four presents the results of trend and sub-trend analysis of annual rainfall, daily average, daily maximum and daily minimum temperature. It also presents the findings from

Standardized Anomaly Index (SAI) of annual rainfall, daily average, daily maximum and daily minimum temperature. Extreme indices of rainfall and temperature has also been identified and analyzed in this section. all the results have also been presented by GIS mapping in this chapter for better understanding.

Finally, **Chapter Five** summarizes the major conclusions from the present study. It also presents limitations of this study and recommendations for future study.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Rigorous review of national and international published journal or conference papers, or reports have been performed to find out the rationale of this study, pros and cons of underlying theories and outcome of past relevant studies, which will facilitate to make this study more informative and authentic. In this Chapter, literature review has been discussed on trend analysis, Standard anomaly index analysis, extreme indices analysis of rainfall and temperature data of various parts of the world and Bangladesh.

2.2 International Studies

Several studies (Alifujiang et al., 2020; Bavil et al., 2018; Cui et al., 2017; Fathian et al., 2016; Girma et al., 2020; Koudahe et al., 2017; Naqi et al., 2021; Sa'adi et al., 2019; Sonali and Kumar, 2013; Wu et al., 2019; Yacoub and Tayfur, 2019) have been carried out to identify the trend in rainfall and temperature data for different parts of the world. In addition to that studies i.e., (Kim et al., 2011; Marigi et al., 2016; Naqi et al., 2021; Razavi et al., 2016)have been undertaken on extreme indices analysis. Details of these studies have been presented in Table 2.1.

2.3 Bangladesh Studies

In recent years, several studies i.e., (Bari et al., 2017; Bhuyan et al., 2018, 2018; Hasan et al., 2014; Islam et al., 2020; Khan et al., 2019; Mehzabin and Mondal, 2021; Noorunnahar and Hossain, 2019, 2019; Rahman et al., 2017; Rahman and Lateh, 2017; Shahid, 2010a, 2010b) have been undertaken to identify trend analysis of rainfall and temperature using parametric (i.e., linear regression) and non-parametric methods i.e., Mann–Kendal (MK) or modified Mann–Kendall (mMK) test in Bangladesh. Bari et al. (2017) assessed rainfall variability, seasonality index and trend using MK and sequential MK method over northern Bangladesh from the year 1964 to 2013 using monthly rainfall data. Hasan et al. (2014) explored annual and seasonal rainfall trend over south-east part of coastal area of Bangladesh using MK and Sen's slope estimator method from the year 1980 to 2011. Khan et. al (2019) has assessed monthly rainfall, temperature, humidity and wind speed data to identify their trend using MK and Sen's slope method and correlation among them using Pearson correlation and Spearman's rho test of entire Bangladesh from the year 1988 to 2017. Mehzabin and Mondal (2021) has assessed rainfall and temperature data of Khulna using Linear regression models, coefficient of variation (CV), mean standardized anomaly (Z), and precipitation concentration index (PCI) and MK test. Rahman et al. (2017) used MK, mMK, Sen's slope and Spearman's rho test to identify rainfall trends, sequential MK for turning points of trend over Bangladesh and used AutoRegressive integrated moving average (ARIMA) model to analyze and predict rainfall trends for the year 1954 to 2913. Rahman and Lateh (2017) used Linear regression, coefficient of variation, inverse distance weighted interpolation techniques to analyze the trends, variability and spatial patterns of temperature and rainfall of entire Bangladesh from the year 1971 to 2010. ARIMA model was used to forecast the temperature and rainfall data. Shahid (2010a) used rainfall and temperature data of 17 stations over the time period 1958–2007 to identify the trend using MK and Sen's slope method. I another study, Shahid (2010b) used MK and Sen's slope to identify trend of rainfall data of 17 stations for the year 1958 to 2007 and identified dry and wet months using Standardized Precipitation Index (SPI) analysis. Noorunnahar and Hossain (2019) analyzed rainfall data from 1952 to 2016 using non-parametric methods like Mann-Kendall, Sen's slope and Sen's T test to detect the trends of seven divisions of Bangladesh. Bhuyan et al. (2018) analyzed rainfall and temperature data of BMD and CMIP5 of north-western region of Bangladesh from the year 1981 to 2008 using MK, Sen's slope, Pearsons r, Spearmans ρ and Kendalls τ correlation methods. They also analyzed trend of future rainfall and temperature. Das et al. (2021) and Islam et al. (2020) have applied ITA method but none of them have applied ITA method for both rainfall and temperature data and analyzed sub-trend of them which is essential to understand the detail pattern and inter relationship of the two climatic variables. Das et al. (2021) used MK, modified MK, ITA method to identify trend, sequential MK to identify changing point , Sen's slope for magnitude of change and Discrete wavelet transform to identify the periodicity of annual and seasonal rainfall. Islam et al. (2020) applied MK, Spearman's rho, ITA to identify trend of daily rainfall data, Sen's slope for magnitude and Probability distribution function for obtain more information about the frequency of daily rainfall ranges with some forthcoming periods (in years).

Table 2.1: Summary of reviewed studies and their findings on climatic variables

S.N.	Reference	Location	Stations	Data	Study Period	Study Method	Findings
Worldwide							
1.	(Alifujiang et al., 2020)	The Issyk-Kul Basin, Kyrgyzstan.	03	Average Precipitation	1951-2012	• Mann Kendall Monotonic Trend Analysis. • Innovative Trend Analysis.	• The Mann-Kendall trend test demonstrates that precipitation for the station Balykchy is increasing in all months except January and July. Cholpon-Ata and Kyzyl-Suu stations, on the other hand, reflect a decreasing trend. • In accordance with the ITA approach, a total of 16 out of the 36 months indicate an increasing trend for all three stations, while the other six months show decreasing trends for "high" monthly precipitation. Four months exhibited a decreasing trend, while 14 months had an increasing trend, based on the "low" monthly precipitations.
2.	(Cui et al., 2017)	Yangtze River Basin, China.	14	Mean Rainfall	1961-2016	• Innovative Trend Analysis • Theil-Sen Approach • Mann-Kendall Analysis	• The YRD demonstrated increasing trends in annual rainfall. Rainfall in the summer and winter exhibited significant increasing trends at all stations, while rainfall in the spring and fall showed a clear rapid decrease at the majority of the stations. • At most locations, high rainfall in the summer and winter showed strong upward trends, but low rainfall in the spring and autumn mostly

S.N.	Reference	Location	Stations	Data	Study Period	Study Method	Findings
							showed downward trends. It suggested that the YRD would experience the risk of a flood in the summer and a springtime agricultural drought.
3.	(Yacoub and Tayfur, 2019)	Trarza Region, Mauritania.	03	• Monthly Precipitation • Monthly Maximum Temperature • Monthly Average Temperature • Monthly Minimum Temperature	1970-2013	• Mann-Kendall Analysis • Spearman's Rho Test • Theil Sen Approach • Pettit's Test	• The annual temperature is being increased. • In all sites, there are noticeable rising patterns for the low temperatures relative to the high as well as the moderate temperatures. • Two stations in the precipitation time series have a positive trend, whereas Nouakchott has no trend.
4.	(Wu and Qian, 2017)	Shaanxi, China.	14	Monthly Rainfall	1950-2014	• Innovative Trend Analysis • Mann Kendall Analysis • Linear Regression	• Significant yearly rainfall trends are all falling at five of the fourteen stations. • The pattern of light precipitation varies from location to region as well as from season to season. Summer often sees an increase in light precipitation, whereas other seasons see a decrease.
5.	(Razavi et al., 2016)	Hamilton, Canada.	49	• Daily Temperature • Daily Precipitation	1950-2011	• Statistical Downscaling • Mann-Kendall Analysis	• Both indices showed similar increasing and declining trends for the majority of the stations but there was still significant diversity.

S.N.	Reference	Location	Stations	Data	Study Period	Study Method	Findings
						• Biased Correlation Technique	• Over the period of the study, no single dataset was uniformly more accurate than the others. Every climate model expected an upward trend.
6.	(Naqi et al., 2021)	Diyala River Basin, Iraq.	03	• Daily Maximum Temperature • Daily Minimum Temperature • Daily Precipitation	2000-2020	• Mann Kendal Analysis • Sen's Slope Analysis	• Only three indices indicated statistically significant positive trends in temperature. For all parameters, the temperature trends at the Baghdad station were positive. • Compared to temperature trends, precipitation trends were almost universally non-significant and difficult to predict. • Percentile-based indices revealed a greater number of warm and dry events than wet and cold events.
7.	(Fathian et al., 2016)		25Temp & 37 Precipitation station	• Monthly & Annual Temperature • Monthly & Annual Precipitation • Monthly & Annual Streamflow	1950-2007 1960-2007 1970-2007	• MK test • MK test considering lag-1 autocorrelation. • MK test considering all autocorrelation or sample size. • MK test considering the Hurst coefficient	• Temperature at the annual time scale showed an increase increasing various parts of the ULB. • Rainfall showed a significantly decreasing trend. • Drawdown trends have been observed for streamflow.

S.N.	Reference	Location	Stations	Data	Study Period	Study Method	Findings
8.	(Girma et al., 2020)	Upper Huai River Basin, China	06	• Daily Rainfall • Daily Temperature	1960-2016	• Innovative Trend Analysis • Mann-Kendal Analysis • Sen's Slope Estimator	• Precipitation in the studied area is unpredictable, falling, and concentrated during the summer season. Mean annual precipitation showed a significant downward trend. Only the Fuyang station showed a statistically significant growing trend. • All relevant stations displayed an overall increase in temperature.
9.	(Bavil et al., 2018)	Urima Lake, Iran	60	Daily Precipitation	1981-2011	• Mann Kendall Analysis • Spearman Rho Test • Linear Regression	• Daily precipitation less than 5 mm showed a significant increasing trend; no trend between 5 and 10 mm, a significant lowering trend between 10 and 15 mm, and a non-significant decreasing trend between 15 and 20 mm and over 20 mm. • The frequency of low precipitation, which is more sensitive to evaporation losses, has been growing during this time, whilst the frequency of above 10- and 15-mm precipitation, which might alter the ensuing runoff, has been decreasing.
10.	(Kim et al., 2011)	Overall South Korea	66	• Daily Precipitation • Average Temperature	1882-2001	• Extreme Indices	• The longest dry time is getting shorter while the frequency of heavy rainfall is increasing. In the central region's inland area, both the heavy rainfall threshold and the maximum 5-day rainfall duration increased noticeably for the

S.N.	Reference	Location	Stations	Data	Study Period	Study Method	Findings
							summer; for the autumn, an increase in the trend was noted in Jejudo and the south coast. • The summertime temperature increase was more noticeable in Jejudo and nearby areas of the south coast than it was during the winter. In the inland, wintertime temperatures were more likely to rise than summertime ones.
11.	(Koudahe et al., 2017)	Southern Togo, West Africa.	04	• Daily Rainfall • Annual Rainfall • Daily Temperature • Annual Temperature	1970-2014	• Standardized Anomaly Index (SAI) • Standardized Precipitation Index (SPI). • Mann Kendall Analysis	• Temperature had increased for most stations but significantly dropped for some stations such as Tabligho. • Rainfall mostly depicts an increasing trend.
12.	(Marigi et al., 2016)	Eastern Kenya	05	• Daily Rainfall • Maximum Temperature • Minimum Temperature	1961-2009	• Regression Homogeneity Test. • Kendall's Tau Slope Estimator.	• A decrease had been observed in yearly rainfall, rainfall intensity, and consecutive wet days, but an increase in consecutive dry days. • The maximum and minimum temperatures, both showed steady warming patterns.
13.	(Sa'adi et al., 2019)	Sarawak, Malaysia	31	Daily Rainfall	1980-2014	• Mann Kendall Analysis • Modified Mann Kendall Analysis	• For most of the stations no significant trend has been found.

S.N.	Reference	Location	Stations	Data	Study Period	Study Method	Findings
14.	(Sonali and Kumar, 2013)	Over all India	N/A	• Maximum Temperature • Minimum Temperature	1901-2003 1948-2003 1970-2003	• Mann Kendall Test • Spearman Rho Test • Sen's Slope Estimator • Linear Regression • Innovative Trend Analysis • Adaptive Cumulative Sum • Variance Correlation	• Most of the methods depict increasing trends for all types of temperature.
15.	(Wu et al., 2019)	Hainan Island, China	06	• Daily Rainfall	1950-2014	• Partial Trend Analysis • Mann Kendall Analysis	• Except for Sanya station, the rainfall trend Is decreasing. • The annual number of rainy days is decreasing for most stations but for Sanya, it increased.
16.	(Zhang et al., 2011)	North America		• Daily Precipitation • Daily Temperature		• Extreme Indices	• Identifies the strength and weaknesses of ETCCDI developed indices
				Bangladesh			
1.	(Bari et al., 2017)	The northern region,	09	Monthly Rainfall	1964-2013	• Coefficient of Variability.	• Rainfall variability is greatest during the winter.

S.N.	Reference	Location	Stations	Data	Study Period	Study Method	Findings
		Bangladesh.				• Seasonality Index.	• Bangladesh's rainfall is distinctly seasonal, with a long dry season. • Sylhet, Srimangal, and Mymensingh stations have shorter dry seasons when the seasonality index is lower.
2.	(Bhuyan et al., 2018)	North-Western Region, Bangladesh.	06	• Daily Maximum Temperature • Normal Daily Rainfall	1981-2008	• Mann-Kendal Analysis • Sen's Slope Analysis • MPI-ESM-LR (CMIP5) Model	• Exception of winter, according to BMD data, all seasons have resulted in a significant increase in maximum temperature. However, according to model data, the maximum temperature is rising in the area. • Monsoon rainfall was highest according to both BMD data and MPI-ESM-LR (CMIP5) model, whereas winter rainfall was lowest. In general, the northwest is experiencing decreased rainfall.
3.	(Das et al., 2021)	Overall Bangladesh	23	Monthly Rainfall	1966-2019	• Precipitation Concentration Index. • Seasonality Index. • Innovative Trend Analysis. • Percent Bias. • Mann-Kendall Analysis.	• The climate has changed significantly between 1966 and 2019 and with the exception of a few small locations, the whole research area has experienced a significant change in precipitation. This type of alteration in most stations makes the region the most vulnerable, and so this practice continues at a medium to high rate, potentially affecting crop cycles, crop rotation, and the country's overall agricultural system.

S.N.	Reference	Location	Stations	Data	Study Period	Study Method	Findings
						• Modified Mann-Kendal Analysis. • Sen’s Slope Estimator. • Discrete Wavelet Transform	
4.	(Khan et al., 2019)	Overall Bangladesh	35	• Maximum Temperature • Minimum Temperature • Average Temperature • Total Precipitation • Relative Humidity • Wind Speed	1988-2017	• Mann-Kendall Analysis • Sen’s Slope Analysis • Pearson Correlation Test • Spearman’s Rho Test	• All temperature extremes in most places show a temperature increase, and the daily average temperature has risen significantly. • The rate of increase in monsoonal precipitation in coastal areas is comparatively faster than in other locations; nonetheless, it has massively reduced in the country's northwest region. • Wind speed has significantly decreased. • Throughout all seasons and annual series in all regions significant negative connections between precipitation, humidity, wind speed, and temperature variables have been discovered in Bangladesh, reaching extremes in the northwestern regions.
5.	(Mehzabin and Mondal, 2021)	Khulna, South-West Coastal Region	01	• Monthly Rainfall • Average Temperature	1978-2017	• Coefficient of variation • Standardized Precipitation Anomaly	• In terms of temperature, there has been a large increase in the dry season, monsoon season, and annual average temperatures in southwest coastal Bangladesh, but there has been little or no increase in rainfall.

S.N.	Reference	Location	Stations	Data	Study Period	Study Method	Findings
		Bangladesh.				• Precipitation Concentration Index • Linear Regression • Mann-Kendall Analysis • Livelihood Vulnerability Index	• The dry season has seen the most diversity in rainfall patterns.
6.	(Rahman and Lateh, 2017)	Overall Bangladesh	34	• Mean Temperature • Maximum Temperature • Minimum Temperature • Mean Rainfall	1971-2010	• Linear Regression • Coefficient of Variation • Inverse Distance Weighted Interpolation • Geographical Information System	• Temperature analysis indicates that the average temperature will rise. The mean minimum temperature is expected to rise faster than the mean maximum temperature. The minimum temperature increased more in the northern, northwestern, northeastern, central, and central southern parts, although the maximum temperature increased more throughout the southern, southeastern, and northeastern parts. • Predictions of rainfall show that rainfall will continue to fall and a drying situation will persist, particularly even during pre- and post-monsoon seasons. • The spatial patterns of temperature and rainfall trend and variability indicate that the northwest, western, and southwestern regions of the country are more affected by climate

S.N.	Reference	Location	Statio ns	Data	Study Period	Study Method	Findings
							change in terms of rising temperatures, high variability, and rain insufficiencies, particularly during the pre-and post-monsoon rains.
7.	(Islam et al., 2020)	Overall Banglade sh	23	Daily Rainfall	1975-2017	• Autocorrelation Test • Mann-Kendall Analysis • Spearman's Rho Test • Linear Regression • Sen's Slope Estimator • Pettit's Test • Partial Trend Method • Probability Distribution Function	• According to the temporal studies, the low and heavy rainfall categories showed an insignificant decrease trend, while the medium rainfall ranges showed an insignificant increasing trend. The medium ranges had the greatest number of stations with a minor descending trend, while the small and large ranges had the greatest number of stations with an insignificant increasing trend. • Regionally, varied trend patterns were recognized in almost all ranges, with an ascending trend detected in the northeastern, southeastern, and central areas of Bangladesh and a declining trend detected in the northwest and western regions. • Frequency of rainfall across Bangladesh follows a monotonous, negligible trend pattern.
8.	(Rahman et al., 2017)	Overall Banglade sh	14	Average Rainfall	1954-2013	• Modified Mann-Kendall • Spearman Rho Test	• There is no noticeable trend in the yearly rainfall pattern, except for Cox's Bazar, Khulna, and Satkhira areas and decreasing tendencies for Srimangal districts.

S.N.	Reference	Location	Stations	Data	Study Period	Study Method	Findings
						• Sen's Slope Estimator	• Only the Bogra area showed a discernible decreasing trend during the dry season. • Long-term monthly patterns showed a mixed pattern, with both positive and negative changes being found.
9.	(Hasan et al., 2014)	South-East Region Bangladesh	05	Monthly Rainfall	1980-2011	• Mann Kendall Analysis • Sen's Slope estimator	• Winter receives the least amount of rainfall, and it is becoming drier. • According to trend study, the other three seasons, notably Pre-Monsoon, Rainy Monsoon, and Post-Monsoon, are increasing wetter.
10.	(Noorunnahar and Hossain, 2019)	Overall Bangladesh	07	Daily Rainfall	1952-2016	• Mann Kendall Analysis • Sen's T Analysis	• Monsoon rainfall was reduced in parts of northern Bangladesh but not severely (Rajshahi and Rangpur Station). • Winter rainfall has reduced in all parts of Bangladesh. The mean annual rainfall figures indicated that the highest rainfall occurs in the Sylhet division, while the lowest rainfall occurs in Rajshahi.
11.	(Shahid, 2010a)	Overall Bangladesh	17	• Daily Rainfall • Daily Temperature	1958-2007	• Mann Kendall Analysis • Sen's Slope Analysis	• Over Bangladesh, there has been a significant rise in mean temperature and average rainfall. • Monsoon rainfall has risen in the western half of Bangladesh, according to the spatial pattern. • Increased sea surface temperature may have influenced wind patterns in western Bangladesh.

S.N.	Reference	Location	Stations	Data	Study Period	Study Method	Findings
12.	(Shahid, 2010b)	Overall Bangladesh	17	Daily Rainfall	1958-2007	• Mann Kendall Analysis • Sens's Slope Analysis • Standardized Precipitation Index	• The finding demonstrates a considerable rise in Bangladesh's average annual and pre-monsoon rainfall. • In most sections of the country, the number of wet months is increasing while the number of dry months is decreasing. • Seasonal comparison of wet and dry months reveals a considerable decrease in dry months throughout the monsoon and pre-monsoon seasons.
13.	(Zannat et al., 2019)	North-Western Region Bangladesh	06	• Monthly Rainfall • Groundwater Level	1976-2016	• Mann Kendall Analysis • Sen's Slope Analysis • Spearman Rho Test • Coefficient of Variation • Linear Regression	• The yearly and seasonal rainfall trends in the northeastern region have been decreasing, especially in the last decade. • The relationship between rainfall and groundwater level suggests that rainfall decreased as groundwater level declined in the studied location. • Notably, a considerable high declining trend of annual rainfall is identified in Rangpur, although the annual groundwater level depth in Rangpur is less increased at the same time.

CHAPTER 3 METHODOLOGY

3.1 Introduction

This Chapter presents the methods used in this research. This study quantifies the frequency, severity and occurrence of extreme events in Bangladesh. Furthermore, seasonal and annual climate change pattern i.e., trend and sub-trend of occurrence of “low”, “medium” and “high” intensity rainfall and temperature in Bangladesh has also been identified from the study.

3.2 Study area and Data collection

Bangladesh is a tropical monsoon country in Southeast Asia. The spatial extent of Bangladesh is between 20° 34′ N to 26° 38′ N latitude and 88° 01′ E to 92° 41′ E longitude (Figure 1) with an area of 144,000 km^2. Heavy rainfall, high temperatures and seasonal variation constitutes the unusual characteristics of the climate of Bangladesh from other tropical regions (Bhuyan et al., 2018).

Bangladesh faces maximum rainfall in the monsoon and least during the winter. Temperature rises during pre-monsoon and post monsoon period. This phenomenon leads to either flooding or declining of available water which results in severe dryness.

It is the largest delta in the world, with the Brahmaputra, Ganges, and Meghna river systems flowing toward the Bay of Bengal, a huge portion of Bangladesh’s land area experiences frequent flooding, especially flash floods. The eastern parts of Bangladesh, comprising the Sylhet and Chattogram divisions, are prone to flash floods. On the other hand, the Barind track on the northern and northeastern sides of Bangladesh experiences frequent drought (Asian Development Bank, 2021).

The climate of Bangladesh is characterized by four distinct climatic seasons, namely Pre-Monsoon (March-April-May), Monsoon (June-July-August-September), Post-Monsoon (October-November), and Winter (December-January-February). Average temperature of Bangladesh ranges between 15°C and 34°C, mean annual rainfall is about 2,400 mm and 70%

of rainfall occurs during monsoon (June to September) according to National Adaptation Plan of Bangladesh (NAP) (2023-2050).

For Climate change analysis, daily rainfall and temperature data has been collected from Bangladesh Meteorological Department (BMD). There are 34 BMD stations in Bangladesh but some of them were recently introduced and data of some stations are not consistent. As a result of this, data of 26 stations which have consistent data from the year 1975 to 2019 has been analyzed for this study which covers entire Bangladesh.

Daily rainfall, maximum temperature, minimum temperature and average temperature data has been used to evaluate the trend, sub trend, extreme climatic indices and occurrence of extreme events in Bangladesh. Details of the BMD locations are presented in Table 3.1

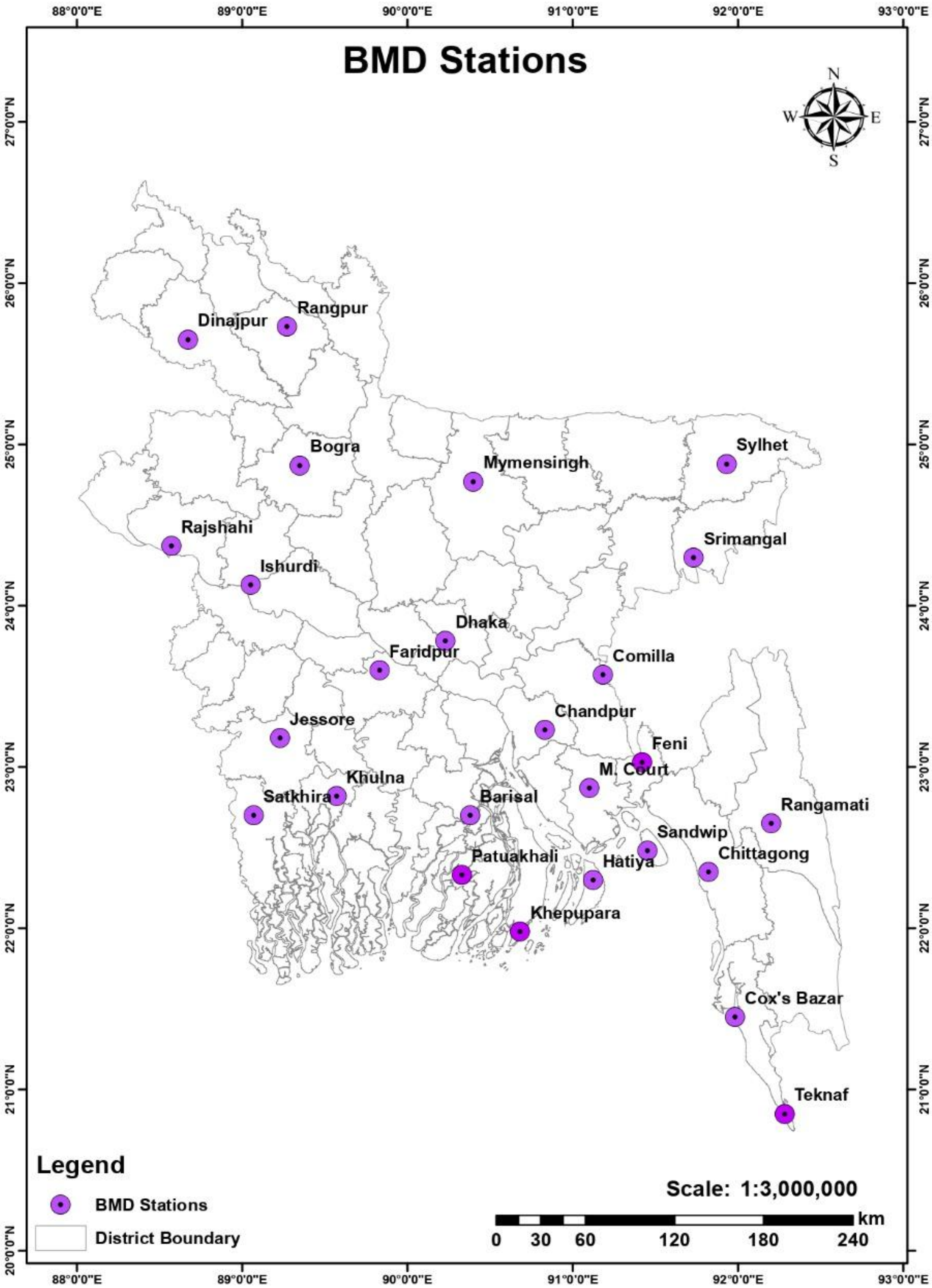


Figure 3.1: Study Area and BMD stations for Data collection and analysis

Table 3.1: Details of BMD locations

SI. NO.	Stations	Co-ordinate	
		Latitude	Longitude
1.	Barisal	22.72	90.37
2.	Bogra	24.85	89.37
3.	Chandpur	23.23	90.7
4.	Chittagong	22.22	91.8
5.	Comilla	23.43	91.18
6.	Cox's Bazar	21.45	91.97
7.	Dhaka	23.77	90.38
8.	Dinajpur	25.65	88.67
9.	Faridpur	23.6	89.85
10.	Feni	23.03	91.42
11.	Hatiya	22.45	91.1
12.	Ishurdi	24.15	89.03
13.	Jessore	23.2	89.33
14.	Khepupara	21.98	90.68
15.	Khulna	22.82	89.57
16.	M. Court	22.87	91.1
17.	Mymensingh	24.73	90.42
18.	Patuakhali	22.33	90.33
19.	Rajshahi	24.37	88.7
20.	Rangamati	22.37	92.15
21.	Rangpur	25.73	89.27
22.	Sandwip	22.48	91.45
23.	Satkhira	22.72	89.08
24.	Srimangal	24.3	91.73
25.	Sylhet	24.9	91.88
26.	Teknaf	20.85	92.28

The monthly data of different stations have been plotted using boxplot method to understand the rainfall and temperature data variation and data range for each month and the graphical illustrations of some of them are presented in Figure 3.2.

The boxplot of daily precipitation data of Dhaka shows that precipitation is minimum in the month of January and lower and upper quartile value are between 0~10mm. Maximum daily precipitation is found in the month of May where the lower and upper quartile value are between 10~30mm. Boxplot of daily maximum temperature shows that lowest maximum temperature prevails in the month of January and lower and upper quartile value are between 24°C ~26°C. Highest maximum temperature prevails in the month of April and lower and upper quartile value are between 33°C ~35°C. Boxplot of daily minimum temperature shows that lowest minimum temperature prevails in the month of January and lower and upper quartile value are between 12°C ~15°C. Highest minimum temperature prevails in the month of June and lower and upper quartile value are between 25°C ~27°C. The box plot of diurnal temperature shows that maximum temperature difference is found in the month of February and December.

The boxplot of daily precipitation data of Barisal shows that precipitation is minimum in the month of January and lower and upper quartile value are between 0~10mm. Maximum daily precipitation is found in the month of June where the lower and upper quartile value are between 5~35mm. Boxplot of daily maximum temperature shows that lowest maximum temperature prevails in the month of January and lower and upper quartile value are between 24°C ~27°C. Highest maximum temperature prevails in the month of April and May and lower and upper quartile value are between 33°C ~35°C. Boxplot of daily minimum temperature shows that lowest minimum temperature prevails in the month of January and lower and upper quartile value are between 10°C ~13°C. Highest minimum temperature prevails in the month of June and lower and upper quartile value are between 25°C ~27°C. The box plot of diurnal temperature shows that maximum temperature difference is found in the month of February and March.

The boxplot of daily precipitation data of Chittagong shows that precipitation is minimum in the month of January and lower and upper quartile value are between 0~10mm. Maximum daily precipitation is found in the month of June where the lower and upper quartile value are between 10~50mm. Boxplot of daily maximum temperature shows that lowest maximum temperature prevails in the month of January and lower and upper quartile value are between 25°C ~27°C. Highest maximum temperature prevails in the month of May and lower and upper quartile value are between 32°C ~33°C. Boxplot of daily minimum temperature shows that lowest minimum temperature prevails in the month of January and lower and upper quartile value are between 13°C ~15°C. Highest minimum temperature prevails in the month of May and lower and upper quartile value are between 24°C ~26°C. The box plot of diurnal temperature shows that maximum temperature difference is found in the month of February and March.

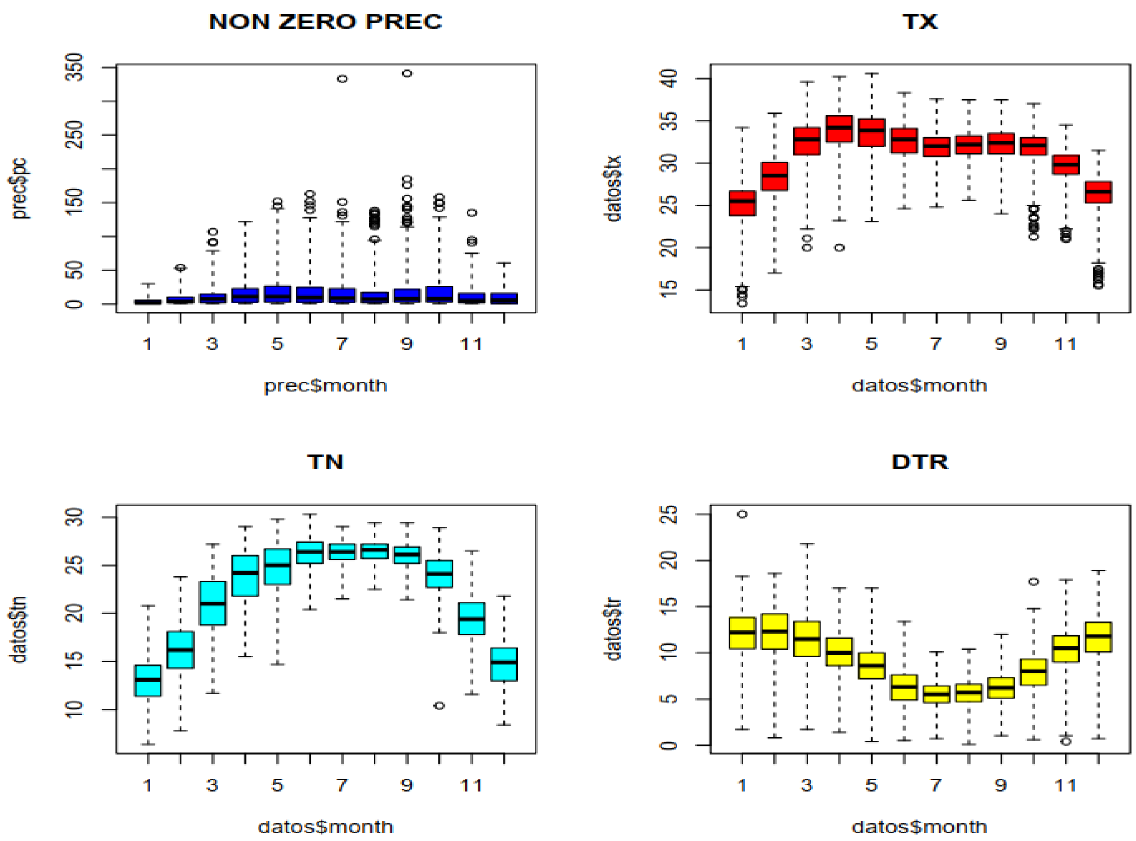
The boxplot of daily precipitation data of Khulna shows that precipitation is minimum in the month of December and lower and upper quartile value are between 0~5mm. Maximum daily precipitation is found in the month of June where the lower and upper quartile value are between 5~30mm. Boxplot of daily maximum temperature shows that lowest maximum temperature prevails in the month of January and lower and upper quartile value are between 24^oC ~27^oC. Highest maximum temperature prevails in the month of April and May and lower and upper quartile value are between 33^oC ~36^oC. Boxplot of daily minimum temperature shows that lowest minimum temperature prevails in the month of January and lower and upper quartile value are between 11^oC ~14^oC. Highest minimum temperature prevails in the month of June and lower and upper quartile value are between 25^oC ~27^oC. The box plot of diurnal temperature shows that maximum temperature difference is found in the month of February.

The boxplot of daily precipitation data of Mymensingh shows that precipitation is minimum in the month of January and lower and upper quartile value are between 0~10mm. Maximum daily precipitation is found in the month of May where the lower and upper quartile value are between 5~40mm. Boxplot of daily maximum temperature shows that lowest maximum temperature prevails in the month of January and lower and upper quartile value are between 23^oC ~26^oC. Highest maximum temperature prevails in the month of April and lower and upper quartile value are between 30^oC ~34^oC. Boxplot of daily minimum temperature shows that lowest minimum temperature prevails in the month of January and lower and upper quartile value are between 11^oC ~13^oC. Highest minimum temperature prevails in the month of June, July and August and lower and upper quartile value are between 24^oC ~27^oC. The box plot of diurnal temperature shows that maximum temperature difference is found in the month from December to March.

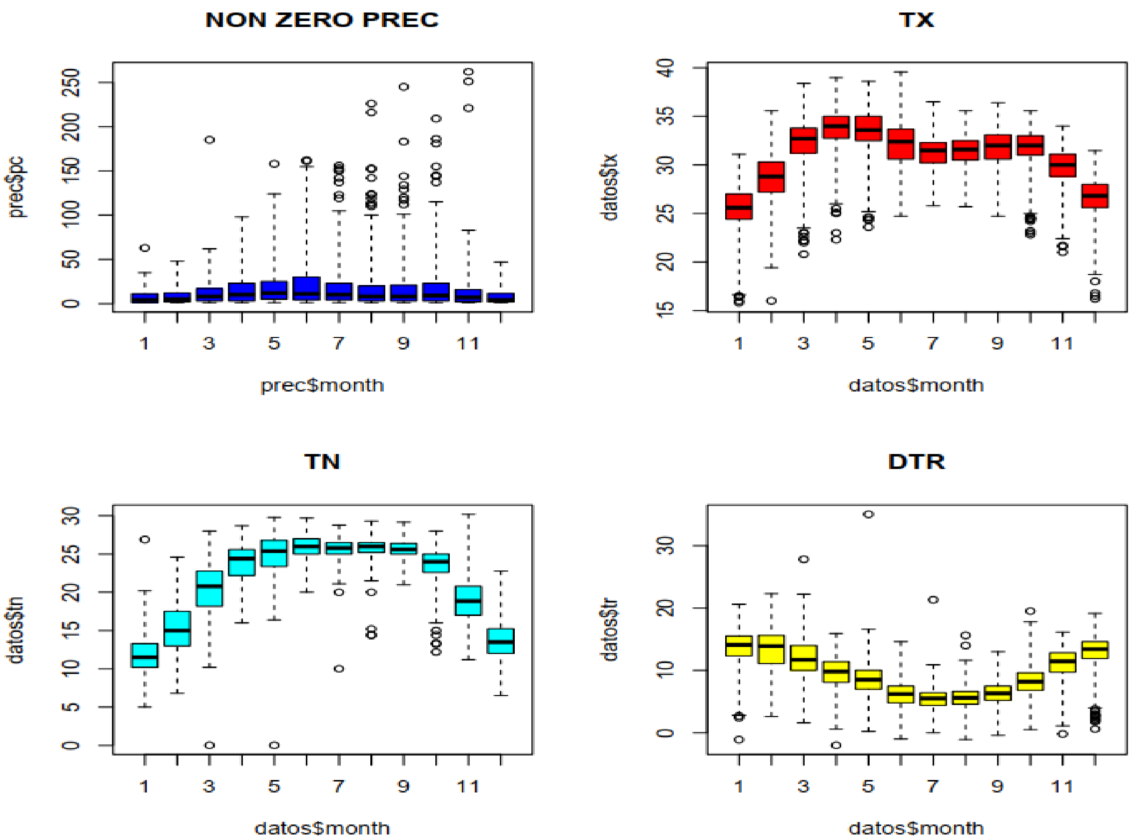
The boxplot of daily precipitation data of Rajshahi shows that precipitation is minimum in the month of January and lower and upper quartile value are between 0~10mm. Maximum daily precipitation is found in the month of June where the lower and upper quartile value are between 10~50mm. Boxplot of daily maximum temperature shows that lowest maximum temperature prevails in the month of January and lower and upper quartile value are between 23^oC ~26^oC. Highest maximum temperature prevails in the month of April and lower and upper quartile value are between 33^{o}C ~37^{o}C. Boxplot of daily minimum temperature shows that lowest minimum temperature prevails in the month of January and lower and upper quartile value are between 9^{o}C ~12^{o}C. Highest minimum temperature prevails in the month of June and lower and upper quartile value are between 24^{o}C ~26^{o}C. The box plot of diurnal temperature shows that maximum temperature difference is found in the month of March.

The boxplot of daily precipitation data of Rangpur shows that precipitation is minimum in the month of November and lower and upper quartile value are between 0~5 mm. Maximum daily precipitation is found in the month of June and July where the lower and upper quartile value are between 5~30mm. Boxplot of daily maximum temperature shows that lowest maximum temperature prevails in the month of January and lower and upper quartile value are between 22^{o}C ~25^{o}C. Highest maximum temperature prevails in the month of April and lower and upper quartile value are between 28^{o}C ~33^{o}C. Boxplot of daily minimum temperature shows that lowest minimum temperature prevails in the month of January and lower and upper quartile value are between 10^{o}C ~14^{o}C. Highest minimum temperature prevails in the month of June and lower and upper quartile value are between 24^{o}C ~26^{o}C. The box plot of diurnal temperature shows that maximum temperature difference is found in the month of February and March.

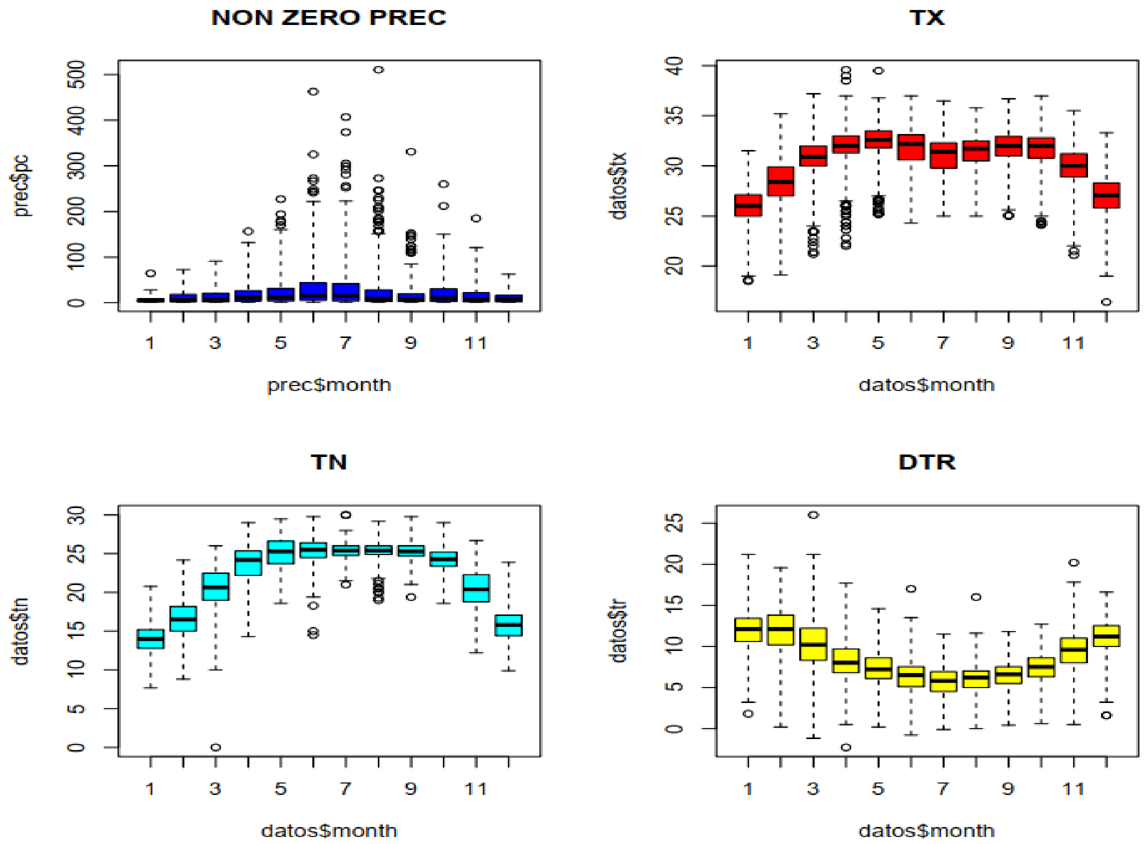
The boxplot of daily precipitation data of Sylhet shows that precipitation is minimum in the month of January and lower and upper quartile value are between 0~5 mm. Maximum daily precipitation is found in the month of June where the lower and upper quartile value are between 10~40 mm. Boxplot of daily maximum temperature shows that lowest maximum temperature prevails in the month of January and lower and upper quartile value are between 24^{o}C ~27^{o}C. Highest maximum temperature prevails in the month of August and lower and upper quartile value are between 30^{o}C ~33^{o}C. Boxplot of daily minimum temperature shows that lowest minimum temperature prevails in the month of January and lower and upper quartile value are between 12^{o}C ~14^{o}C. Highest minimum temperature prevails in the month of July and August and lower and upper quartile value are between 23^{o}C ~25^{o}C. The box plot of diurnal temperature shows that maximum temperature difference is found in the month of February.



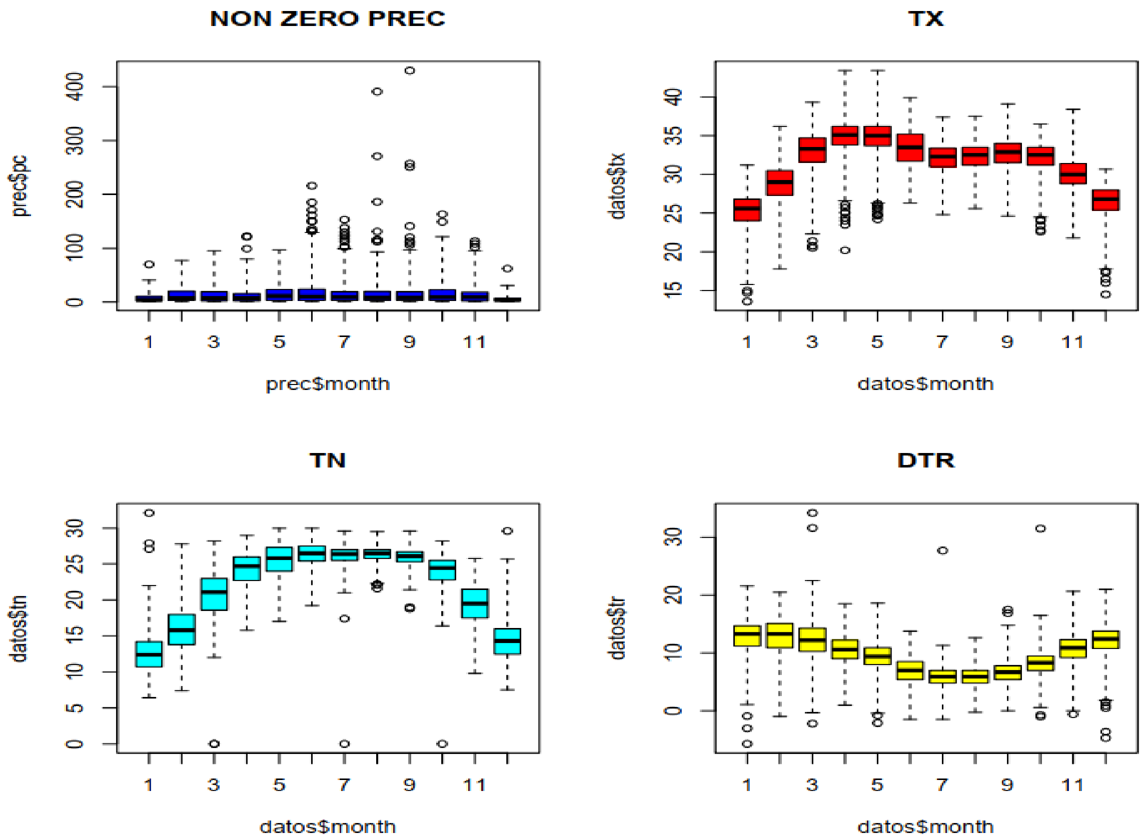
(a) Dhaka



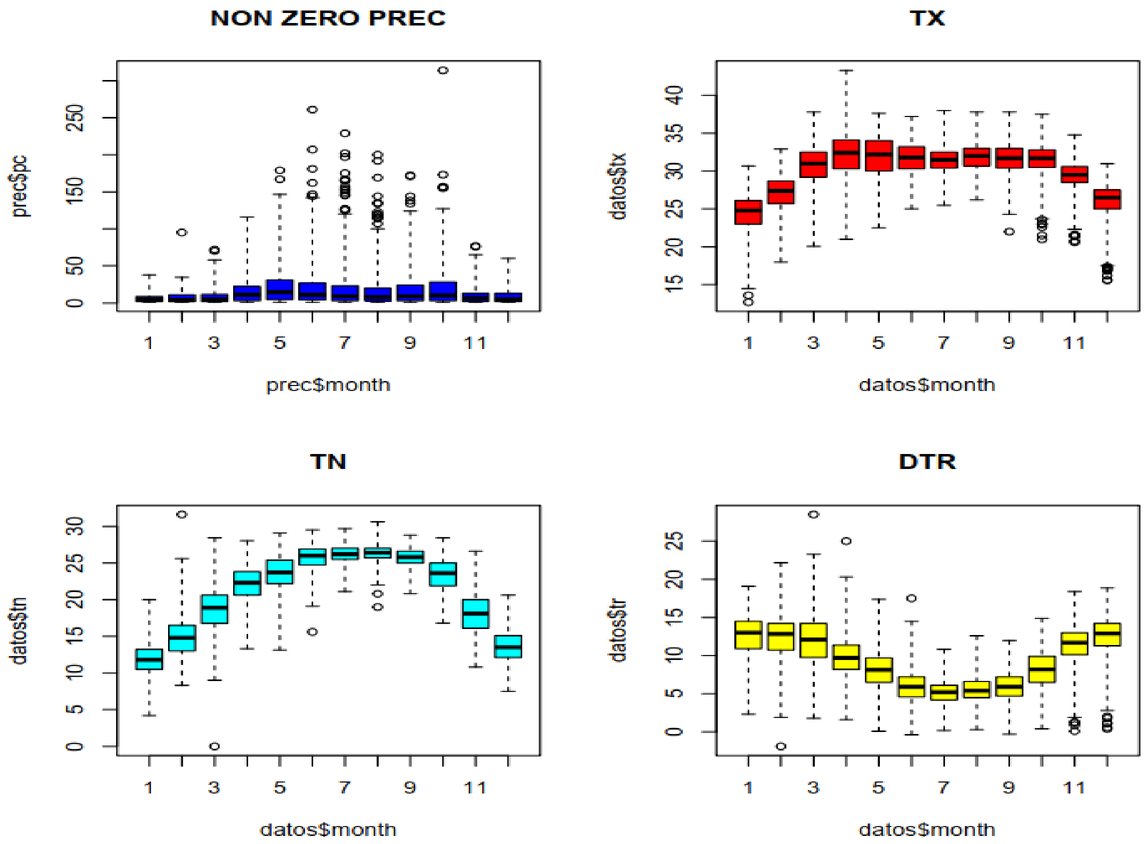
(b) Barisal



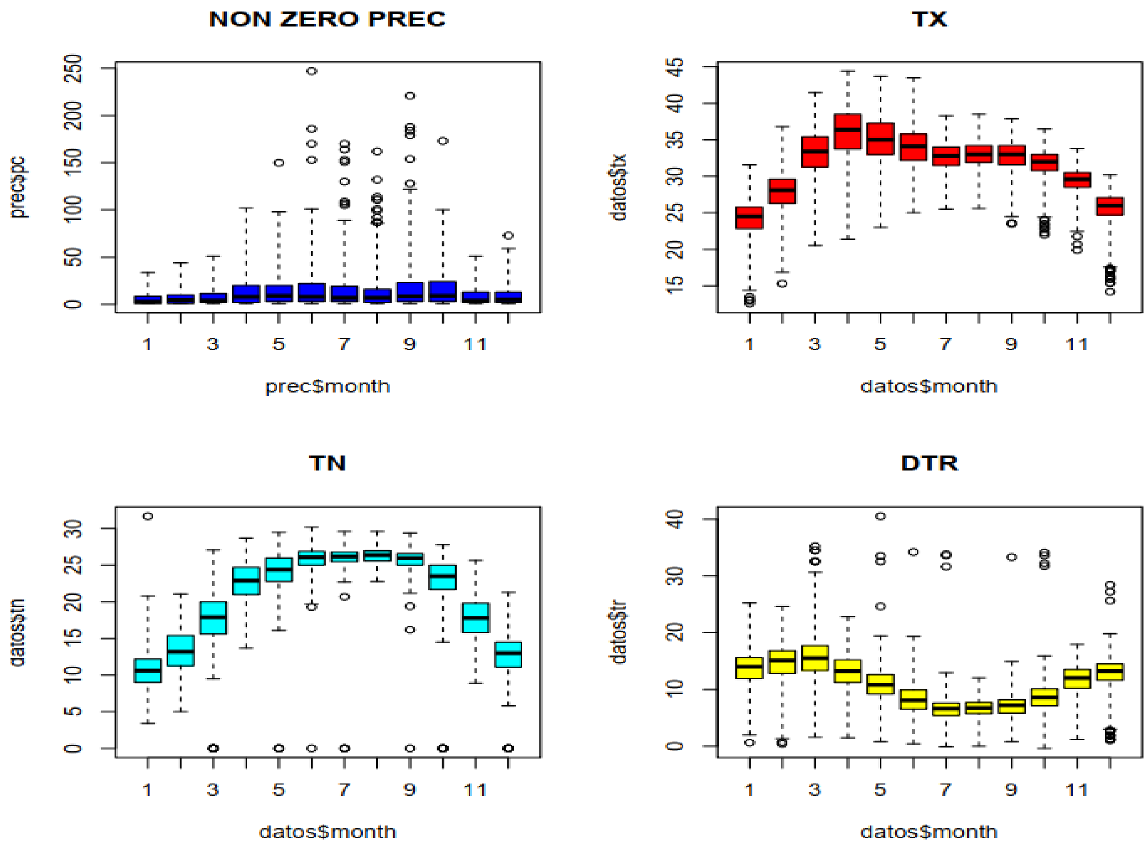
(c) Chittagong



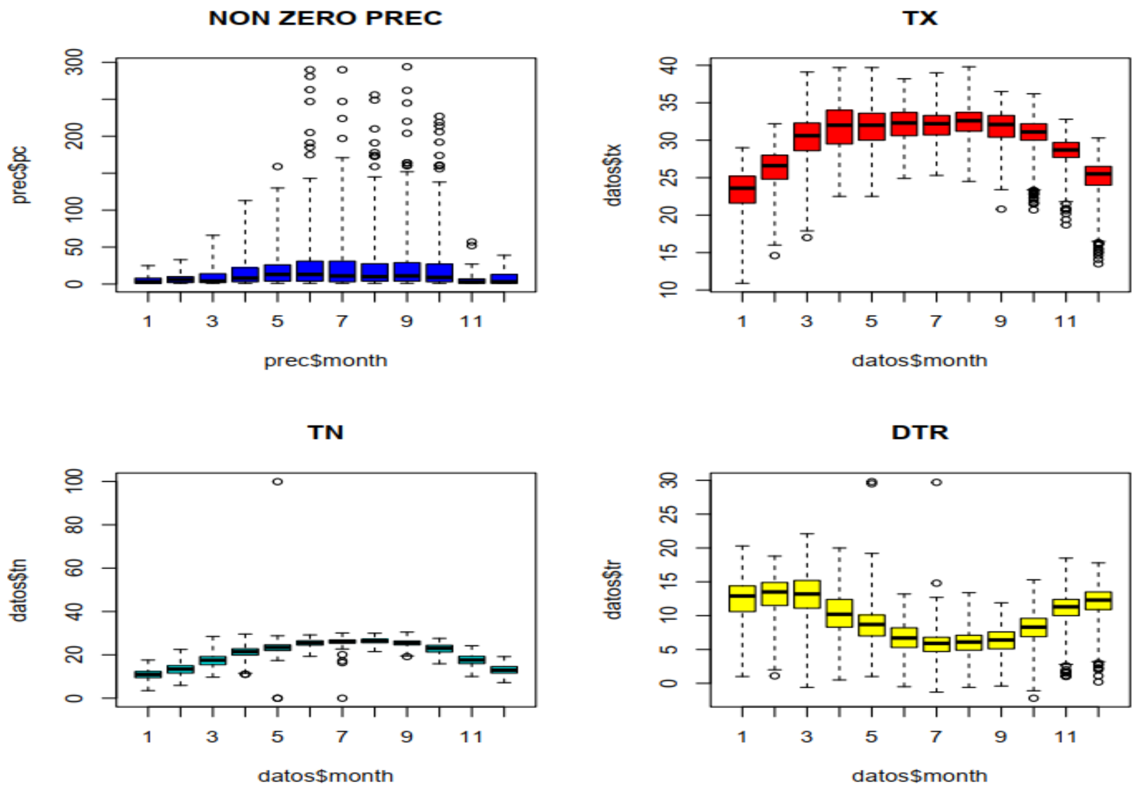
(d) Khulna



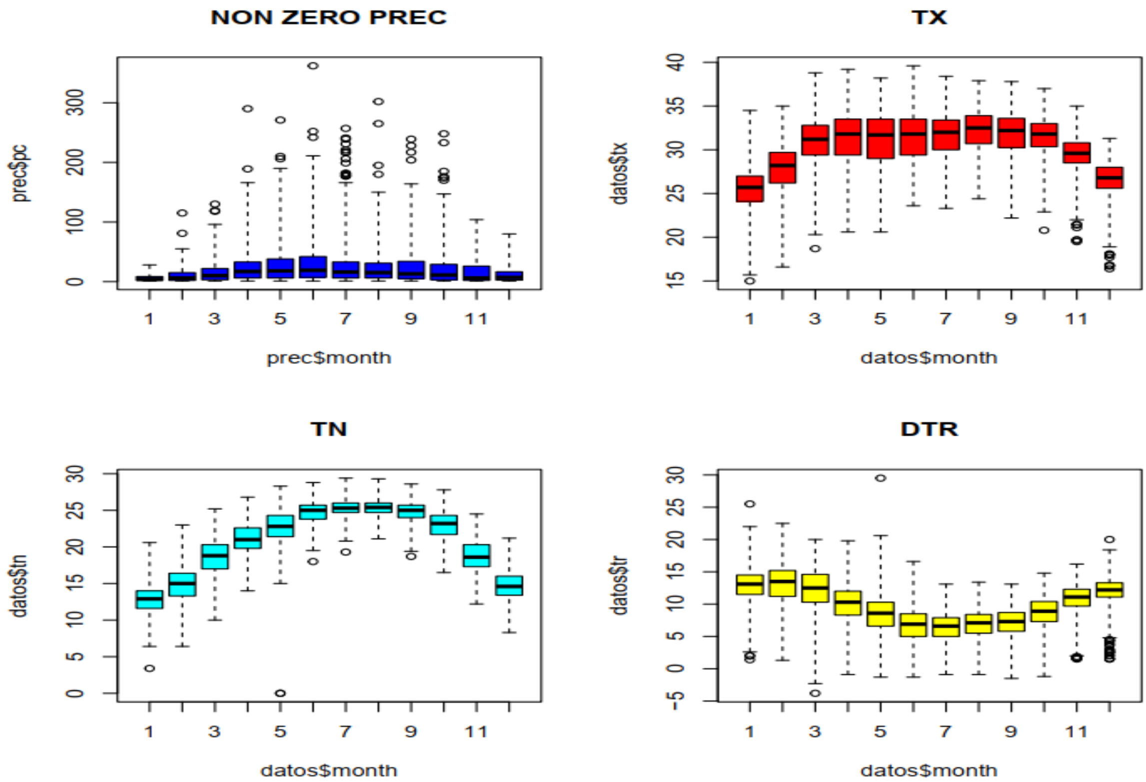
(e) Mymensingh



(f) Rajshahi



(g) Rangpur



(h) Sylhet

Figure 3.2: Monthly precipitation, maximum temperature, minimum temperature and diurnal temperature distribution at various stations

3.3 Statistical Analysis

The missing data in the time series has been calculated using the mean imputation method. ITA has been used to identify trends along with sub-trend analysis to evaluate the climate pattern of annual and seasonal rainfall and temperature data and the reliability of ITA method has been checked with the traditional approach i.e., MK, mMK. Sen's slope estimator has been used to find the magnitude of trend. The time series has been pre-whitened to eliminate serial correlation before applying MK test.

Standard Anomaly Index (SAI) and Rainfall anomaly Index (RAI) have been used to identify frequency, severity and occurrence of extreme natural events i.e., drought and flooding in Bangladesh. At last, ClimPACT2 software has been used to check homogeneity and calculate extremes of temperature and rainfall using daily observed data. Arc GIS 10.3 and R 4.0.2 software has been used for mapping and data analyzing.

3.3.1 Serial correlation

In time series data, serial dependence or existence of autocorrelation creates confounding effect which is a significant problem in analyzing time series datasets and identifying trend patterns (Islam et al., 2020; Rahman et al., 2017). It should be removed in order to obtain the Mann-Kendal test's true results because it may indicate an unusual trend.

The non-parametric test will specifically imply a significant trend in a time series that is actually random more frequently than allowed by the significance level if there is a positive serial correlation in the time series (Kulkarni and Von Storch, 1995). In this regard, Von Storch (1995) suggested that the time series should be 'pre-whitened' to eliminate the effect of serial correlation before applying the Mann–Kendall test (Noorunnahar and Hossain, 2019).

3.3.2 Mann Kendal (MK) Test

The M-K trend test is a non-parametric test and can be used with any distribution but it must be free of serial correlation. The null hypothesis (H_0) for the test is that the series does not have a monotonic trend. Alternative hypothesis (H_A) is that there is a trend which can be neutral, positive, or negative. The idea of this assumption is that if a pattern exists, the symbol values should tend to increase or decrease on a regular basis. The test statistic (S) of the series x_1, x_2, x_3…, and x_n is calculated by using the following formula (Kendall, 1955; Mann, 1945).

$$S = \sum_{j=1}^{n-1} \sum_{k=j+1}^{n} sign(y_k - y_j) \quad \text{(i)}$$

Here, n is the number of records, and yk and yj are the record points of time k and j.

$$Sign\left(x_j - x_k\right) = \begin{cases} +1\ if\ y_k - y_j > 0 \\ 0\ if\ y_k - y_j = 0 \\ -1\ if\ y_k - y_j < 0 \end{cases} \quad \text{(ii)}$$

The variance of S, VAR(S), is calculated as:

$$VAR(S) = \frac{1}{18}\{n(n-1)(2n+5) - \sum_{j=1}^{g} t_j(t_j - 1)(2t_j + 5)\} \quad \text{(iii)}$$

The estimation of (S) and VAR(S) is calculated to develop the standardized test measurement Z as follows when n > 10.

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(s)}}, if\ S > 0 \\ 0, if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(s)}}, if\ S < 0 \end{cases} \quad \text{(iv)}$$

The Z is the actual indicator of the trend and indicates significant trend if falls beyond level ± 1.96 at 5% significance level. Positive and negative value of Z represents increasing and decreasing trends respectively. The null hypothesis (H_0) or 0 value indicates that there is no trend in the time series.

3.3.3 Modified Mann–Kendall (mMK) test

Modified Mann Kendal method is basically the updated form of traditional MK method. The traditional MK method sometimes may have some false positive error due to the auto correlation function. That is why modified MK approach have been used to eliminate the error and modified VAR(S) statistic can be estimated as (Hamed and Rao, 1998)

$$VAR(S) = (\frac{n(n-1)(2n+5)}{18})(\frac{n}{n_e^*}) \tag{v}$$

Here, the correction factor $(\frac{n}{n_e^*})$ is adjusted to the autocorrelated data as:

$$\left(\frac{n}{n_e^*}\right) = 1 + (\frac{2}{n^3 - 3n^2 + 2n})\sum_{f=1}^{n-1}(n-f)(n-f-1)(n-f-2)\rho_e(f) \tag{vi}$$

$\rho_e(f)$ represents the autocorrelation function between ranks of observations and can be estimated as:

$$\rho(f) = 2\sin(\frac{\pi}{6}\rho_e(f)) \tag{vii}$$

$$\tau = \begin{cases} \frac{S-1}{\sqrt{VAR(s)}}, if\ S > 0 \\ 0, if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(s)}}, if\ S < 0 \end{cases} \tag{viii}$$

Positive and negative value of τ represents increasing and decreasing trends respectively. S is calculated according to the equation (i). The null hypothesis (H_0) or 0 value indicates that there is no trend in the time series.

3.3.4 Sens Slope Estimator

Sen's slope (Sen, 1968) estimator was used to calculate the magnitudes of the rainfall and temperature trend (slope Q). The slope Q could be calculated with N sets of data as follows:

$$Q_i = \frac{x_k - x_j}{k - j}, i = 1,2,3, \dots \dots \dots N, k > j \quad \text{(ix)}$$

where x_k and x_j represent values of data at k and j times, and Q_i is the median slope respectively. Positive and negative value of slope estimator indicates ascending and descending rate of magnitude respectively.

3.3.5 Innovative Trend Analysis (ITA) method

Şen (2012) was the first to suggest the visual non-parametric ITA approach. This method follows dividing the time series in two equal parts and plotting them against each other on the Cartesian coordinate system where the first half of data is plotted on the x-axis and the other on the y-axis. If all the data point falls along the 1:1 (45^o) line then there is no trend. But if they fall above the 1:1 (45^o) line and in the upper triangular area then then there is positive trend and vice versa (Şen, 2012). It can also deal with autocorrelation and outliers. The following equation is used to compute ITA's slope:

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

where B represents the ITA slope, n denotes the extent of individual sub-series, x_j and x_k represent the values of the consecutive sub-series, and $\overline{x}$ represents the mean of the 1st sub-series (x_k).

The high, medium, and low values of the given data can be graphically evaluated in this approach and they can be classified in “low”, ‘’medium’ and “high” value groups as per the Figure 3.3. The data is classified based on the data range of a station as all the stations don’t receive same amount of rainfall due to geographic and land use condition. Two 5% and 10% confidence bands have been plotted along the 1:1 line to understand the significance of the sub-trend and difference between the trend line and the data points.

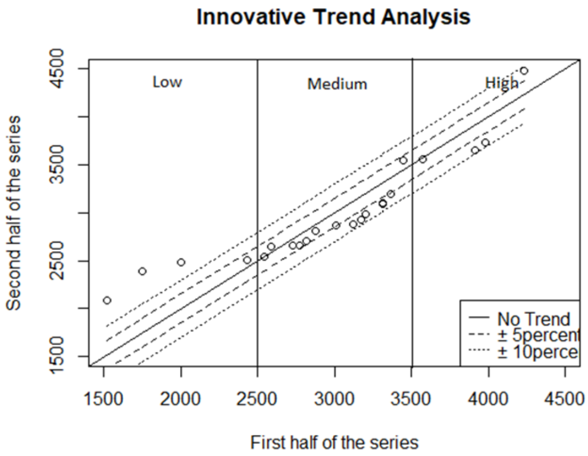


Figure 3.3: Example of the innovative trend analysis (ITA) method

3.3.6 Standardized Anomaly Index (SAI)

Standardized Anomaly Index (SAI) is a frequently used index to identify the fluctuations where temperature or rainfall is manifested as a standardized departure x_i from the long-term mean (i.e. the mean of the base period), calculated as:

$$x_i = \frac{r - r_i}{\sigma} \quad \text{(xi)}$$

where r is the mean temperature or rainfall of the year, r_i is the long-term mean, and σ is the standard deviation of annual mean temperature or rainfall for the long-term. For temperature when x_i represents a value below long-term average then it is considered as cooling years and when above long-term average then considered as warming years (Koudahe et al., 2017). Similarly, positive values refer to wet years and negative value refer to dry years in case of using rainfall data. It measures the frequency and severity of droughts. In this paper SAI for Rainfall and Temperature have been denoted with RAI and SAI respectively. RAI and SAI value classification is as the Table 3.2 below:

Table 3.2: RAI and SAI value classification

Rainfall		Temperature	
RAI value	**Category**	**SAI value**	**Category**
> 2.0	Extremely Wet	> 2.0	Extremely Warm
1.5 to 1.99	Severely Wet	1.5 to 1.99	Severely Warm
1.0 to 1.49	Moderately Wet	1.0 to 1.49	Moderately Warm
-0.99 to 0.99	Near Normal	-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry	-1.0 to -1.49	Moderately Cold
-1.5 to -1.99	Severely Dry	-1.5 to -1.99	Severely Cold
< -2.0	Extremely dry	< 2.0	Extremely Cold

3.3.7 Extreme Climate Indices

A core set of 27 extreme indices for temperature and precipitation was developed by the ETCCDI. The indices describe particular characteristics of extremes, including frequency, amplitude and persistence (Tank et al., 2009). Zhang et al. (2011) stated that, it is possible to assimilate the results of studies of different parts of the world to attain a coherent picture of global extreme changes by using such extreme metrics. The extremes of temperature and precipitation has been calculated using ClimPACT2 software using 45 years (1975–2019) of daily recorded data. We accounted 14 core indices and 7 non-core indices (Table 3.3) as they are relevant to the climatic condition of the study area in identifying extremes related to maximum and minimum temperatures and precipitation.

Table 3.3: Extreme temperature and precipitation indicators

S N.	Indicator	Long Name	Definition	Unit
Core ET-SCI indices				
1.	WSDI	Warm spell duration indicator	Annual number of days with at least 6 consecutive days when TX > 90th percentile	days
2.	CSDI	Cold spell duration indicator	Annual number of days with at least 6 consecutive days when TN < 10th percentile	days
3.	TXx	Max TX	Warmest daily TX	°C
4.	TNn	Min TN	Coldest daily TN	°C

S N.	Indicator	Long Name	Definition	Unit
5.	TR	Tropical nights	Annual number of days when TN > 20 °C	days
6.	SU25	Hot days	Annual number of days when TX >= 25 °C	days
7.	CDD	Consecutive dry days	Maximum annual number of consecutive dry days (when PR < 1.0 mm)	days
8.	R20mm	Number of very heavy rain days	Annual number of days when PR >= 20 mm	days
9.	RX3days	3 consecutive days PR amount	Maximum consecutive 3-day total precipitation	mm
10.	PRCPTOT	Annual total wet days PR	Annual sum of daily PR >= 1.0 mm	mm
11.	R95pTOT	Contribution from very wet days	100*r95p / PRCPTOT	%
12.	R99pTOT	Contribution from extremely wet days	100*r99p / PRCPTOT	%
13.	GSL	Growing season Length	Annual number of days between the first occurrence of 6 consecutive days with TM > 5 °C and the first occurrence of 6 consecutive days with TM < 5 °C	days
14.	SPI	Standardized Precipitation Index	Measure of "drought" using the Standardized Precipitation Index on 12-month time scale.	unitless
Non-core ET-SCI indices				
15.	DTR	Daily temperature range	Mean difference between daily TX and daily TN	°C
16.	TX10p	Amount of cool days	Percentage of days when TX < 10th percentile	%
17.	TX90p	Amount of hot days	Percentage of days when TX > 90th percentile	%
18.	TN10p	Amount of cold nights	Percentage of days when TN < 10th percentile	%
19.	TN90p	Amount of hot nights	Percentage of days when TN > 90th percentile	%
20.	CWD	Consecutive wet days	Maximum annual number of consecutive wet days (when PR >= 1.0 mm)	days
21.	R10mm	Number of heavy rain days	Annual number of days when PR >= 10 mm	days

The above-mentioned statistical analysis has been performed to evaluate and quantify the variable of climate change in Bangladesh using the historical rainfall and temperature data in this study.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction

To detect the trend of rainfall or temperature, MK, modified MK and ITA have been performed. Sen's slope has been performed to identify the magnitudes of the increase or decrease in rainfall or temperature. SAI has been performed to identify the extreme cold, warm, wet or dry years and extreme indices has been performed to identify consecutive warm or cold days, consecutive dry and wet days, annual number of days when precipitation or temperature is higher or lower than average precipitation or temperature respectively, frequency and severity of dry and wet years etc. The results have been discussed in the following sections.

4.2 Trend Analysis

4.2.1 Trend Analysis of Annual Rainfall

From IT analysis (Table 4.1 and Figure 4.1) of annual rainfall from the year 1975-2019, negative trend was found in 50% stations i.e., Barisal, Bogra, Chandpur, Dhaka, Dinajpur, Faridpur, Ishurdi, M. Court, Mymensingh, Patuakhali, Rajshahi, Rangpur, Sylhet district and positive trend was found in 35% of the stations i.e., Chittagong, Comilla, Cox's Bazar, Khepupara, Khulna, Rangamati, Sandwip, Srimangal, Teknaf at 5% significance level. Non-significant trend was found in Jessore, Satkhira and Feni.

The increasing trend is mainly observed in the south-west, south, south-east and east side of the country. The decreasing trend was observed in west, north and central part of the country. The highest increasing trend was observed in Sandwip which is an island in the Bay of Bengal at south of the country and the highest decreasing trend was observed in Faridpur which is situated in the central part of the country.

The station Faridpur shows maximum rate of rainfall decrease 11.84 mm/year and Dhaka shows rate of decrease 9.31 mm/year. The maximum growth rate of rainfall is 13.42 mm/year at Sandwip and the posterior growth rate of rainfall is 10.9 mm/year at Hatiya.

From MK and mMK test, around 27% stations show increasing trend among them only Khepupara shows significant increasing trend at 5% significant level i.e., 10.375 mm/year. The rest of the 73% stations show decreasing trend among them only Faridpur (11.84 mm/year), Ishurdi (8.61 mm/year) and Rajshahi (8.02 mm/year) shows significant decreasing trend.

Table 4.1: Details of annual rainfall trends in Bangladesh

Station	Z	Sen's Slope (mm/year)	τ	ITA-Slope (mm/year)	Trend
Barisal	-0.69	-3.63	-0.07	-3.00	↓
Bogra	-1.26	-6.81	-0.13	-7.15	↓
Chandpur	-0.60	-3.94	-0.06	-6.13	↓
Chittagong	0.88	7.28	0.09	6.89	↑
Comilla	-0.37	-1.82	-0.04	3.22	↑
Cox's Bazar	0.95	10.06	0.10	16.59	↑
Dhaka	-1.72	-9.31	-0.18	-6.28	↓
Dinajpur	-1.44	-1.44	-0.15	-6.64	↓
Faridpur	-2.48*	-11.84	-0.26	-9.89	↓
Feni	-0.23	-4.83	-0.03	-0.44	↓
Hatiya	1.36	10.90	0.14	23.99	↑
Ishurdi	-2.15*	-8.61	-0.22	-7.39	↓
Jessore	0.13	0.05	0.01	1.94	↑
Khepupara	2.12*	10.38	0.22	9.57	↑
Khulna	0.19	0.43	0.02	2.73	↑
M. Court	-0.96	-5.67	-0.10	-7.27	↓
Mymensingh	-1.16	-6.40	-0.12	-7.23	↓
Patuakhali	-1.39	-8.15	-0.14	-8.05	↓
Rajshahi	-2.42*	-8.02	-0.25	-3.43	↓
Rangamati	0.40	2.96	0.04	4.81	↑
Rangpur	-1.20	-5.94	-0.13	-5.56	↓
Sandwip	1.39	13.42	0.14	31.54	↑
Satkhira	-0.56	-2.92	-0.06	0.25	↑
Srimangal	0.13	0.35	0.01	4.31	↑
Sylhet	-0.73	-6.11	-0.08	-9.44	↓
Teknaf	1.50	10.24	0.16	19.46	↑

*N.B.: * Trends at the 95% confidence level(Z=1.96); ** Trends at the 99% confidence level(Z=2.58).*

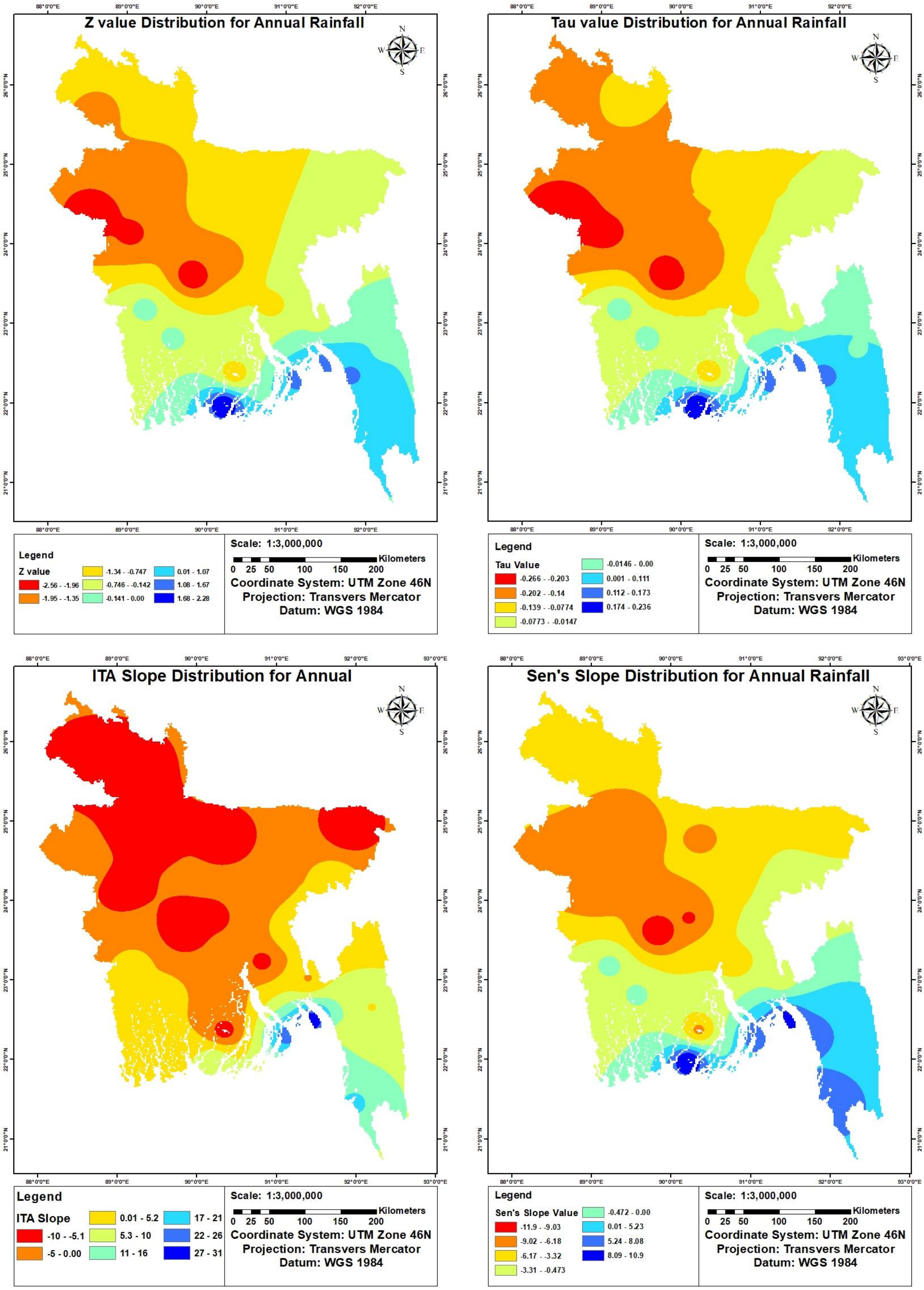


Figure 4.1: GIS mapping of annual rainfall trend from MK, mMK and IT analysis and magnitude from slope from Sen's slope analysis

4.2.2 Trend Analysis of Seasonal Rainfall

Pre-monsoon

The results of MK, mMK, ITA and Sen's slope of rainfall during pre-monsoon have been presented in Table 4.2 and Figure 4.2. The result from ITA reveals that 46% of the stations i.e., Barisal, Chandpur, Chittagong, Comilla, Dhaka, Faridpur, Feni, Ishurdi, Khulna, M. Court, Mymensingh, Patuakhali which are west, south west and central part of the country have decremental trend where only Faridpur is statistically significant at 95% confidence level. Cox's Bazar, Rangpur, Sandwip, Srimangal, and Teknaf which are very north west, northeast and very south east side of the country show growing trends but none of them is significant.

From MK and mMK results show decreasing trends in more districts (58%) among which Dhaka, Faridpur and Ishurdi shows decreasing trend statistically significant at 95% confidence level. Cox's Bazar, Rajshahi, Rangpur and Teknaf show increasing trends but none of them are significant.

The highest growing magnitude was found 1.04 mm/year at Teknaf and lowest 1.73 mm/year and 1.72 mm/year at Dhaka and Faridpur respectively.

Monsoon

The ITA slope for rainfall during monsoon season shows (Table 4.2 and Figure 4.2) increasing trend in 46% of the stations i.e., Chittagong, Cox's Bazar, Comilla, Feni, Hatiya, Jessore, Khepupara, Khulna, Rangamati, Sandwip, Srimangal and Teknaf. Chittagong, Cox's Bazar, Hatiya, Khepupara, Sandwip and Teknaf, the southern belt near the Bay of Bengal shows significant increasing trend. Decreasing trend dominates in 38% of the stations i.e., Bogra, Dinajpur, Faridpur, Ishurdi, M. Court, Mymensingh, Patuakhali, Rajshahi, Rangpur and Sylhet which is the northern and central part of Bangladesh. Only Sylhet shows significant decreasing trend of rainfall during monsoon season.

The MK and mMK test show similar results. The maximum increasing magnitude was found 3.43 mm/year in Sandwip and maximum decreasing magnitude was found 2.23 mm/year in Rajshahi.

Post-monsoon

The IT analysis shows (Table 4.2 and Figure 4.2) increasing trend in 62% stations i.e., Bogra, Chandpur, Dinajpur, Feni, Hatiya, Ishurdi, Jessore, Khepupara, Khulna, M. court, Patuakhali, Rangpur, Sandwip, Satkhira, Srimangal, Teknaf where only Hatiya shows significant increase at 95% confidence level. Other stations mostly north eastern part shows insignificant decreasing trends.

MK and mMK show more or less similar results for both increasing and decreasing trends.

The maximum increasing magnitude was found 1.90 mm/year in Hatiya and maximum decreasing magnitude was found 0.67 mm/year in Dhaka.

Dry

The results of the IT analysis exhibit (Table 4.2 and Figure 4.2) that all the stations except Teknaf show decreasing trend. The increasing trend in Teknaf is not significant for IT, MK and mMK tests. According to IT analysis none of the decreasing trend is significant.

From MK and mMK test, Dinajpur and Feni shows significant decreasing trend at 95% confidence level.

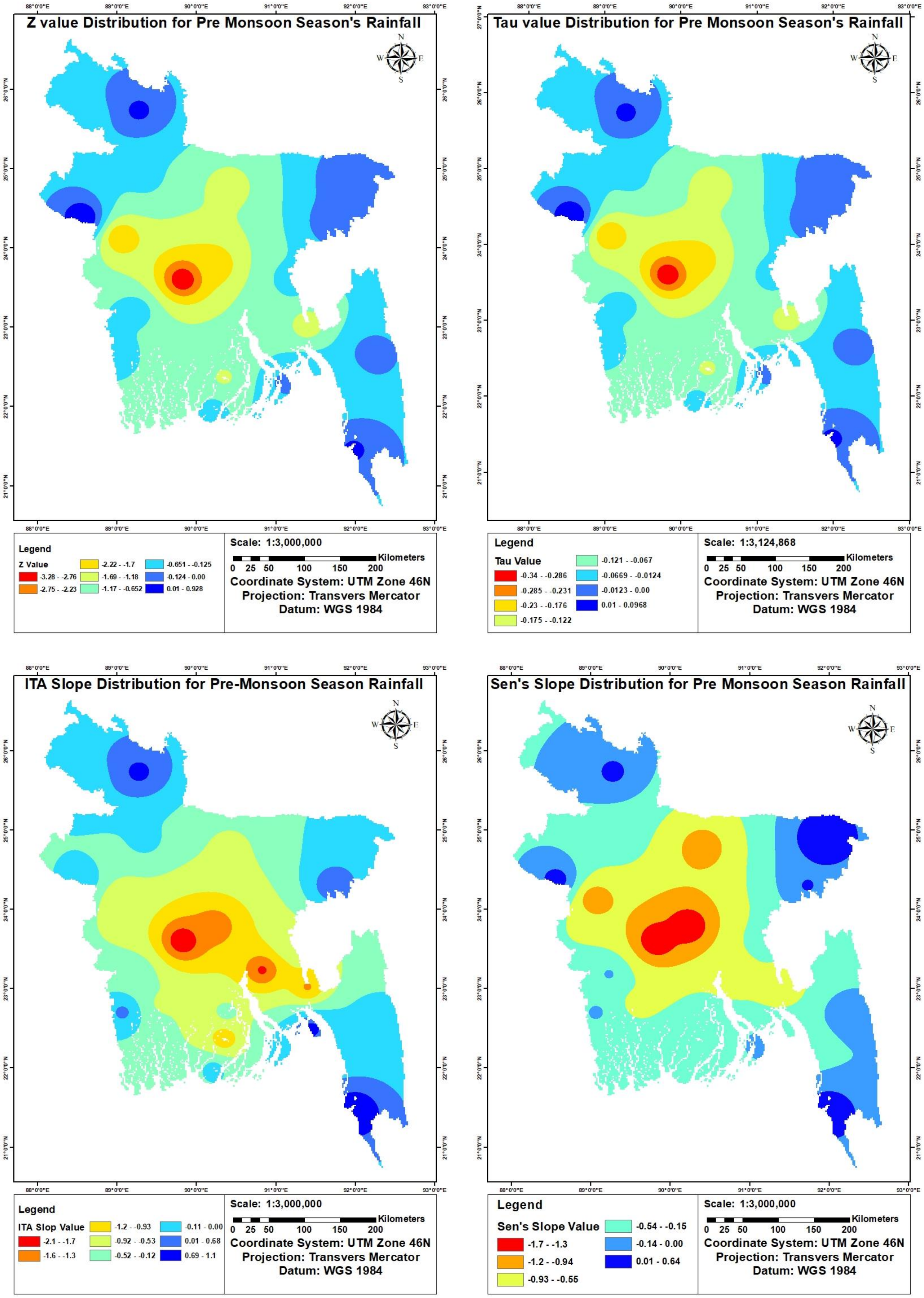
The maximum decreasing magnitude was found 0.23 mm/year in Feni from Sen's slope analysis.

Table 4.2: Details of seasonal rainfall trends in Bangladesh

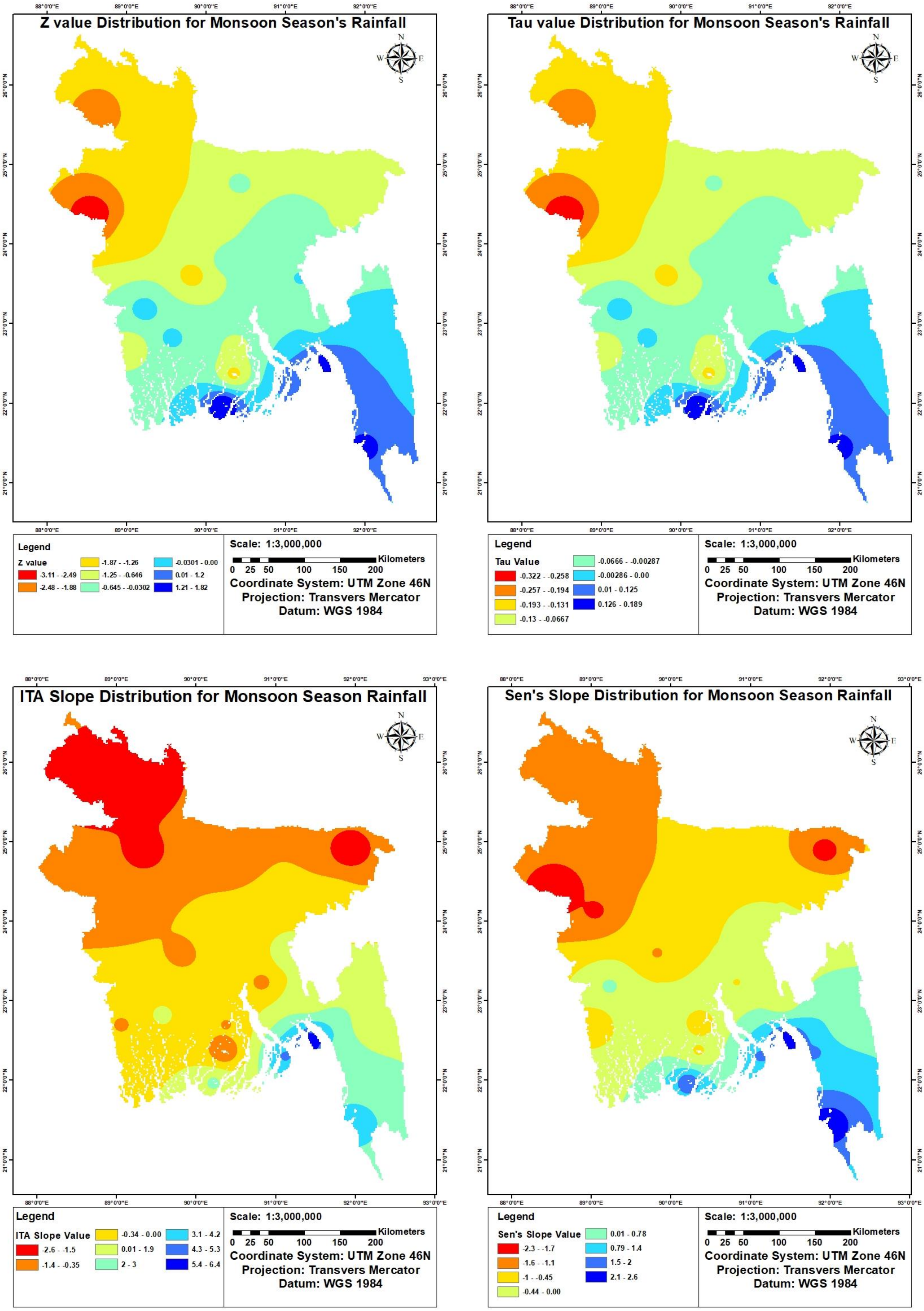
Stations	Pre-monsoon					Monsoon					Post-monsoon					Dry				
	Z	Sen's Slope (mm/year)	τ	IT-Slope (mm/year)	Trend	Z	Sen's Slope (mm/year)	τ	IT-Slope (mm/year)	Trend	Z	Sen's Slope (mm/year)	τ	IT-Slope (mm/year)	Trend	Z	Sen's Slope (mm/year)	τ	IT-Slope (mm/year)	Trend
Barisal	-0.88	-0.39	-0.09	-0.41	↓	-0.78	-0.71	-0.08	-0.39	↓	0.59	0.34	0.06	0.07	↑	-0.73	-0.11	-0.08	-0.11	↓
Bogra	-0.55	-0.38	-0.06	-0.03	↓	-1.63	-1.37	-0.17	-1.80	↓	0.91	0.51	0.09	0.32	↑	-0.39	-0.04	-0.04	-0.17	↓
Chandpur	-0.96	-0.76	-0.10	-1.87	↓	0.02	0.03	0.00	-0.38	↓	0.89	0.64	0.09	0.64	↑	-0.29	-0.03	-0.03	-0.09	↓
Chittagong	-0.95	-0.83	-0.10	-0.62	↓	1.09	2.05	0.11	2.24	↑	0.08	0.21	0.01	0.04	↑	-0.81	-0.05	-0.08	-0.10	↓
Comilla	-0.48	-0.44	-0.05	-0.73	↓	0.07	0.03	0.01	1.42	↑	-0.51	-0.30	-0.05	-0.33	↓	-0.93	-0.08	-0.10	-0.12	↓
Cox's Bazar	0.45	0.61	0.05	1.05	↑	1.31	2.85	0.14	3.63	↑	0.74	0.98	0.08	-0.30	↓	-0.45	-0.02	-0.05	-0.16	↓
Dhaka	-2.12*	-1.73	-0.22	-1.63	↓	-0.53	-0.64	-0.06	0.26	↑	-1.27	-0.67	-0.13	-0.81	↓	-1.03	-0.13	-0.11	-0.27	↓
Dinajpur	-0.06	-0.05	-0.01	0.07	↑	-1.32	-1.51	-0.14	-1.94	↓	-0.60	-0.40	-0.06	0.76	↑	-2.08*	-0.16	-0.22	-0.21	↓
Faridpur	-3.19**	-1.72	-0.33	-2.14	↓	-1.30	-1.00	-0.14	-0.61	↓	-0.56	-0.32	-0.06	-0.23	↓	-0.73	-0.06	-0.08	-0.20	↓
Feni	-0.93	-0.97	-0.10	-1.28	↓	0.04	-0.38	0.01	0.87	↑	0.59	0.69	0.06	0.47	↑	-2.20*	-0.23	-0.23	-0.33	↓
Hatiya	-0.02	0.07	0.00	0.00	↑	1.28	2.14	0.13	4.92	↑	1.62	1.90	0.17	2.37	↑	-0.36	-0.04	-0.04	-0.15	↓
Ishurdi	-2.03*	-1.13	-0.21	-0.93	↓	-1.71	-1.66	-0.18	-1.31	↓	-0.06	-0.02	-0.01	0.61	↑	0.09	0.00	0.01	-0.19	↓
Jessore	-0.19	-0.20	-0.02	-0.18	↓	0.22	0.22	0.02	0.73	↑	0.66	0.36	0.07	0.44	↑	-1.07	-0.20	-0.11	-0.43	↓
Khepupara	-0.65	-0.53	-0.07	-0.05	↓	1.84	1.70	0.19	2.12	↑	1.33	1.61	0.14	0.79	↑	-0.20	-0.03	-0.02	-0.11	↓
Khulna	-1.17	-0.70	-0.12	-0.58	↓	0.31	0.20	0.03	1.05	↑	1.26	0.71	0.13	0.67	↑	-0.78	-0.14	-0.08	-0.35	↓
M. Court	-0.36	-0.16	-0.04	-0.56	↓	-1.05	-0.89	-0.11	-1.57	↓	1.08	1.20	0.11	0.83	↑	-1.24	-0.18	-0.13	-0.33	↓
Mymensingh	-1.37	-1.11	-0.14	-0.58	↓	-0.59	-0.58	-0.06	-0.84	↓	-0.39	-0.23	-0.04	-0.66	↓	0.21	0.01	0.02	-0.27	↓
Patuakhali	-0.98	-0.62	-0.10	-1.09	↓	-1.58	-1.98	-0.16	-1.49	↓	1.35	1.48	0.14	0.86	↑	-0.82	-0.11	-0.09	-0.17	↓
Rajshahi	1.07	0.47	0.11	0.14	↑	-3.05**	-2.23	-0.32	-0.70	↓	-0.35	-0.35	-0.04	-0.15	↓	-1.00	-0.08	-0.10	-0.30	↓

Stations	Pre-monsoon					Monsoon					Post-monsoon					Dry				
	Z	Sen's Slope (mm/year)	τ	IT-Slope (mm/year)	Trend	Z	Sen's Slope (mm/year)	τ	IT-Slope (mm/year)	Trend	Z	Sen's Slope (mm/year)	τ	IT-Slope (mm/year)	Trend	Z	Sen's Slope (mm/year)	τ	IT-Slope (mm/year)	Trend
Rangamati	0.25	0.18	0.03	0.06	↑	0.30	0.26	0.03	1.21	↑	1.16	0.76	0.12	0.05	↑	-0.12	-0.02	-0.01	-0.10	↓
Rangpur	0.51	0.33	0.05	0.77	↑	-1.46	-1.26	-0.15	-2.53	↓	0.29	0.29	0.03	1.36	↑	-0.88	-0.08	-0.09	-0.15	↓
Sandwip	-0.71	-0.56	-0.07	0.60	↑	1.65	3.43	0.17	6.79	↑	1.16	1.39	0.12	1.62	↑	-1.58	-0.18	-0.16	-0.23	↓
Satkhira	-0.23	-0.19	-0.03	0.39	↑	-0.99	-0.81	-0.10	-0.45	↓	1.24	0.72	0.13	0.82	↑	-0.88	-0.18	-0.09	-0.25	↓
Srimangal	0.45	0.32	0.05	0.57	↑	0.12	0.13	0.01	0.48	↑	1.08	0.60	0.11	0.45	↑	-0.14	-0.02	-0.02	-0.07	↓
Sylhet	0.34	0.60	0.04	0.18	↑	-1.12	-1.88	-0.12	-2.06	↓	-0.50	-0.43	-0.05	-0.87	↓	-0.43	-0.05	-0.05	-0.18	↓
Teknaf	0.92	1.04	0.10	1.59	↑	1.04	1.63	0.11	3.12	↑	1.12	1.41	0.12	1.08	↑	0.29	0.00	0.03	0.01	↑

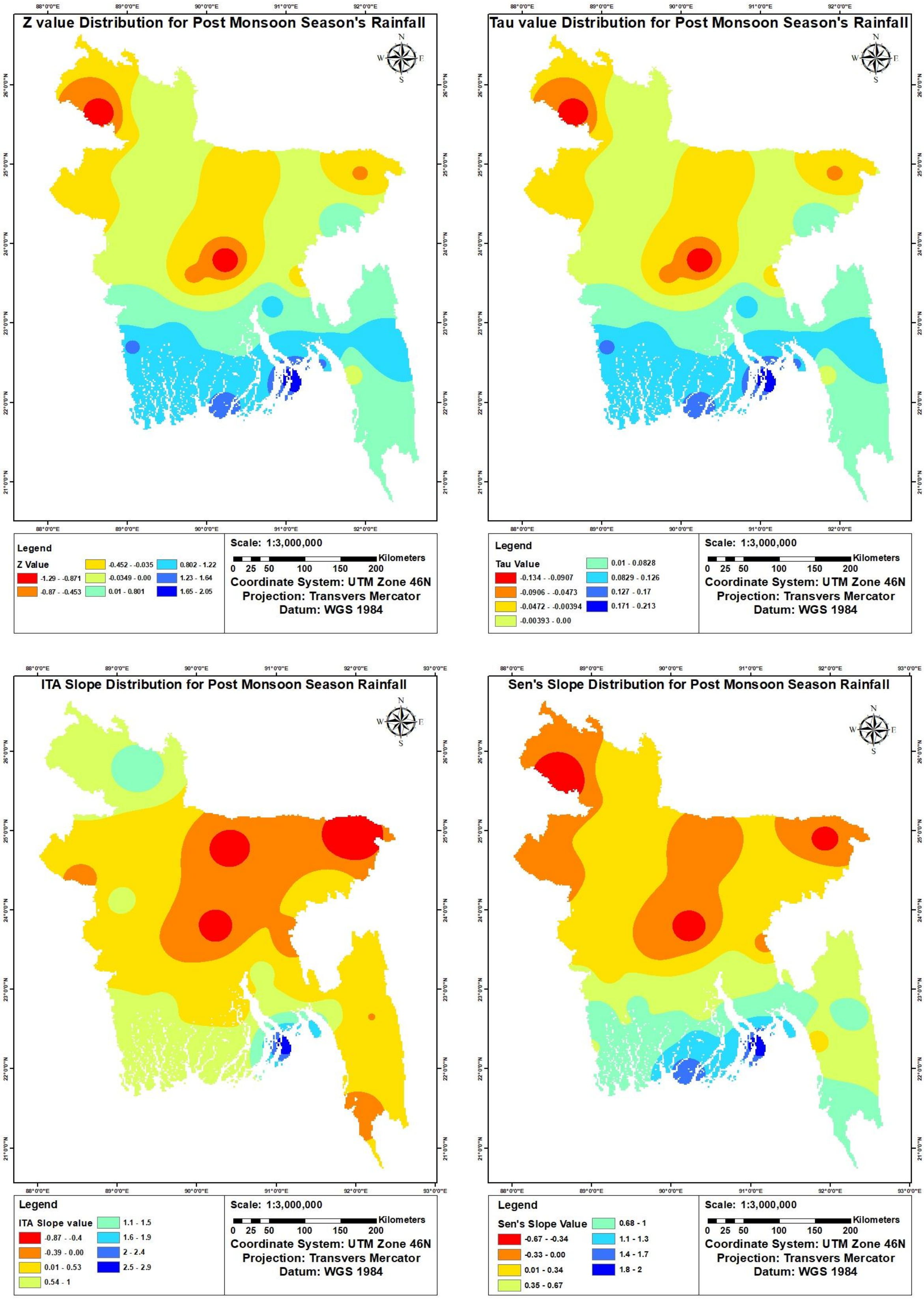
*N.B.: * Trends at the 95% confidence level(Z=1.96); ** Trends at the 99% confidence level(Z=2.58).*



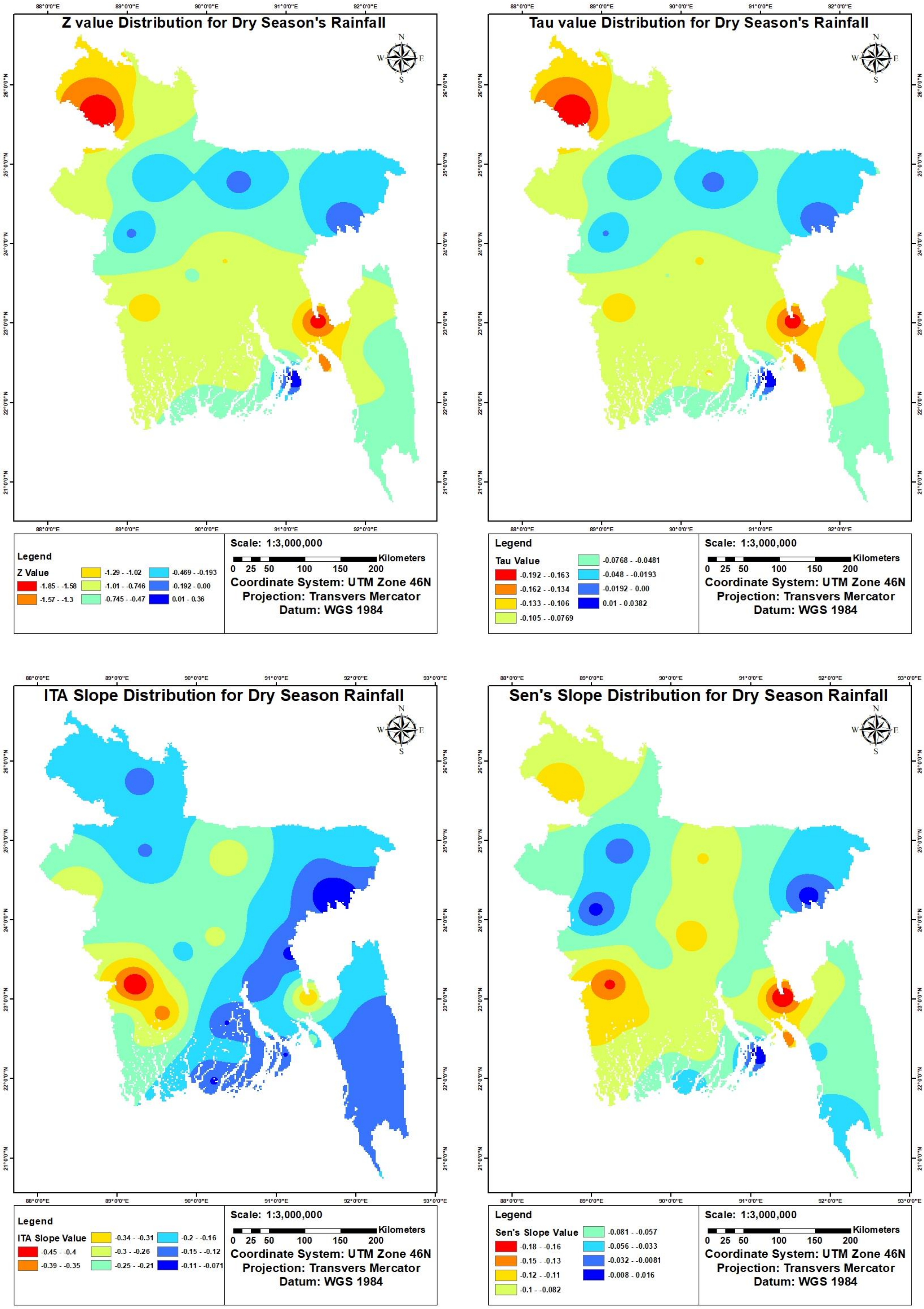
(a) Pre-monsoon


Z value Distribution for Monsoon Season's Rainfall
Legend
Z value
-3.11 - -2.49
-2.48 - -1.88
-1.87 - -1.26
-1.25 - -0.646
-0.645 - -0.0302
-0.0301 - 0.00
0.01 - 1.2
1.21 - 1.82
Tau value Distribution for Monsoon Season's Rainfall
Legend
Tau Value
-0.322 - -0.258
-0.257 - -0.194
-0.193 - -0.131
-0.13 - -0.0667
-0.0666 - -0.00287
-0.00286 - 0.00
0.01 - 0.125
0.126 - 0.189
ITA Slope Distribution for Monsoon Season Rainfall
Legend
ITA Slope Value
-2.6 - -1.5
-1.4 - -0.35
-0.34 - 0.00
0.01 - 1.9
2 - 3
3.1 - 4.2
4.3 - 5.3
5.4 - 6.4
Sen's Slope Distribution for Monsoon Season Rainfall
Legend
Sen's Slope Value
-2.3 - -1.7
-1.6 - -1.1
-1 - -0.45
-0.44 - 0.00
0.01 - 0.78
0.79 - 1.4
1.5 - 2
2.1 - 2.6
Scale: 1:3,000,000
Kilometers
0 25 50 100 150 200
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984

(b) Monsoon



(c) Post-monsoon



(d) Dry

Figure 4.2: GIS mapping of seasonal rainfall trend from MK, mMK and IT analysis and magnitude from slope from Sen's slope analysis

4.2.3 Trend Analysis of Annual Average Temperature

IT Analysis shows that (Table 4.3, Figure 4.3) 65% of the stations show increasing trend where Rangpur, Sylhet, Dhaka and Chandpur show higher values. Dinajpur, Hatiya, Khepupara, Mymensingh, Patuakhali, Rangamati, Satkhira, Srimangal and Teknaf shows decreasing trend Satkhira shows highest decreasing trend among them.

MK and mMK analysis show almost similar result but some exception is that MK shows significant trend in some stations and some stations also shows opposite trend then that of ITA. MK result shows significant increasing trend at 27% of the stations which represents west, south-west, south-east, north-east and central part of the country and significant decreasing trend at Satkhira. The highest increasing trend was observed in Sylhet and decreasing trend in Satkhira.

Sen's slope analysis shows that, Sylhet has a maximum increase rate of 0.021^{o}C/year and Mymensingh has a maximum decrease rate of 0.014^{o}C/year.

Table 4.3: Details of annual average temperature trends in Bangladesh

Station	Z	Sen's Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend
Barisal	1.829	0.008	0.271	0.007	↑
Bogra	1.027	0.011	0.358	0.011	↑
Chandpur	3.649**	0.020	0.495	0.017	↑
Chittagong	3.923**	0.018	0.451	0.016	↑
Comilla	0.910	0.008	0.176	0.005	↑
Cox's Bazar	3.531**	0.013	0.434	0.013	↑
Dhaka	3.610**	0.020	0.475	0.017	↑
Dinajpur	-1.105	-0.005	-0.055	-0.013	↓
Faridpur	2.318*	0.010	0.240	0.002	↑
Feni	0.010	0.000	0.000	0.001	↑
Hatiya	-1.418	-0.002	-0.081	-0.003	↓
Ishurdi	0.068	0.005	0.121	0.004	↑
Jessore	1.477	0.007	0.263	0.008	↑
Khepupara	-1.868	-0.009	-0.259	-0.014	↓
Khulna	1.829	0.018	0.347	0.014	↑
M. Court	1.154	0.007	0.223	0.005	↑
Mymensingh	-1.653	-0.014	-0.257	-0.022	↓
Patuakhali	-1.653	-0.008	-0.168	-0.009	↓
Rajshahi	-1.771	0.006	0.113	0.002	↑
Rangamati	-1.771	-0.007	-0.125	-0.006	↓
Rangpur	1.986*	0.017	0.414	0.025	↑
Sandwip	-0.186	0.006	0.180	0.005	↑
Satkhira	-2.181*	-0.010	-0.158	-0.025	↓
Srimangal	-0.303	0.003	0.075	-0.009	↓
Sylhet	4.079**	0.021	0.547	0.024	↑
Teknaf	-1.379	-0.008	-0.110	-0.005	↓

*N.B.: * Trends at the 95% confidence level(Z=1.96); ** Trends at the 99% confidence level(Z=2.58).*

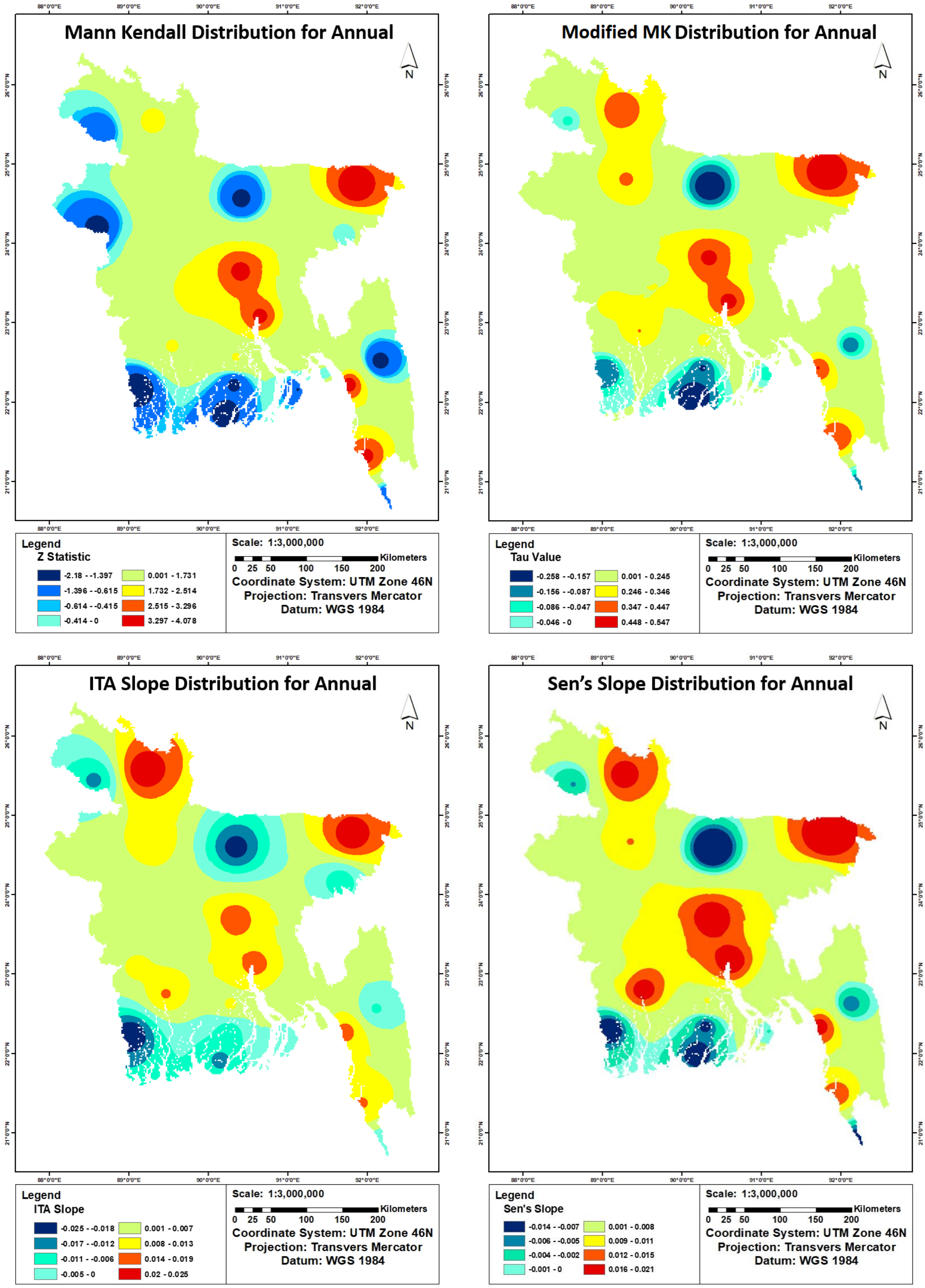


Figure 4.3: GIS mapping of annual average temperature trend from MK, mMK and IT analysis and magnitude from slope from Sen's slope analysis

4.2.4 Trend Analysis of Seasonal Average Temperature

Pre-monsoon

IT analysis shows (Table 4.4 and Figure 4.4) increasing trend in 54% of the stations and only some certain small region i.e., north central, north western and south western side show decreasing trend.

mMK analysis shows similar results but MK analysis shows slightly different results. MK analysis shows significant increasing trend at 23% of the stations i.e., Chandpur, Chittagong, Cox's Bazar, Dhaka, Khulna and Sylhet which are central, south eastern and south western part of the country and significant decreasing trend at Teknaf. The highest increasing trend was observed in Chittagong and decreasing trend in Teknaf.

According to Sen's slope analysis, Chittagong and Dhaka show maximum increase rate of 0.023^{o}C/year and Mymensingh shows maximum decrease rate of 0.026 ^{o}C/year.

Monsoon

IT analysis shows (Table 4.4 and Figure 4.4) increasing trend at all the stations but none of them is significant.

MK and mMK analysis also show similar result but MK analysis shows significant increasing trend at some of the stations. 46% stations i.e., Chittagong, Comilla, Cox's Bazar, Faridpur, Feni, Hatiya, Ishurdi, Khepupara, Khulna, M. Court, Rangamati and Sandwip show significantly increasing trend at 95% confidence level according to MK analysis which are central and southern part of the country. Among them Cox's Bazar shows highest increasing trend.

From Sen's slope analysis, Jessore and Rangpur show maximum increase rate of 0.025^{o}C/year.

Post-monsoon

IT analysis shows (Table 4.4 and Figure 4.4) increasing trend in 54% of the stations, decreasing in 38% stations and no trend in 2 stations i.e., Faridpur and Feni.

But trend analysis result is different for MK, mMK and Sen's slope. MK shows decreasing trend in 62% stations among them Hatiya, Khepupara, Rajshahi, Rangamati, Sandwip, Satkhira and Teknaf show significant decreasing trend which are southern part of the country and Dhaka, and Sylhet show significant increasing trend at 95% confidence level.

Sylhet shows maximum rate of increase 0.020^{o}C/year and Mymensingh, Satkhira show maximum decrease 0.029^{o}C/year according to Sen's slope analysis.

Dry

IT analysis shows (Table 4.4 and Figure 4.4) decreasing trend in 69% stations and increasing trend in Chandpur, Chittagong, Cox's Bazar, Dhaka, Khulna, Rangpur and Sylhet.

MK and mMK analysis show similar result. Dinajpur, Hatiya, Khepupara, Mymensingh, Patuakhali, Rajshahi, Rangamati, Sandwip, Satkhira and Teknaf show statistically significant decreasing trend and Chittagong shows significantly increasing trend at 95% confidence level.

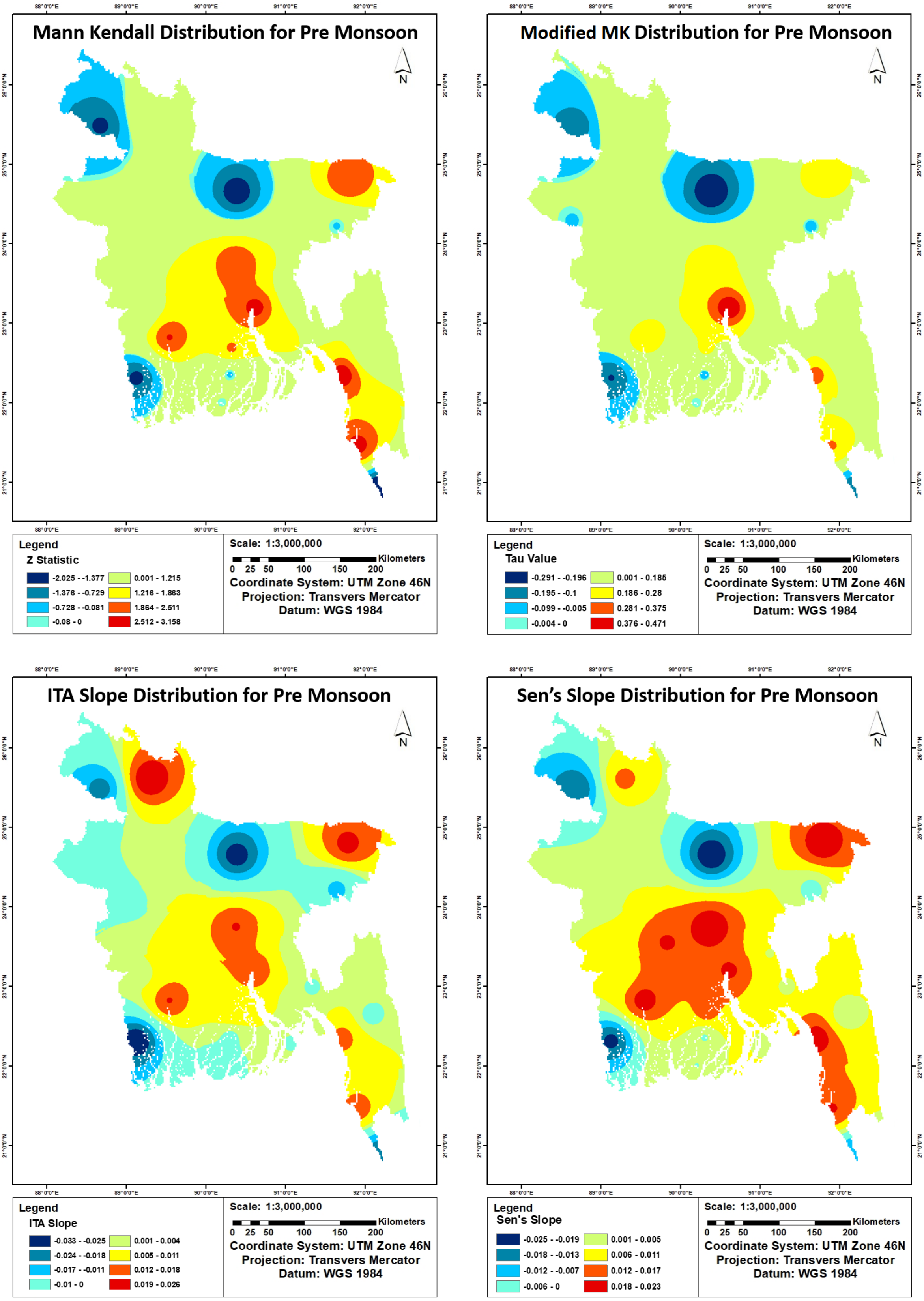
From Sen's slope analysis, Sylhet shows maximum increase rate 0.023^{o}C/year and Khepupara and Patuakhali show maximum decrease rate 0.044^{o}C/year.

Table 4.4: Details of seasonal average temperature trends in Bangladesh

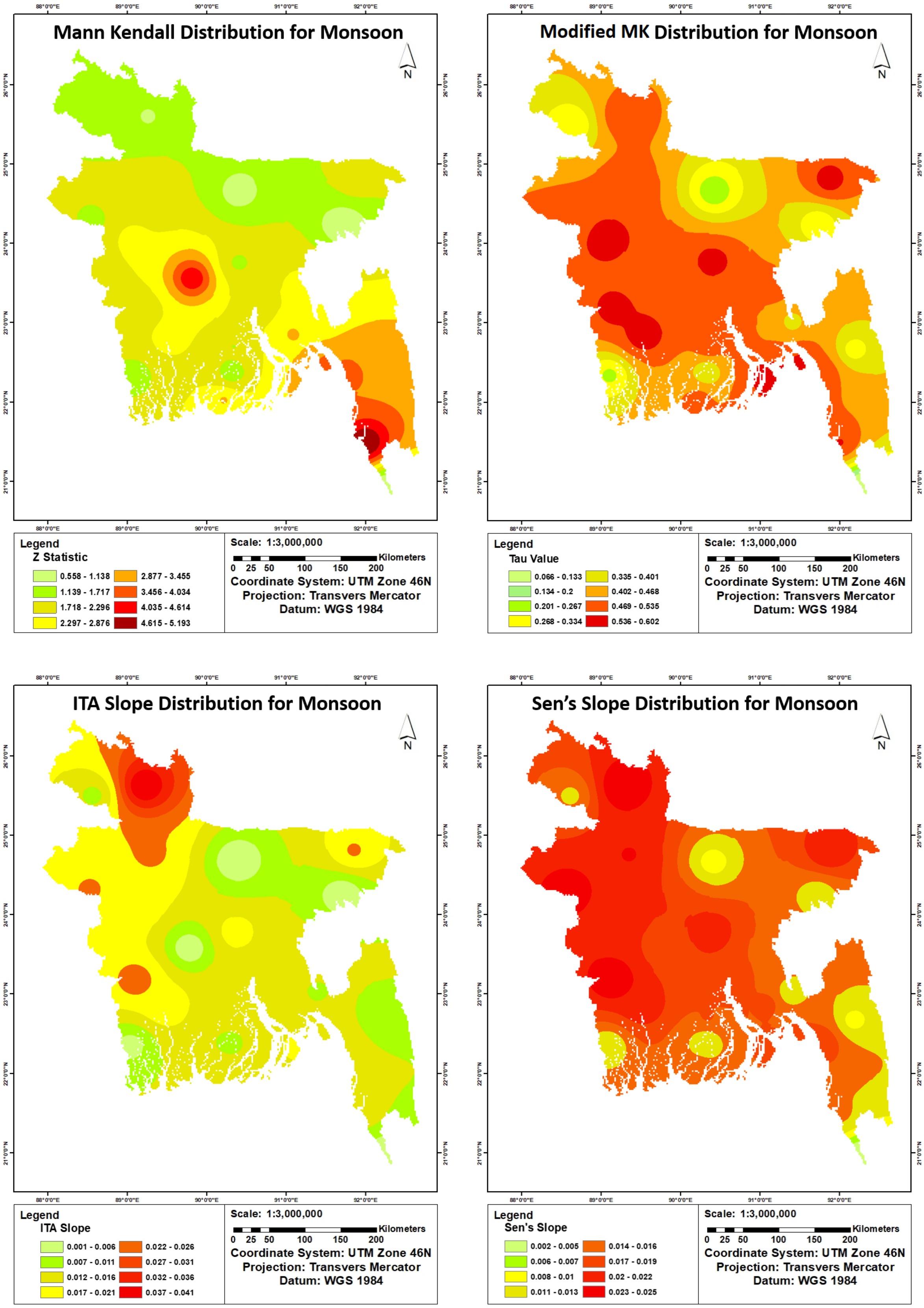
Stations	Pre-monsoon					Monsoon					Post-monsoon					Dry				
	Z	Sen's Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen's Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen's Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen's Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend
Barisal	1.947	0.014	0.202	0.008	↑	1.712	0.016	0.509	0.013	↑	-0.147	-0.001	-0.016	0.003	↑	-0.675	-0.003	-0.071	0.002	↑
Bogra	0.108	0.002	0.012	0.003	↑	1.888	0.022	0.513	0.022	↑	0.401	0.015	0.265	0.020	↑	-0.401	-0.005	-0.042	-0.004	↓
Chandpur	2.808*	0.019	0.471	0.017	↑	1.751	0.019	0.471	0.015	↑	1.868	0.019	0.317	0.019	↑	1.301	0.015	0.200	0.016	↑
Chittagong	3.160**	0.023	0.327	0.016	↑	3.727**	0.019	0.507	0.014	↑	1.673	0.009	0.174	0.016	↑	2.768**	0.016	0.297	0.019	↑
Comilla	0.323	0.005	0.034	0.001	↑	2.475*	0.014	0.495	0.014	↑	1.184	0.009	0.123	0.008	↑	-0.382	-0.006	-0.065	-0.005	↓
Cox's Bazar	2.768**	0.018	0.287	0.015	↑	5.194**	0.014	0.537	0.013	↑	1.575	0.006	0.164	0.011	↑	1.771	0.012	0.232	0.014	↑
Dhaka	2.475*	0.023	0.257	0.019	↑	1.634	0.022	0.570	0.019	↑	2.260*	0.011	0.234	0.013	↑	0.929	0.018	0.261	0.016	↑
Dinajpur	-1.497	-0.019	-0.156	-0.021	↓	1.614	0.013	0.273	0.010	↑	-1.731	-0.014	-0.099	-0.011	↓	-2.416*	-0.031	-0.240	-0.038	↓
Faridpur	1.673	0.018	0.174	0.011	↑	4.549**	0.017	0.471	0.002	↑	-0.225	-0.001	-0.024	0.000	↑	-0.929	-0.008	-0.097	-0.007	↓
Feni	0.421	0.004	0.044	-0.001	↓	2.377*	0.011	0.376	0.010	↑	-1.360	-0.008	-0.141	0.000	↑	-1.888	-0.013	-0.196	-0.009	↓
Hatiya	0.440	0.002	0.046	-0.001	↓	2.905**	0.017	0.602	0.017	↑	-3.179**	-0.015	-0.329	-0.011	↓	-2.788**	-0.026	-0.410	-0.027	↓
Ishurdi	0.245	0.004	0.026	-0.001	↓	2.436*	0.022	0.576	0.021	↑	-1.184	-0.008	-0.125	0.001	↑	-1.477	-0.010	-0.154	-0.009	↓
Jessore	0.597	0.006	0.063	0.003	↑	1.771	0.025	0.556	0.024	↑	0.655	0.002	0.069	0.009	↑	-1.399	-0.010	-0.145	-0.010	↓
Khepupara	-0.029	0.000	-0.004	-0.004	↓	2.905**	0.015	0.489	0.013	↑	-3.023**	-0.023	-0.406	-0.015	↓	-4.627**	-0.044	-0.560	-0.040	↓
Khulna	2.553*	0.021	0.265	0.019	↑	2.534*	0.022	0.584	0.020	↑	0.068	0.007	0.123	0.007	↑	-0.205	-0.001	-0.016	0.004	↑
M. Court	1.467	0.010	0.153	0.003	↑	2.935**	0.017	0.466	0.016	↑	-0.391	-0.003	-0.041	0.001	↑	-0.470	-0.004	-0.049	-0.004	↓
Mymensingh	-1.829	-0.026	-0.291	-0.029	↓	0.890	0.009	0.220	0.001	↑	-1.595	-0.029	-0.382	-0.031	↓	-2.064*	-0.037	-0.327	-0.038	↓
Patuakhali	-0.127	0.000	-0.014	-0.001	↓	1.379	0.011	0.339	0.010	↑	-1.829	-0.017	-0.253	-0.018	↓	-2.279*	-0.044	-0.442	-0.037	↓

Stations	Pre-monsoon					Monsoon					Post-monsoon					Dry				
	Z	Sen's Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen's Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen's Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen's Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend
Rajshahi	0.108	0.002	-0.008	-0.003	↓	1.614	0.024	0.493	0.022	↑	-3.121**	-0.010	-0.154	-0.004	↓	-2.592**	-0.020	-0.255	-0.014	↓
Rangamati	0.108	0.001	0.012	-0.001	↓	2.944**	0.009	0.305	0.006	↑	-3.121**	-0.024	-0.323	-0.017	↓	-3.277**	-0.022	-0.295	-0.022	↓
Rangpur	0.851	0.013	0.176	0.026	↑	1.105	0.025	0.517	0.041	↑	0.734	0.024	0.345	0.031	↑	-0.303	-0.002	-0.032	0.001	↑
Sandwip	1.360	0.011	0.141	0.002	↑	3.551**	0.017	0.549	0.016	↑	-2.592**	-0.006	-0.087	0.001	↑	-2.534*	-0.007	-0.091	-0.002	↓
Satkhira	-1.536	-0.021	-0.200	-0.033	↓	1.458	0.011	0.253	0.004	↑	-2.299*	-0.029	-0.299	-0.031	↓	-2.514*	-0.040	-0.368	-0.050	↓
Srimangal	-0.108	-0.002	-0.012	-0.013	↓	0.558	0.012	0.283	0.002	↑	-1.203	-0.008	-0.083	-0.011	↓	-1.360	-0.012	-0.044	-0.021	↓
Sylhet	2.475*	0.022	0.257	0.021	↑	1.947	0.022	0.560	0.022	↑	3.512**	0.020	0.364	0.023	↑	1.634	0.023	0.299	0.031	↑
Teknaf	-2.025*	-0.013	-0.157	-0.022	↓	0.626	0.002	0.066	0.001	↑	-2.583**	-0.026	-0.268	-0.023	↓	-3.101**	-0.034	-0.395	-0.040	↓

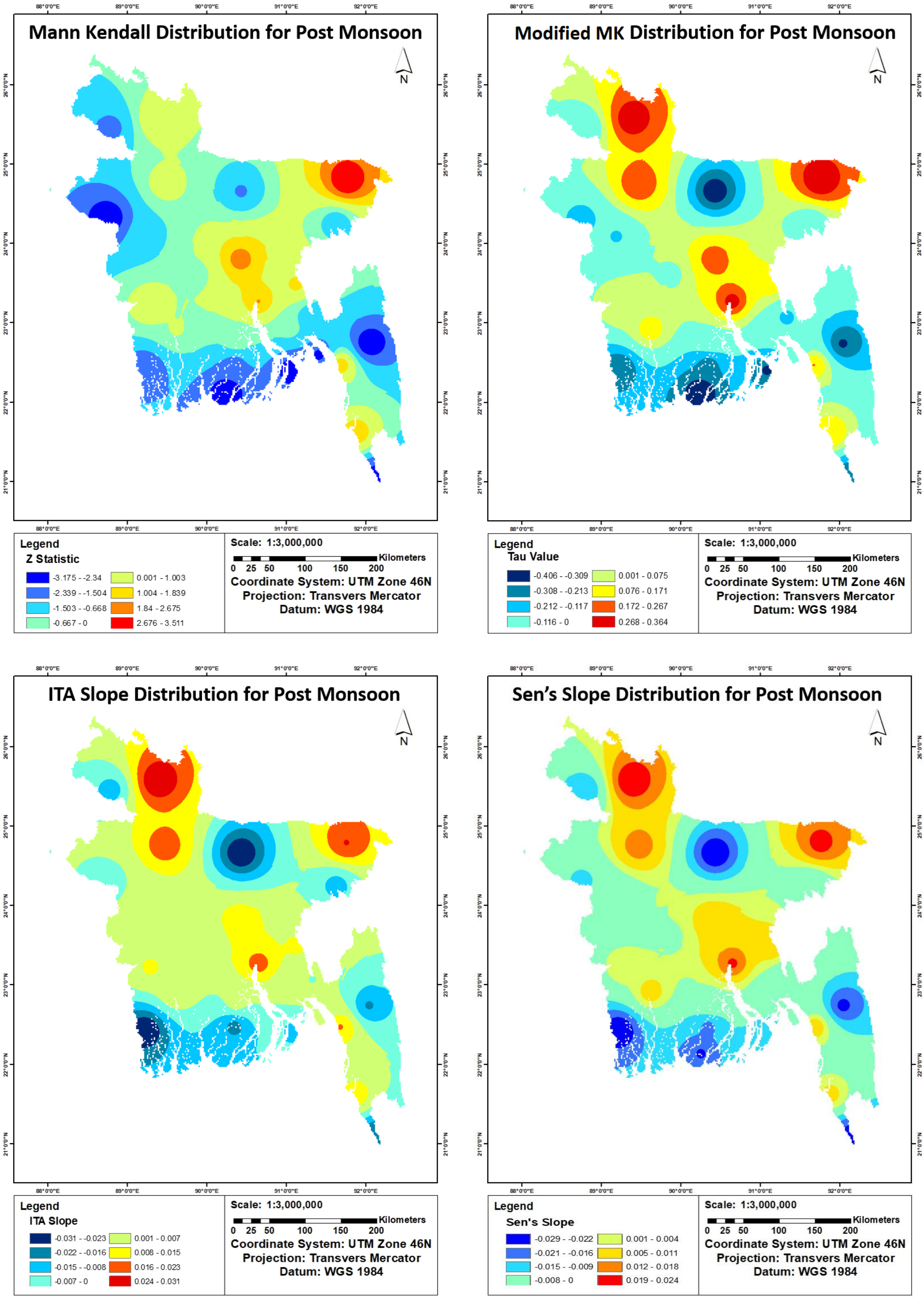
*N.B.: * Trends at the 95% confidence level(Z=1.96); ** Trends at the 99% confidence level(Z=2.58).*



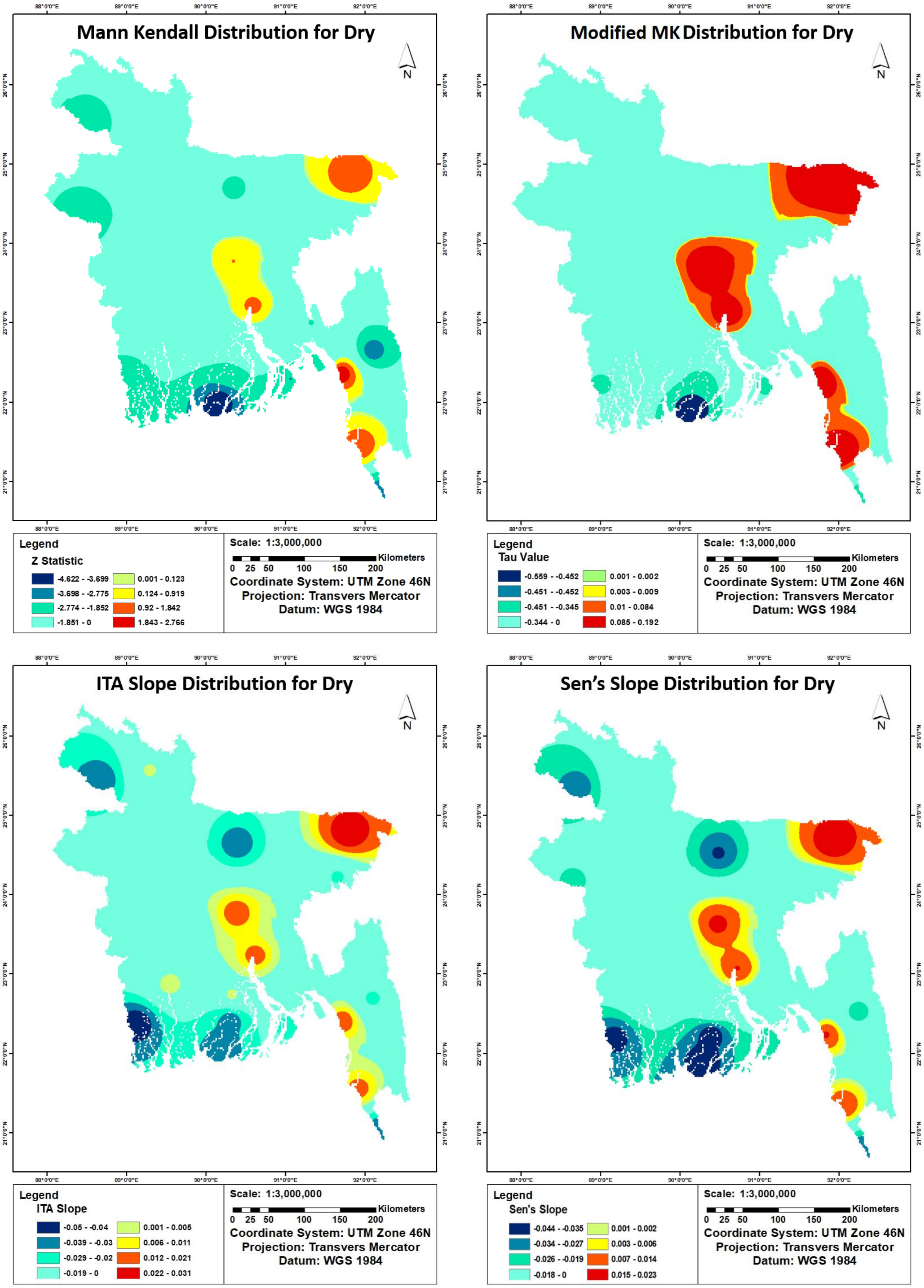
(a) Pre-monsoon


Mann Kendall Distribution for Monsoon
N
Legend
Z Statistic
0.558 - 1.138
1.139 - 1.717
1.718 - 2.296
2.297 - 2.876
2.877 - 3.455
3.456 - 4.034
4.035 - 4.614
4.615 - 5.193
Scale: 1:3,000,000
0 25 50 100 150 200
Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984
Modified MK Distribution for Monsoon
N
Legend
Tau Value
0.066 - 0.133
0.134 - 0.2
0.201 - 0.267
0.268 - 0.334
0.335 - 0.401
0.402 - 0.468
0.469 - 0.535
0.536 - 0.602
Scale: 1:3,000,000
0 25 50 100 150 200
Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984
ITA Slope Distribution for Monsoon
N
Legend
ITA Slope
0.001 - 0.006
0.007 - 0.011
0.012 - 0.016
0.017 - 0.021
0.022 - 0.026
0.027 - 0.031
0.032 - 0.036
0.037 - 0.041
Scale: 1:3,000,000
0 25 50 100 150 200
Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984
Sen's Slope Distribution for Monsoon
N
Legend
Sen's Slope
0.002 - 0.005
0.006 - 0.007
0.008 - 0.01
0.011 - 0.013
0.014 - 0.016
0.017 - 0.019
0.02 - 0.022
0.023 - 0.025
Scale: 1:3,000,000
0 25 50 100 150 200
Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984

(b) Monsoon



(c) Post-monsoon



(d) Dry

Figure 4.4: GIS mapping of seasonal average temperature trend from MK, mMK and IT analysis and magnitude from slope from Sen's slope analysis

4.2.5 Trend Analysis of Annual Maximum Temperature

Except Satkhira all the other stations show increasing trend from IT analysis. MK and mMK also show similar trend results. Barisal, Chandpur, Chittagong, Comilla, Cox's Bazar, Dinajpur, Faridpur, Feni, Hatiya, Jessore, Khepupara, M.Court, Patuakhali, Rajshahi, Rangamati, Rangpur, Sandwip, Srimangal, Sylhet and Teknaf show significant increasing trend and only Satkhira shows decreasing trend which is not statistically significant at 95% confidence level from MK analysis.

Sen's slope analysis shows that, Satkhira shows maximum decreasing rate of 0.007°C/year and Sandwip shows maximum increasing rate of 0.052°C/year (Table 4.5 and Figure A.1).

Table 4.5: Details of annual maximum temperature trends in Bangladesh

Station	Z	Sen's Slope (°C/year)	τ	ITA-Slope (°C/year)	Trend
Barisal	4.520**	0.021	0.468	0.022	↑
Bogra	1.301	0.009	0.157	0.005	↑
Chandpur	3.531**	0.031	0.442	0.030	↑
Chittagong	2.397*	0.022	0.327	0.027	↑
Comilla	2.886**	0.015	0.373	0.013	↑
Cox's Bazar	4.686**	0.037	0.607	0.054	↑
Dhaka	1.888	0.018	0.320	0.010	↑
Dinajpur	2.260*	0.017	0.327	0.015	↑
Faridpur	4.099**	0.025	0.424	0.020	↑
Feni	2.035*	0.009	0.211	0.008	↑
Hatiya	4.255**	0.031	0.510	0.032	↑
Ishurdi	0.851	0.009	0.127	0.006	↑
Jessore	2.084*	0.022	0.332	0.021	↑
Khepupara	3.473**	0.032	0.472	0.027	↑
Khulna	1.937	0.019	0.271	0.015	↑
M. Court	3.434**	0.029	0.496	0.032	↑
Mymensingh	0.421	0.009	0.201	0.004	↑
Patuakhali	4.314**	0.036	0.567	0.043	↑
Rajshahi	2.103*	0.018	0.298	0.013	↑
Rangamati	4.373**	0.037	0.542	0.038	↑
Rangpur	2.671**	0.012	0.280	0.007	↑
Sandwip	4.627**	0.052	0.532	0.058	↑
Satkhira	-1.731	-0.007	-0.134	-0.015	↓

Station	Z	Sen's Slope (°C/year)	τ	ITA-Slope (°C/year)	Trend
Srimangal	2.710**	0.017	0.281	0.016	↑
Sylhet	4.842**	0.043	0.618	0.046	↑
Teknaf	2.005*	0.009	0.208	0.015	↑

*N.B.: * Trends at the 95% confidence level(Z=1.96); ** Trends at the 99% confidence level(Z=2.58).*

4.2.6 Trend Analysis of Seasonal Maximum Temperature

Pre-monsoon

About 54% stations show increasing trend from IT analysis.

MK and mMK shows, about 69% stations show increasing trend. According to MK analysis, Barisal, Chittagong, Cox's Bazar, Hatiya, Khepupara, Patuakhali, Rangamati, Sandwip and Sylhet i.e., south central and eastern part of the country show significantly increasing trend and Bogra and Rangpur show significantly decreasing trend at 95% confidence level.

Sen's slope analysis shows that, Bogra shows maximum decreasing rate of 0.03°C/year and Sandwip shows maximum increasing rate of 0.058°C/year (Table 4.6 and Figure A.1).

Monsoon

All the stations show increasing trend during monsoon period.

MK and mMK show similar result. According to MK analysis, all stations show significant increasing trend except Chittagong and Satkhira.

Highest rate of increasing trend shows Sandwip (0.055°C/year) and lowest rate of increasing trend shows Satkhira (0.006°C/year) from Sen's slope analysis (Table 4.6 and Figure A.1).

Table 4.6: Details of seasonal maximum temperature trends in Bangladesh

Stations	Pre-monsoon					Monsoon					Post-monsoon					Dry				
	Z	Sen’s Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen’s Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen’s Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen’s Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend
Barisal	2.202*	0.021	0.228	0.016	↑	3.807**	0.025	0.394	0.024	↑	3.173**	0.019	0.328	0.024	↑	2.261*	0.015	0.234	0.022	↑
Bogra	-2.494*	-0.029	-0.218	-0.031	↓	2.886**	0.032	0.414	0.029	↑	2.301*	0.025	0.238	0.018	↑	-0.695	0.002	0.031	0.002	↑
Chandpur	1.692	0.024	0.272	0.021	↑	3.766**	0.036	0.422	0.036	↑	2.221*	0.034	0.353	0.029	↑	4.130**	0.039	0.427	0.032	↑
Chittagong	2.094*	0.019	0.217	0.032	↑	1.497	0.015	0.179	0.015	↑	1.252	0.028	0.266	0.035	↑	2.152*	0.048	0.428	0.049	↑
Comilla	0.822	0.008	0.086	0.001	↑	3.864**	0.024	0.469	0.021	↑	1.790	0.027	0.358	0.029	↑	0.616	0.008	0.107	0.002	↑
Cox's Bazar	3.717**	0.042	0.479	0.052	↑	3.453**	0.032	0.408	0.039	↑	2.289**	0.034	0.402	0.072	↑	3.659**	0.052	0.503	0.066	↑
Dhaka	0.098	0.000	0.011	-0.010	↓	3.394**	0.029	0.504	0.026	↑	1.888	0.028	0.325	0.020	↑	1.233	0.010	0.128	0.001	↑
Dinajpur	-0.802	-0.010	-0.084	-0.016	↓	3.062**	0.033	0.415	0.033	↑	2.270*	0.029	0.293	0.026	↑	2.017*	0.017	0.209	0.016	↑
Faridpur	0.225	0.006	0.024	-0.004	↓	4.640**	0.035	0.480	0.036	↑	3.800**	0.039	0.393	0.030	↑	2.378*	0.018	0.246	0.016	↑
Feni	1.038	0.010	0.108	0.002	↑	2.828**	0.014	0.293	0.014	↑	2.058*	0.014	0.213	0.012	↑	0.196	0.000	0.021	0.003	↑
Hatiya	2.506*	0.023	0.260	0.029	↑	2.348*	0.024	0.400	0.022	↑	3.519**	0.027	0.364	0.035	↑	2.964**	0.036	0.367	0.048	↑
Ishurdi	-0.793	-0.009	-0.083	-0.023	↓	2.103*	0.032	0.292	0.026	↑	2.008*	0.017	0.208	0.014	↑	-0.205	0.001	0.005	0.002	↑
Jessore	0.763	0.019	0.080	0.006	↑	3.346**	0.040	0.480	0.040	↑	2.547*	0.023	0.264	0.028	↑	0.920	0.008	0.096	0.006	↑
Khepupara	1.987*	0.019	0.206	-0.005	↓	3.649**	0.043	0.516	0.040	↑	4.103**	0.031	0.424	0.037	↑	3.875**	0.037	0.401	0.035	↑
Khulna	0.176	0.004	0.019	0.005	↑	3.778**	0.030	0.391	0.025	↑	1.174	0.022	0.203	0.020	↑	0.910	0.004	0.095	0.008	↑
M. Court	1.859	0.026	0.293	0.031	↑	3.747**	0.050	0.511	0.050	↑	2.438*	0.029	0.253	0.025	↑	0.636	0.011	0.163	0.012	↑
Mymensingh	-1.301	-0.017	-0.188	-0.022	↓	3.093**	0.025	0.417	0.025	↑	0.655	0.012	0.140	0.006	↑	-0.206	0.000	0.015	-0.001	↓
Patuakhali	2.944**	0.043	0.486	0.046	↑	3.844**	0.039	0.522	0.046	↑	3.035**	0.029	0.314	0.032	↑	2.798**	0.033	0.377	0.042	↑

Stations	Pre-monsoon					Monsoon					Post-monsoon					Dry				
	Z	Sen’ s Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen’ s Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen’ s Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen’ s Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend
Rajshahi	-1.076	-0.014	-0.112	-0.015	↓	2.788**	0.042	0.371	0.034	↑	3.045**	0.027	0.315	0.023	↑	0.724	0.011	0.105	0.007	↑
Rangamati	3.023**	0.033	0.257	0.033	↑	3.453**	0.034	0.590	0.037	↑	2.789**	0.032	0.413	0.033	↑	3.885**	0.040	0.402	0.048	↑
Rangpur	-2.025*	-0.015	-0.131	-0.029	↓	2.888**	0.019	0.299	0.017	↑	3.453**	0.028	0.342	0.025	↑	2.387*	0.023	0.300	0.019	↑
Sandwip	3.434**	0.058	0.462	0.067	↑	3.952**	0.055	0.605	0.060	↑	3.531**	0.047	0.428	0.061	↑	2.162*	0.059	0.454	0.058	↑
Satkhira	-1.174	-0.013	-0.122	-0.023	↓	0.646	0.006	0.125	0.001	↑	-0.646	-0.006	-0.068	-0.018	↓	-2.603 **	-0.027	-0.270	-0.026	↓
Srimangal	-0.490	-0.005	-0.052	-0.007	↓	4.081**	0.021	0.422	0.019	↑	3.221**	0.030	0.333	0.032	↑	1.644	0.024	0.171	0.025	↑
Sylhet	2.965**	0.037	0.307	0.039	↑	4.803**	0.050	0.619	0.043	↑	2.612**	0.045	0.438	0.049	↑	4.511**	0.046	0.467	0.054	↑
Teknaf	-0.822	-0.008	-0.086	-0.008	↓	2.005*	0.012	0.208	0.010	↑	1.392	0.006	0.144	0.010	↑	2.300*	0.018	0.238	0.025	↑

*N.B.: * Trends at the 95% confidence level(Z=1.96); ** Trends at the 99% confidence level(Z=2.58).*

Post-monsoon

The IT, MK and mMK analysis exhibit that all stations show increasing trend except Satkhira. MK analysis shows that about 77% stations show statistically significant increasing trend and only Chittagong, Comilla, Dhaka, Khulna, Mymensingh, and Teknaf show insignificant increasing trend at 95% confidence level. Satkhira shows insignificant decreasing trend and rate of decrease is 0.006°C/year. Highest increasing rate shows Sandwip (0.048°C/year) (Table 4.6 and Figure A.1).

Dry

IT, MK and mMK shows almost similar result (Table 4.6 and Figure A.1). IT shows that only Mymensingh and Satkhira show decreasing trend and MK shows that Bogra, Ishurdi, Mymensingh and Satkhira show decreasing trend where only Satkhira shows significant decreasing trend. According to MK analysis, Barisal, Chandpur, Chittagong, Cox's Bazar, Dinajpur, Faridpur, Hatiya, Khepupara, Patuakhali, Rangamati, Rangpur, Sandwip Sylhet and Teknaf show significant increasing trend. Satkhira shows decreasing rate of 0.027°C/year and highest increasing rate shows Sandwip (0.059°C/year).

4.2.7 Trend Analysis of Annual Minimum Temperature

All the stations except Hatiya, Rangamati and Sandwip show increasing trend from IT analysis (Table 4.7 and Figure A.2). According to MK analysis, Barisal, Bogra, Chandpur, Chittagong, Comilla, Cox's Bazar, Dhaka, Dinajpur, Faridpur, Ishurdi, Jessore, Khulna, M. Court, Mymensingh, Rangpur and Sylhet show significant increasing rate. Rangamati shows significant decreasing rate and highest rate of decrease is 0.029°C/year. Highest increasing rate shows Chittagong (0.043°C/year).

Table 4.7: Details of annual minimum temperature trend in Bangladesh

Station	Z	Sen's Slope (°C/year)	τ	ITA-Slope (°C/year)	Trend
Barisal	3.727**	0.024	0.444	0.031	↑
Bogra	2.768**	0.022	0.331	0.028	↑
Chandpur	2.690**	0.019	0.317	0.028	↑
Chittagong	4.451**	0.043	0.531	0.033	↑
Comilla	3.131**	0.016	0.324	0.017	↑
Cox's Bazar	3.512**	0.029	0.426	0.022	↑
Dhaka	3.786**	0.034	0.518	0.030	↑

Station	Z	Sen's Slope (°C/year)	τ	ITA-Slope (°C/year)	Trend
Dinajpur	3.003**	0.022	0.340	0.033	↑
Faridpur	3.003**	0.018	0.353	0.026	↑
Feni	1.986*	0.016	0.284	0.025	↑
Hatiya	-1.399	-0.011	-0.149	-0.013	↓
Ishurdi	3.727**	0.031	0.509	0.037	↑
Jessore	3.042**	0.022	0.364	0.023	↑
Khepupara	0.831	0.005	0.122	0.000	↑
Khulna	2.690**	0.026	0.392	0.031	↑
M. Court	3.688**	0.025	0.443	0.028	↑
Mymensingh	3.395**	0.017	0.352	0.021	↑
Patuakhali	1.702	0.008	0.177	0.005	↑
Rajshahi	0.558	0.010	0.133	0.024	↑
Rangamati	-2.925**	-0.029	-0.375	-0.025	↓
Rangpur	3.473**	0.031	0.513	0.034	↑
Sandwip	-1.418	-0.011	-0.127	-0.018	↓
Satkhira	1.497	0.012	0.222	0.010	↑
Srimangal	0.382	0.005	0.119	0.002	↑
Sylhet	4.833**	0.035	0.574	0.037	↑
Teknaf	1.614	0.018	0.269	0.019	↑

*N.B.: * Trends at the 95% confidence level(Z=1.96); ** Trends at the 99% confidence level(Z=2.58).*

4.2.8 Trend Analysis of Seasonal Minimum Temperature

Pre-monsoon

According to IT analysis except Khepupara, Patuakhali, Rangamati and Sandwip all the other stations show increasing trend. mMK and Sen's slope analysis shows only Rangamati has decreasing trend at a rate of 0.025°C/year and Chittagong shows highest increasing rate 0.053°C/year. According to MK, Barisal, Bogra, Chittagong, Cox's Bazar, Dhaka, Faridpur, Feni, Ishurdi, Jessore, Khulna, M. Court, Rajshahi, Rangamati, Rangpur, Sylhet and Teknaf shows significantly increasing trend (Table 4.7 and Figure A.2).

Monsoon

IT, MK, mMK and Sen's slope shows increasing trend at all stations. Except Dhaka, Hatiya, Rangamati, Sandwip and Teknaf all the other stations show significantly increasing trend. Highest rate of increase is found at Chittagong 0.049°C/year. (Table 4.7 and Figure A.2).

Table 4.8: Details of annual minimum temperature trends in Bangladesh

Stations	Pre-monsoon					Monsoon					Post-monsoon					Dry				
	Z	Sen's Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen's Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen's Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend	Z	Sen's Slope (ºC/year)	τ	ITA-Slope (ºC/year)	Trend
Barisal	2.653**	0.029	0.275	0.021	↑	3.903**	0.038	0.484	0.048	↑	1.204	0.014	0.125	0.036	↑	1.253	0.017	0.130	0.015	↑
Bogra	3.318**	0.033	0.343	0.032	↑	4.197**	0.038	0.504	0.045	↑	1.057	0.019	0.110	0.031	↑	-0.176	-0.004	-0.019	-0.001	↓
Chandpur	1.321	0.018	0.177	0.029	↑	3.788**	0.016	0.392	0.029	↑	2.084*	0.036	0.216	0.040	↑	1.683	0.014	0.175	0.019	↑
Chittagong	3.610**	0.053	0.486	0.040	↑	3.844**	0.049	0.464	0.036	↑	2.320*	0.030	0.240	0.035	↑	2.750**	0.030	0.285	0.020	↑
Comilla	1.664	0.017	0.173	0.022	↑	2.906**	0.017	0.301	0.017	↑	1.419	0.025	0.147	0.031	↑	0.225	0.001	0.024	0.002	↑
Cox's Bazar	3.269**	0.033	0.338	0.031	↑	3.355**	0.028	0.394	0.020	↑	1.657	0.015	0.172	0.020	↑	2.702**	0.029	0.280	0.017	↑
Dhaka	2.759**	0.041	0.381	0.038	↑	1.477	0.015	0.242	0.008	↑	2.946**	0.031	0.305	0.042	↑	2.201*	0.049	0.397	0.043	↑
Dinajpur	2.944**	0.040	0.345	0.053	↑	3.776**	0.043	0.515	0.051	↑	1.605	0.019	0.167	0.030	↑	-1.038	-0.010	-0.108	-0.009	↓
Faridpur	3.424**	0.042	0.398	0.043	↑	4.825**	0.036	0.499	0.045	↑	-0.764	-0.012	-0.080	0.003	↑	-1.233	-0.013	-0.128	-0.003	↓
Feni	2.104*	0.023	0.218	0.038	↑	3.541**	0.026	0.430	0.034	↑	0.480	0.006	0.051	0.020	↑	0.509	0.003	0.054	0.003	↑
Hatiya	0.538	0.008	0.057	0.005	↑	1.712	0.019	0.259	0.020	↑	-2.524*	-0.042	-0.323	-0.043	↓	-2.925**	-0.044	-0.415	-0.057	↓
Ishurdi	3.473**	0.046	0.458	0.056	↑	4.216**	0.041	0.592	0.044	↑	0.392	0.006	0.041	0.028	↑	1.125	0.007	0.117	0.016	↑
Jessore	3.238**	0.040	0.315	0.039	↑	4.854**	0.032	0.502	0.041	↑	0.333	0.005	0.035	0.017	↑	-0.783	-0.010	-0.082	-0.011	↓
Khepupara	1.409	0.016	0.146	-0.004	↓	3.894**	0.031	0.403	0.034	↑	-1.987*	-0.025	-0.206	-0.011	↓	-2.084*	-0.031	-0.346	-0.033	↓
Khulna	3.492**	0.044	0.424	0.041	↑	3.327**	0.027	0.344	0.027	↑	-1.047	0.000	-0.010	0.014	↑	2.427*	0.031	0.252	0.038	↑
M. Court	3.670**	0.041	0.380	0.045	↑	2.504*	0.018	0.318	0.020	↑	1.194	0.016	0.124	0.023	↑	2.701**	0.024	0.280	0.027	↑
Mymensingh	3.189**	0.033	0.330	0.039	↑	4.629**	0.025	0.479	0.033	↑	-0.176	-0.004	-0.019	-0.003	↓	0.440	0.003	0.046	0.001	↑
Patuakhali	1.448	0.017	0.151	-0.002	↓	4.493**	0.037	0.465	0.039	↑	-0.832	-0.017	-0.087	-0.003	↓	-1.742	-0.021	-0.181	-0.027	↓

Stations	Pre-monsoon					Monsoon					Post-monsoon					Dry				
	Z	**Sen’s Slope (ºC/year)**	**τ**	**ITA-Slope (ºC/year)**	**Trend**	**Z**	**Sen’s Slope (ºC/year)**	**τ**	**ITA-Slope (ºC/year)**	**Trend**	**Z**	**Sen’s Slope (ºC/year)**	**τ**	**ITA-Slope (ºC/year)**	**Trend**	**Z**	**Sen’s Slope (ºC/year)**	**τ**	**ITA-Slope (ºC/year)**	**Trend**
Rajshahi	2.563*	0.031	0.289	0.040	↑	4.431**	0.040	0.514	0.048	↑	-1.214	-0.020	-0.126	0.007	↑	-2.674**	-0.029	-0.277	-0.013	↓
Rangamati	-2.377*	-0.025	-0.261	-0.019	↓	1.859	0.013	0.193	0.023	↑	-3.003**	-0.067	-0.417	-0.052	↓	-4.431**	-0.080	-0.417	-0.076	↓
Rangpur	2.201*	0.048	0.388	0.057	↑	3.375**	0.030	0.416	0.030	↑	3.758**	0.048	0.389	0.047	↑	0.499	0.004	0.053	0.008	↑
Sandwip	0.578	0.006	0.061	-0.004	↓	0.646	0.010	0.167	0.003	↑	-2.819**	-0.031	-0.292	-0.022	↓	-3.668**	-0.046	-0.340	-0.059	↓
Satkhira	1.027	0.015	0.107	0.002	↑	2.142*	0.021	0.276	0.023	↑	0.754	0.010	0.079	0.019	↑	0.039	0.000	0.005	-0.006	↓
Srimangal	-0.068	0.002	0.031	0.003	↑	3.503**	0.023	0.363	0.009	↑	-1.752	-0.024	-0.182	-0.004	↓	0.294	0.001	0.031	-0.003	↓
Sylhet	4.424**	0.042	0.458	0.043	↑	4.080**	0.029	0.492	0.036	↑	2.554*	0.023	0.265	0.025	↑	3.473**	0.046	0.360	0.041	↑
Teknaf	2.506*	0.028	0.260	0.029	↑	1.908	0.029	0.439	0.032	↑	1.459	0.016	0.152	0.030	↑	-1.830	-0.020	-0.190	-0.020	↓

*N.B.: * Trends at the 95% confidence level(Z=1.96); ** Trends at the 99% confidence level(Z=2.58).*

Post-monsoon

Except Hatiya, Khepupara, Mymensingh, Patuakhali, Rangamati, Sandwip and Srimangal all the other stations show increasing trend from IT analysis. According to MK the very south-central area i.e., only Hatiya, Khepupara, Sandwip and Rangamati show significant decreasing trend. Rangamati shows highest rate of decreasing 0.067^{o}C/year. Significant increasing trend is observed at Chandpur, Chittagong, Dhaka, Rangpur and Sylhet. Highest increasing rate 0.048^{o}C/year is observed at Rangpur. (Table 4.7 and Figure A.2).

Dry

There is almost equal share of stations for increasing (54%) and decreasing (46%) trend according to IT analysis. Significant increasing trend was observed at Chittagong, Cox's Bazar, Dhaka, Khulna, M. Court and Sylhet where as Hatiya, Khepupara, Rajshahi, Rangamati and Sandwip show significant decreasing trend. Rangamati shows highest rate of decrease is 0.08^{o}C/year. Highest increasing rate shows Dhaka (0.049^{o}C/year). (Table 4.7 and Figure A.2).

4.3 Sub-trend Analysis

4.3.1 Sub-trend Analysis of Annual Rainfall

Chandpur shows more than 10% decreasing trend for high intensity rainfall (>2800 mm) but shows increasing sub-trend for low intensity rainfall (<1600mm). Feni also shows increasing sub-trend for rainfall <2500mm. Hatiya has more than 10% increasing trend for high (> 2500 mm) amount of annual precipitation. M. Court shows decreasing trend of 10% for medium to high precipitation (3500mm~5000mm) but shows increasing sub-trend for low intensity rainfall (<2500mm). Mymensingh shows 10% increasing sub-trend for low intensity (<1500 mm) rainfall. Satkhira shows decreasing sub-trend for rainfall intensity <1600mm shown in Figure 4.5. ITA graph of all the stations of annual rainfall is presented in Figure A.3.

4.3.2 Sub-trend Analysis of Seasonal Rainfall

Pre-monsoon

Though Bogra, Comilla, Mymensingh show negative trend but shows increasing sub-trend of low intensity rainfall (<100mm). Though Hatiya shows no trend but has sub-trend of increasing rainfall of intensity <150mm and decreasing sub-trend of rainfall intensity >250mm. Srimangal shows positive trend but shows decreasing sub-trend for high intensity rainfall (>300mm). All the ITA graphs for Pre-monsoon season for Average rainfall is presented in Figure A.3.

Monsoon

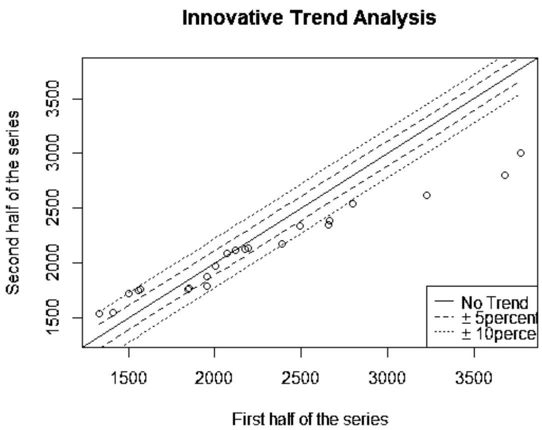
Dhaka shows insignificant increasing trend but it shows decreasing sub-trend for low intensity rainfall (200mm~300mm). Feni shows increasing trend for rainfall intensity <400mm but shows decreasing trend for high intensity rainfall (>500mm). Rajshahi shows negative trend but it has increasing sub-trend for high intensity rainfall (>350mm). All the ITA graphs for monsoon season for Average rainfall is presented in Figure A.3.

Post-monsoon

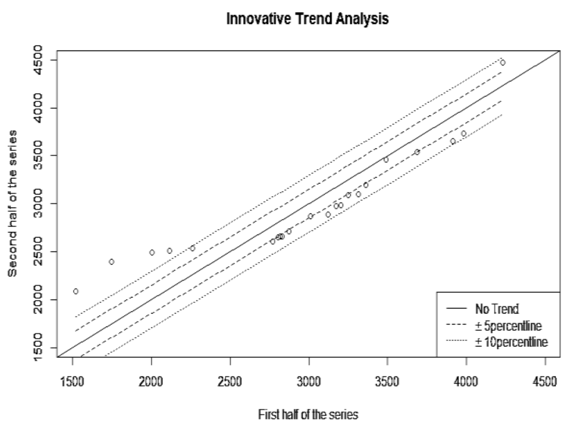
Barisal, Bogra, Chandpur, Dhaka, Feni show increasing trend but it has sub-trend of decreasing for high intensity rainfall (>200mm). Though Cox's Bazar shows decreasing trend but it has sub-trend of increasing rainfall for intensity <200m. Mymensingh, Rajshahi show negative trend for post monsoonal rainfall but shows increasing sub-trend for rainfall >150mm. All the ITA graphs for Post-monsoon season for Average rainfall is presented in Figure A.3.

Dry

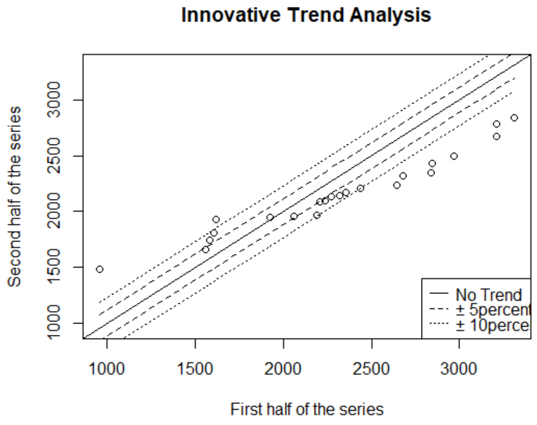
Srimangal shows decreasing trend but shows sub-trend of increasing rainfall of intensity >25mm. Teknaf shows decreasing sub-trend of rainfall intensity <30mm. All the ITA graphs for dry season for Average rainfall is presented in Figure A.3.



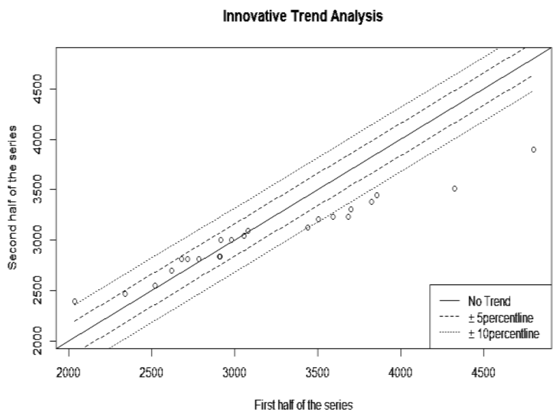
(a) Chandpur



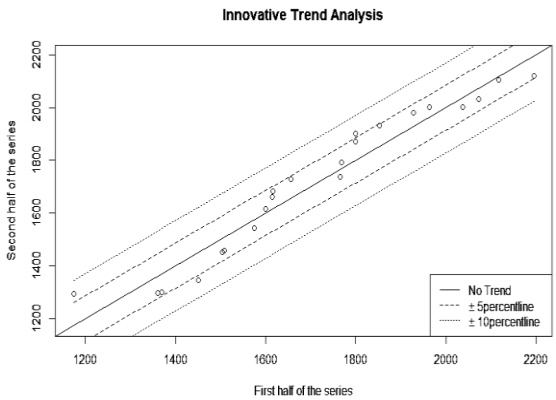
(b) Feni



(c) Mymensingh



(d) M. Court

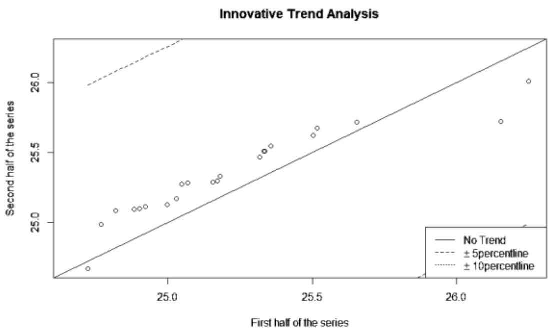


(e) Satkhira

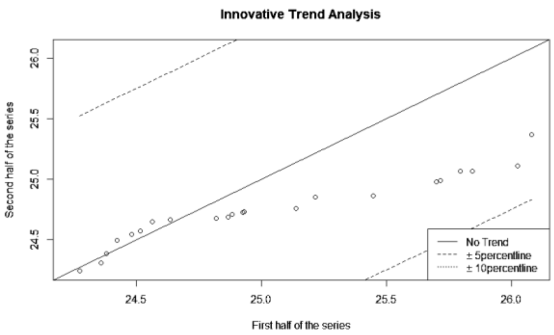
Figure 4.5: ITA graph of annual rainfall for sub-trend analysis

4.3.3 Sub-trend Analysis of Annual Average Temperature

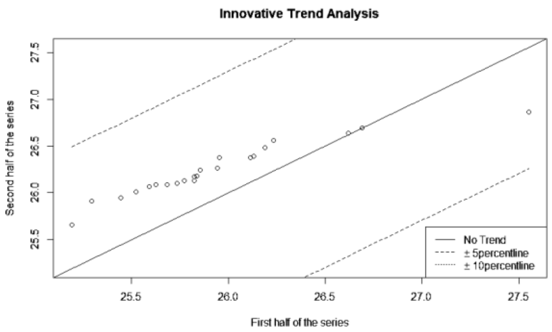
From the analysis it was found that though Comilla shows increasing trend but shows decreasing sub trend for high annual temperature. Dinajpur shows increasing sub trend for low annual temperature. Khulna, M. Court and Rangpur show downward increasing trend which implies decreasing sub trend for high annual temperature. Srimangal and Teknaf shows increasing sub trend for low annual temperature <24.5°C which is presented in Figure 4.6. All the ITA graphs for annual average temperature are presented in Figure A.4.



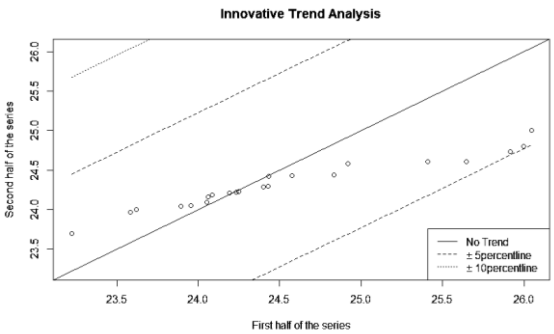
(a) Comilla



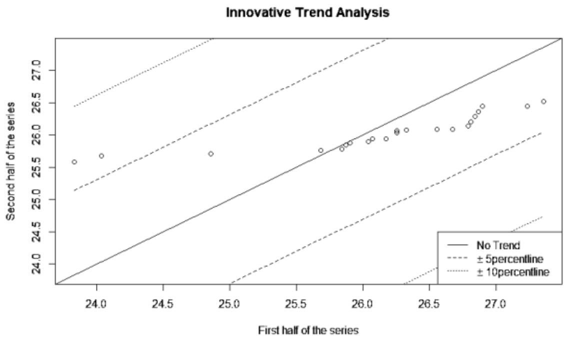
(b) Dinajpur



(c) Khulna



(d) Srimangal



(e) Teknaf

Figure 4.6: ITA graph of daily average temperature for sub-trend analysis

4.3.4 Sub-trend Analysis of Seasonal Average Temperature

Pre-monsoon

Dinajpur, Ishurdi, Patuakhali, Rajshahi show increasing sub trend for low temperature (<27^{o}C). Faridpur and Khulna show decreasing sub trend for high annual temperature >28^{o}C. Rangamati shows increasing sub trend for high annual temperature (>27.5^{o}C). All the ITA graphs for Pre-monsoon season of Average temperature is presented in Figure A.4.

Monsoon

Dhaka, Feni, Khepupara, M. Court, Rangamati, Rangpur show downward increasing trend which implies decreasing sub trend for high annual temperature. Mymensingh, Satkhira, Srimangal show decreasing sub trend for temperature >29^{o}C. All the ITA graphs for monsoon season of Average temperature is presented in Figure A.4.

Post-monsoon

Dinajpur shows increasing sub trend for low temperature (<24^{o}C). Ishurdi shows increasing trend for high temperature and decreasing sub trend for low temperature. Khulna shows decreasing sub trend for high temperature. Sandwip shows no trend for low temperature value. ITA graphs for Post-monsoon season of Average temperature is presented in Figure A.4.

Dry

Barisal shows decreasing sub trend for low temperature (<20^{o}C) during dry season. Faridpur shows increasing sub trend for high temperature. Srimangal shows increasing sub trend for low temperature (<17^{o}C). All the ITA graphs for dry season of Average temperature is presented in Figure A.4.

4.3.5 Sub-trend Analysis of Annual Maximum Temperature

M. Court, Srimangal show a downward trend line which means decreasing trend for higher maximum temperature >34^{o}C. Mymensingh shows decreasing sub trend for temperature range 31.5^{o}C ~32.5^{o}C.

4.3.6 Sub-trend Analysis of Seasonal Maximum Temperature

Pre-monsoon

Comilla and Satkhira shows decreasing sub-trend for temperature range 33^{o}C~35.5^{o}C, 37^{o}C~38.5^{o}C respectively.

Monsoon

All most all the stations show increasing trend for higher maximum temperature (33^{o}C~36^{o}C) during monsoon. The graphical representation for Bogra, Comilla, Ishurdi, M. Court and Teknaf show decreasing sub trend of higher values for monsoonal rainfall.

Post-monsoon

Barisal, Bogra, Comilla, Dhaka, Faridpur, M. Court, Patuakhali, Rangamati show overall increasing trend but from the graphical representation it is clear that they show a downward trend line which means that they show decreasing sub trends for higher maximum temperature during post-monsoon season.

Dry

Bogra shows decreasing sub trend for temperature range 29^{o}C~30.5^{o}C. M. Court, Mymensingh, Rajshahi and Srimangal show a downward positive trend line which means increasing trends for lower maximum temperature and decreasing sub trend for higher maximum temperature.

4.3.7 Sub-trend Analysis of Annual Minimum Temperature

Chandpur, Chittagong, Dinajpur, Faridpur, Jessore, M. Court, Mymensingh, Rajshahi and Teknaf show a downward positive trend which means it has decreasing trend for higher minimum temperature.

4.3.8 Sub-trend Analysis of Seasonal Minimum Temperature

Pre-monsoon

Chandpur, Dinajpur, Feni, Jessore, M. Court, Mymensingh show a downward positive trend line which means that they have decreasing trend for higher minimum temperature.

Monsoon

Chandpur, Cox's Bazar, Chittagong, Faridpur, Feni, Jessore, Khepupara, Mymensingh, Patuakhali, Rangamati, Sylhet and Teknaf i.e., southern part and eastern part of the country show a downward positive trend line which means that they have increasing trend for lower minimum temperature (<22^{o}C).

Post-monsoon

Feni and Satkhira show a downward positive trend line which means that there is decreasing trend of higher minimum temperature (>18^{o}C). Khulna shows decreasing sub trend for higher minimum temperature >19^{o}C. Sandwip shows increasing sub trend for temperature >20^{o}C.

Dry

Bogra shows increasing sub trend for temperature <9°C. Comilla has decreasing sub trend for medium to higher minimum temperature (>10°C).

4.4 SAI Analysis

4.4.1 SAI of Annual Average Rainfall

Rainfall anomaly index for average rainfall has been analyzed of the 26 stations from the year 1975 to 2019. Almost all the stations i.e., Barisal, Bogra, Chandpur, Chittagong, Comilla, Faridpur, Feni, Ishurdi, Khulna, Patuakhali, Rajshahi, Rangamati, Satkhira, Srimangal, Sylhet showed consecutive dry and wet years.

Cox's Bazar and Dhaka had mostly wet years during the total time period and had extreme drought years in 1976, 1979, 1980, 2014 and 2019.

Wet years prevailed from 1983 to 2005 and dry years prevailed from 2006 to 2019 in Dinajpur. Wet years reigned during 1984 to 1988 and 2002 to 2008 where as dry years prevailed during 1989 to 2001 and 2009 to 2019 in Jessore which shows an increasing trend of dry years in recent times. Rajshahi had mostly wet years during 1977 to 2000 but after that dry years prevailed. Rangpur had wet years during 1984 to 2005 and dry years during 1975 to 1981 and 2006 to 2018. Sylhet also had severe to extreme warm years during 1992 to 2018.

Hatiya showed dry years during 1982 to 1994 and wet years during 1999 to 2017 but again showed dry years in 2018 and 2019. Khepupara had dry years during 1975 to 1989 and wet years during 1990 to 2019 where only year 1992, 2009, 2014 showed extremely drought years. M. Court showed moderately wet and dry years consecutively from year 1985 to 2016 but had extremely drought years in 1978 to 1979 and extremely wet years during 1979 to 1984.

Sandwip had dry years during 1978 to 1997 and wet years during 1998 to 2018 which shows that Sandwip recently encountered wet years. Teknaf mostly experienced wet years from 1991 to 2017 and extreme drought year prevailed in 1979, 1980, 1983. All the SAI graphs for average rainfall are presented in Figure A.5.

4.4.2 SAI of Annual Average Temperature

Temperature anomalies for the 26 stations were analyzed for average, maximum and mean temperature during the year 1975 to 2019.

From the analysis of average temperature, Barisal shows near normal to moderately warm years all through the year 1975 to 2019. Feni shows moderate to severely warm years intermittently from 1980 to 2019. Hatiya shows 2 extremely cold years in 1983 and 1994 and 8 extremely warm years during the time period. Khepupara had severely warm years all through the time period. The analysis shows that Khulna, Patuakhali, Rangamati had mostly moderately warm years during the total time period whereas M. Court, Rangamati had mostly severely warm years.

Bogra, Chandpur had three extreme cold years during 1976 to 1979 and severe to extreme warm years intermittently from year 2004 to 2019. Before 1991 Chittagong had few moderate to extreme cold years whereas after 1991 it had various moderate to extreme warm years. Comilla had 10 severely cold years during 1981 to 1997 and 4 extremely warm years from 2006 to 2016. Cox’s Bazar had extremely cold years before 1981 and moderate to severely warm years during year 1995 to 2019.

Dhaka shows severely cold years before year 1984 and severely warm years after 2005. Jessore had few severely and extremely cold years up to year 1997 but after that it had severely warm to extremely warm years between 2005 to 2017. Sandwip had 4 extremely cold year in 1976, 1979, 1991, 2002 and 14 extremely warm years intermittently, other than these mostly severely warm years prevailed.

Srimangal had extreme cold year in 1975 to 1978, 1983, 1985 and extreme warm years in 1979, 1984, 1986, 1987, 1988, 1999, 2006 and 2016, other than these it had moderately warm years all through the time period. Sylhet had moderate to severe cold years from 1976 to 1993 and moderate to severe warm years after that. Teknaf had only one extreme cold year in 1980, 13 extremely warm years and for the rest of the years had moderate to severe warm years.

Dinajpur shows moderately cold years between 1989 to 2019. Satkhira had one extremely cold year in 1980, extremely warm years during 1979 to 1988 and after that had severely cold years onward. Mymensingh had extremely warm years during 1980 to 1986 and after that had severely to extremely cold years onward.

Faridpur shows overall moderately warm and cold years intermittently. Ishurdi shows alternating cold and warm years where there was only 8 extremely warm years and most of them were between 1999 to 2017. Rajshahi had extremely cold years in 1981, 1983, 1985, 1990, 1997, 2011 and extreme warm years in 1975, 1976, 1979, 1999, 2010 and 2016.

One interesting thing which was noticed is that most of the stations had cold years during 1975 to 1985 except Comilla, Dinajpur, Jessore, Mymensingh, Rajshahi, Satkhira warm years after that period. All the SAI graphs for average temperature are presented in Figure A.6.

4.4.3 SAI of Annual Maximum Temperature

The SAI of maximum temperature data followed the similar pattern of average annual temperature at most of the stations except Bogra, Chandpur, Mymensingh, Rajshahi, Rangpur, Sandwip had warm years all through the time frame. Dinajpur and Dhaka had alternating warm and cold years.

4.4.4 SAI of Annual Minimum Temperature

The SAI of minimum temperature data shows that almost all the stations experienced cold years during the first two decades and warm years during the last two decades. Exceptions were seen in Faridpur, Hatiya, Mymensingh, Patuakhali, Rangamati, Rangpur, Sandwip where they had warm years all through the time frame and Jessore had alternating warm and cold years.

4.5 Extreme Climate Indices Analysis

As some of the indices of ETCCDI is sector-relevant and location relevant so we chose maximum relevant indices for analysis. Prior to the performance of the extreme climatic indices, homogeneity and quality of the daily input data has been checked.

For this analysis, data of 8 divisions (i.e., Barisal, Chittagong, Dhaka, Khulna, Mymensingh, Rajshahi, Rangpur and Sylhet) of Bangladesh have been used. The homogeneity test has been undertaken and adjustment for possible multiple change points, specially shifts in the mean that may have first order autoregressive errors have been conducted using RHtestsV4 software which was proposed by Wang and Feng (2013).

Daily rainfall and temperature data were used to undertake the homogeneity test. This test is important to check the consistency of any data series before under taking any statistical analysis. It is based on the penalized maximal *t* test (Wang et al. 2007) and the penalized maximal *F* test (Wang 2008b). The analysis showed that all the daily data of all the 8 stations were homogenous and they needed no further adjustment for the extreme event analysis.

Shahid (2010b) also found no inhomogeneity in the rainfall and temperature data. The result of extreme climate indices analysis (Table 4.9) using ClimPACT2 software is shown below.

Table 4.9: Temperature and precipitation extreme indices values

Indicator		Barisal	Chittagong	Dhaka	Khulna	Mymensingh	Rajshahi	Rangpur	Sylhet
Temperature Indices									
WSDI (days/year)	Trend	0.051	0.139	0.101	0.083	0.016	-0.043	0.058	0.25
	p-value	0.468	0.228	0.196	0.344	0.716	0.574	0.446	0.002
CSDI (days/year)	Trend	-0.108	-0.138	-0.127	0.302	-0.196	-0.025	-0.179	-0.371
	p-value	0.127	0.163	0.02	0.1	0.266	0.626	0.008	0.016
TXx (°C)	Trend	0.015	0.016	-0.016	-0.003	-0.004	-0.025	-0.029	0.054
	p-value	0.214	0.331	0.284	0.887	0.75	0.234	0.07	0
TNn (°C)	Trend	-0.003	0.065	0.045	0.07	0.017	-0.095	-0.009	0.04
	p-value	0.878	0.021	0.007	0.043	0.552	0.007	0.784	0.193
TR (days/year)	Trend	0.348	0.582	0.515	0.244	0.237	0.104	0.512	0.697
	p-value	0.003	0	0	0.072	0.117	0.359	0	0
SU25 (days/year)	Trend	0.229	0.089	0.094	-0.034	-0.125	-0.033	0.219	0.588
	p-value	0.039	0.475	0.446	0.779	0.377	0.786	0.22	0
GSL (days/year)	Trend	0.021	0.003	0.003	-0.001	-0.008	-0.003	-0.001	-0.004
	p-value	0.134	0.665	0.739	0.836	0.252	0.67	0.916	0.455
DTR (°C)	Trend	0.005	-0.018	-0.012	-0.006	-0.012	0.007	-0.014	0.013
	p-value	0.323	0.016	0.058	0.369	0.078	0.315	0.008	0.024
TX10p (%)	Trend	-0.152	-0.046	-0.088	-0.08	0.005	-0.086	-0.042	-0.186
	p-value	0	0.357	0.013	0.06	0.905	0.01	0.253	0
TX90p (%)	Trend	0.283	0.298	0.202	0.199	0.132	0.221	0.25	0.484
	p-value	0	0.007	0.003	0	0.004	0	0	0
TN10p (%)	Trend	-0.225	-0.304	-0.296	-0.113	-0.232	-0.137	-0.3	-0.412
	p-value	0	0	0	0.13	0.028	0.028	0	0
TN90p (%)	Trend	0.222	0.383	0.286	0.258	0.122	0.065	0.198	0.33

Indicator		Barisal	Chittagong	Dhaka	Khulna	Mymensingh	Rajshahi	Rangpur	Sylhet
	p-value	0.001	0	0	0	0.031	0.269	0	0
Rainfall Indices									
R20mm (days/year)	Trend	-0.084	0.118	-0.119	0.06	-0.035	-0.089	-0.109	0.012
	p-value	0.326	0.129	0.168	0.47	0.749	0.168	0.192	0.929
R10mm (days/year)	Trend	-0.216	0.175	-0.068	0.058	-0.14	-0.106	-0.187	-0.058
	p-value	0.032	0.057	0.523	0.6	0.301	0.215	0.103	0.701
RX3days (mm)	Trend	0.943	0.247	-0.662	-0.667	-0.274	-1.682	-0.099	0.067
	p-value	0.337	0.897	0.511	0.61	0.783	0.046	0.936	0.55
CDD (days/year)	Trend	0.579	0.575	0.58	0.677	0.802	0.684	1.008	0.748
	p-value	0.074	0.169	0.048	0.036	0.026	0.042	0.014	0.016
PRCPTOT (mm)	Trend	-4.011	5.952	-7.835	0.243	-7.19	-8.663	-7.977	-3.435
	p-value	0.364	0.35	0.131	0.956	0.256	0.012	0.171	0.681
R95pTOT (%)	Trend	0.097	-0.009	-0.212	-0.004	-0.094	-0.255	-0.153	-0.11
	p-value	0.478	0.95	0.123	0.979	0.413	0.039	0.27	0.171
R99pTOT (%)	Trend	0.005	-0.044	-0.071	-0.003	-0.05	-0.171	-0.016	-0.092
	p-value	0.96	0.745	0.443	0.978	0.555	0.086	0.862	0.19
SPI	Trend	-0.001	0.001	-0.002	0	0	-0.002	-0.002	-0.001
	p-value	0	0.001	0	0.893	0.204	0	0	0.033
CWD (days/year)	Trend	-0.026	0.005	-0.079	0.045	-0.001	-0.013	-0.071	-0.133
	p-value	0.698	0.923	0.1	0.464	0.983	0.68	0.208	0.189

*N.B.: * Trends at the 95% confidence level ($p < 0.05$)*

The analysis shows that, the indices related to temperature shows more statistically significant results ($p < 0.05$) at a confidence level of 95%, compared to rainfall indices at the 8 stations.

Sylhet shows significant increasing trend for WSDI which means that consecutive days of higher temperature is increasing in Sylhet at a rate of 0.25 days/year. Dhaka, Rangpur and Sylhet show significantly decreasing trend for CSDI which means that occurrence of consecutive cold days is declining.

Sylhet shows significant increasing trend for TXx which means Sylhet is experiencing more warmest days at a rate of 0.054^{o}C/year. Chittagong, Dhaka and Khulna show significant increasing trend for TNn which implies that these stations are facing increasing coldest days and Rajshahi is experiencing the opposite of them.

Barisal, Chittagong, Dhaka, Rangpur and Sylhet show increasing trend for TR i.e., tropical nights which means increase in occurrence of warmer nights. Barisal and Sylhet show significant increasing trend for SU25 which means they are experiencing more annual number of days where TX>25^{o}C.

Barisal, Chittagong and Dhaka show increasing GSL but none of the are statistically significant. For DTR, Chittagong and Rangpur show significant decreasing rate which implies that minimum temperature increase is higher than that of maximum temperature and Sylhet shows increasing rate (0.013^{o}C/year) which means a greater increase in maximum temperature than minimum temperature.

Barisal, Dhaka, Rajshahi and Sylhet show significant decreasing trend for TX10p and increasing trend for TX90p which means days with maximum temperature is in rise at these stations. Chittagong, Khulna, Mymensingh and Rangpur also shows significant increasing trend for TX90p. Barisal, Chittagong, Dhaka, Rangpur and Sylhet show significant decreasing trend for cold nights and increasing trend for hot nights.

Analysis of rainfall indices show less significant trend and majority of them show decreasing trend. Barisal shows significant decreasing trend for R10mm which means it is experiencing decreasing trend for heavy rain days.

Rajshahi shows significant decreasing trend for amount of consecutive precipitation or maximum 3days total precipitation (Rx3day). Dhaka, Khulna, Mymensingh, Rajshahi, Rangpur and Sylhet show significant increasing trend for consecutive dry days.

For annual total wet days, all the stations show decreasing trend where only Rajshahi shows significantly decreasing trend. For contribution from very and extremely wet days, all the stations show decreasing trend where again Rajshahi shows significantly decreasing trend.

For consecutive wet days, all the stations show statistically insignificant trend. All the station shows negative trend for Standardized precipitation index and among them Barisal, Dhaka, Rajshahi, Rangpur and Sylhet show significant drought condition. The graphical representations of the above indices are presented in Figures A.7 to A.14.

4.6 Discussion

From the analysis it is found that, MK, mMK and ITA show almost similar result for both rainfall and temperature data but among them mMK and IT analysis shows similar value of trend with graphical representation which refers that IT analysis provides more precise value and it also helps to find the sub-trend at any stations for both rainfall and temperature data.

Wu and Qian (2017) applied linear regression analysis, the MK trend test, and ITA to detect trends of seasonal and yearly rainfall extremes in Shaanxi, China and concluded that the comparison of the three approaches supports the ITA method. Girma et al. (2020) also found ITA to be reliable and consistent as MK and Sen’s slope estimators.

From rainfall data analysis it was found that the south-west, south central, south-east and east side of the country show increasing trend and west, north and central part of the country show decreasing trend. Cox’s Bazar, Hatiya, Sandwip and Teknaf i.e., the coastal area of Bangladesh shows extensively increasing trend for annual and seasonal rainfall. Central part and Sylhet face the most decreasing trend for annual rainfall.

Das et al. (2021) also concluded that increasing rainfall trend is observed in south eastern, south western and north eastern part of the country. Rahman et al. (2017)also found increasing rainfall trend Cox's Bazar, Khulna, Satkhira and decreasing trend for Srimangal areas. Rahman and Lateh (2017) found that drying condition will dominate in north western, western and south western parts of the country.

Pre monsoon season rainfall analysis shows decreasing trend in central part of the country. During monsoon season the northern part of the country shows severely decreasing rainfall trend. During post monsoon the north eastern part shows decreasing rainfall trend and during dry season all the stations show decreasing trend.

Shahid (2010a) analyzed rainfall data of 17 stations for the year 1958 – 2007 and found increasing trend in annual and pre-monsoon season. This is in contrast to the overall findings of this study but it also supports that the rainfall pattern has changed in the last two decades.

Northern and central part of the country showed significant increasing trend for annual temperature. Increase in maximum temperature is more prominent than in minimum temperature.

Maximum temperature is increasing in the eastern, central and coastal area of Bangladesh. Temperature is in rise during the monsoon season and during dry season it is decreasing. The coastal and hilly areas of Bangladesh show decreasing temperature trend during pre-monsoon and post-monsoon season.

Khan et al. (2019) also found that the daily temperature shows warming trend at all the regions and the rate of increase is higher in monsoon. Bhuyan et al. (2018) also found increasing temperature trend at the north western region of Bangladesh.

In addition to that, studies conducted in the neighboring areas i.e., (Cui et al., 2017; Girma et al., 2020; Sonali and Kumar, 2013; Wu et al., 2019; Wu and Qian, 2017) also found increasing temperature trend all throughout the study period and study area but the findings of Rainfall trend is erratic and inhomogeneous in nature.

SAI analysis for rainfall data shows that almost all the stations show consecutively dry and wet years. Cox's Bazar and Dhaka mostly had wet years during 1975 to 2019 and had extreme drought years in 1976, 1979, 1980, 2014 and 2019. Jessore, Rajshahi and Rangpur had moderate to severely drought years in last two decades. Teknaf, Sandwip, Khepupara, Hatiya i.e., coastal area of Bangladesh experienced moderate to severe wet years in last two decades.

SAI analysis for temperature data shows that almost all part of the Bangladesh shows moderate to severe warm years in the last two decades. Majority stations experienced cold years during the first two decades but after that they all started experiencing warm years. Coastal area of the country experienced warm years all through the time period.

The analysis shows that, the indices related to temperature shows more statistically significant results ($p < 0.05$) at a confidence level of 95%, compared to rainfall indices at the 8 stations. This analysis shows similar pattern for both rainfall and temperature indices.

The National Adaptation Plan of Bangladesh (NAP) (2023-2050) exhibits historical climate trend of overall Bangladesh. According to NAP (2023-2050), the average temperature in Bangladesh is also increasing in the recent decades, the summers are getting hotter and rainfall varies significantly across the entire country. The findings also indicate that the winters are becoming dryer and the CDD also shows significant increasing trend all over the country.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From this study it was found that all the analysis indicates similar pattern of climate change variable across the country which supports the reliability of the study. The study had two objectives and the major findings of them are as below:

5.1.1 Evaluation and Quantification of the Climate Change Variables

- The analysis shows that during the last four decades climate variables changed its pattern and trend heterogeneously.
- Both increasing and decreasing trend of annual rainfall was observed but majority stations showed decreasing trend. The central part of the country showed significant decreasing trend for rainfall.
- Increase in maximum temperature is more prominent than in minimum temperature. Northern and central part of the country showed significant increasing trend for annual temperature.
- Maximum temperature is increasing in the eastern, central and coastal area of Bangladesh. Temperature is in rise during the monsoon season and during dry season it is decreasing.
- The coastal and hilly areas of Bangladesh show decreasing temperature trend during pre-monsoon and post-monsoon season.
- The rainfall and maximum temperature are inversely related during monsoon and dry season as rainfall follows decreasing trend (0.65mm/year) and temperature shows increasing trend (0.017^{o}C/year).
- Pre-monsoon and post-monsoonal rainfall also reflect decreasing trend which indicates prevailing drought condition specially in northern and central part of the country.
- The sub-trend analysis shows that the stations which show overall positive trend, shows decreasing sub-trend for medium to high intensity rainfall. For temperature the sub-trend analysis shows that lower maximum and minimum temperature is increasing

which is minimizing the seasonal variation of temperature and causing a warming weather throughout the whole year.

5.1.2 Occurrence of Extreme Events and Calculation of Extreme Indices

- The SAI analysis shows that, the occurrence of drought and wet year is alternating in nature in almost all the stations. In the past 20 years, the country's western region has had more drought years while the coastal region experienced more wet years.
- Majority stations experienced cold years during 1975 to 1995 and after wards warm years prevailed. Exception was found at some certain small region i.e., Dinajpur, Mymensingh and Satkhira.
- The overall result of extreme indices analysis suggests that, Sylhet is vulnerable to temperature rise as well as drought condition.
- Chittagong, Dhaka, Rangpur and Khulna also experience fewer cold days or minimum temperatures which also support the trend analysis result. Where all the station experiences negative trends in rainfall indices, Barisal and Rajshahi is susceptible to significant drought condition.

This study is anticipated to aid in understanding regional climate change in the South Asian region as well as in defining appropriate policies and plans to mitigate the effects of climate change in Bangladesh. On a regional and national scale, the temperature and rainfall trend and sub-trend directions, magnitudes, extreme indices analysis and spatial patterns may also offer useful information on global warming and drought condition. In addition to that, it is expected that the above study will contribute in the management of water resources, agricultural output, food security, and the standard of living for the general populace.

5.2 Limitations of the Study

i. Among various climatic parameters (i.e., Precipitation, air pressure, sunshine, radiation, wind speed, humidity, temperature) only two parameters i.e., rainfall and temperature were analyzed in this study. Study of other parameters may show different dynamics of relationship between the variables;

ii. As the data were collected from BMD and some of the stations have missing data which were calculated using mean imputation so it cannot be claimed that the result represents the climatic condition of Bangladesh unbiasedly;

5.3 Recommendations for Future Research

The following recommendations can be made for future research in this field:

i. Other climatic parameters especially 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;

ii. Future projection of climate change can be undertaken using Statistical Downscaling Models.

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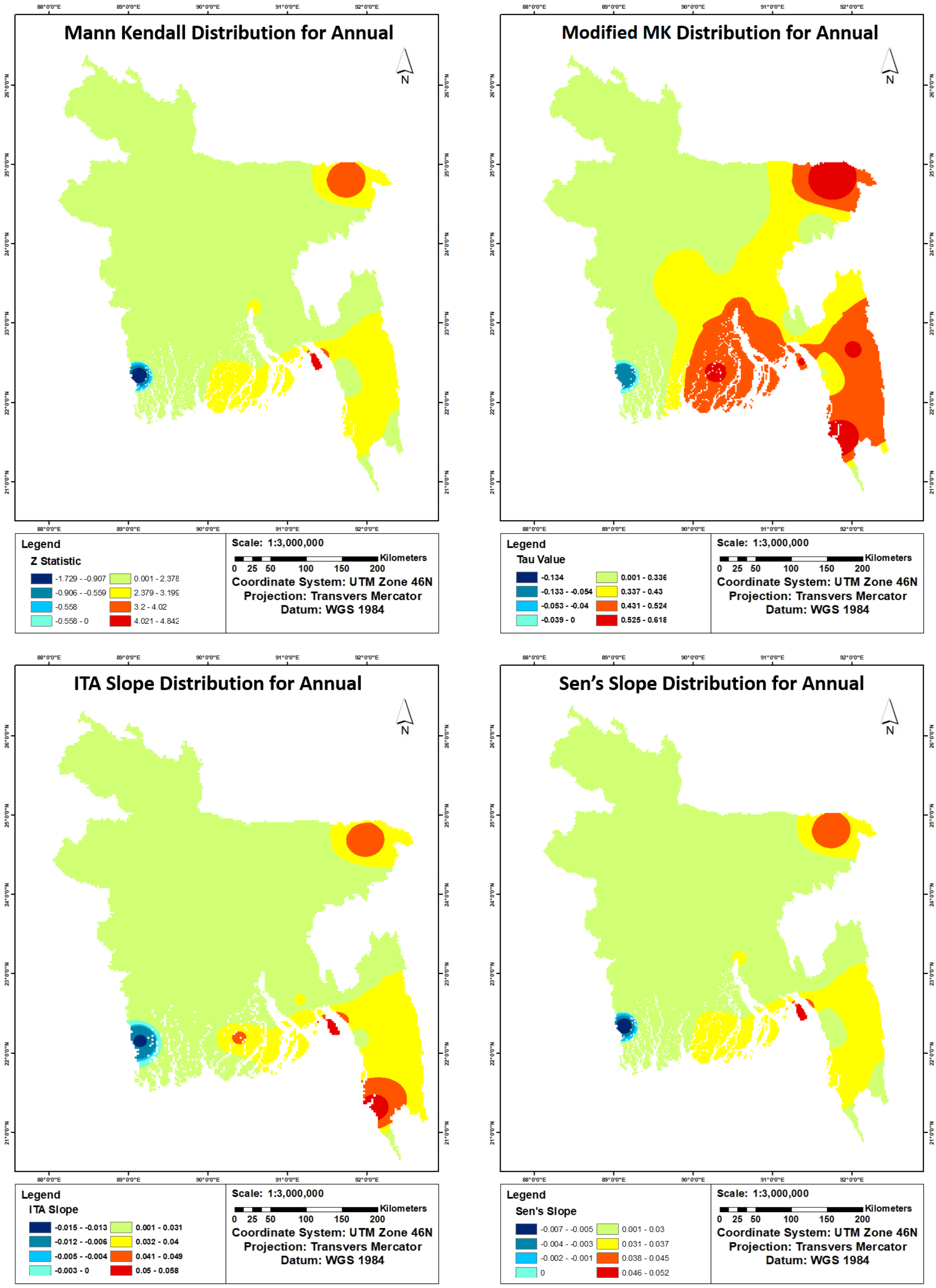
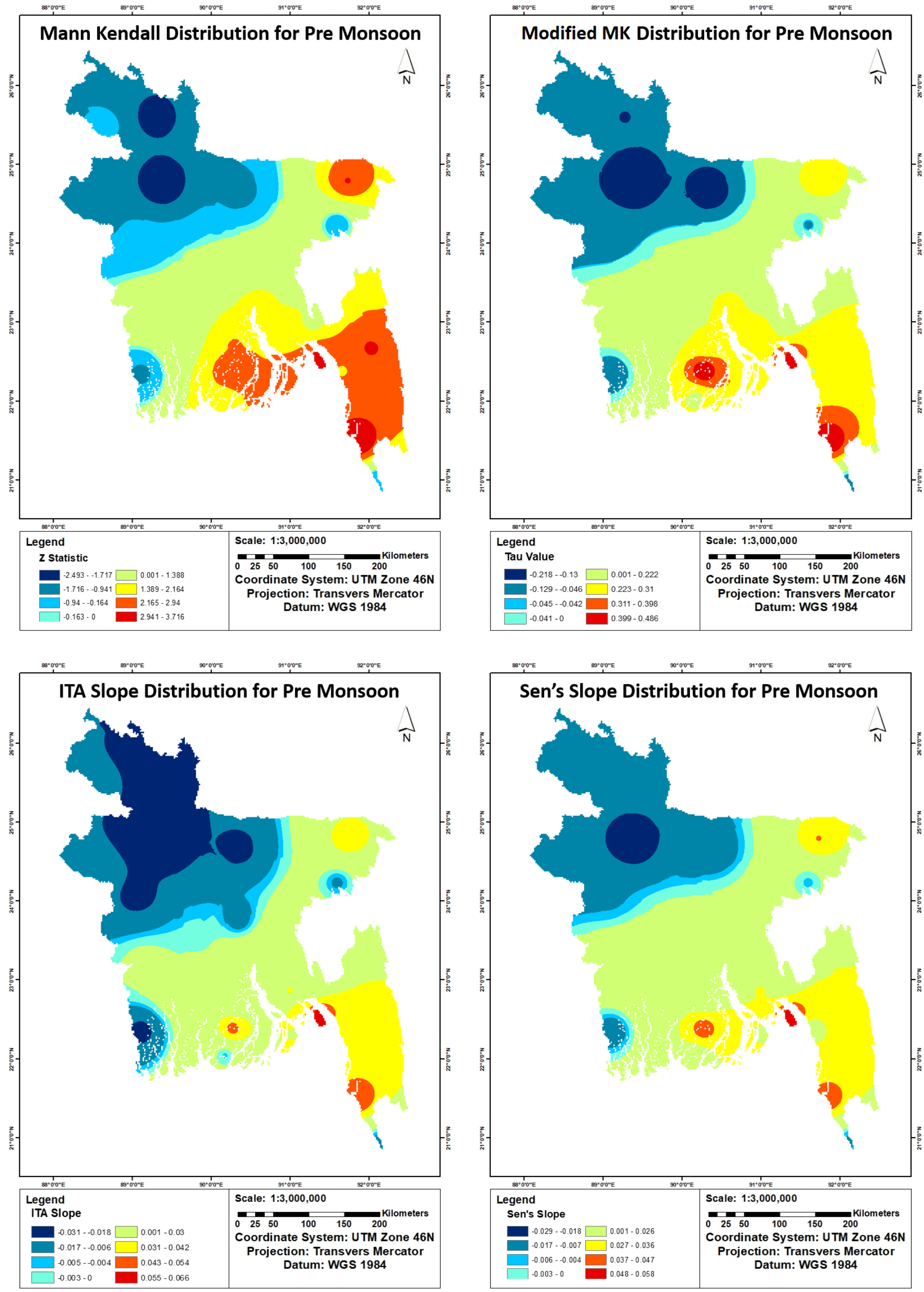
APPENDICES

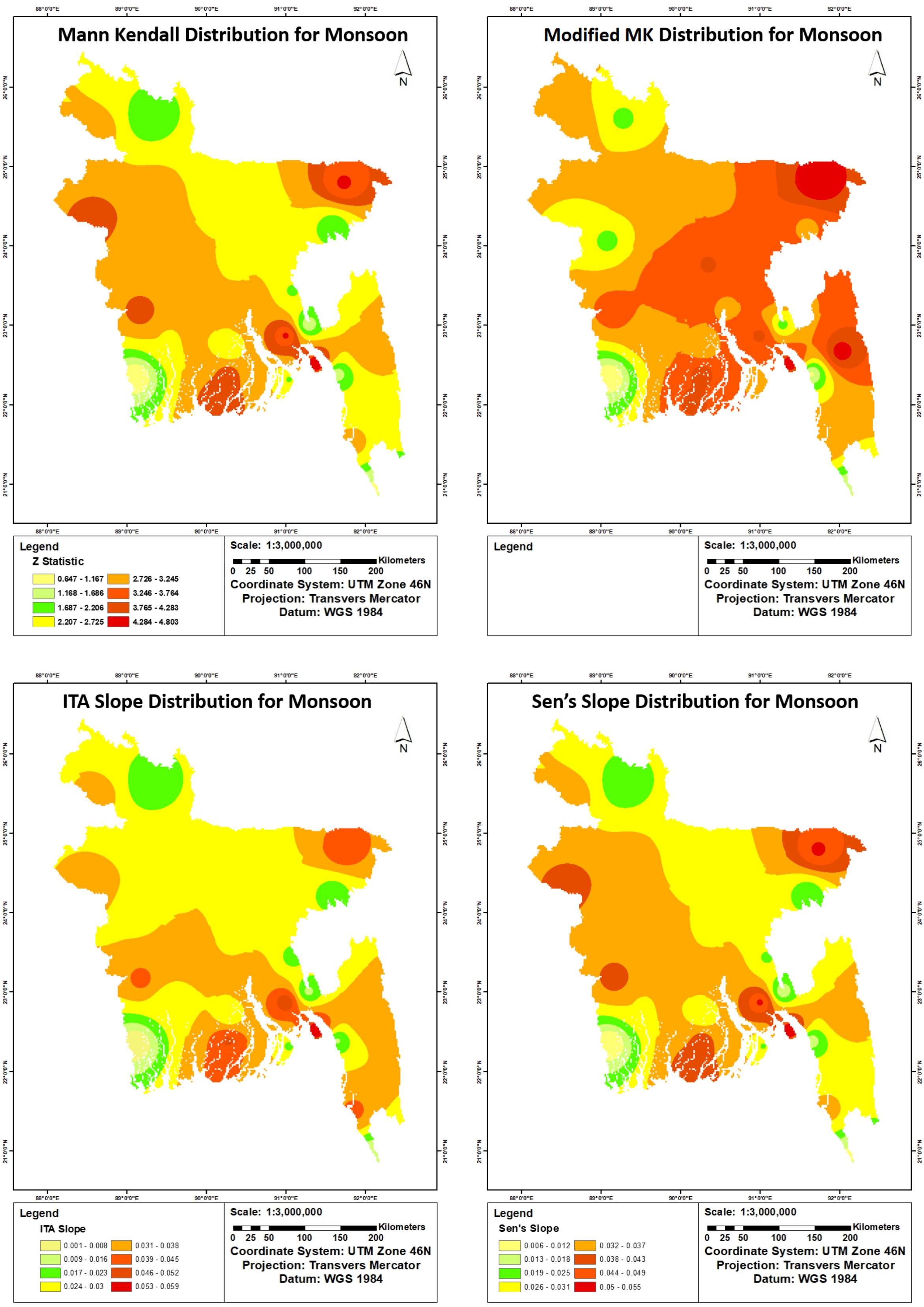
APPENDIX A: Figures



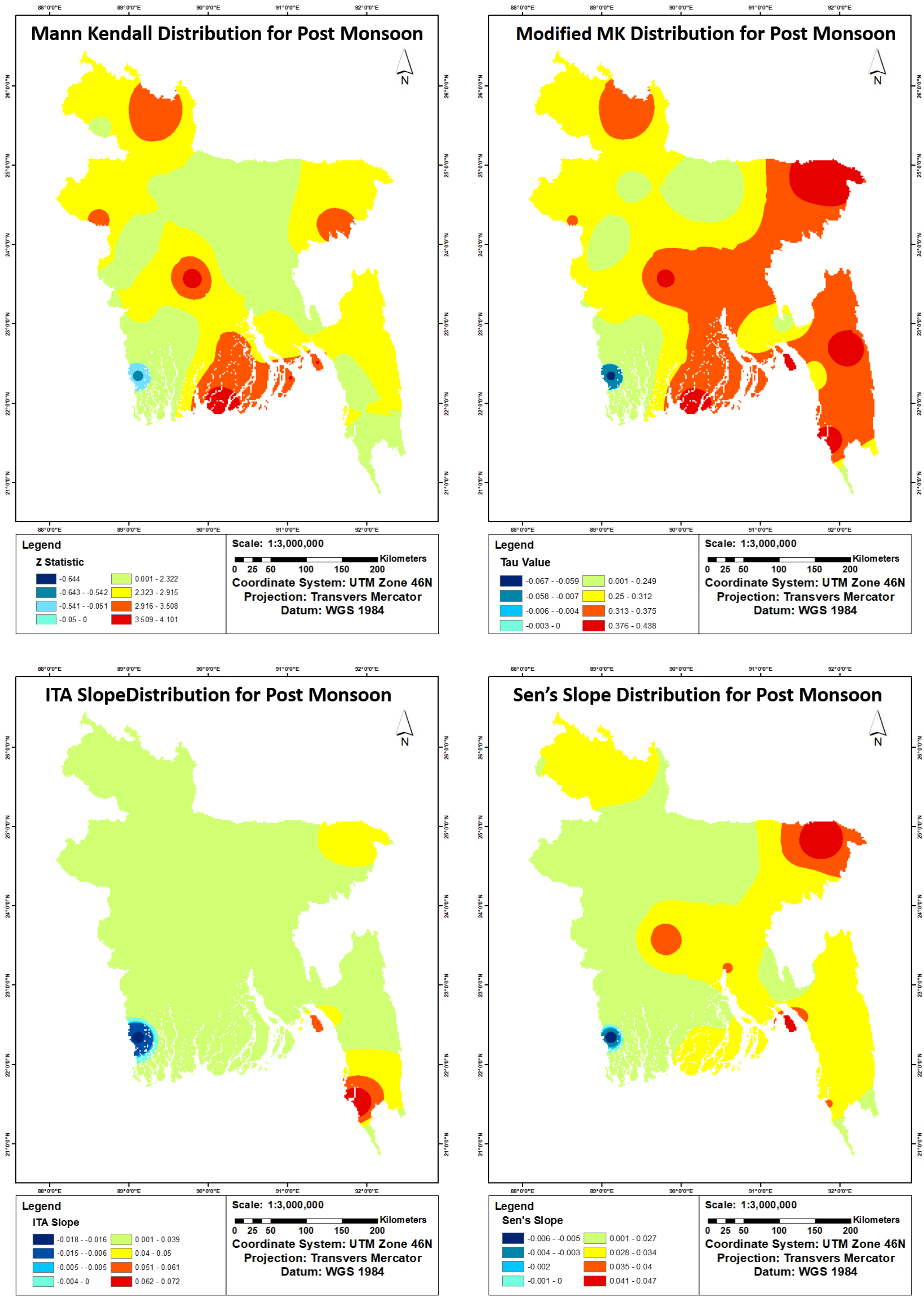
Annual


Mann Kendall Distribution for Pre Monsoon
N
Legend
Z Statistic
-2.493 - -1.717
-1.716 - -0.941
-0.94 - -0.164
-0.163 - 0
0.001 - 1.388
1.389 - 2.164
2.165 - 2.94
2.941 - 3.716
Scale: 1:3,000,000
0 25 50 100 150 200 Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984
Modified MK Distribution for Pre Monsoon
N
Legend
Tau Value
-0.218 - -0.13
-0.129 - -0.046
-0.045 - -0.042
-0.041 - 0
0.001 - 0.222
0.223 - 0.31
0.311 - 0.398
0.399 - 0.486
Scale: 1:3,000,000
0 25 50 100 150 200 Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984
ITA Slope Distribution for Pre Monsoon
N
Legend
ITA Slope
-0.031 - -0.018
-0.017 - -0.006
-0.005 - -0.004
-0.003 - 0
0.001 - 0.03
0.031 - 0.042
0.043 - 0.054
0.055 - 0.066
Scale: 1:3,000,000
0 25 50 100 150 200 Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984
Sen's Slope Distribution for Pre Monsoon
N
Legend
Sen's Slope
-0.029 - -0.018
-0.017 - -0.007
-0.006 - -0.004
-0.003 - 0
0.001 - 0.026
0.027 - 0.036
0.037 - 0.047
0.048 - 0.058
Scale: 1:3,000,000
0 25 50 100 150 200 Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984

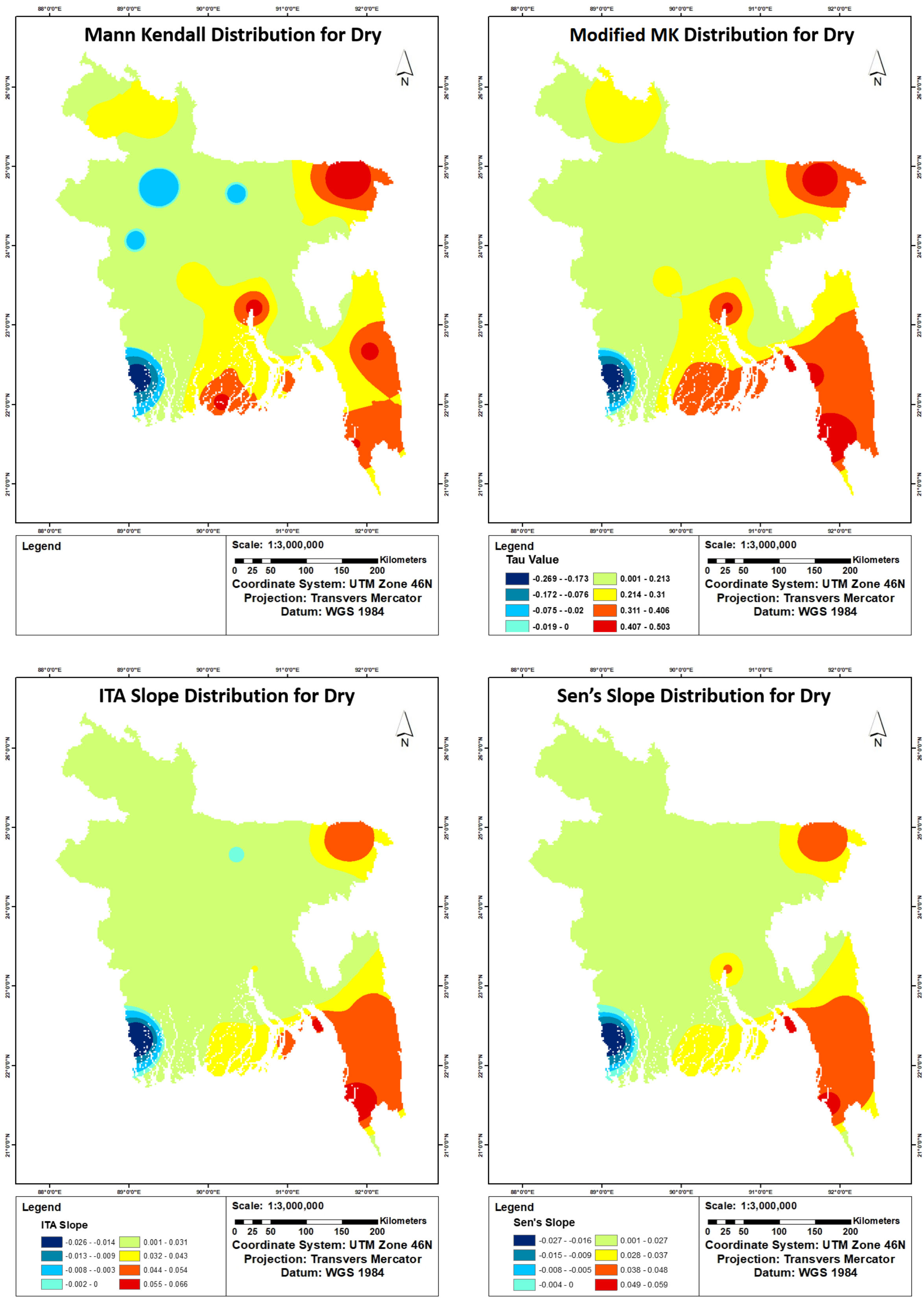
Pre-monsoon


Mann Kendall Distribution for Monsoon
N
Legend
Z Statistic
0.647 - 1.167
1.168 - 1.686
1.687 - 2.206
2.207 - 2.725
2.726 - 3.245
3.246 - 3.764
3.765 - 4.283
4.284 - 4.803
Scale: 1:3,000,000
0 25 50 100 150 200 Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984
Modified MK Distribution for Monsoon
N
Legend
Scale: 1:3,000,000
0 25 50 100 150 200 Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984
ITA Slope Distribution for Monsoon
N
Legend
ITA Slope
0.001 - 0.008
0.009 - 0.016
0.017 - 0.023
0.024 - 0.03
0.031 - 0.038
0.039 - 0.045
0.046 - 0.052
0.053 - 0.059
Scale: 1:3,000,000
0 25 50 100 150 200 Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984
Sen's Slope Distribution for Monsoon
N
Legend
Sen's Slope
0.006 - 0.012
0.013 - 0.018
0.019 - 0.025
0.026 - 0.031
0.032 - 0.037
0.038 - 0.043
0.044 - 0.049
0.05 - 0.055
Scale: 1:3,000,000
0 25 50 100 150 200 Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984

Monsoon

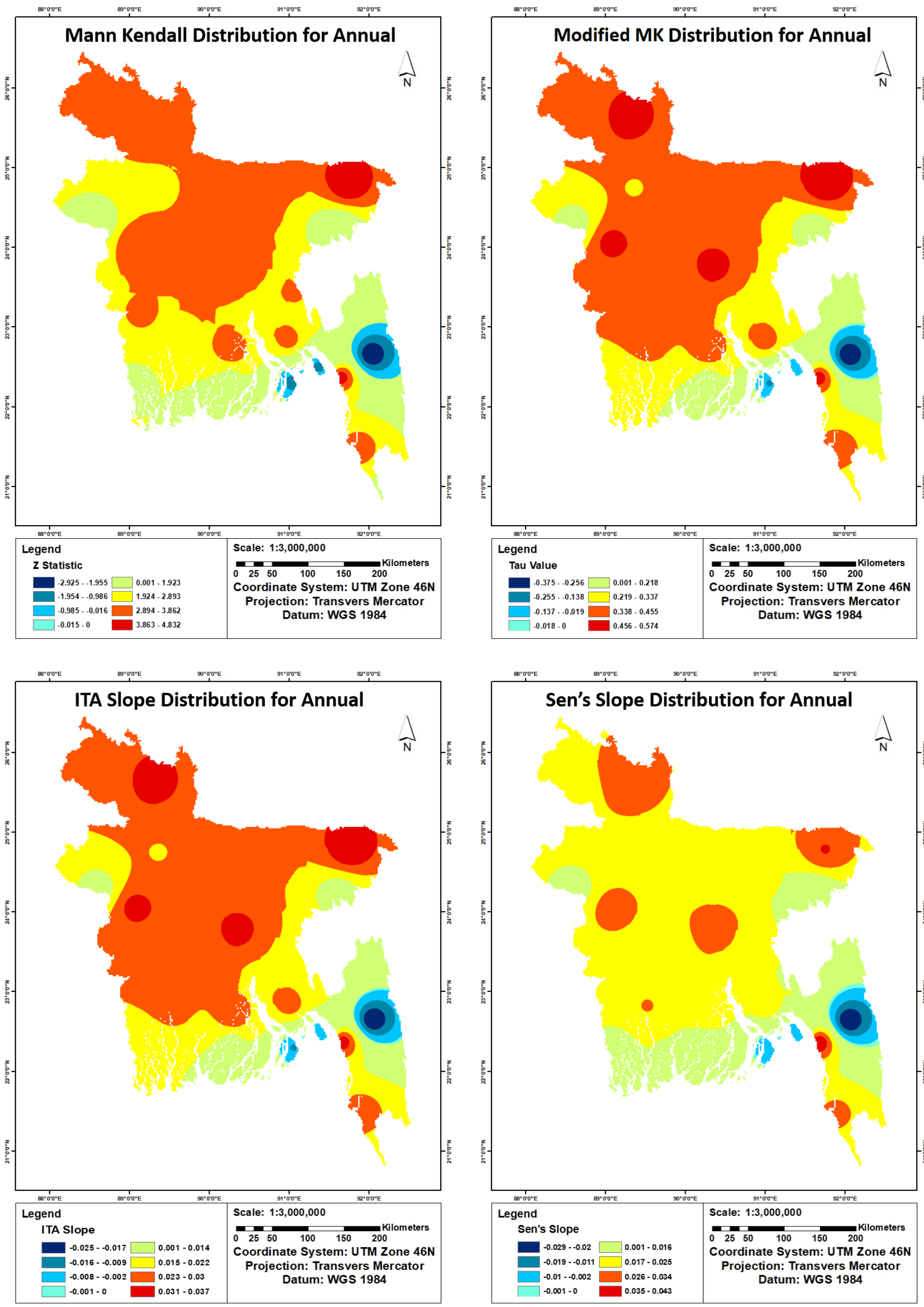


Post-monsoon

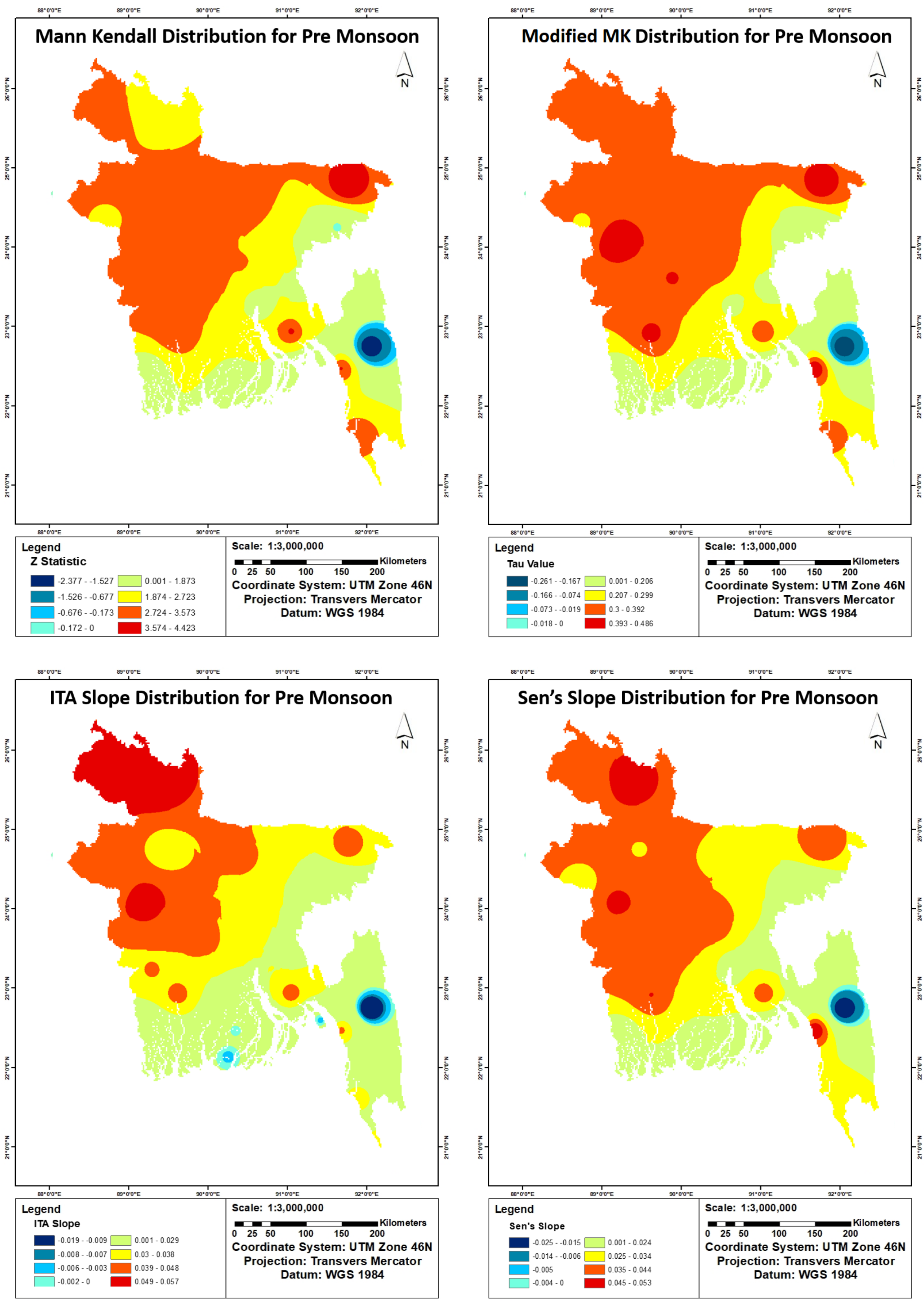


Dry

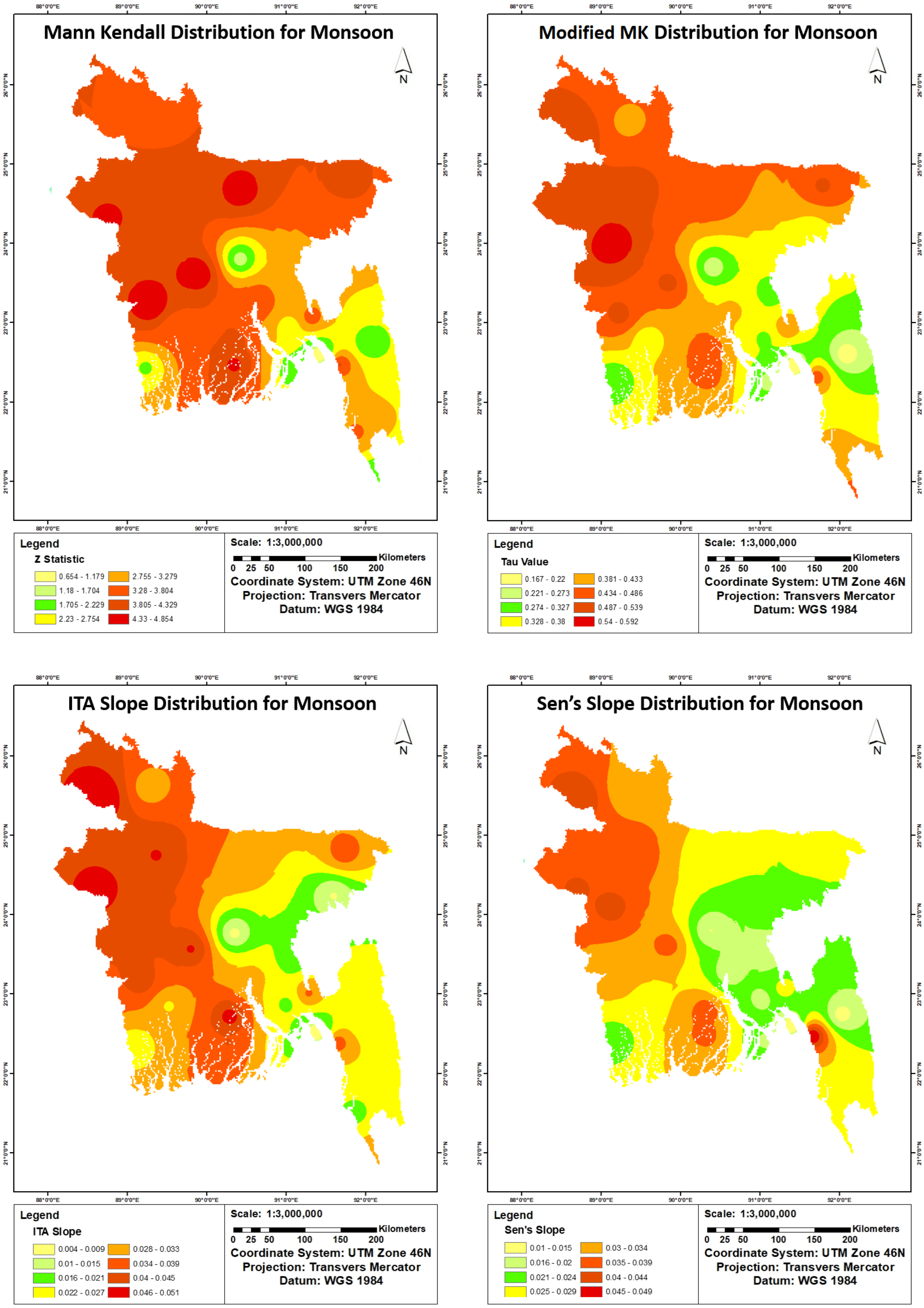
Figure A.1: GIS mapping of annual maximum temperature trend from MK, mMK and IT analysis and magnitude of slope from Sen's slope analysis


Mann Kendall Distribution for Annual
Legend
Z Statistic
-2.925 - -1.955
-1.954 - -0.986
-0.985 - -0.016
-0.015 - 0
0.001 - 1.923
1.924 - 2.893
2.894 - 3.862
3.863 - 4.832
Modified MK Distribution for Annual
Legend
Tau Value
-0.375 - -0.256
-0.255 - -0.138
-0.137 - -0.019
-0.018 - 0
0.001 - 0.218
0.219 - 0.337
0.338 - 0.455
0.456 - 0.574
ITA Slope Distribution for Annual
Legend
ITA Slope
-0.025 - -0.017
-0.016 - -0.009
-0.008 - -0.002
-0.001 - 0
0.001 - 0.014
0.015 - 0.022
0.023 - 0.03
0.031 - 0.037
Sen's Slope Distribution for Annual
Legend
Sen's Slope
-0.029 - -0.02
-0.019 - -0.011
-0.01 - -0.002
-0.001 - 0
0.001 - 0.016
0.017 - 0.025
0.026 - 0.034
0.035 - 0.043
Scale: 1:3,000,000
Kilometers
0 25 50 100 150 200
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984

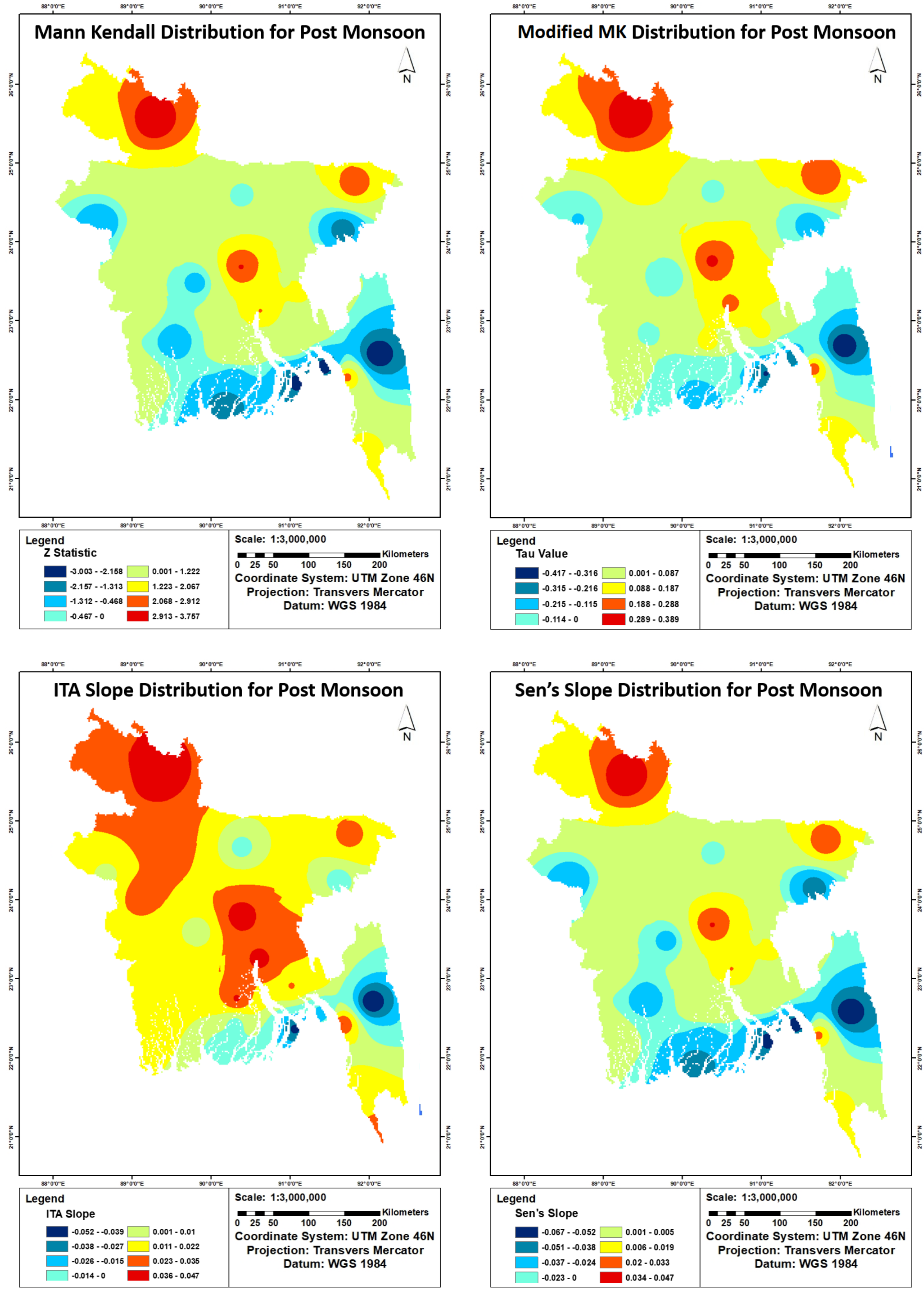
Annual


Mann Kendall Distribution for Pre Monsoon
Legend
Z Statistic
-2.377 - -1.527
-1.526 - -0.677
-0.676 - -0.173
-0.172 - 0
0.001 - 1.873
1.874 - 2.723
2.724 - 3.573
3.574 - 4.423
Modified MK Distribution for Pre Monsoon
Legend
Tau Value
-0.261 - -0.167
-0.166 - -0.074
-0.073 - -0.019
-0.018 - 0
0.001 - 0.206
0.207 - 0.299
0.3 - 0.392
0.393 - 0.486
ITA Slope Distribution for Pre Monsoon
Legend
ITA Slope
-0.019 - -0.009
-0.008 - -0.007
-0.006 - -0.003
-0.002 - 0
0.001 - 0.029
0.03 - 0.038
0.039 - 0.048
0.049 - 0.057
Sen's Slope Distribution for Pre Monsoon
Legend
Sen's Slope
-0.025 - -0.015
-0.014 - -0.006
-0.005
-0.004 - 0
0.001 - 0.024
0.025 - 0.034
0.035 - 0.044
0.045 - 0.053
N
Scale: 1:3,000,000
0 25 50 100 150 200 Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984

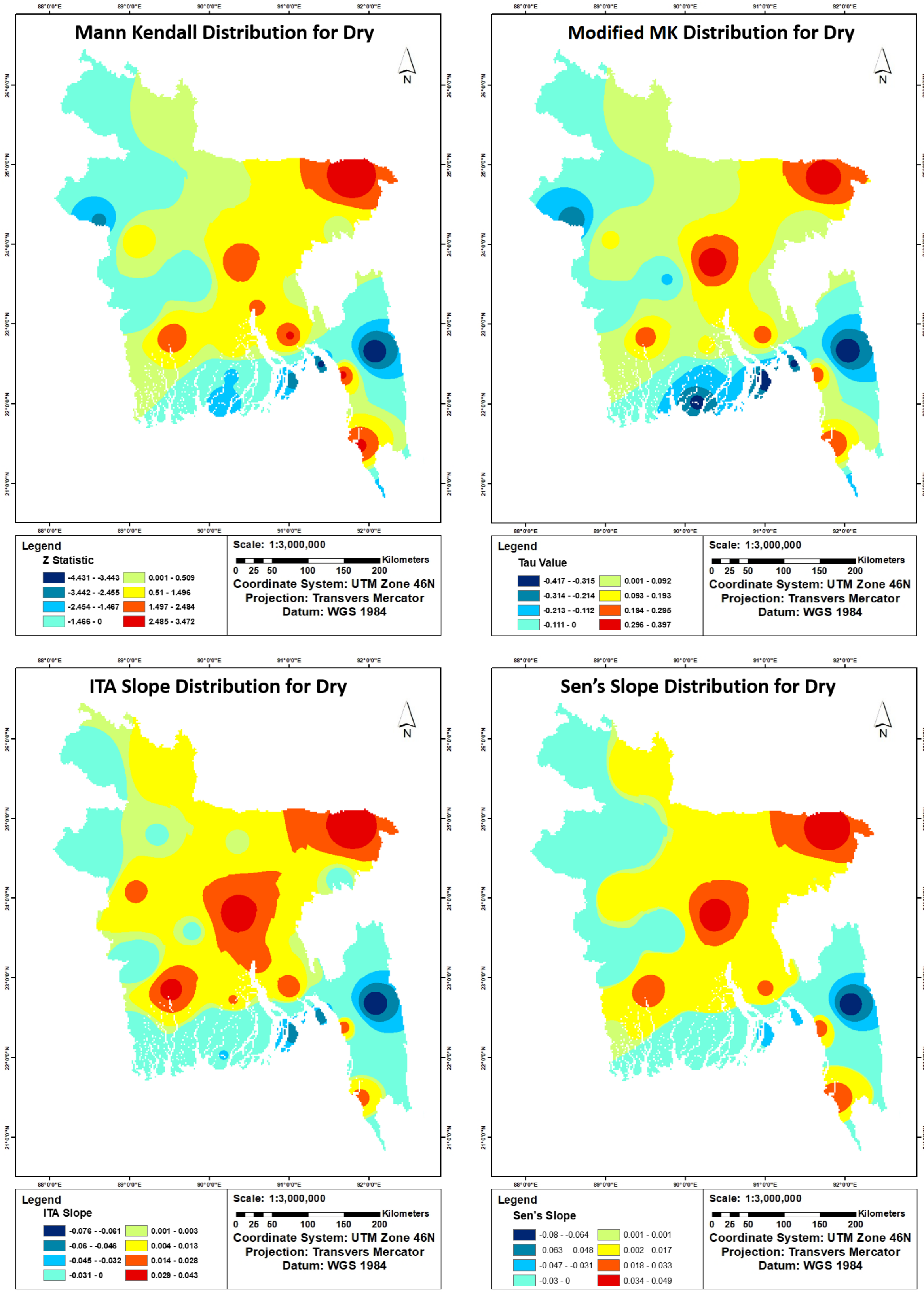
Pre-monsoon


Mann Kendall Distribution for Monsoon
N
Legend
Z Statistic
0.654 - 1.179
1.18 - 1.704
1.705 - 2.229
2.23 - 2.754
2.755 - 3.279
3.28 - 3.804
3.805 - 4.329
4.33 - 4.854
Scale: 1:3,000,000
0 25 50 100 150 200 Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984
Modified MK Distribution for Monsoon
N
Legend
Tau Value
0.167 - 0.22
0.221 - 0.273
0.274 - 0.327
0.328 - 0.38
0.381 - 0.433
0.434 - 0.486
0.487 - 0.539
0.54 - 0.592
Scale: 1:3,000,000
0 25 50 100 150 200 Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984
ITA Slope Distribution for Monsoon
N
Legend
ITA Slope
0.004 - 0.009
0.01 - 0.015
0.016 - 0.021
0.022 - 0.027
0.028 - 0.033
0.034 - 0.039
0.04 - 0.045
0.046 - 0.051
Scale: 1:3,000,000
0 25 50 100 150 200 Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984
Sen's Slope Distribution for Monsoon
N
Legend
Sen's Slope
0.01 - 0.015
0.016 - 0.02
0.021 - 0.024
0.025 - 0.029
0.03 - 0.034
0.035 - 0.039
0.04 - 0.044
0.045 - 0.049
Scale: 1:3,000,000
0 25 50 100 150 200 Kilometers
Coordinate System: UTM Zone 46N
Projection: Transvers Mercator
Datum: WGS 1984

Monsoon

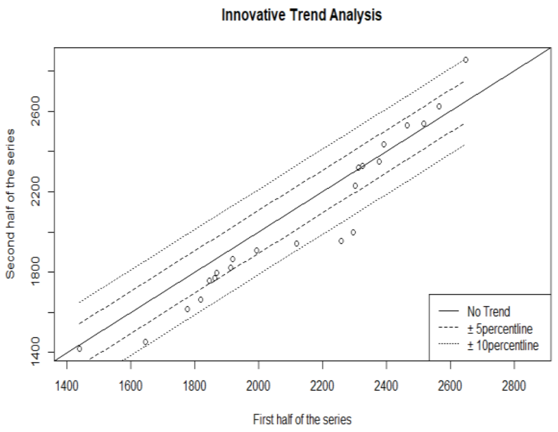


Post-monsoon

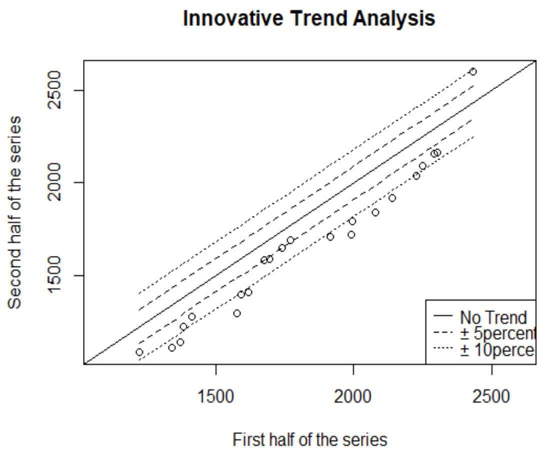


Dry

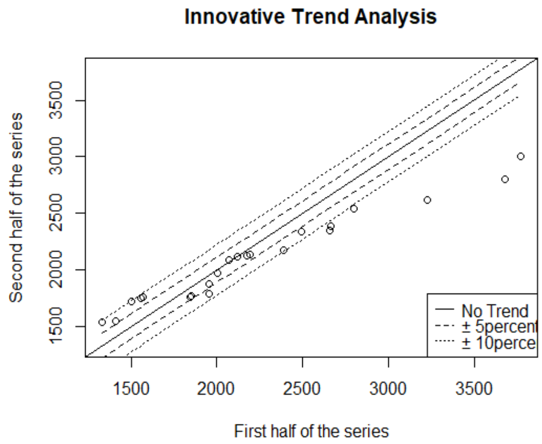
Figure A.2: GIS mapping of annual minimum temperature trend from MK, mMK and IT analysis and magnitude of slope from Sen's slope analysis



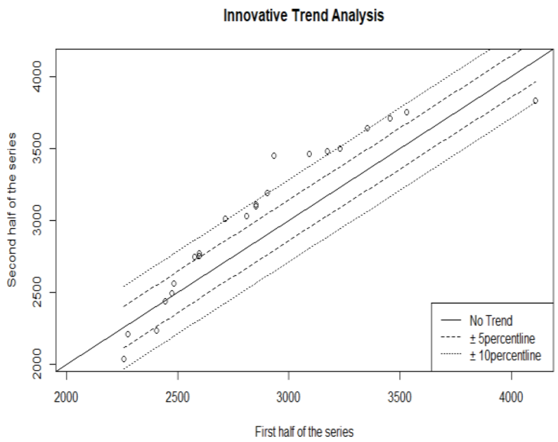
Barisal



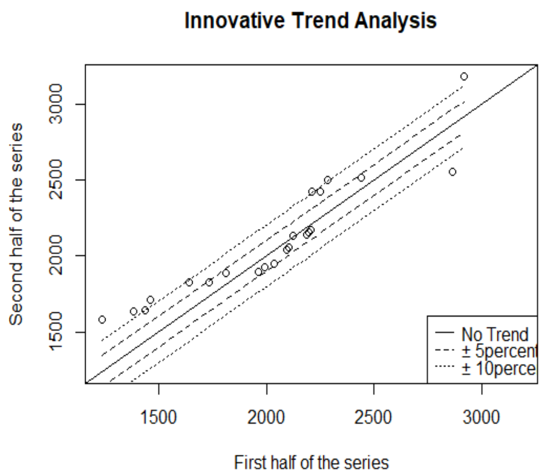
Bogra



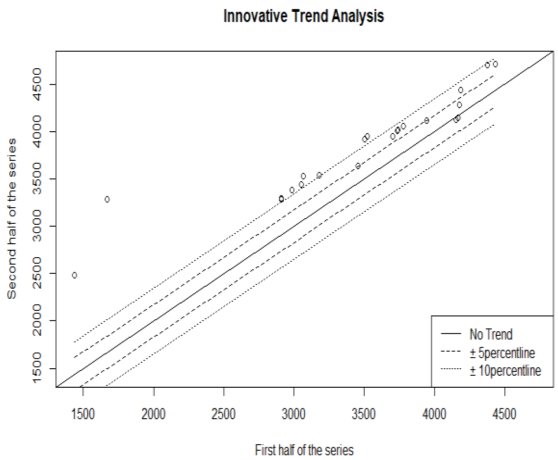
Chandpur



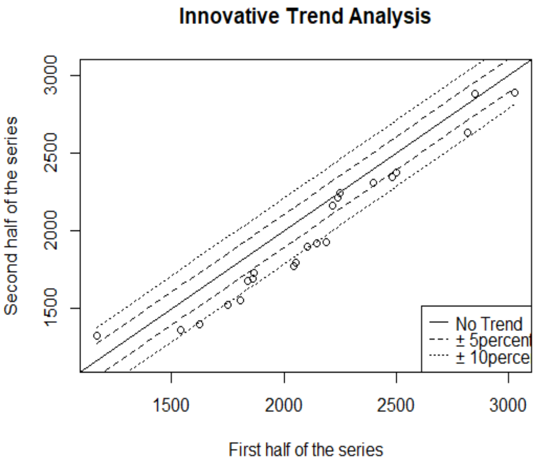
Chittagong



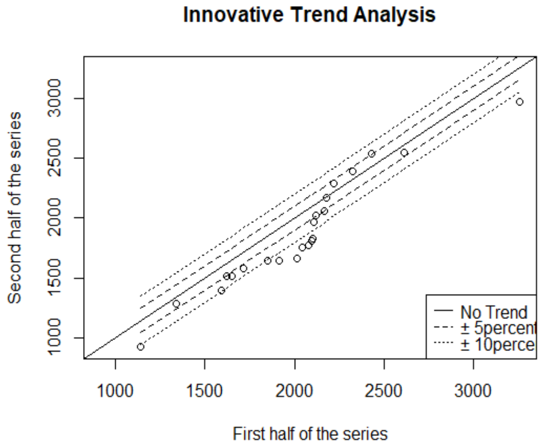
Comilla



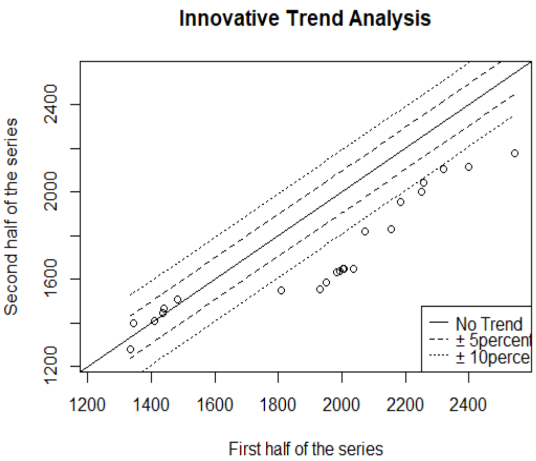
Cox’s Bazar



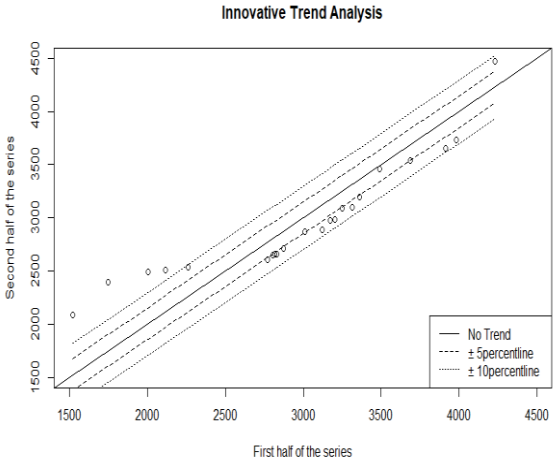
Dhaka



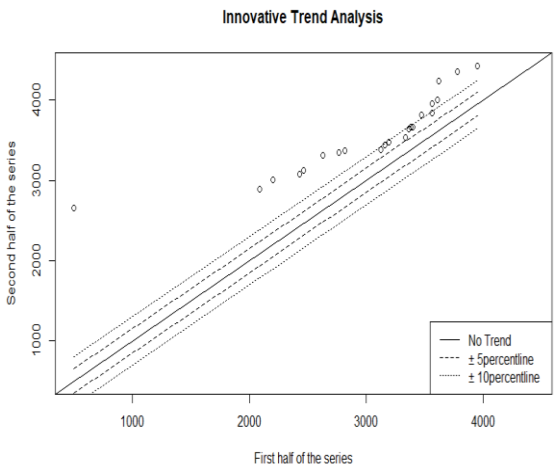
Dinajpur



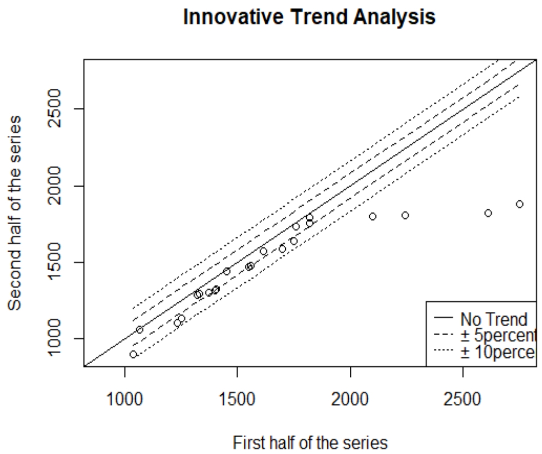
Faridpur



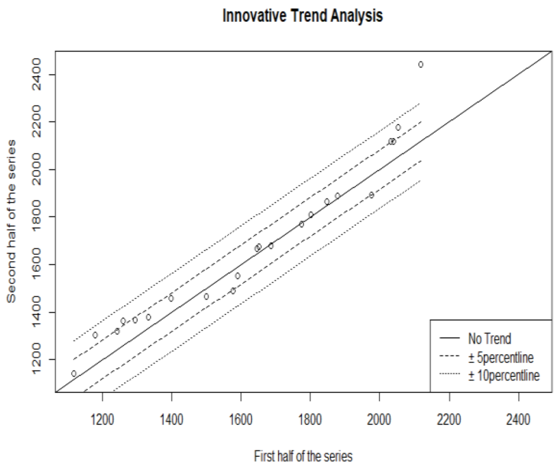
Feni



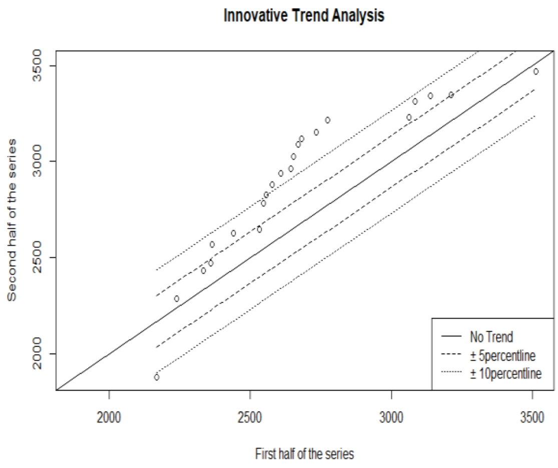
Hatiya



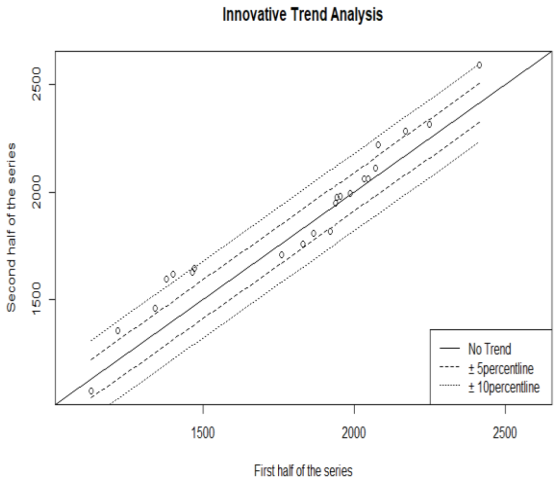
Ishurdi



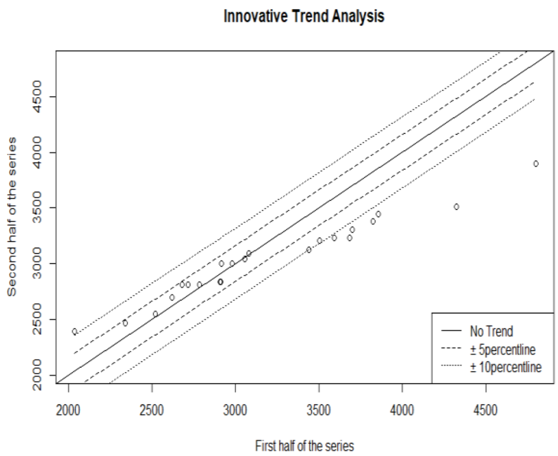
Jessore



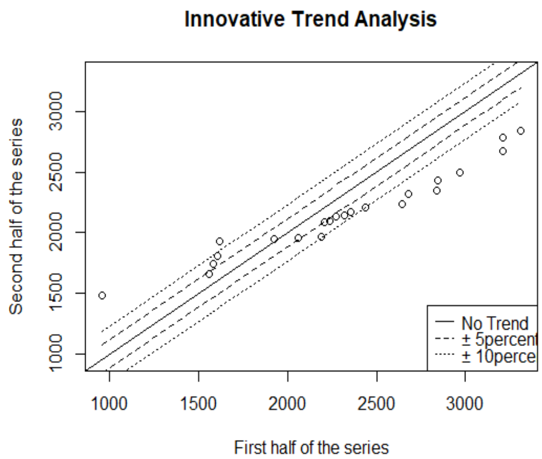
Khepupara



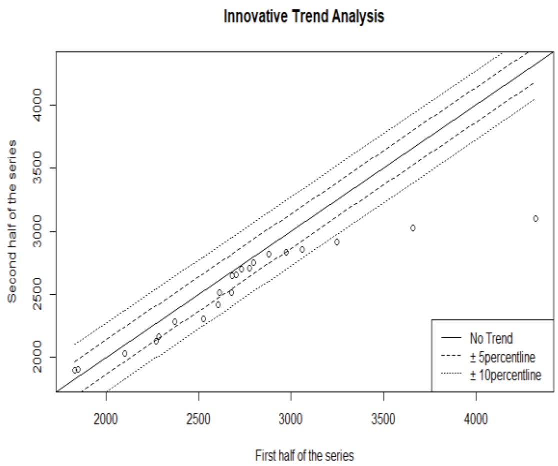
Khulna



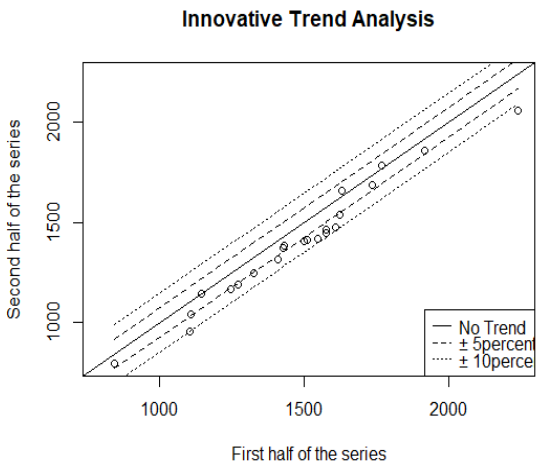
M. Court



Mymensingh



Patuakhali



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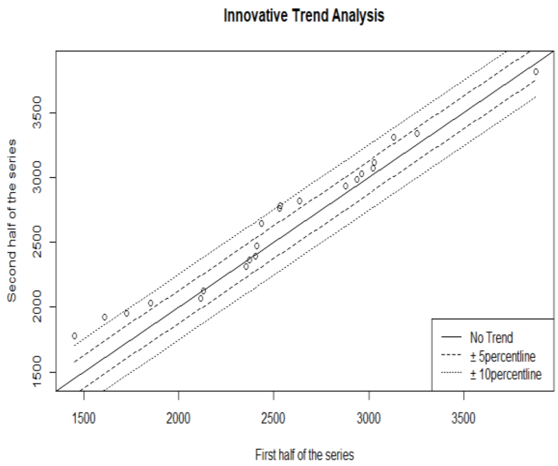
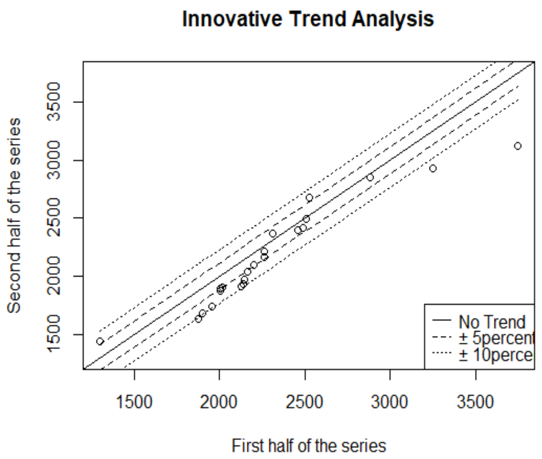
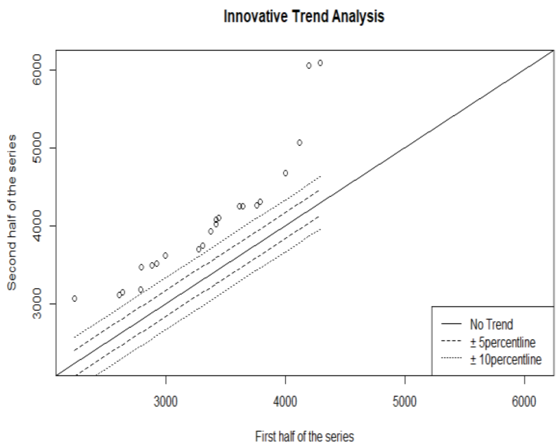


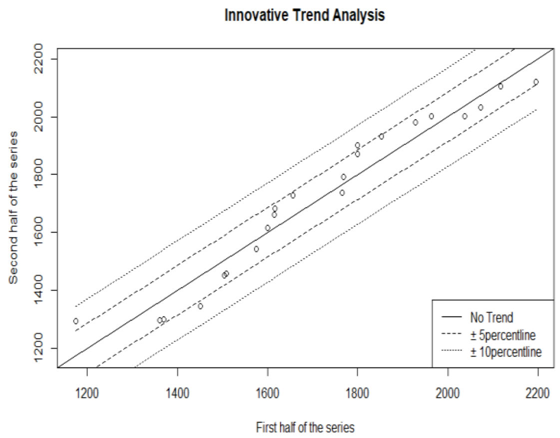
Rangamati



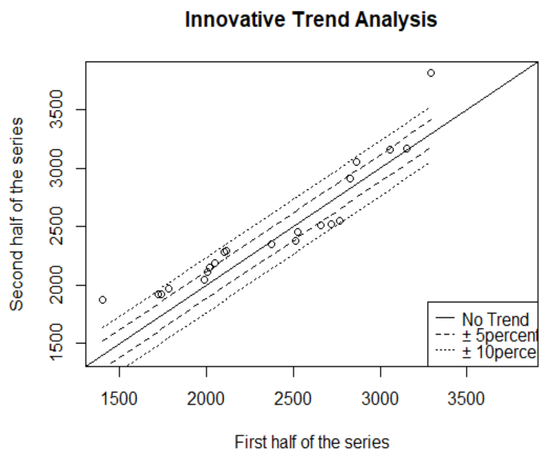
Rangpur



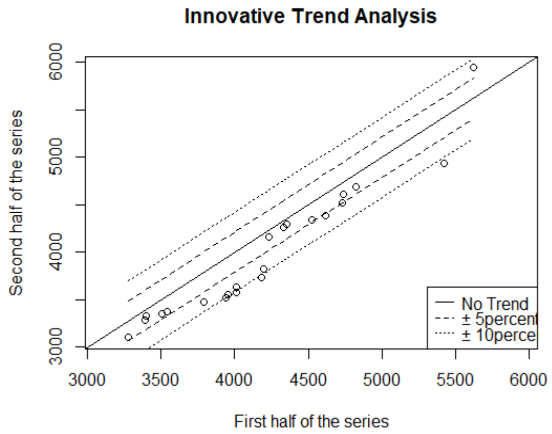
Sandwip



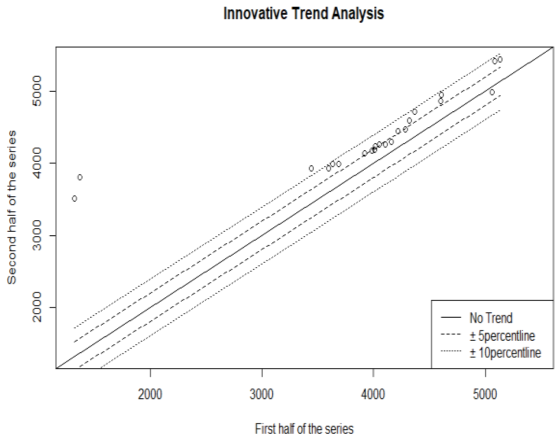
Satkhira



Srimangal

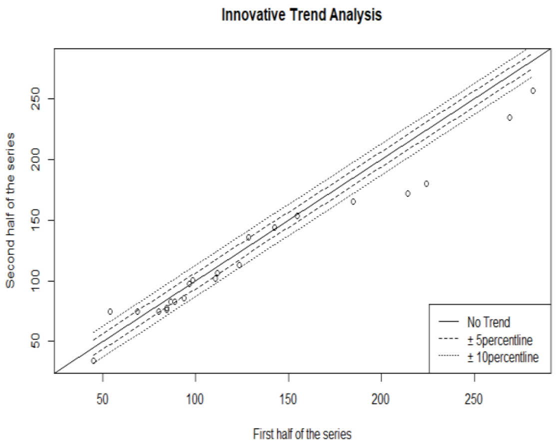


Sylhet

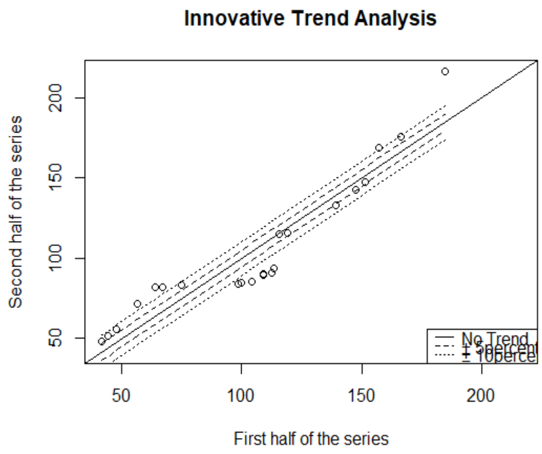


Teknaf

Annual



Barisal



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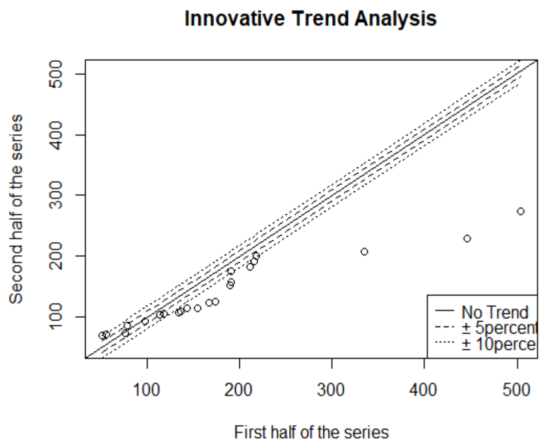
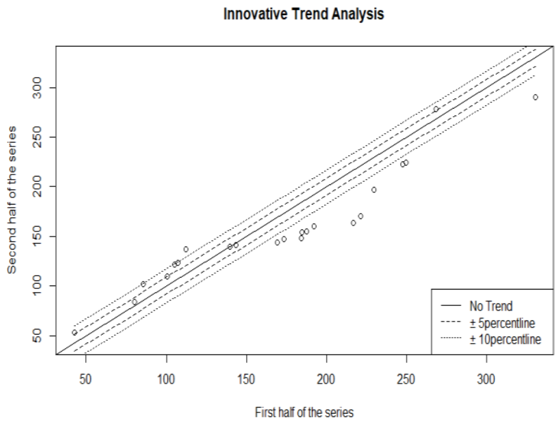
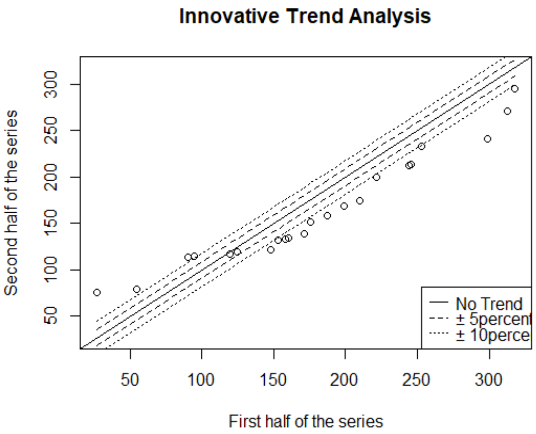


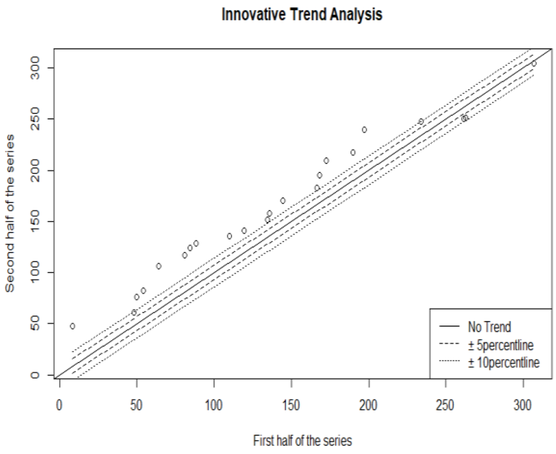
Chandpur



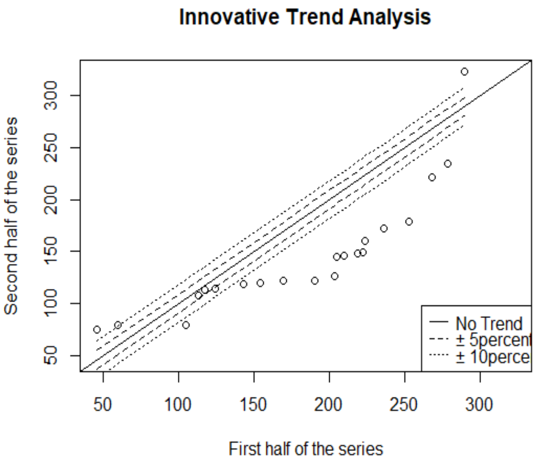
Chittagong



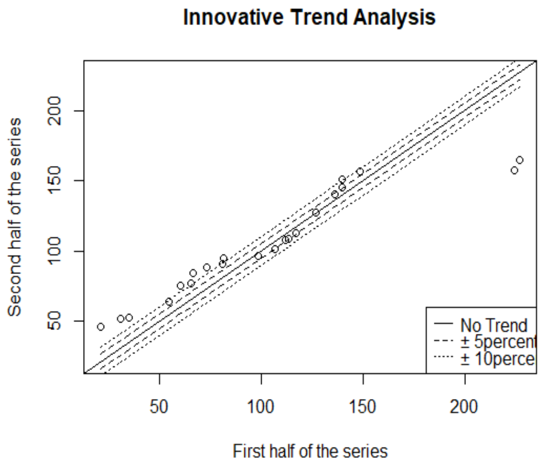
Comilla



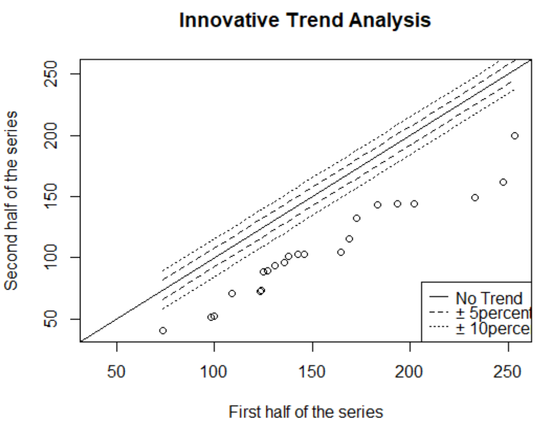
Cox's Bazar



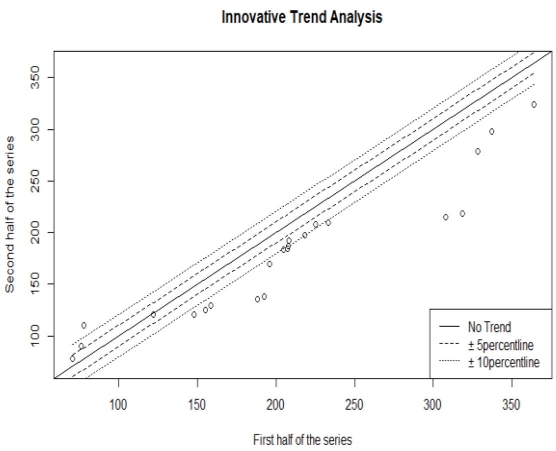
Dhaka



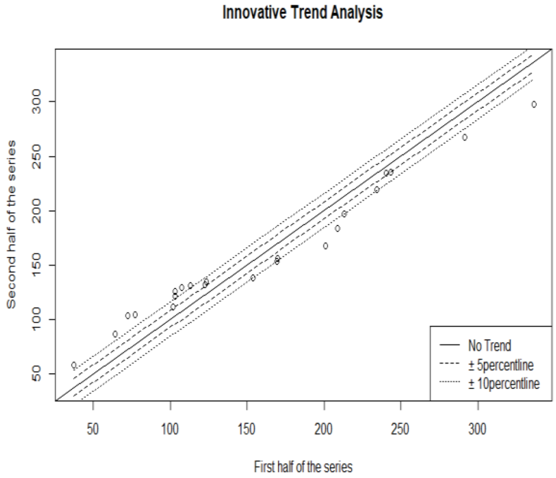
Dinajpur



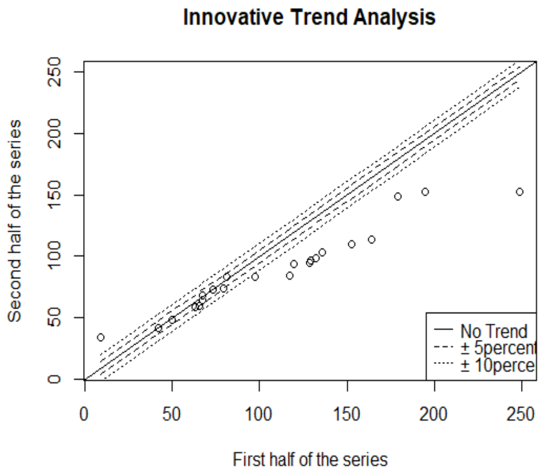
Faridpur



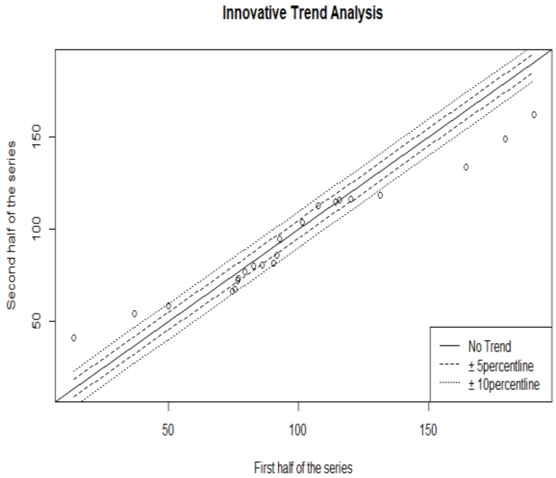
Feni



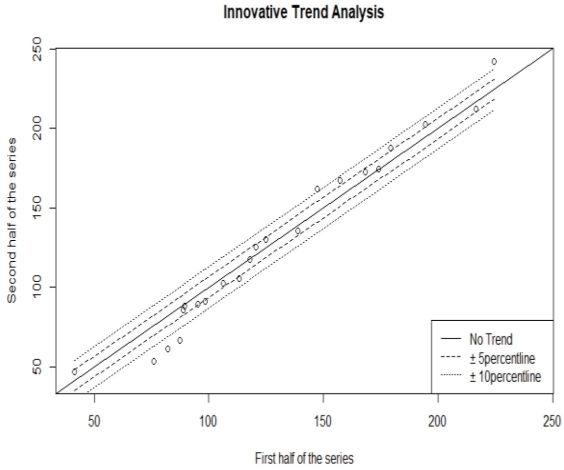
Hatiya



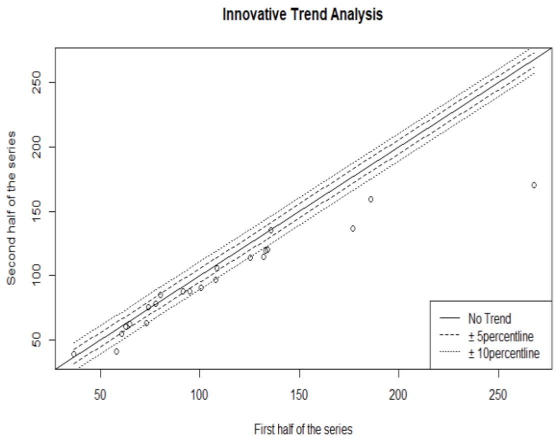
Ishurdi



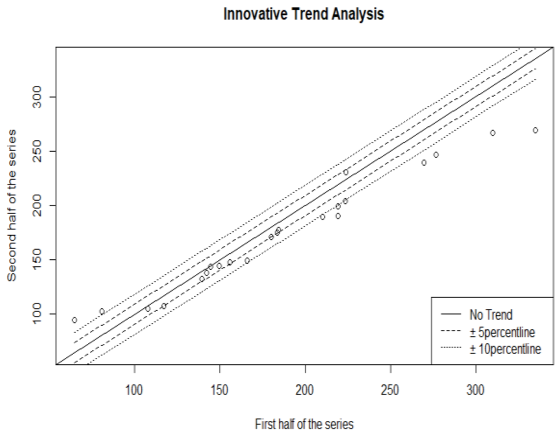
Jessore



Khepupara



Khulna



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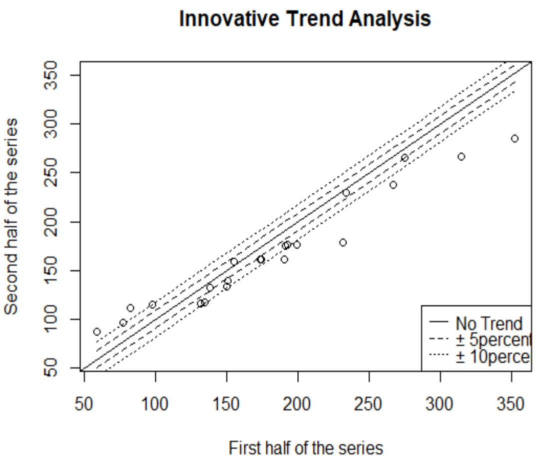

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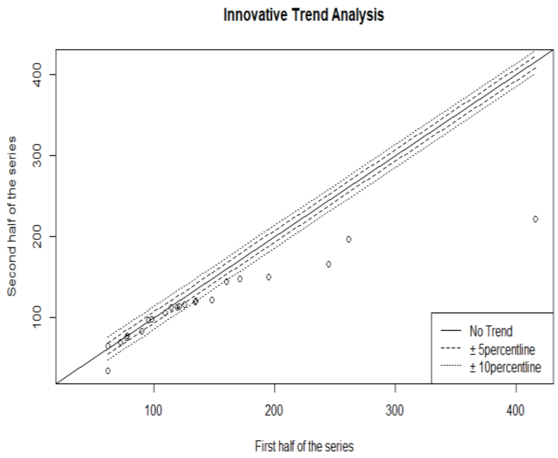

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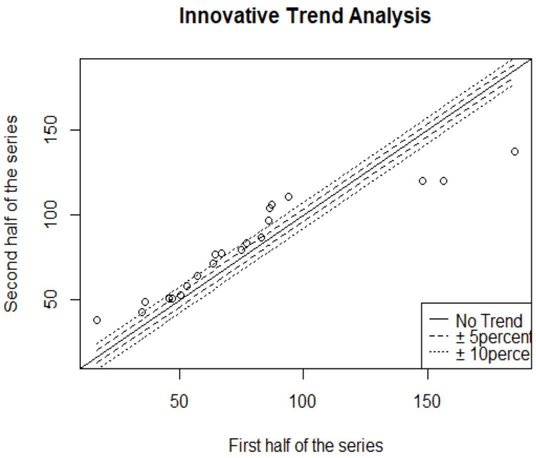

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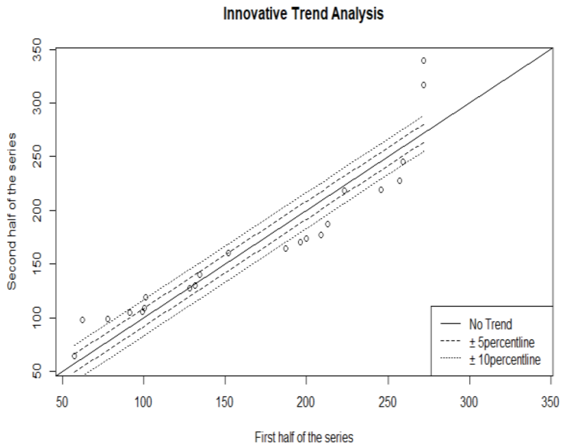

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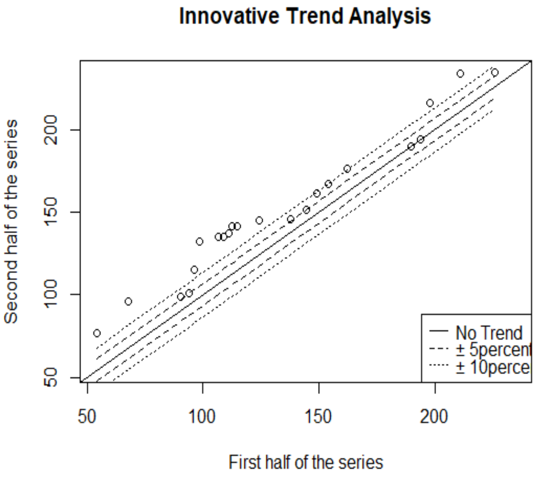

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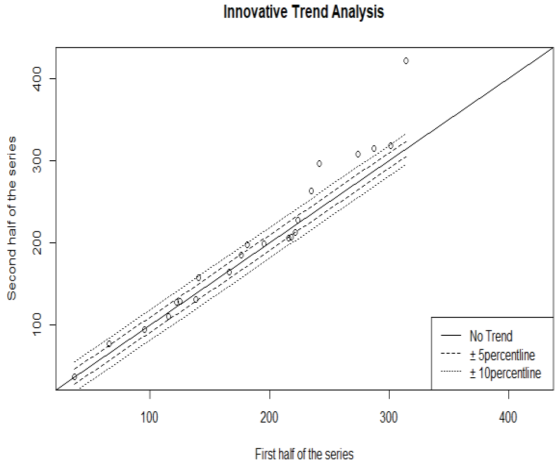

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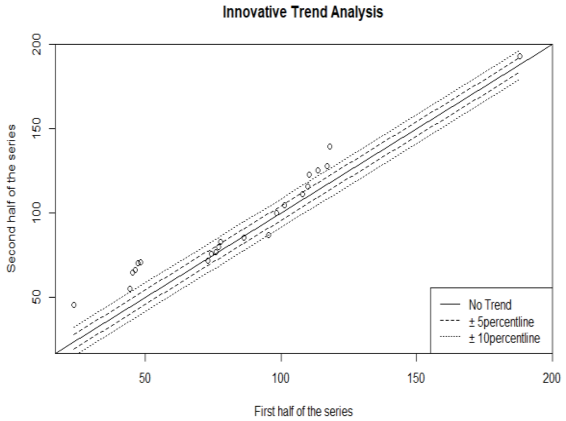

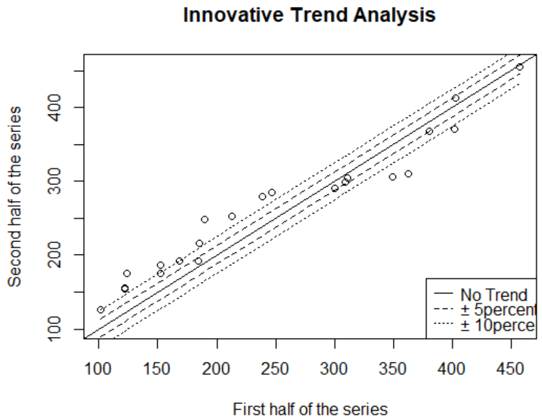

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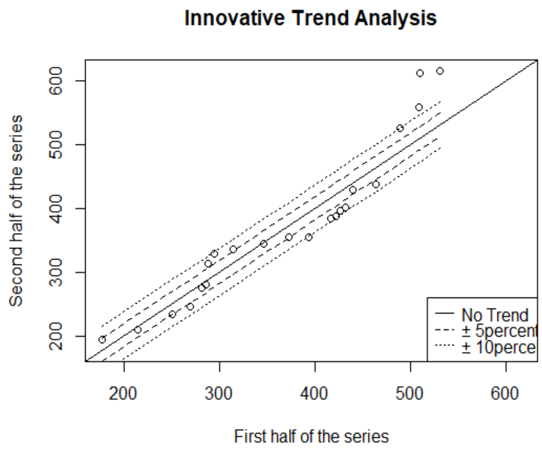

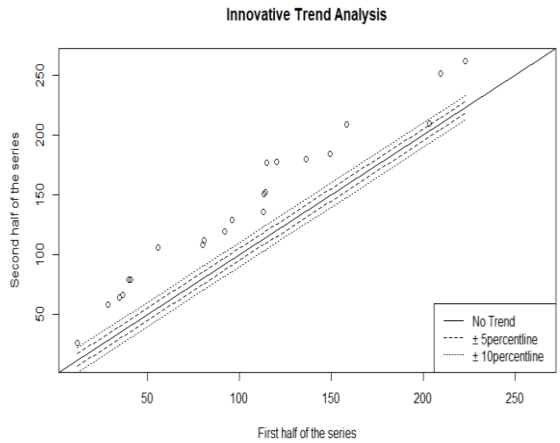

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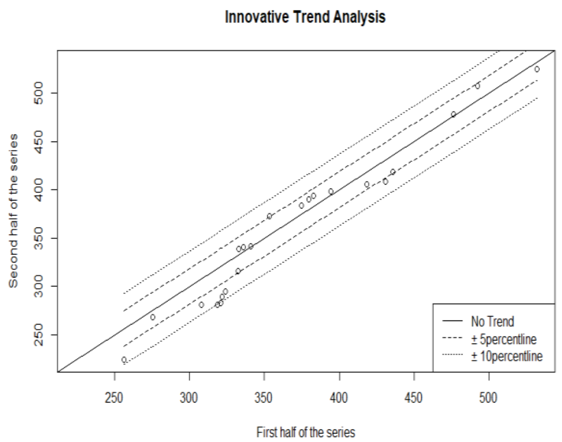
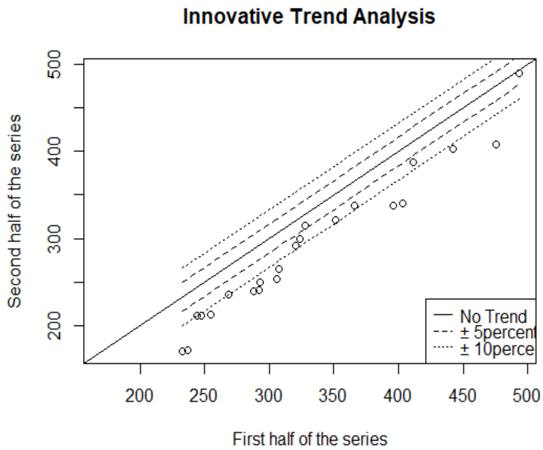
Teknaf

Pre-Monsoon





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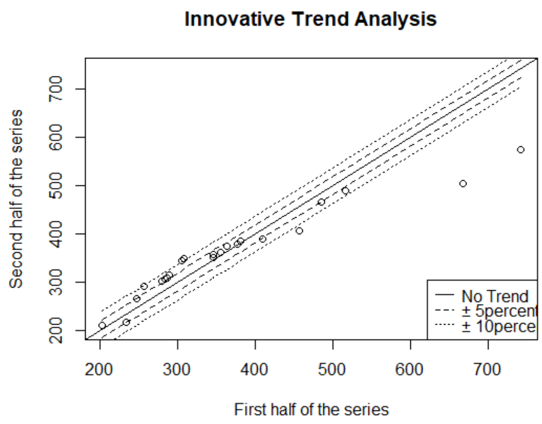

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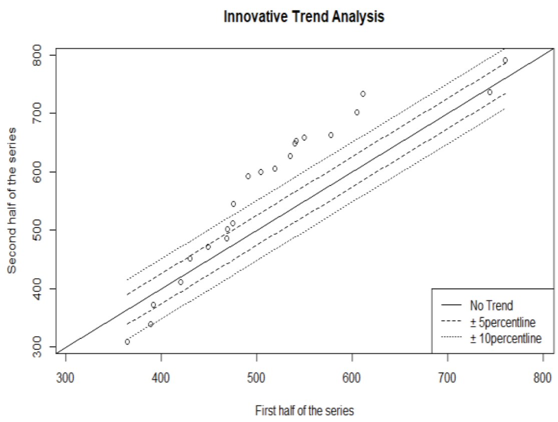

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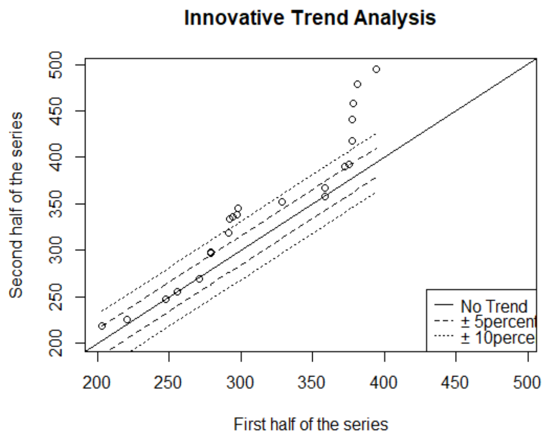

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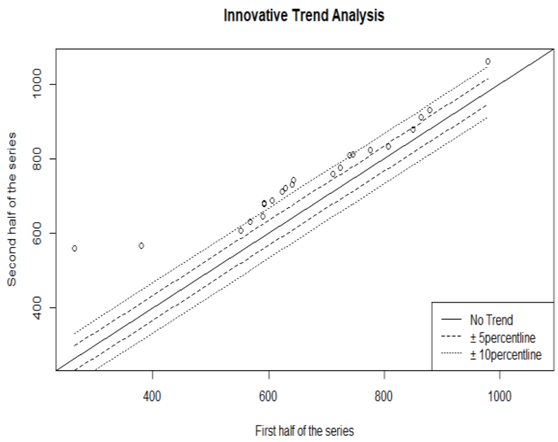

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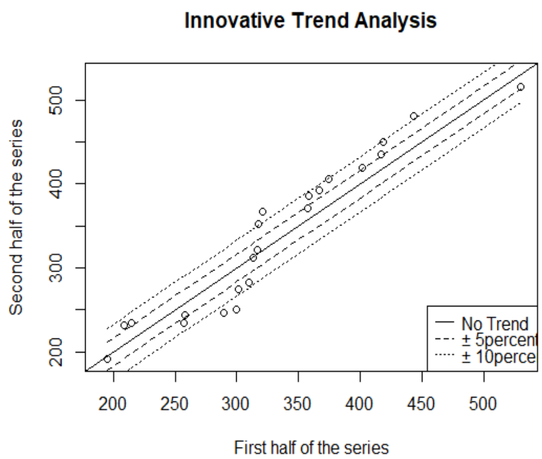

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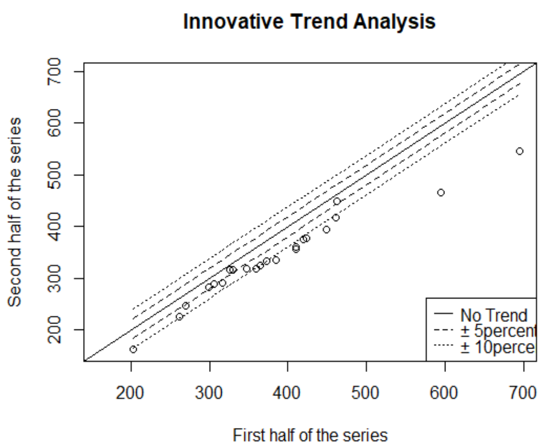

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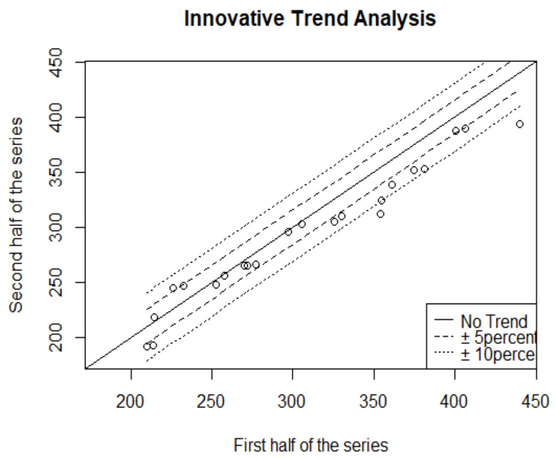

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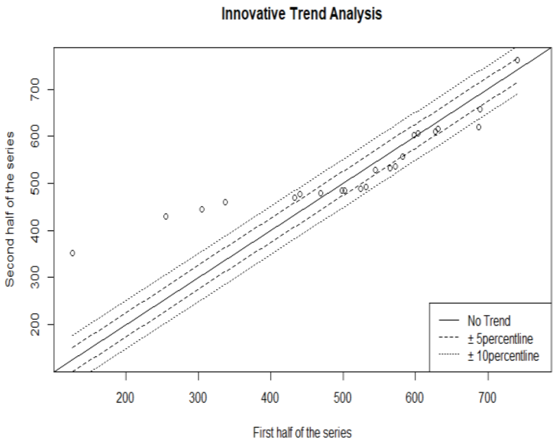

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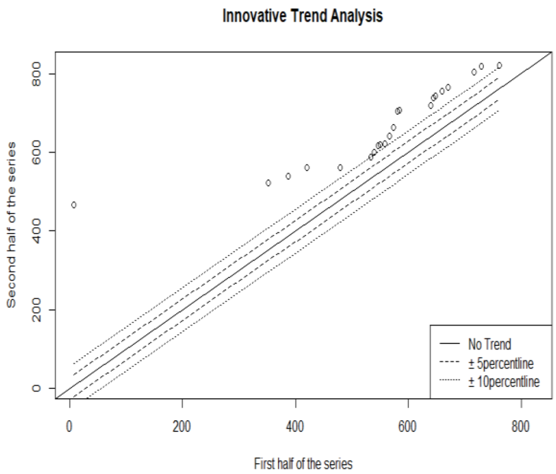

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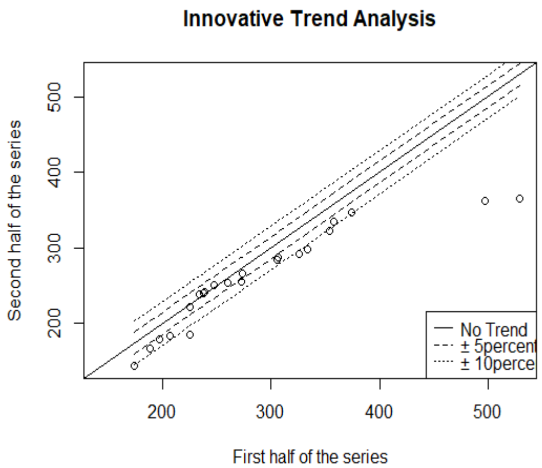

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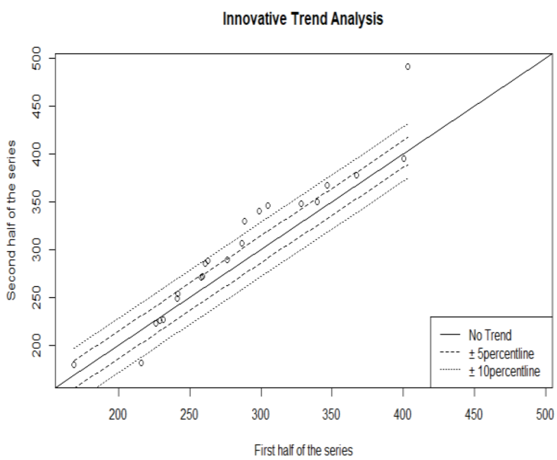

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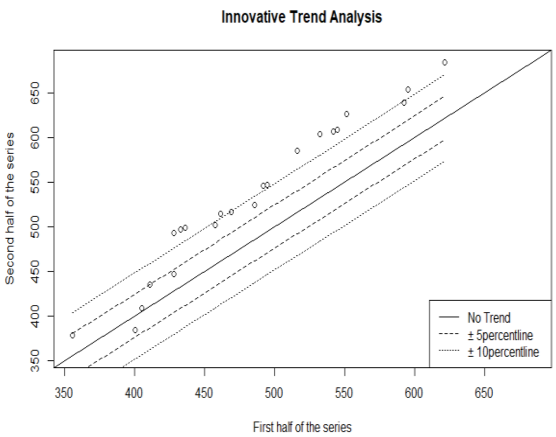

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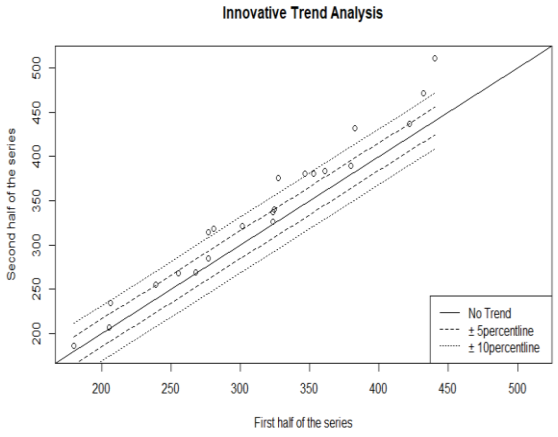

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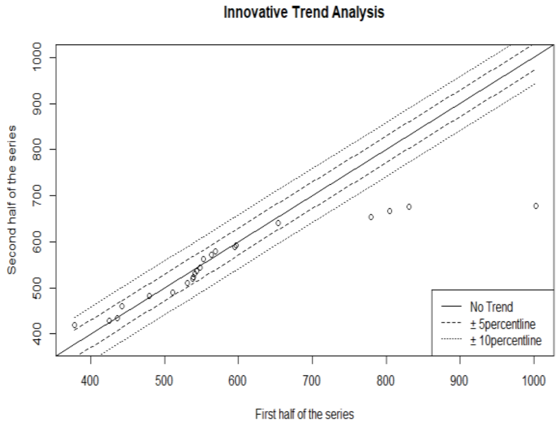

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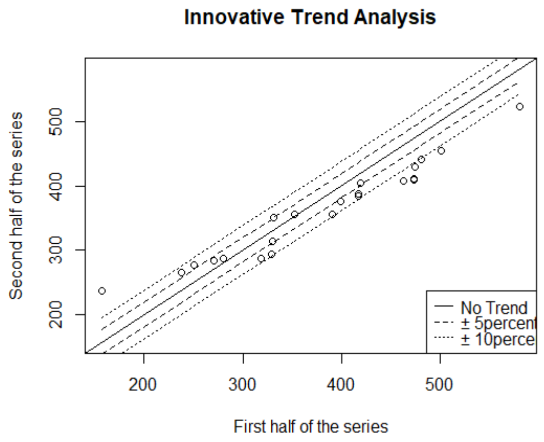

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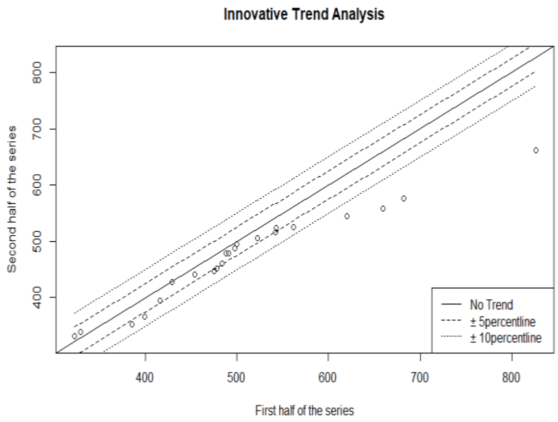

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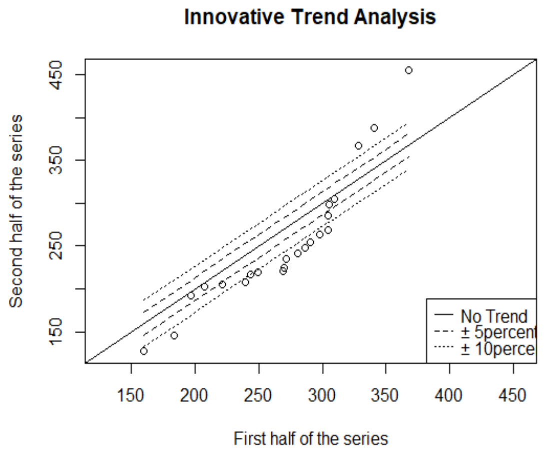

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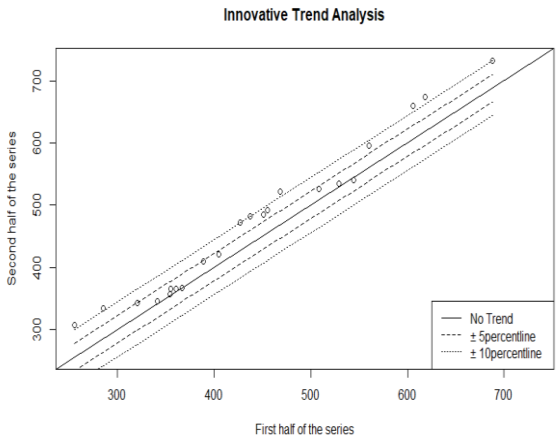

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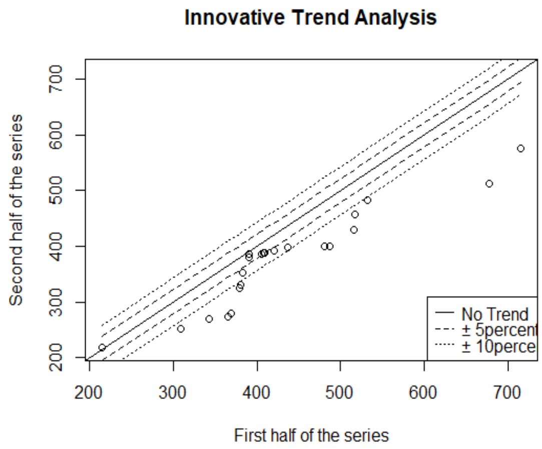

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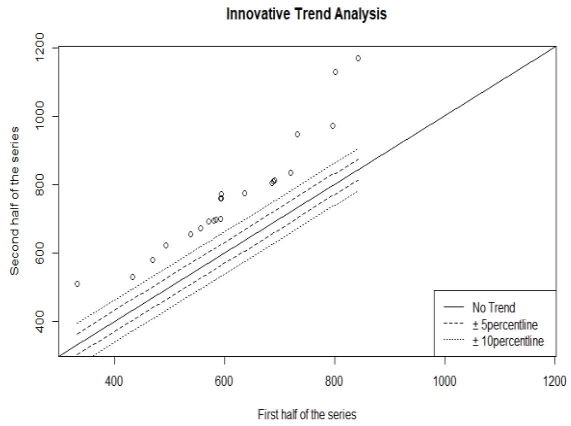

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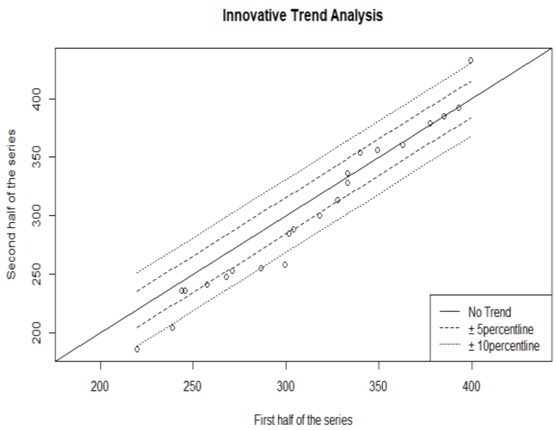

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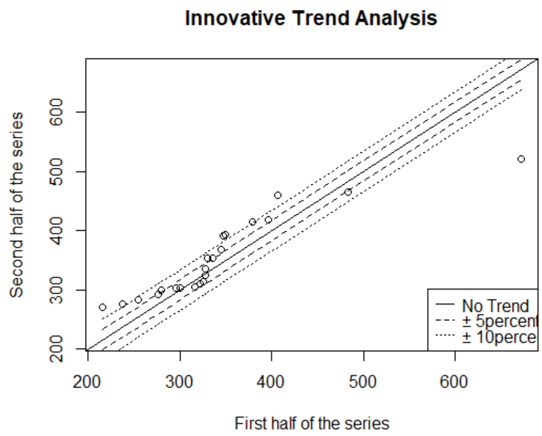

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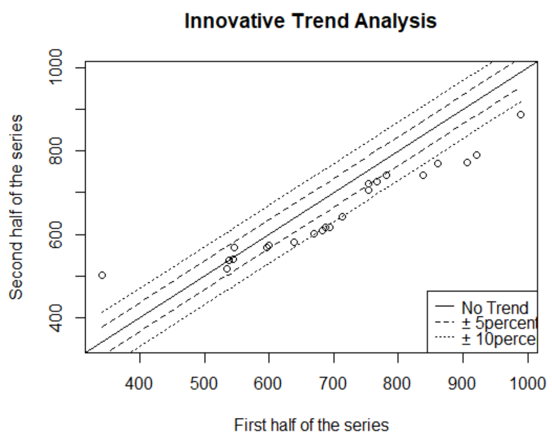

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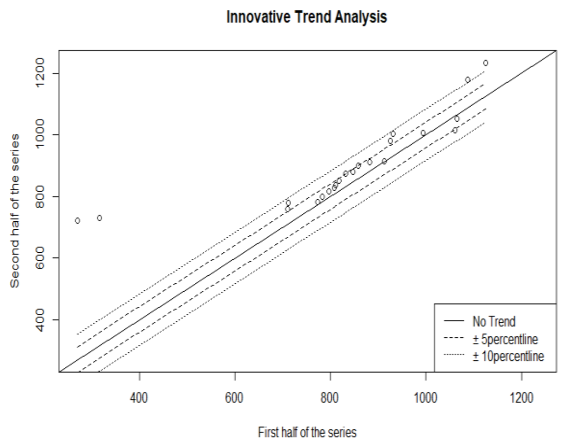

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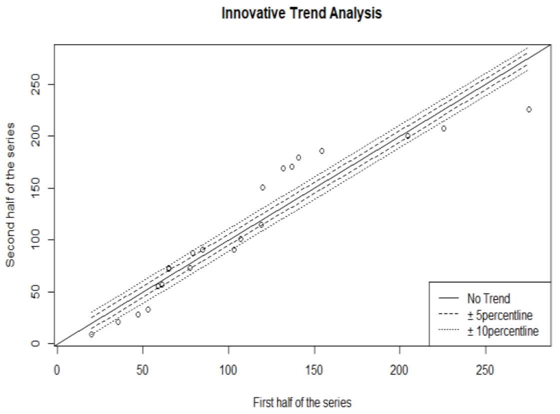

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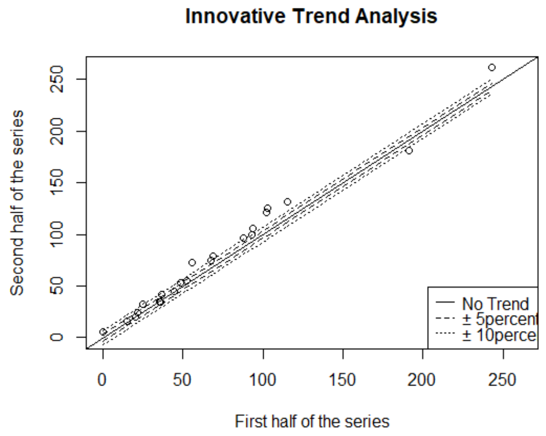

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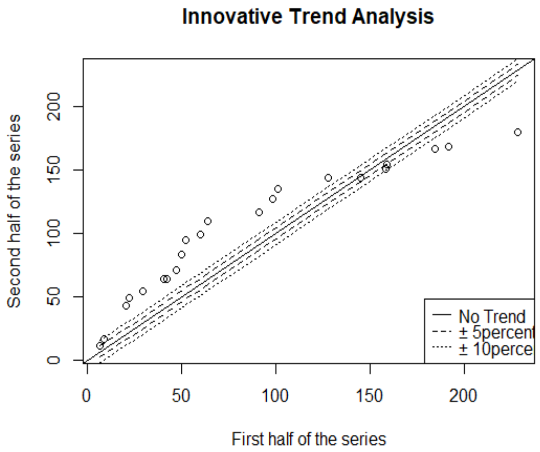

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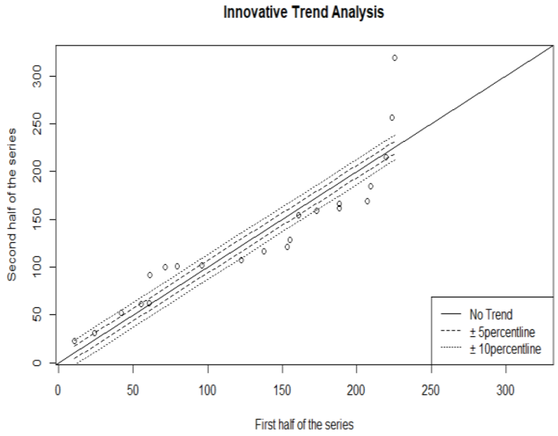

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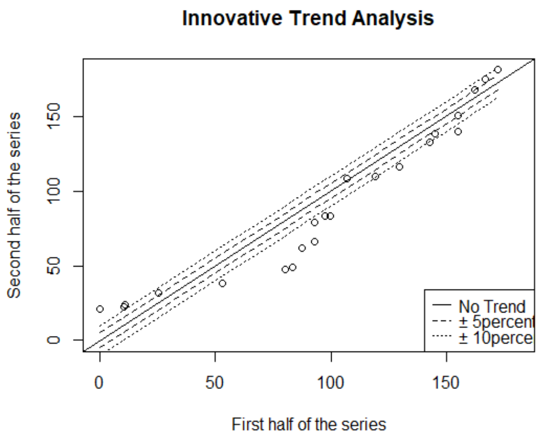

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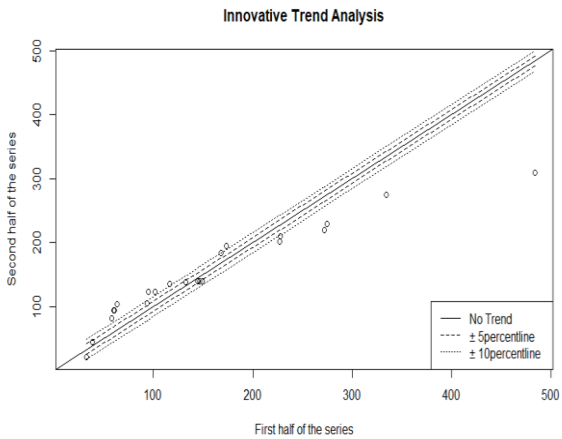
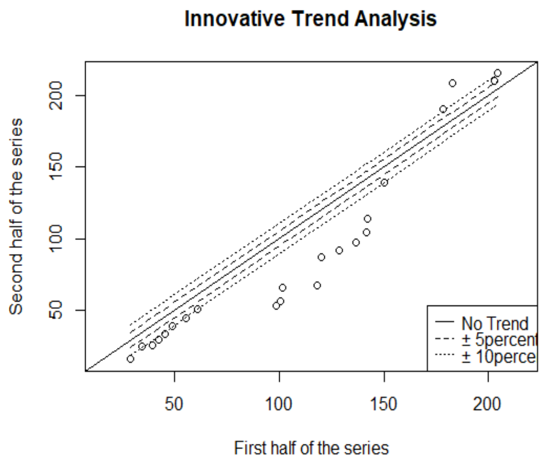


Cox's Bazar



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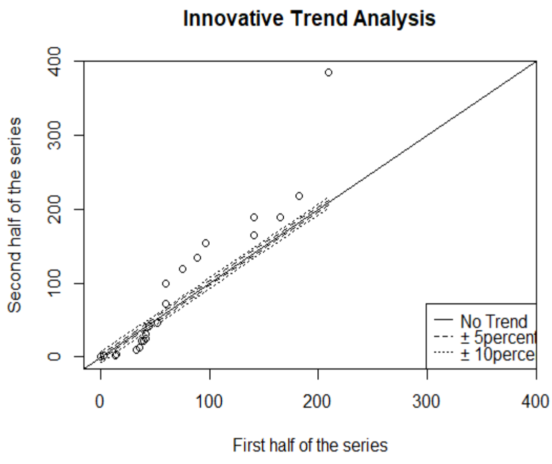

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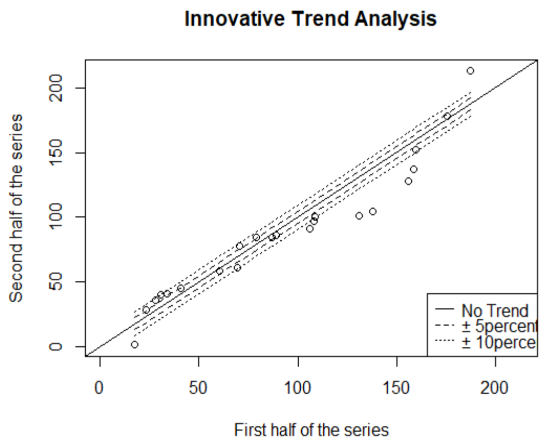

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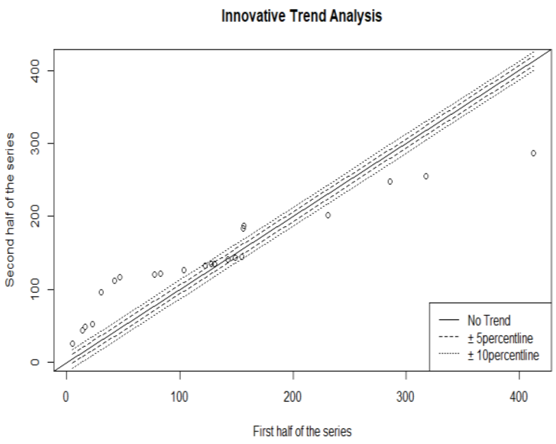

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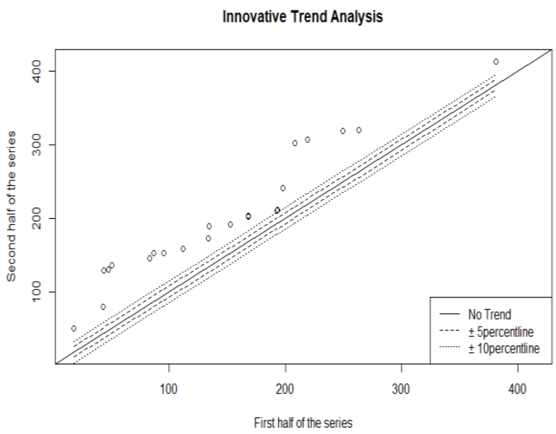

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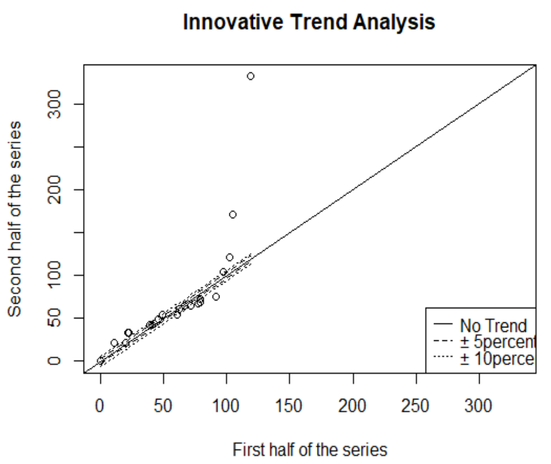

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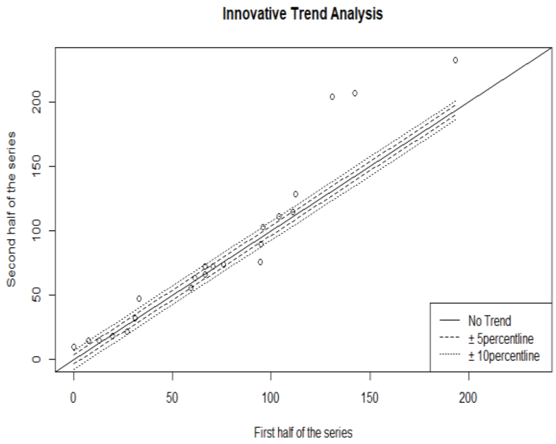

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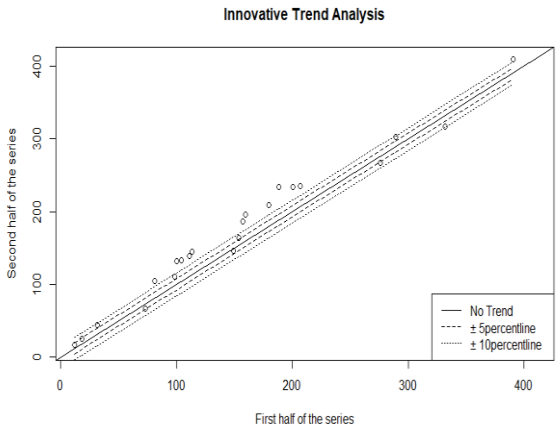

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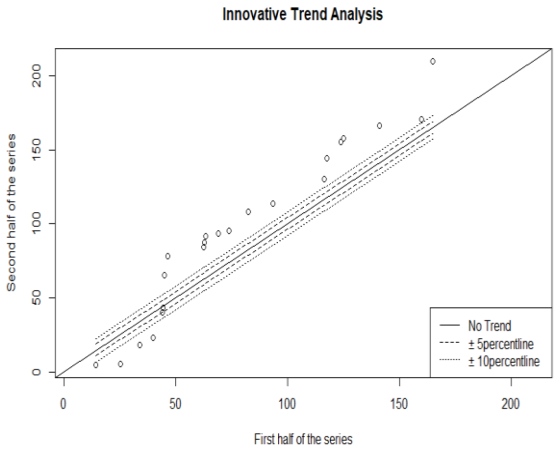

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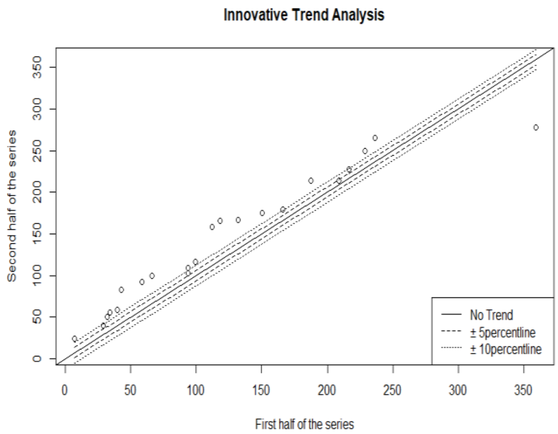

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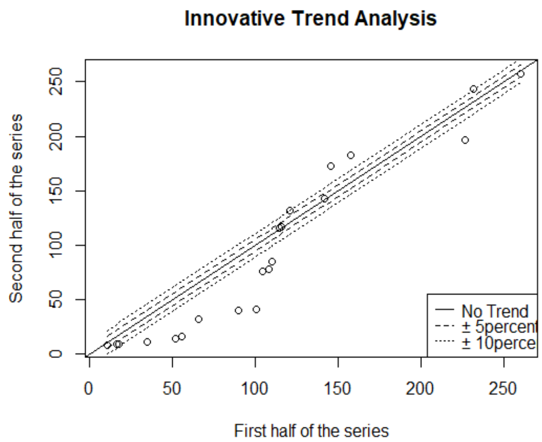

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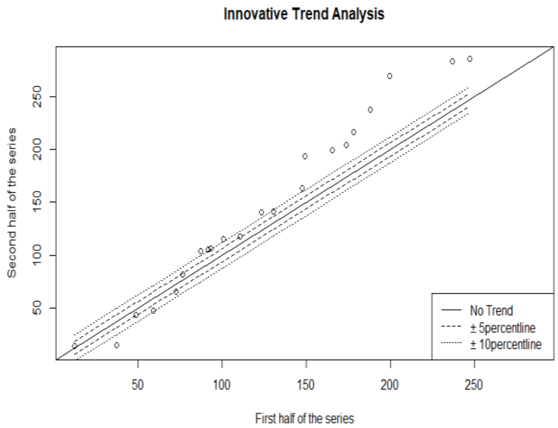

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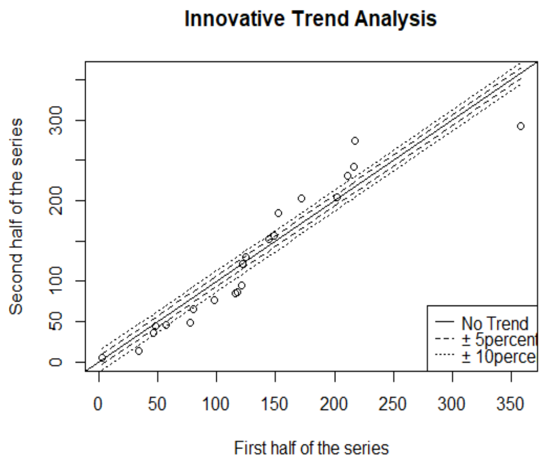

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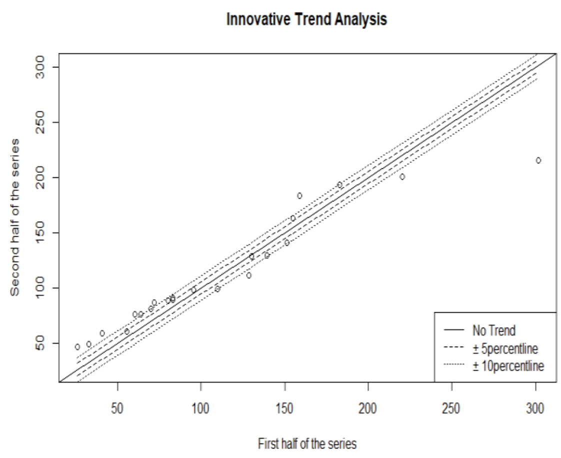

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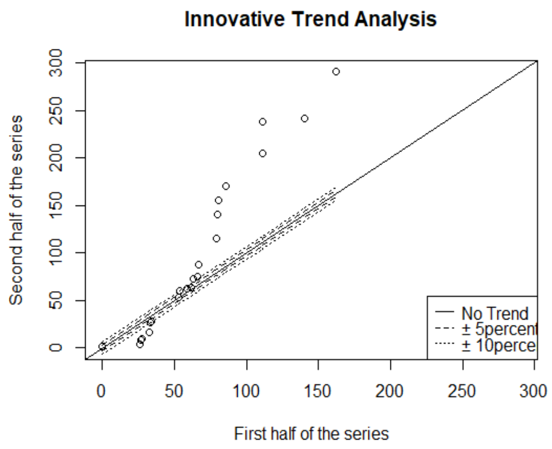

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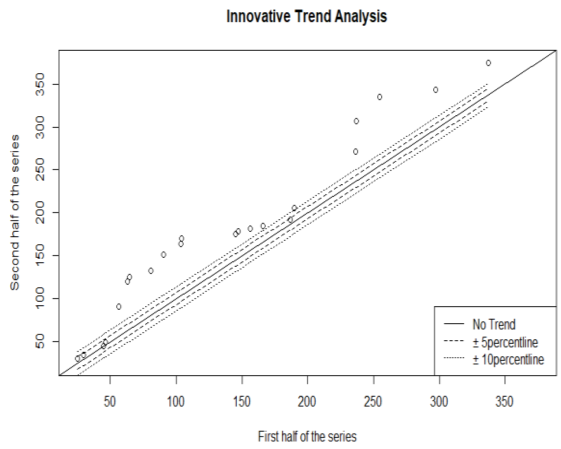

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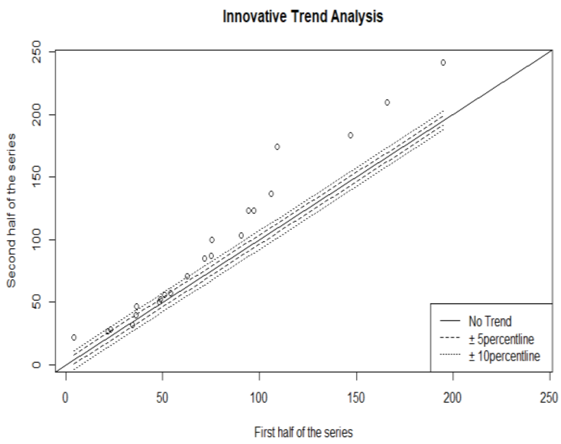

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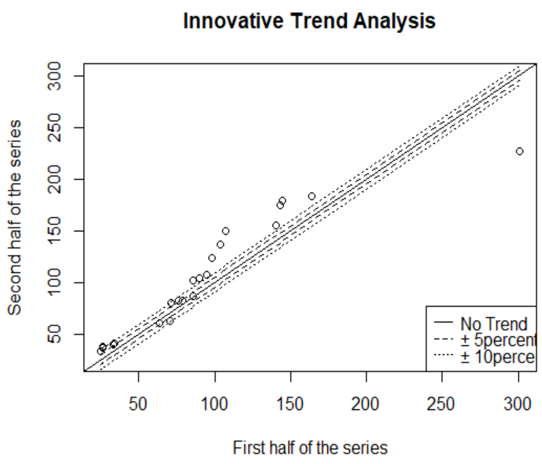

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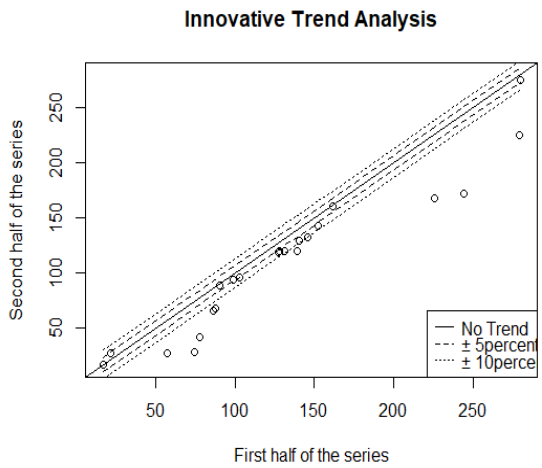

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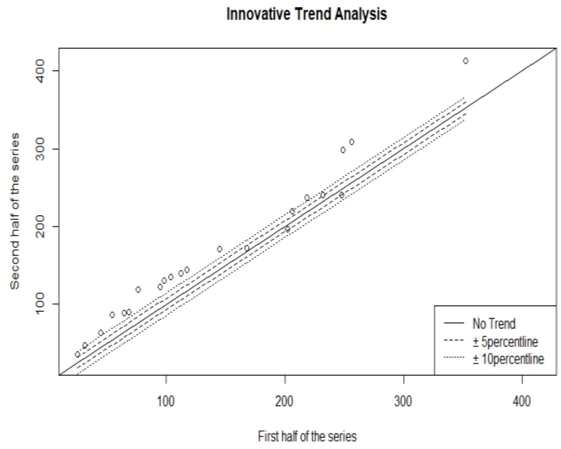

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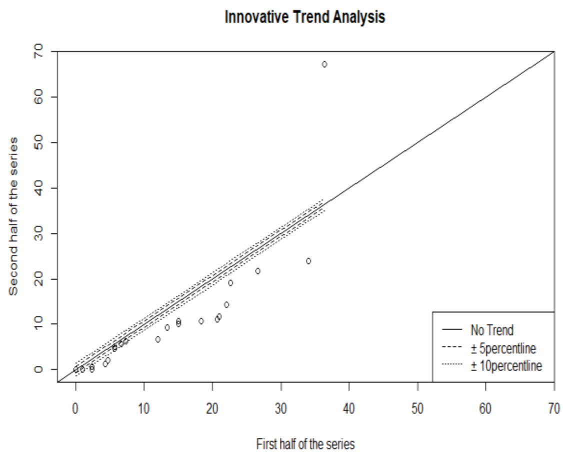

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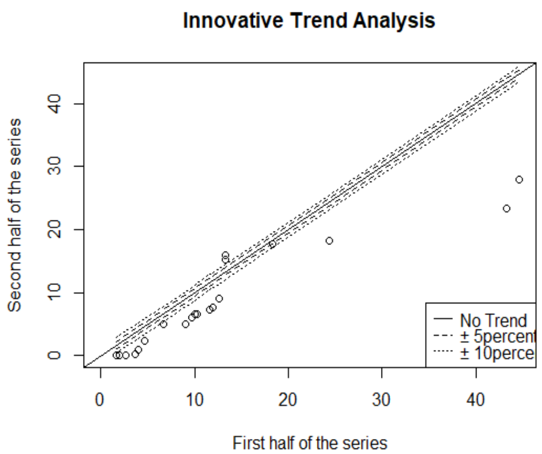

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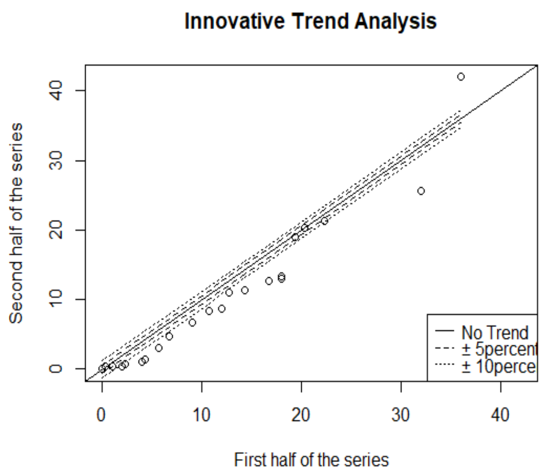

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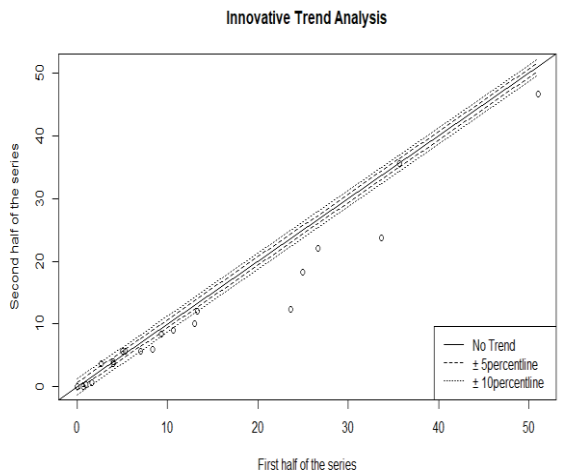

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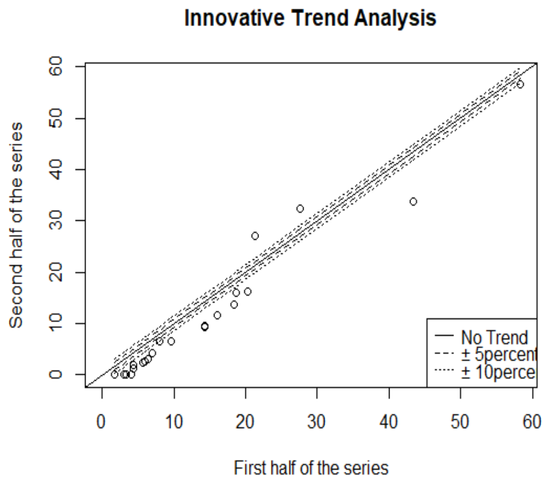

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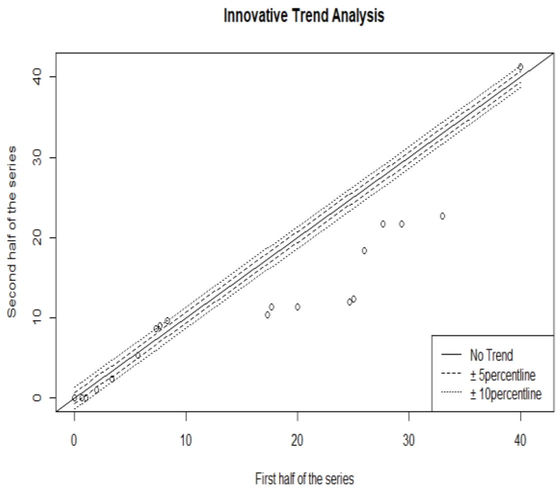
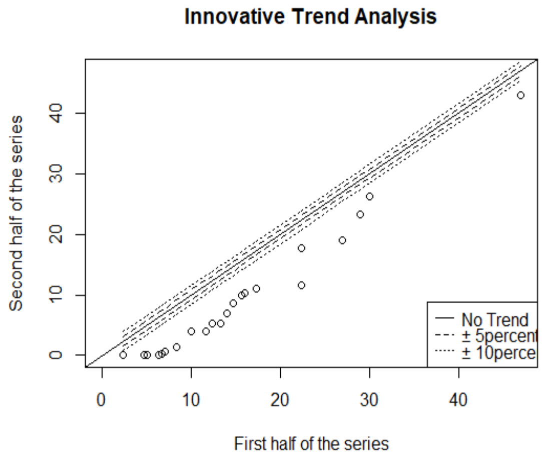


Cox's Bazar



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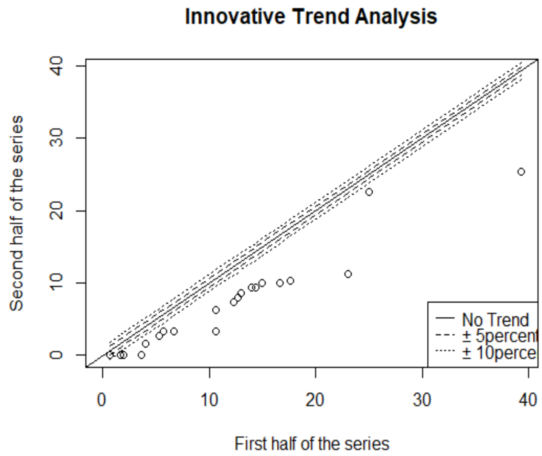

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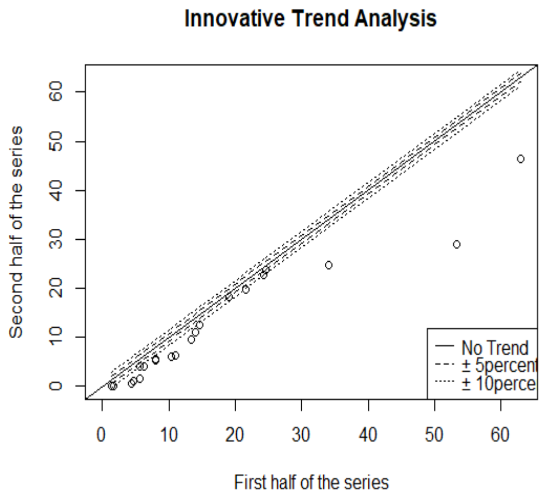

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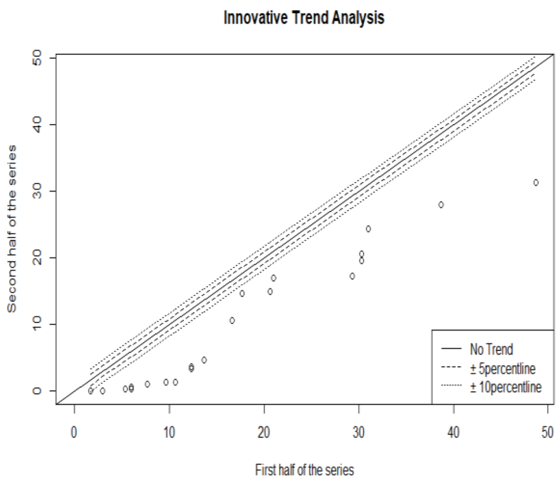
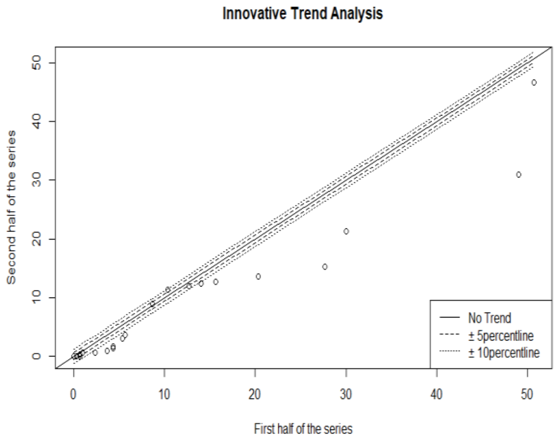


Feni



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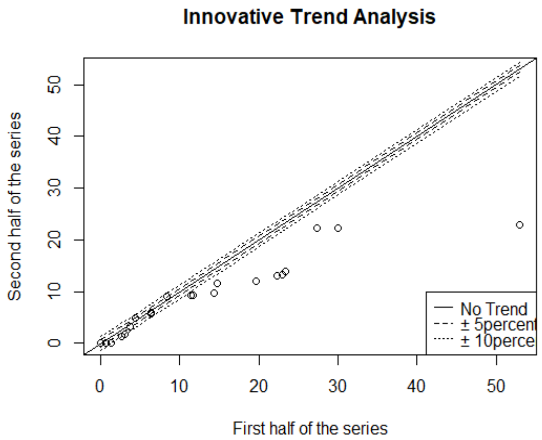

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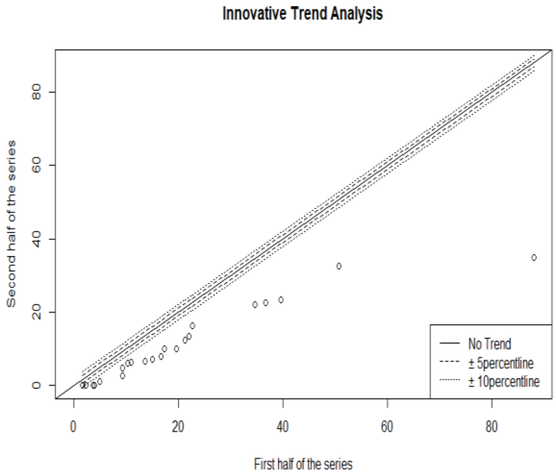

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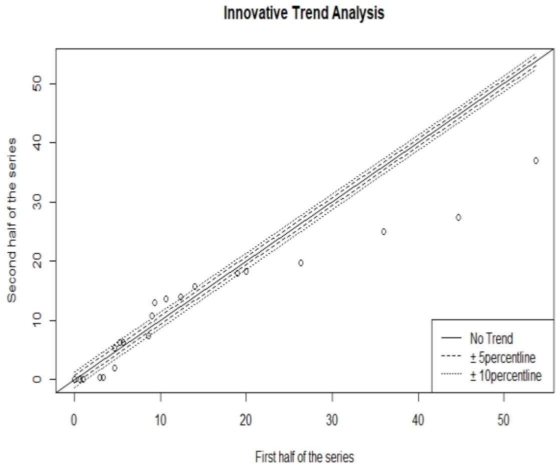

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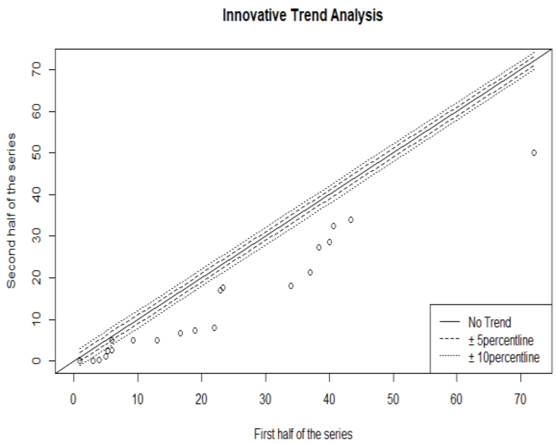

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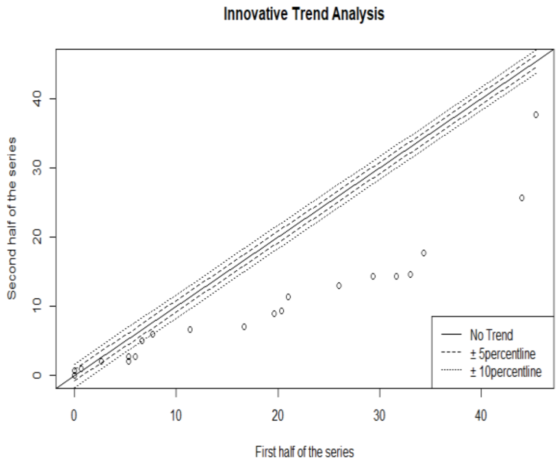

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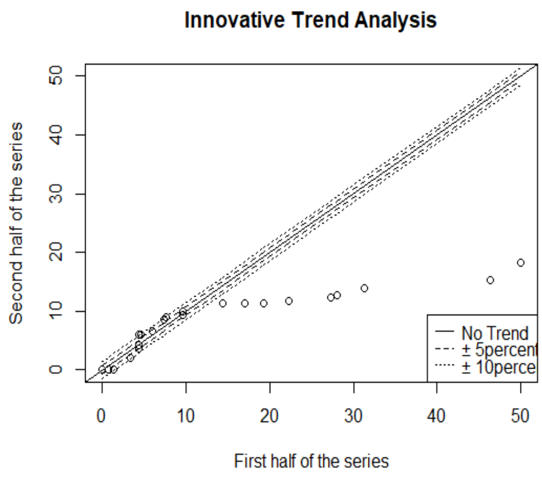

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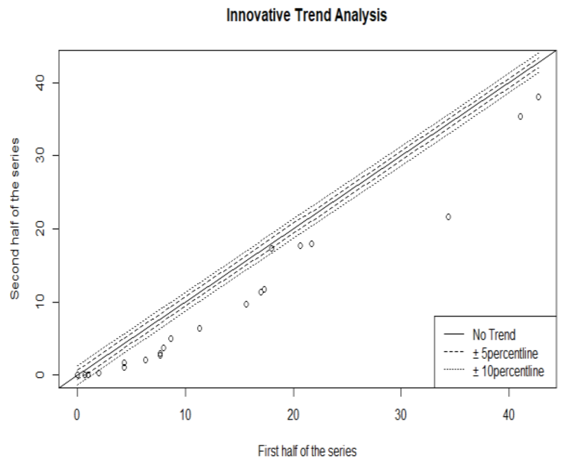

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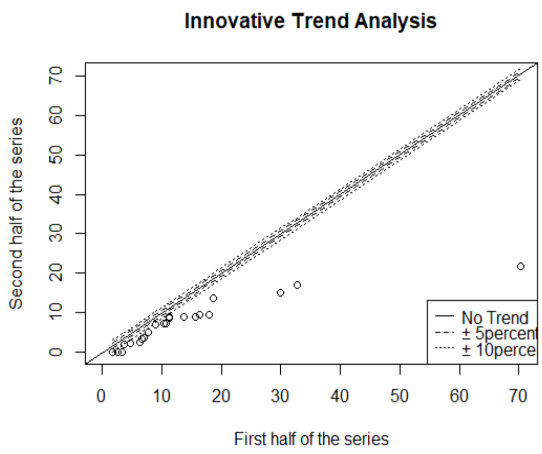

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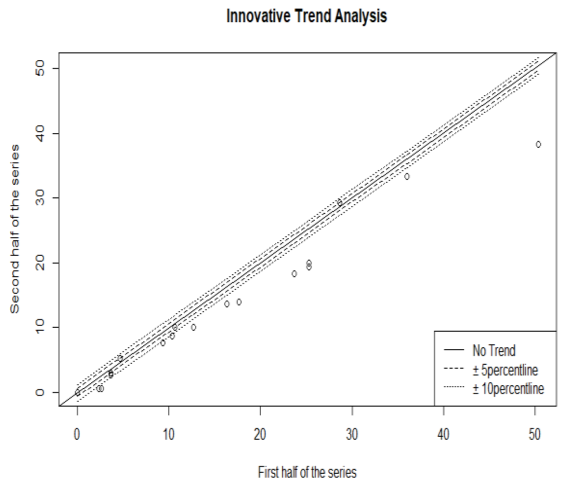

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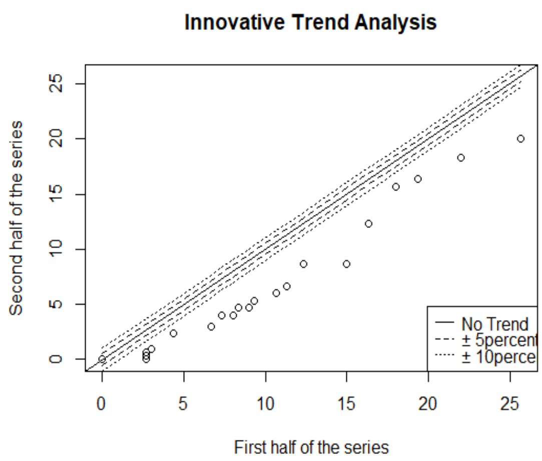

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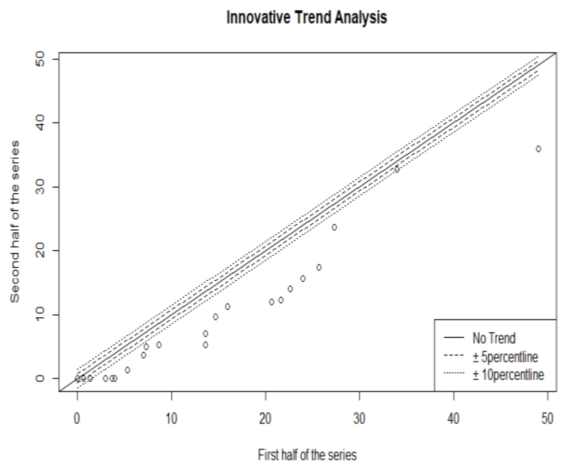

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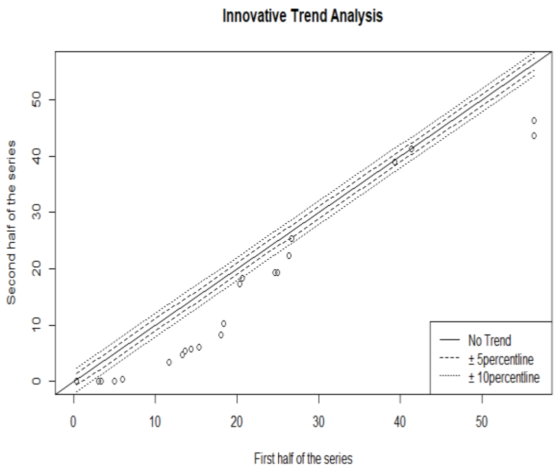

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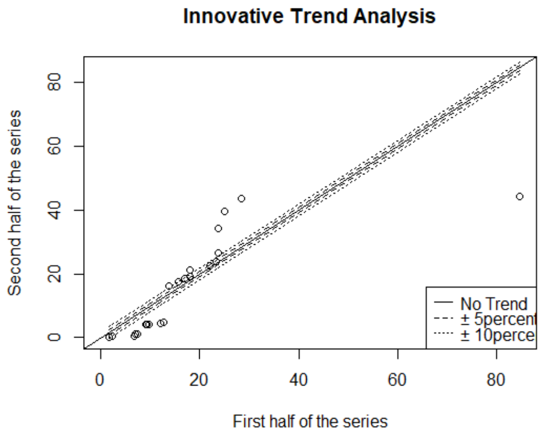

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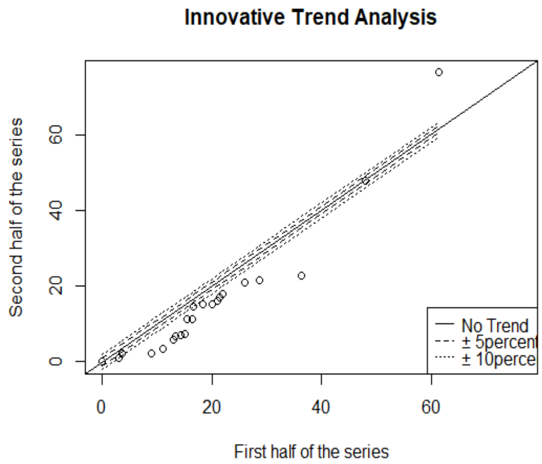

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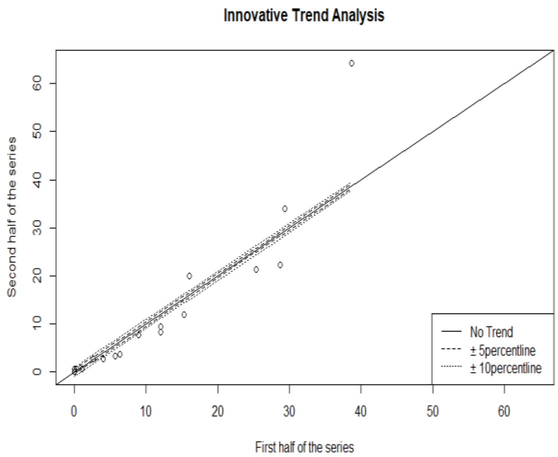
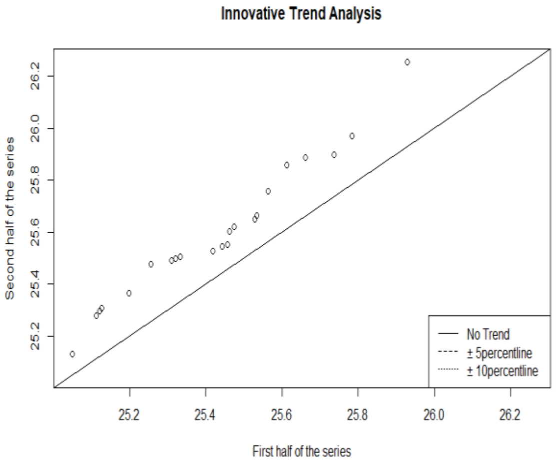


Teknaf

Dry

Figure A.3: Plot of innovative trends of annual average rainfall series for the time period of 1975–2019



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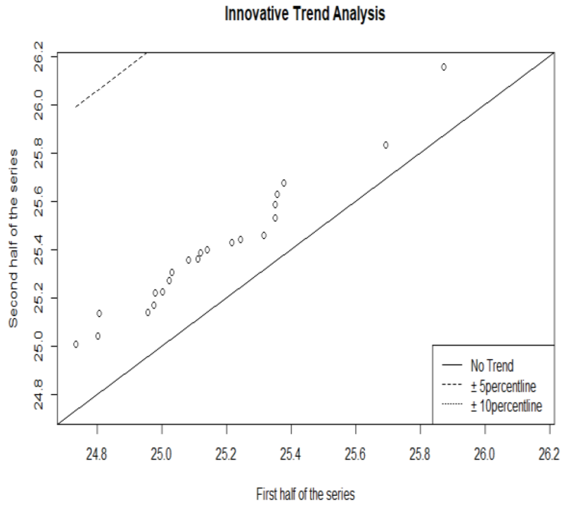
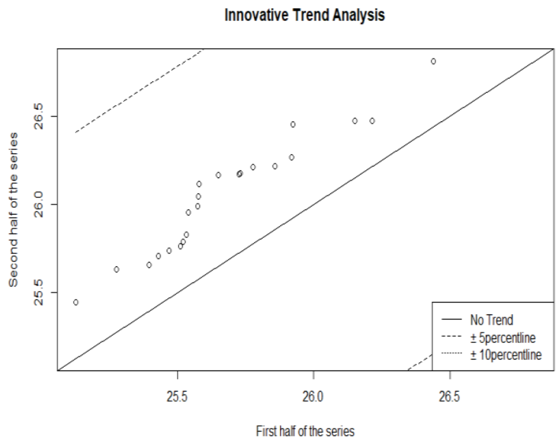


Bogra



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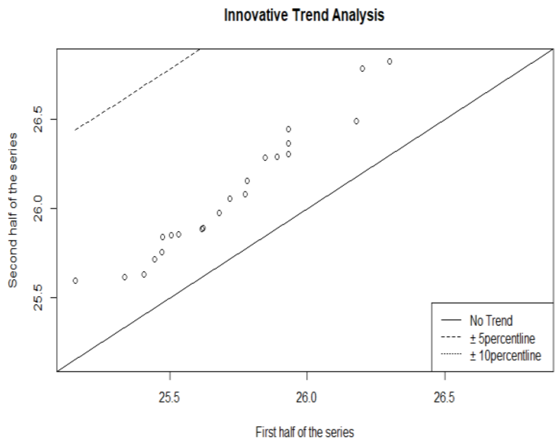

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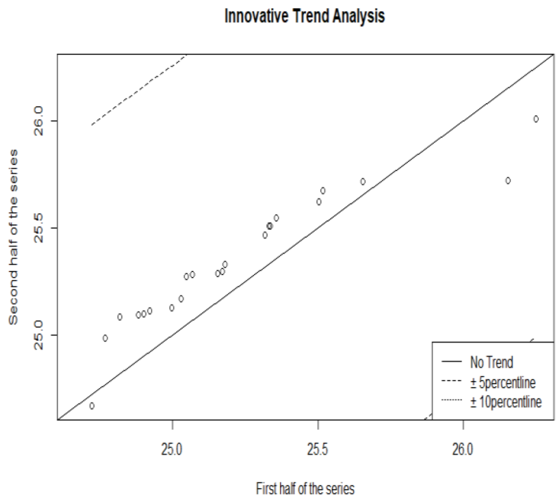

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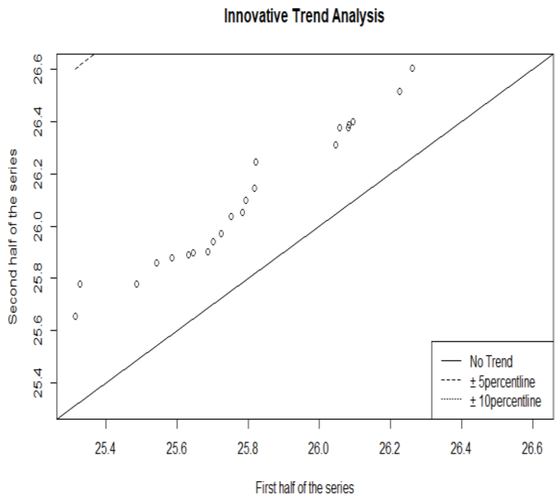
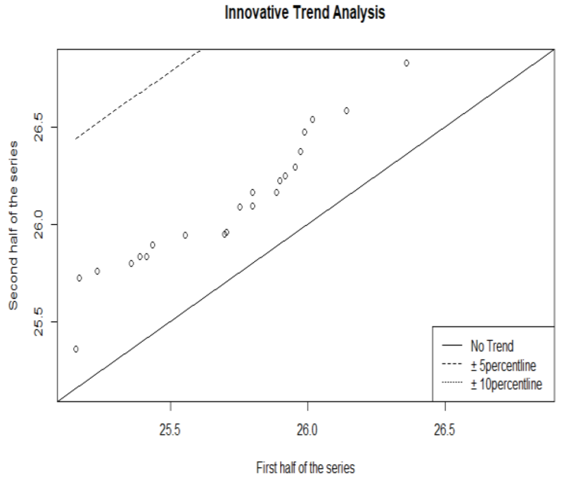
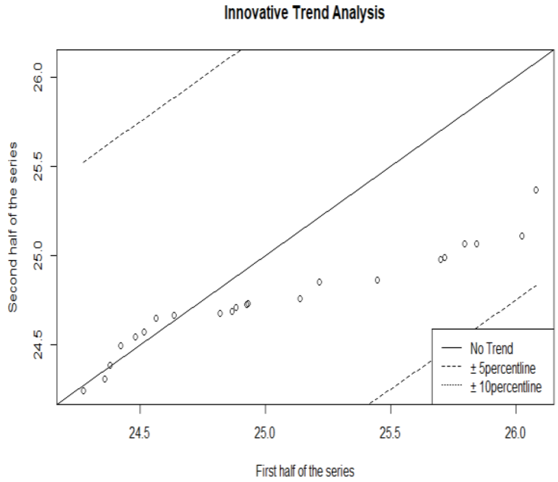


Cox's Bazar



Dhaka



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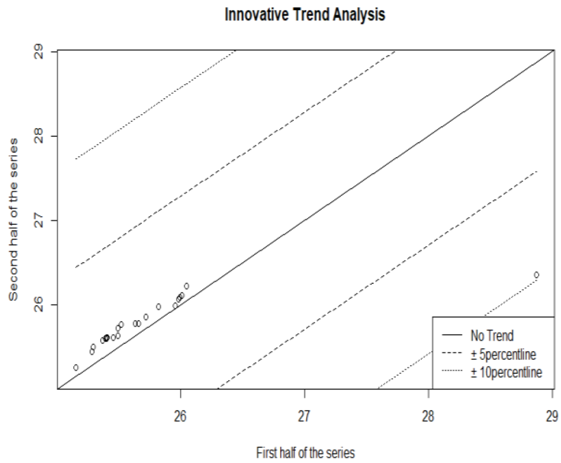

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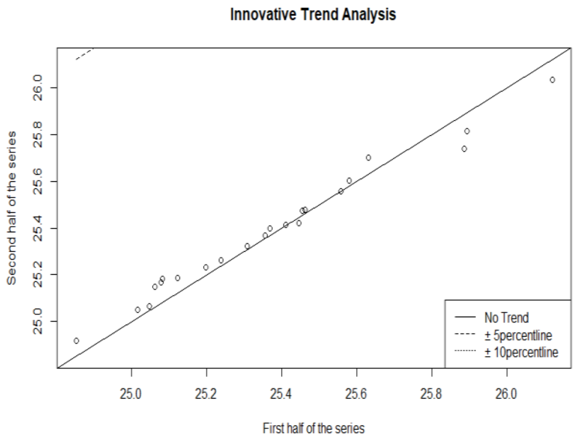

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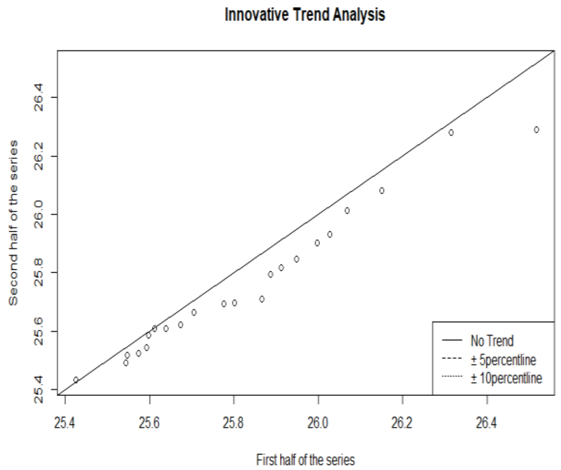

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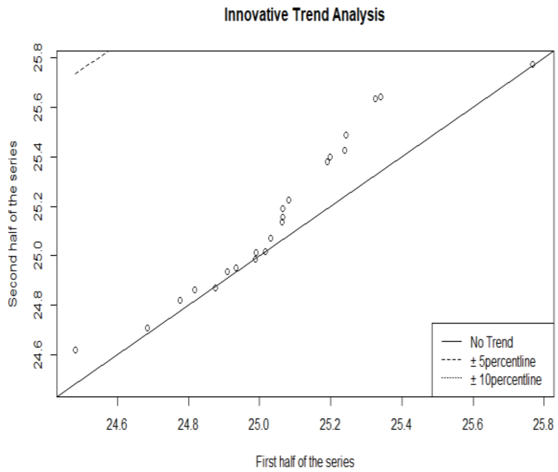

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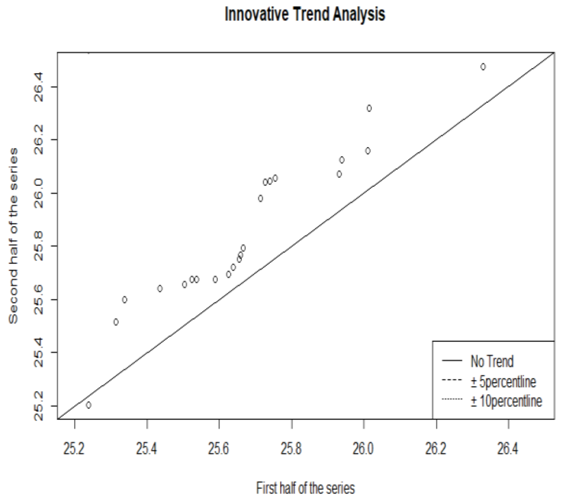

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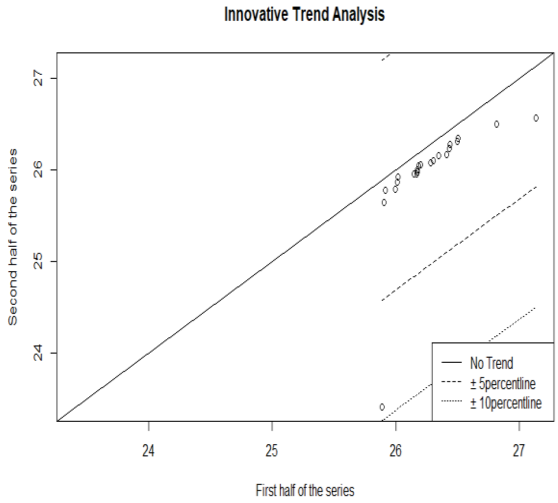

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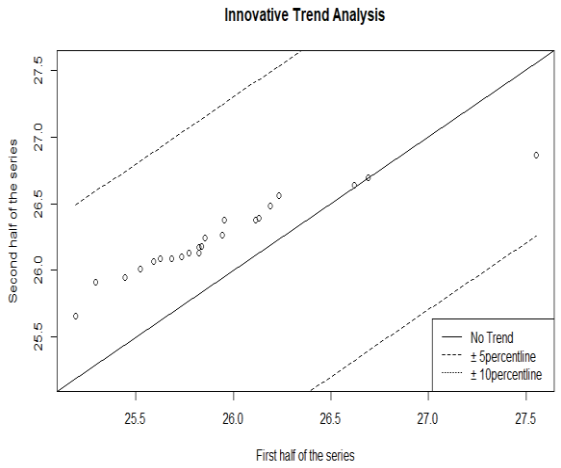

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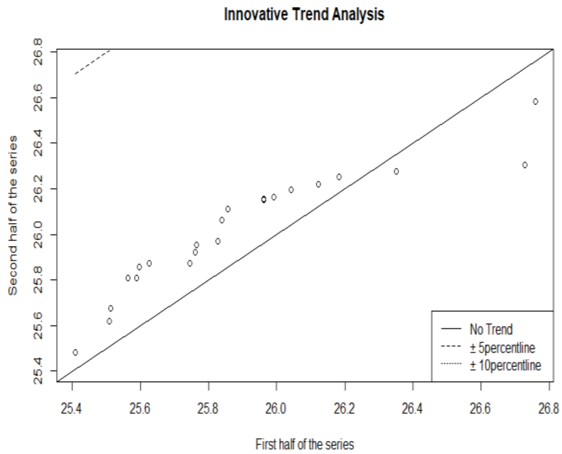
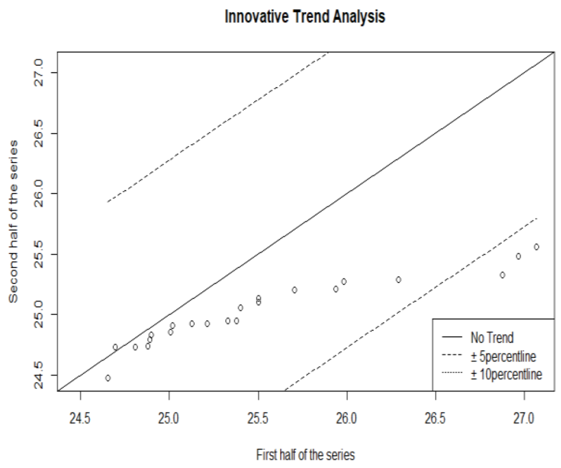


M. Court



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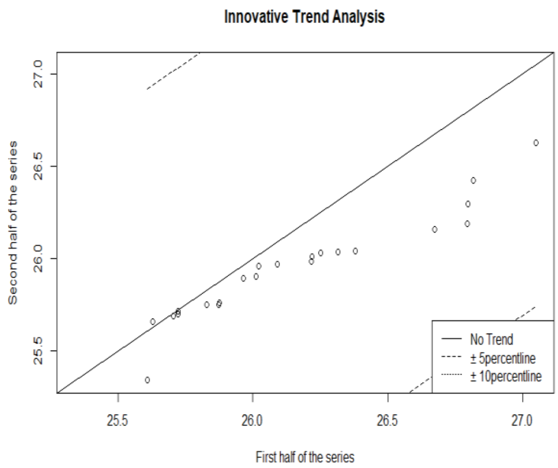

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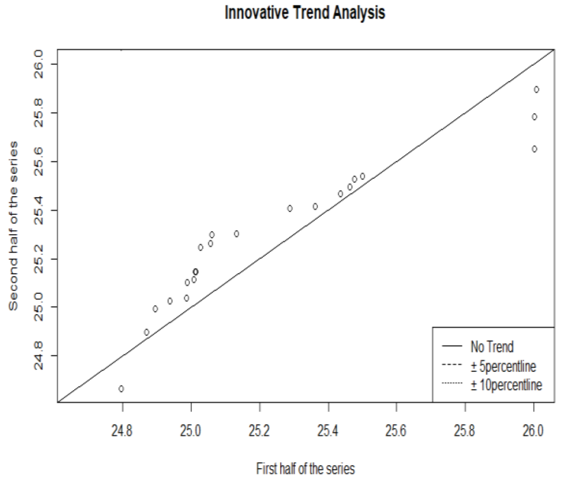

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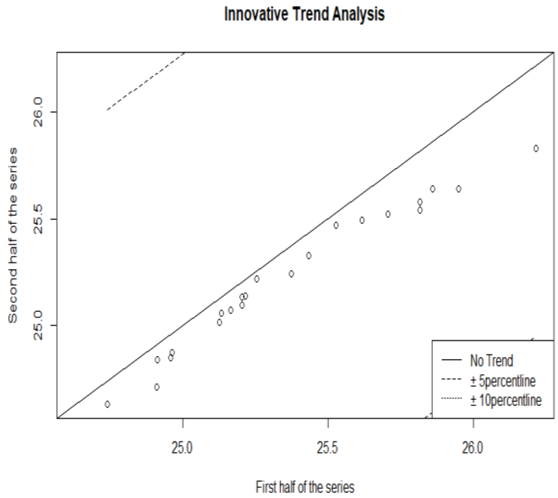

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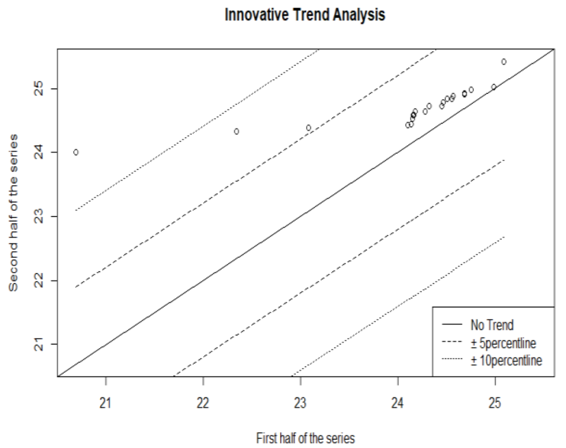

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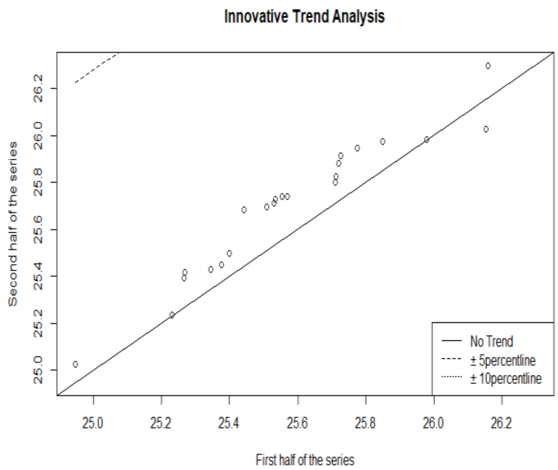

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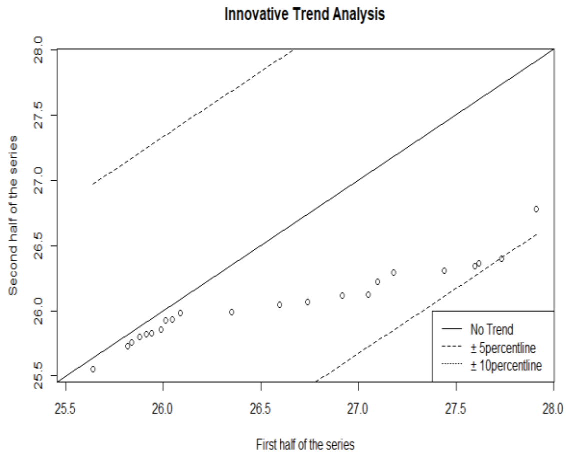

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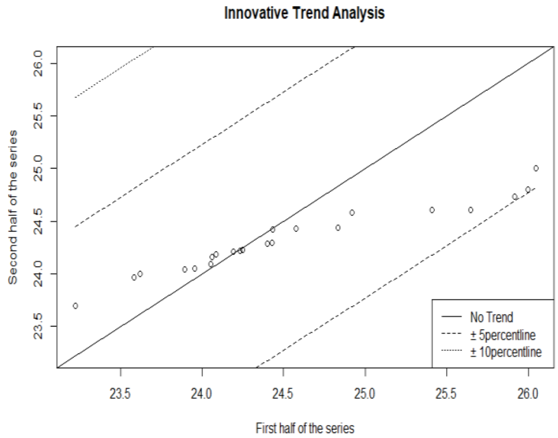

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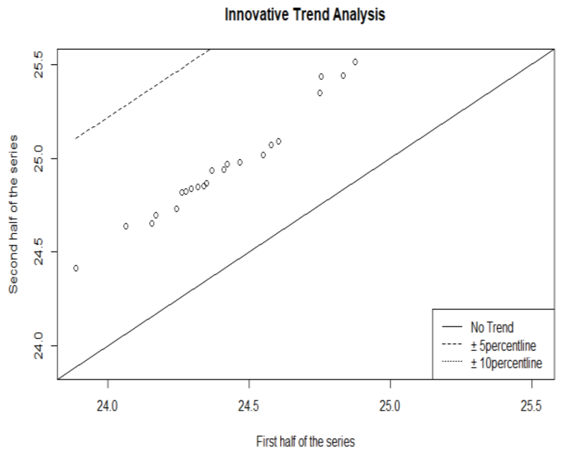

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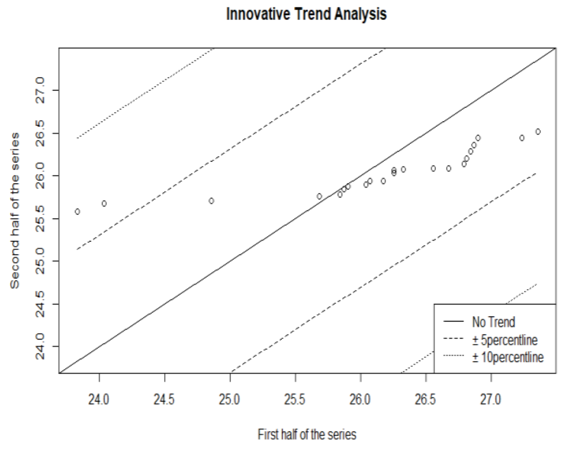

Teknaf

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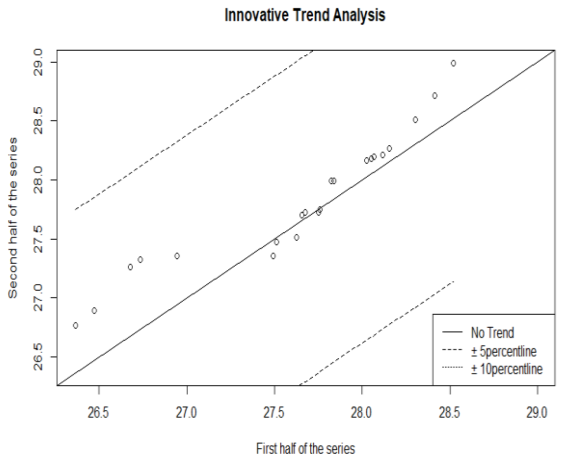

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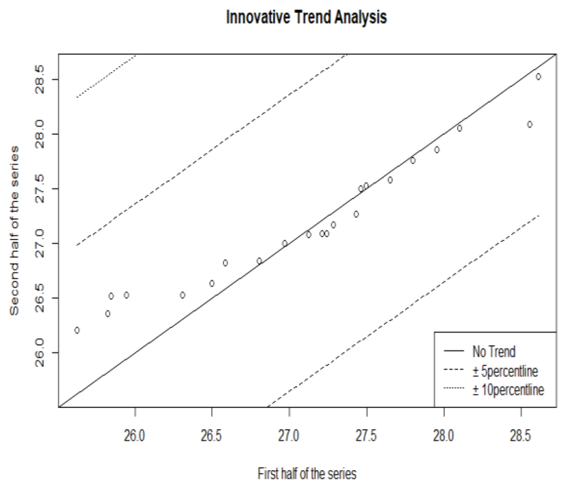

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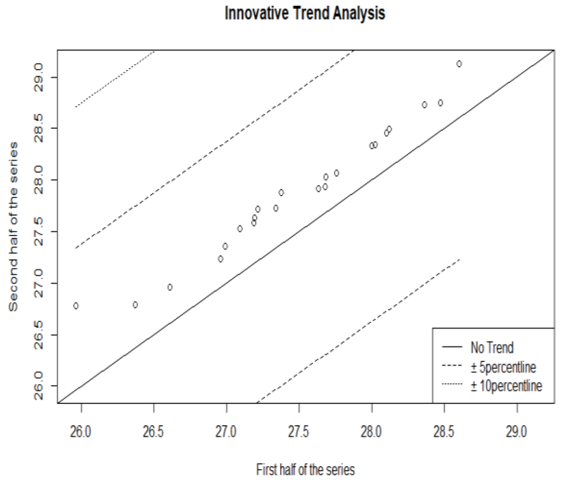

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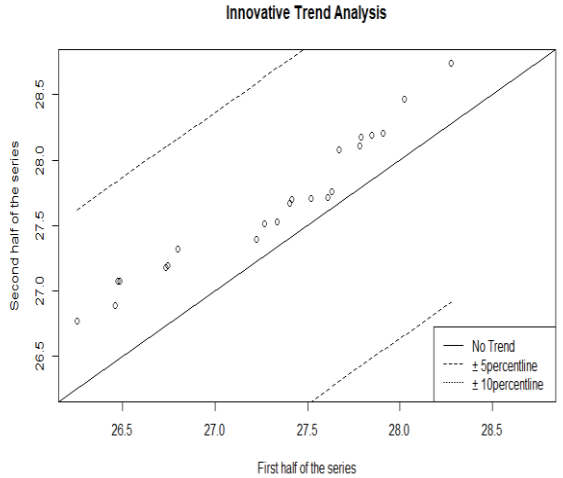

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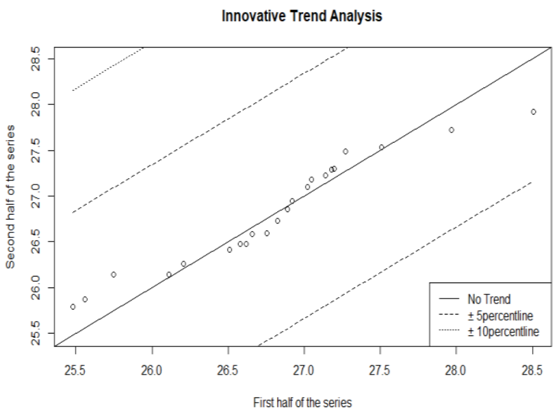

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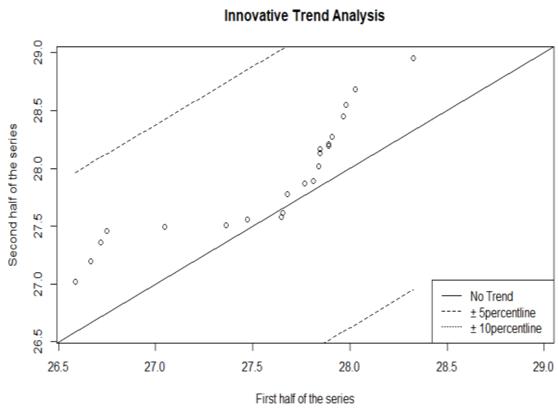

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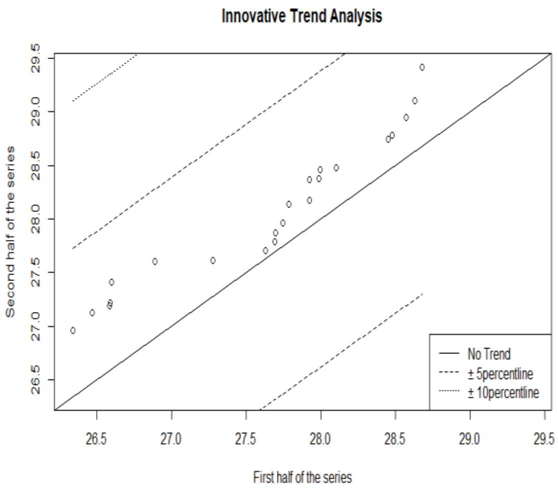

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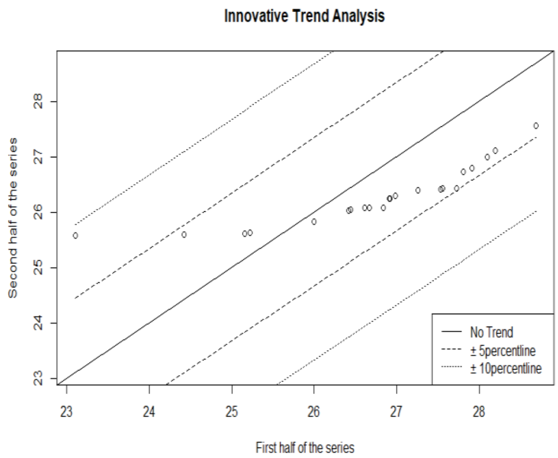

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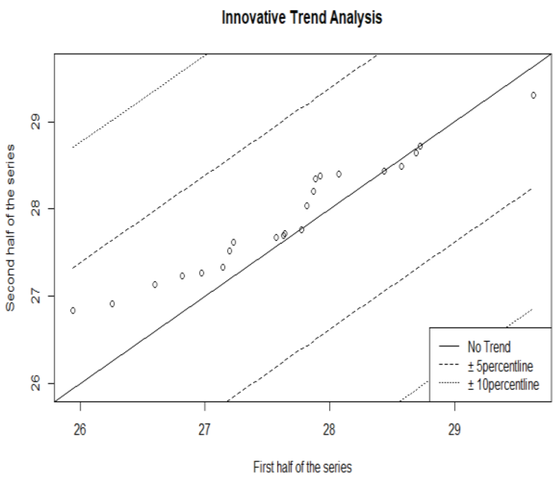

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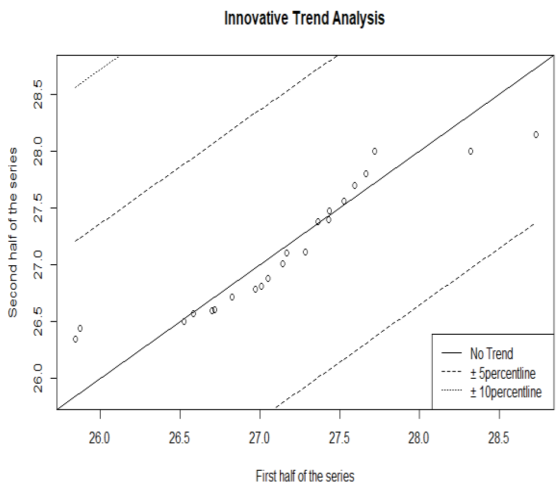

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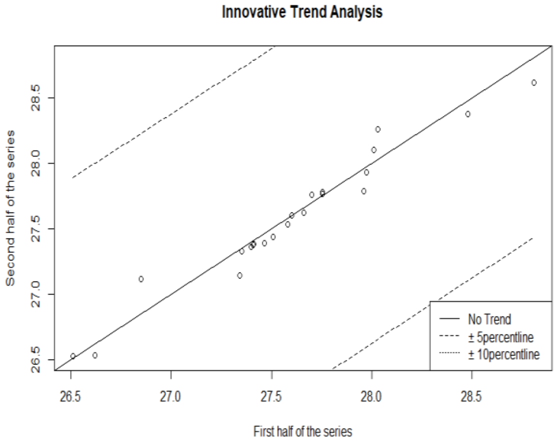

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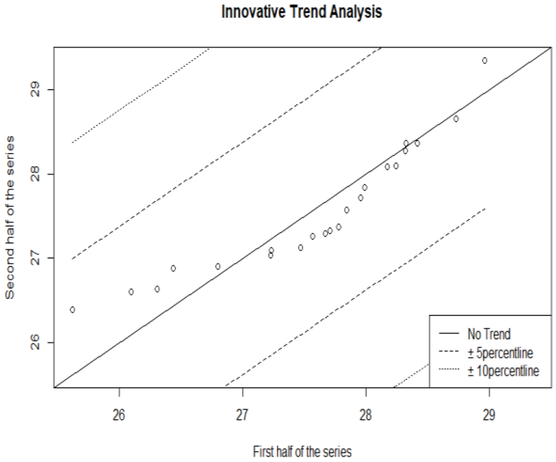

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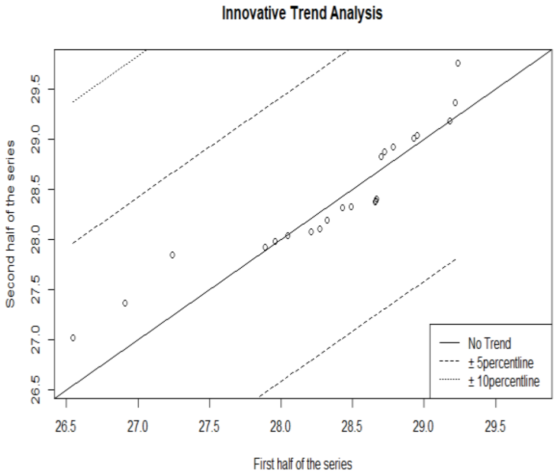

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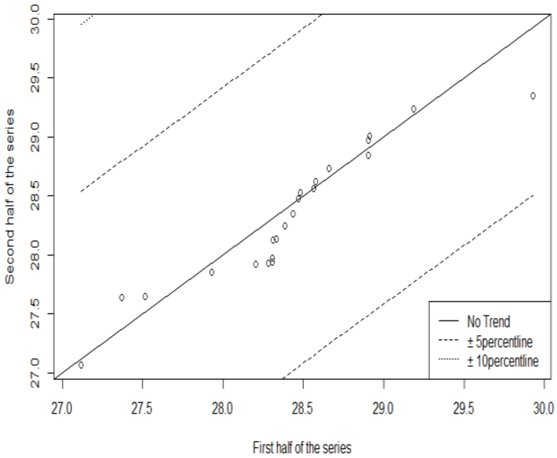

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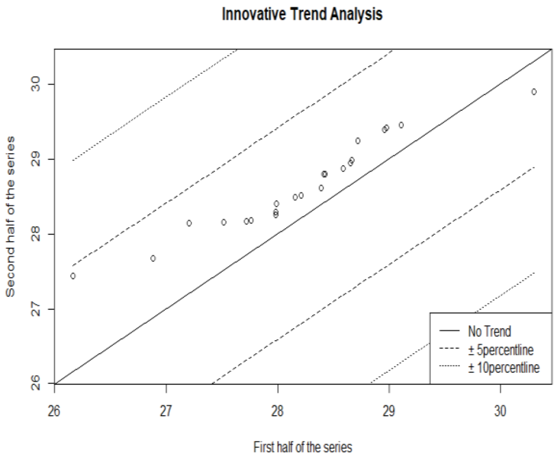

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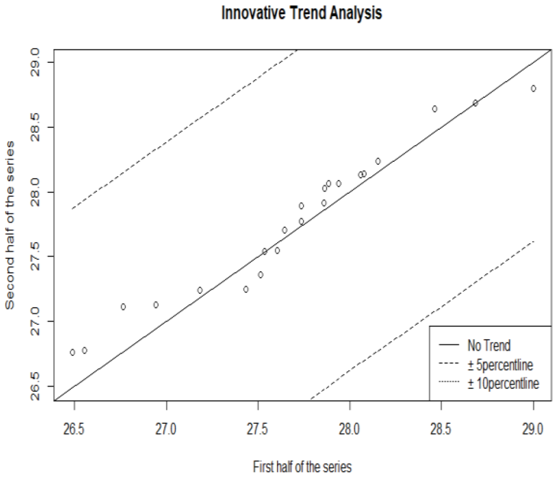

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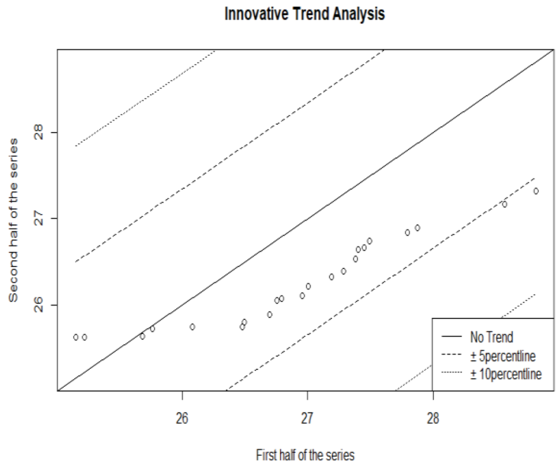

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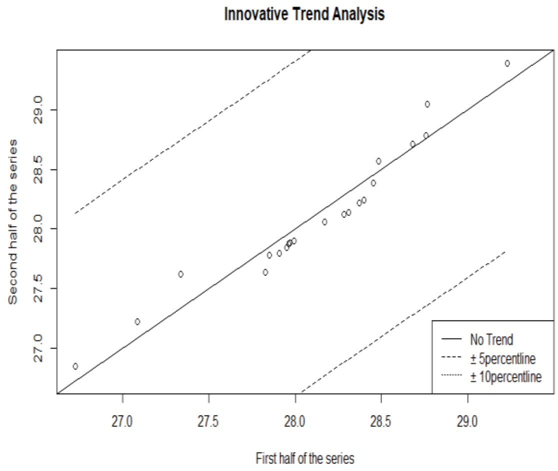

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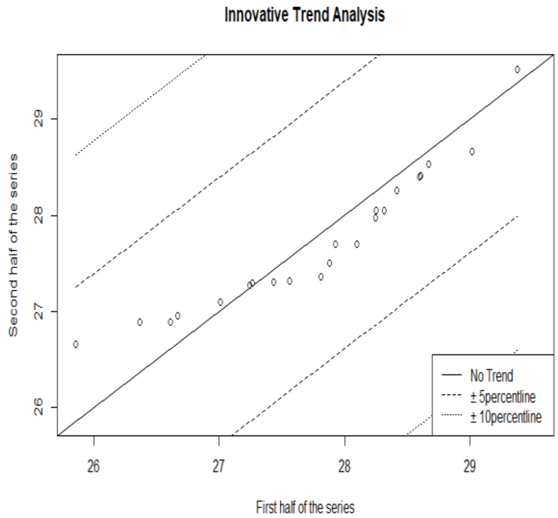

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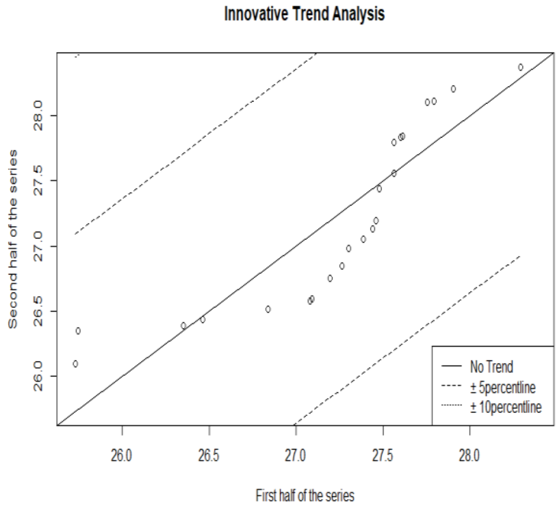

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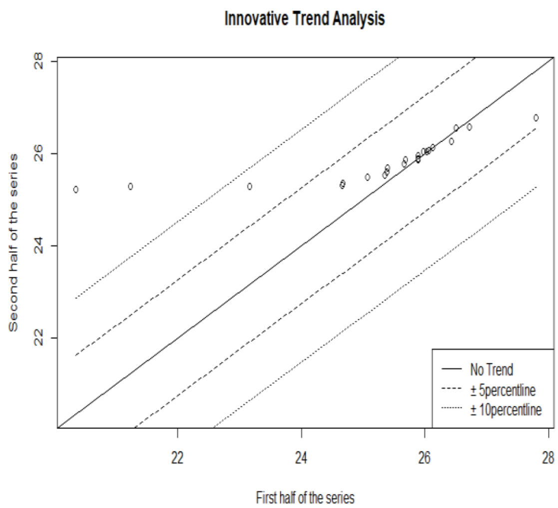

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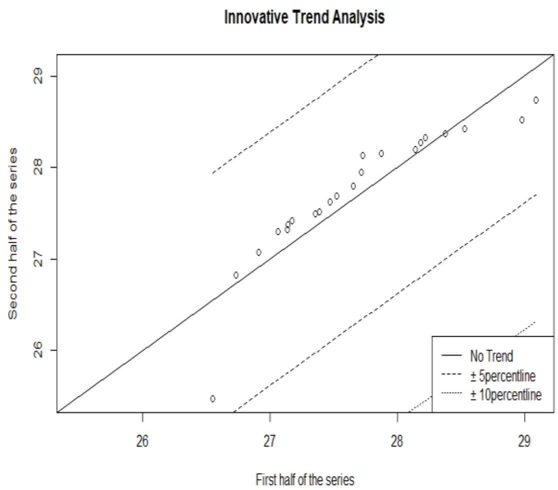

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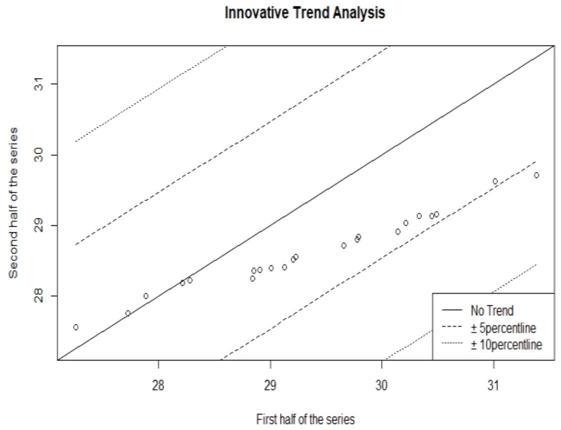

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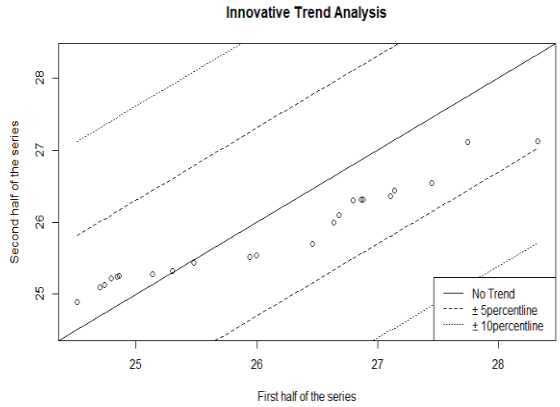

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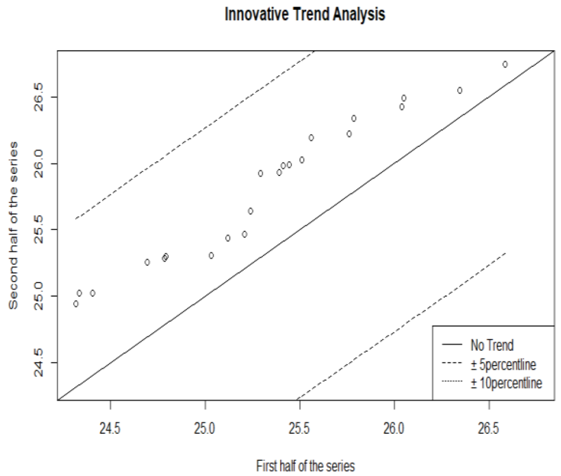

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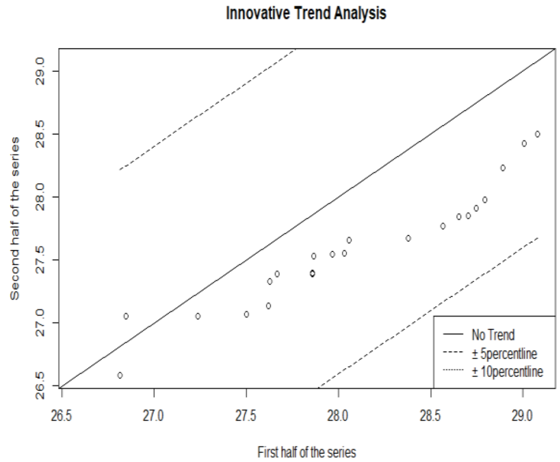
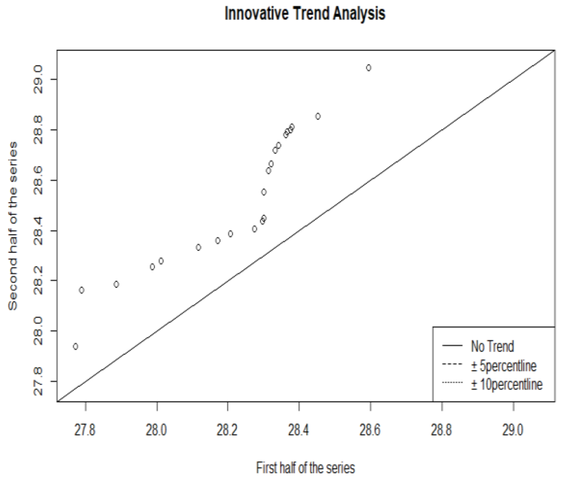


Teknaf

Pre-Monsoon



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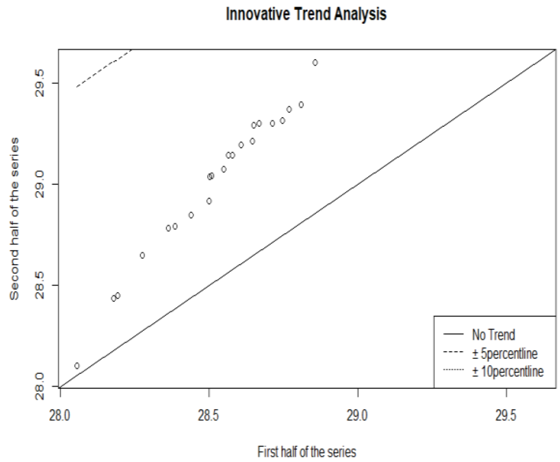

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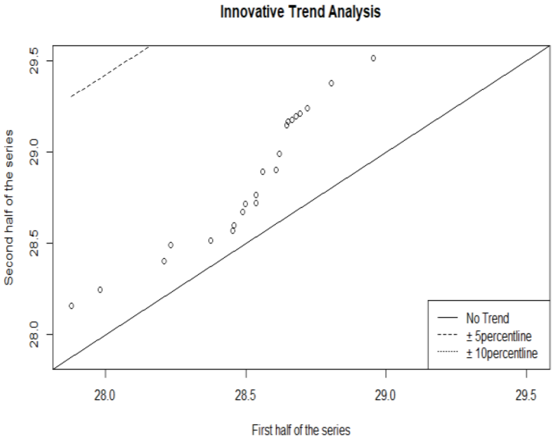

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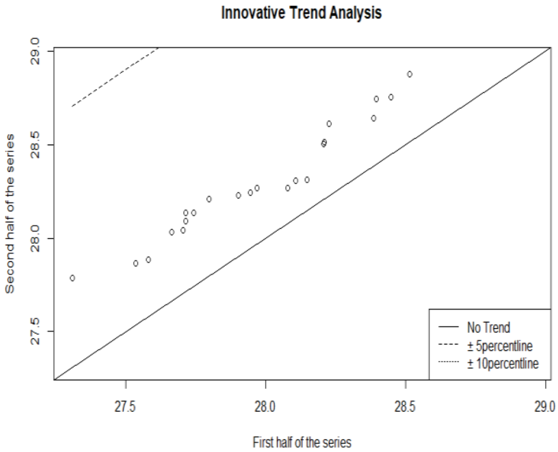

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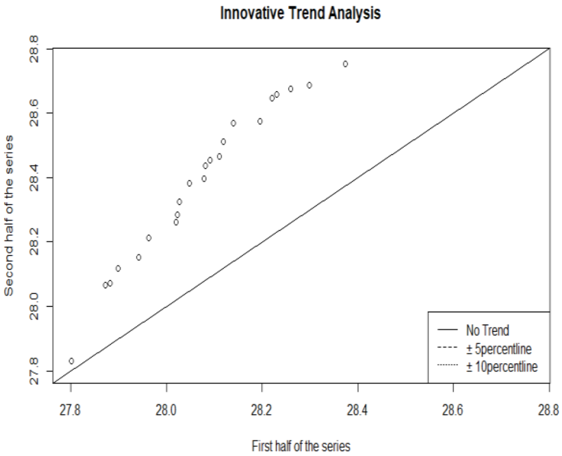

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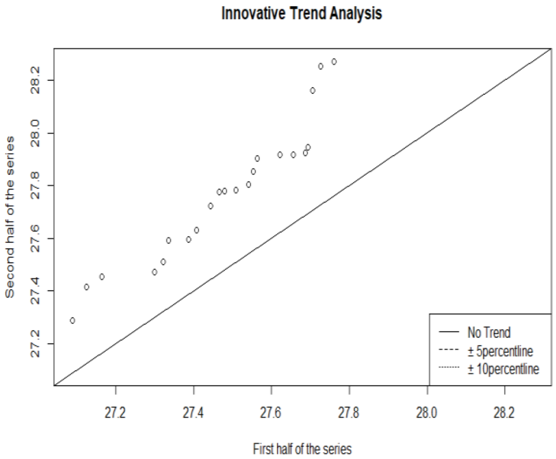

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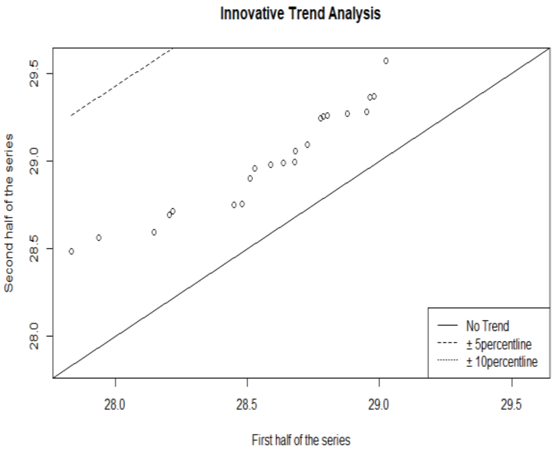

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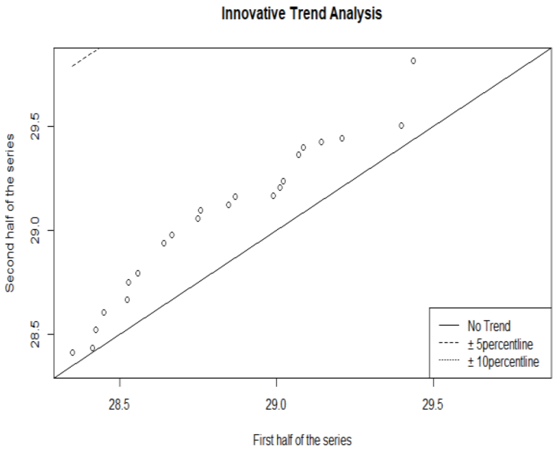

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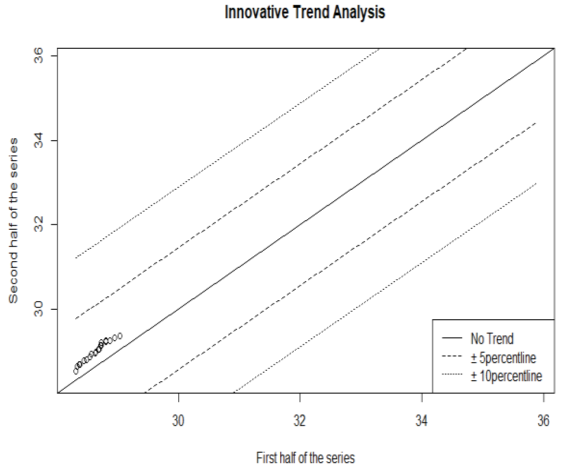

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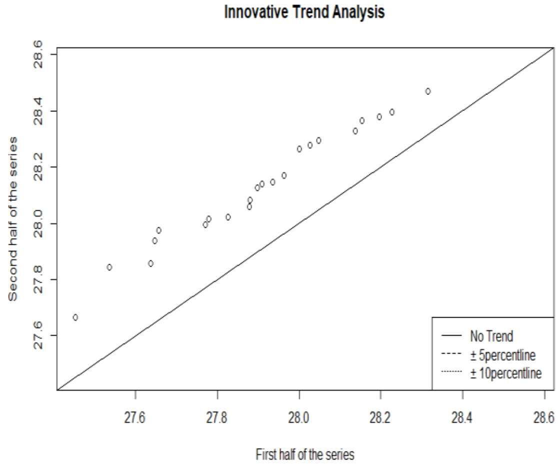

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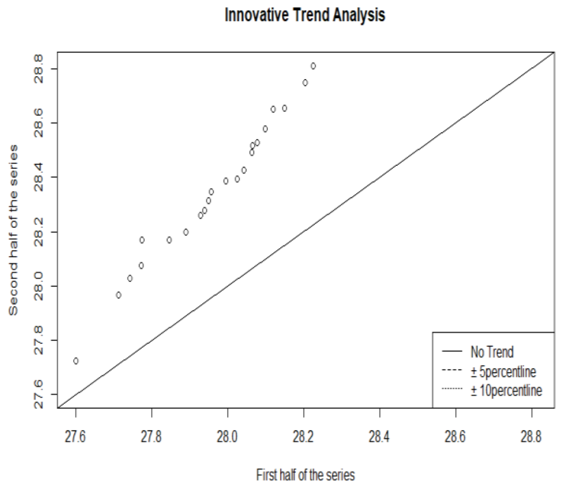

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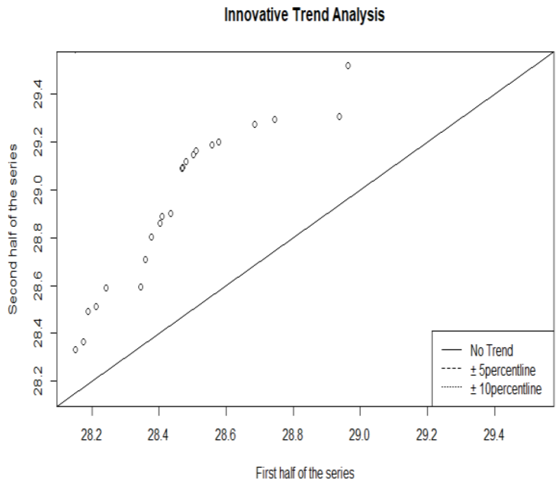

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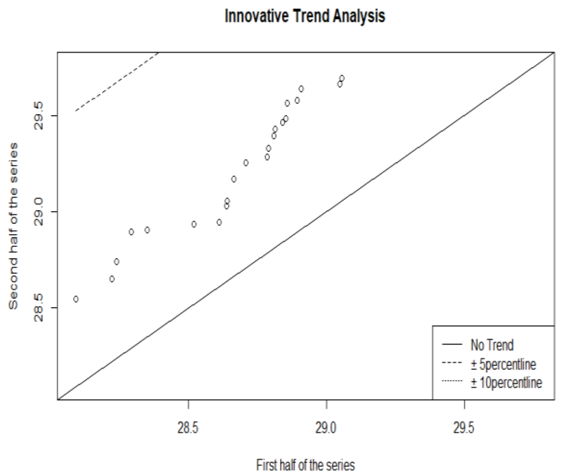

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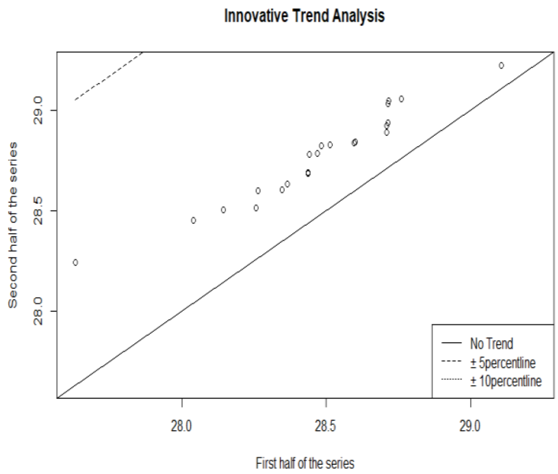

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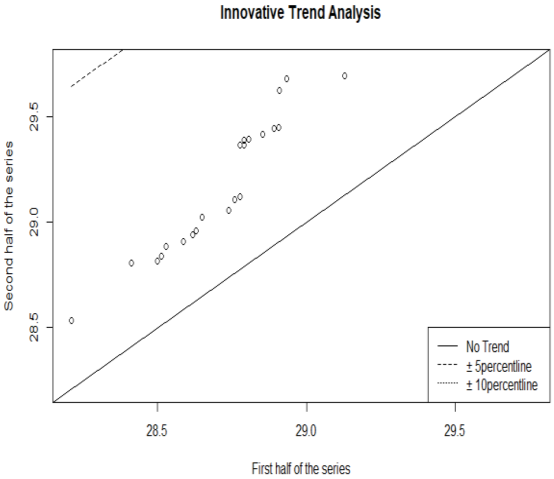

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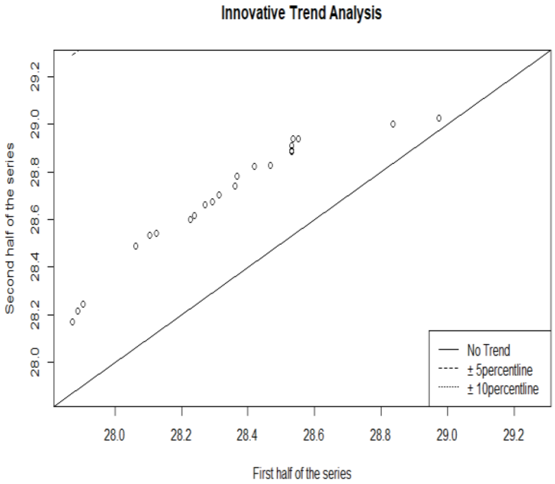

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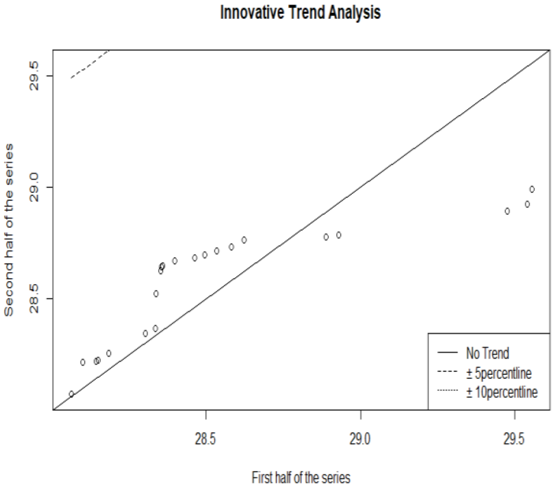

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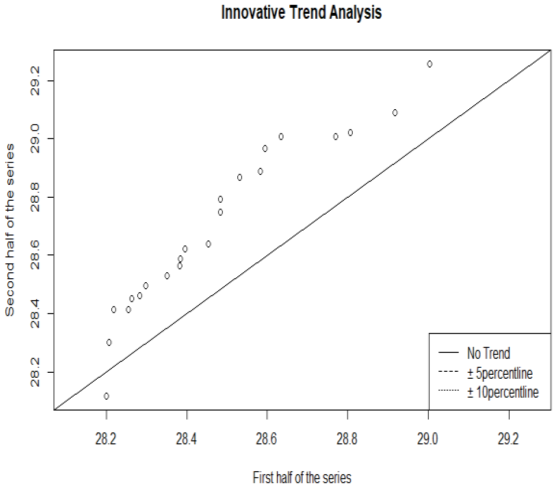

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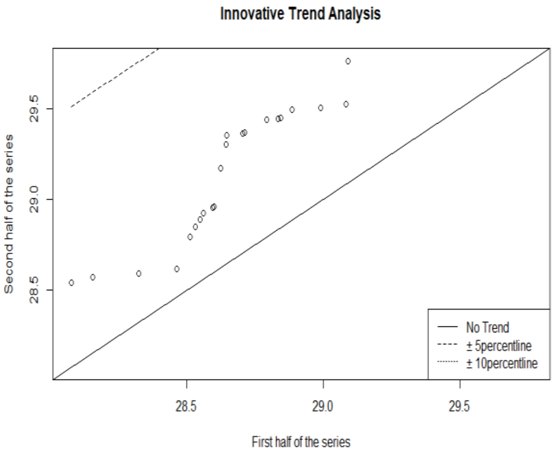

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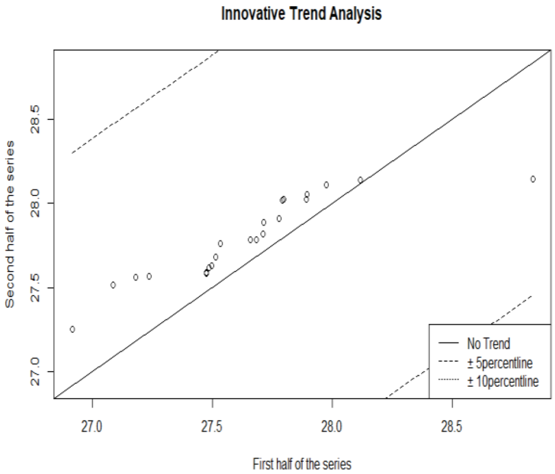

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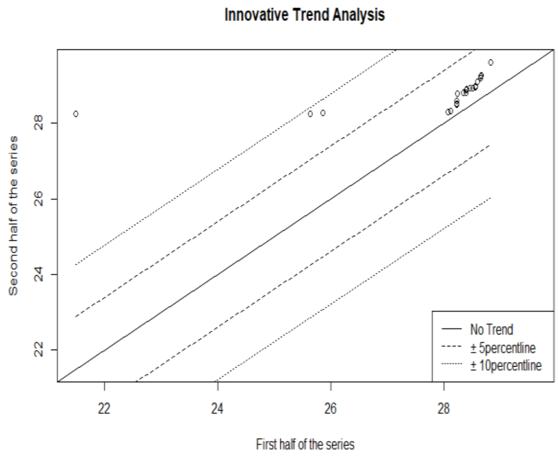

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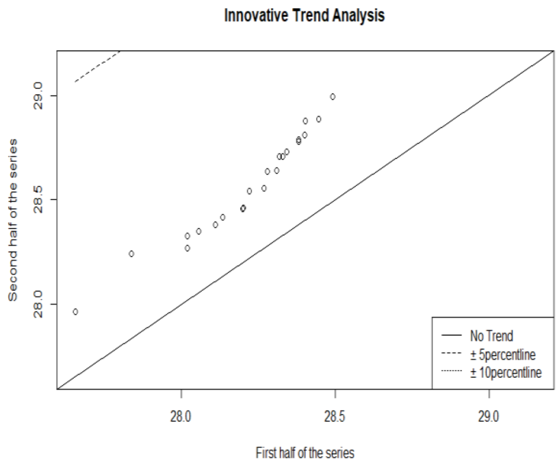

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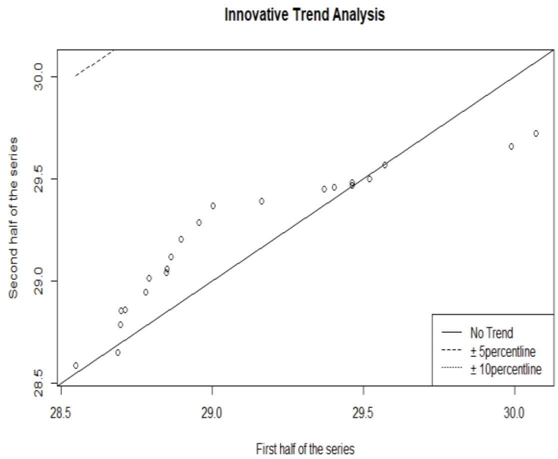

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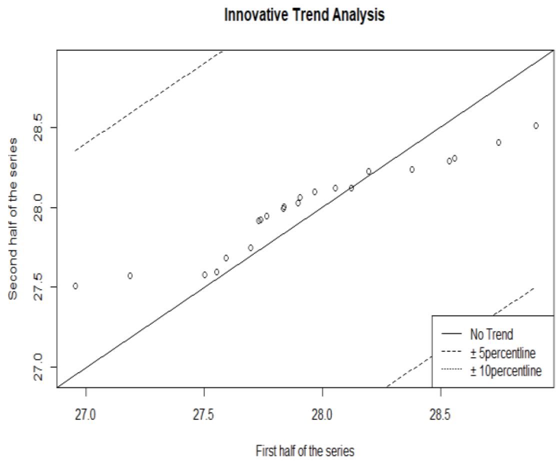

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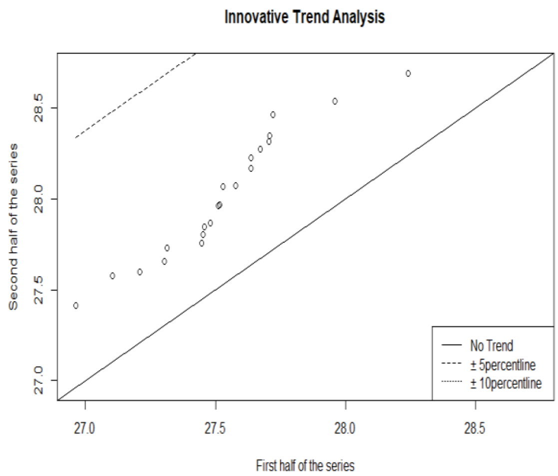

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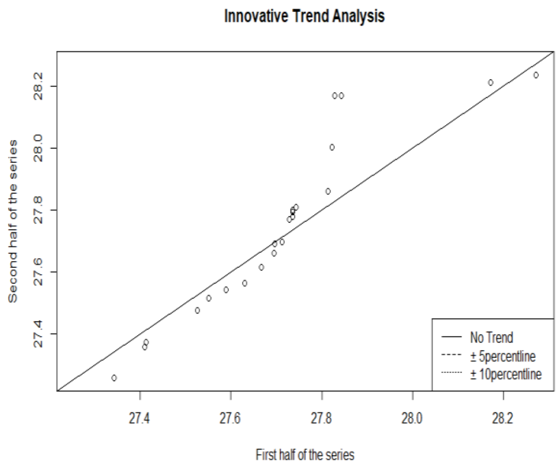

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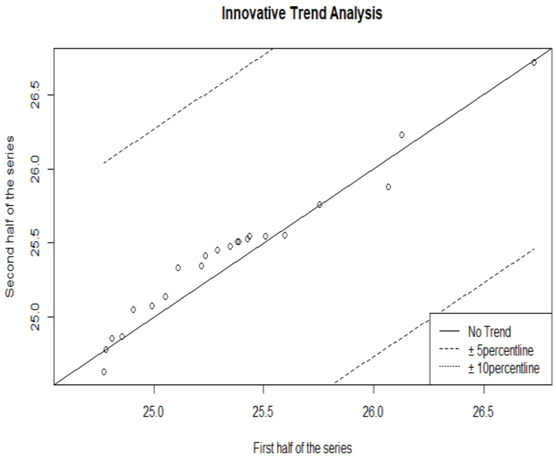

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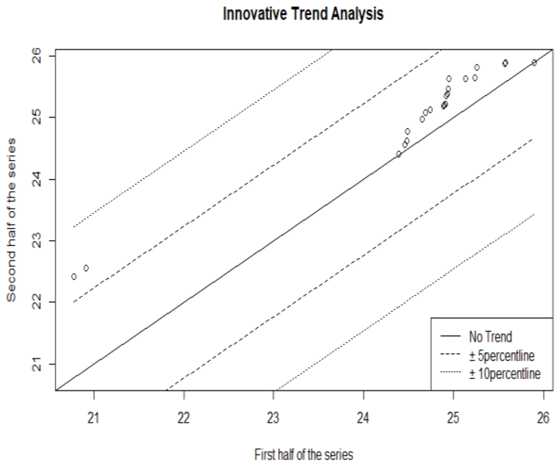

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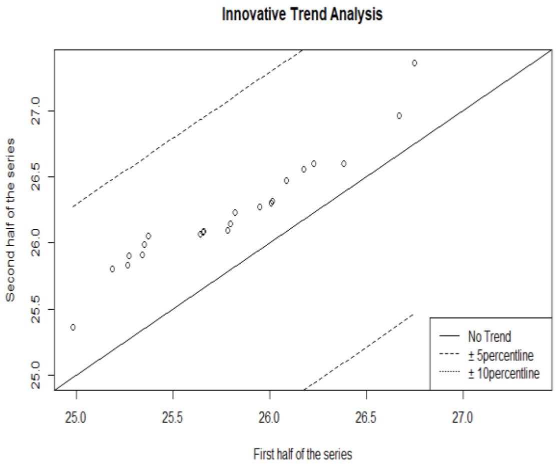

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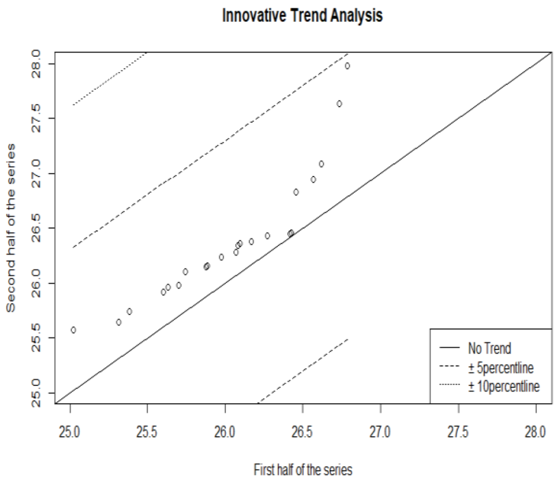

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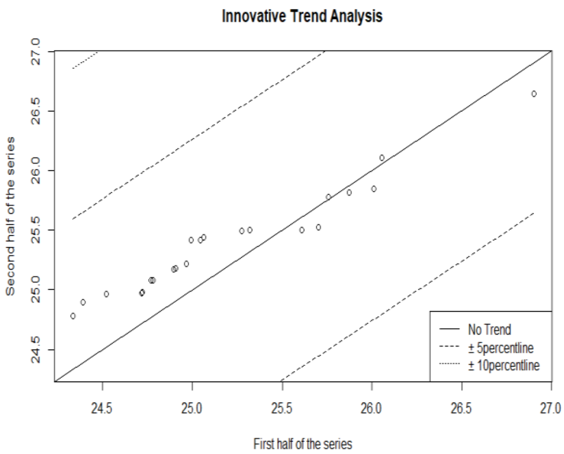

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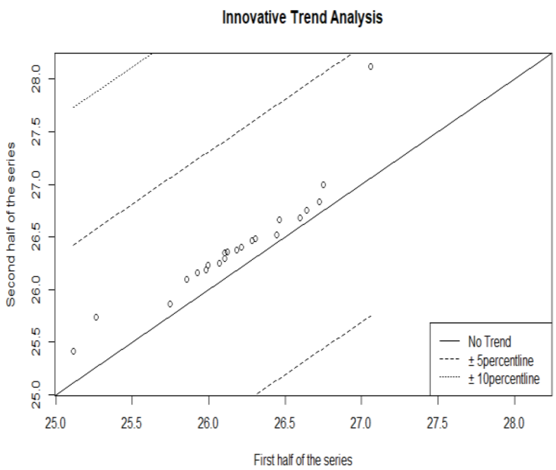

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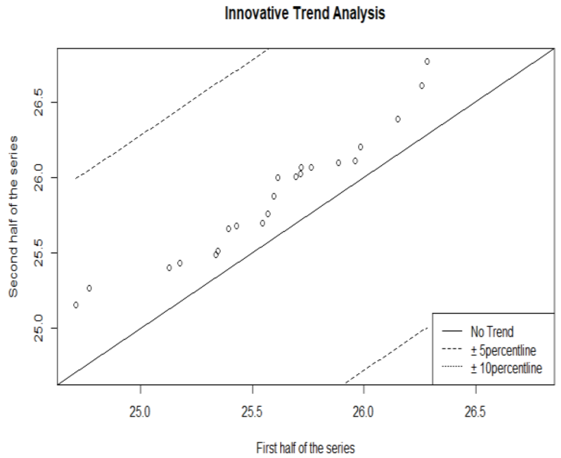

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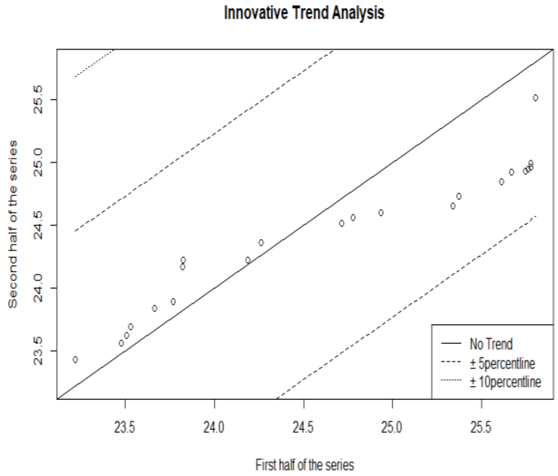

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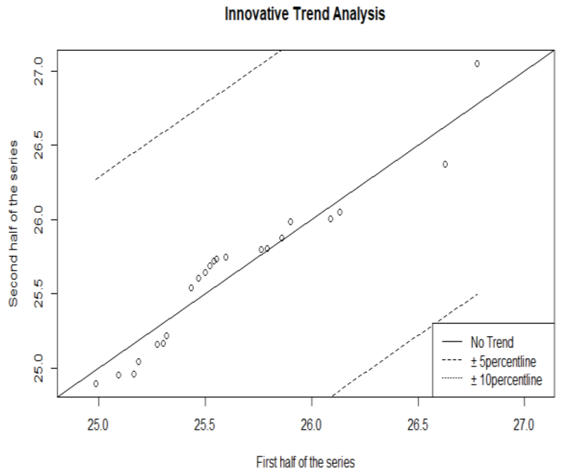

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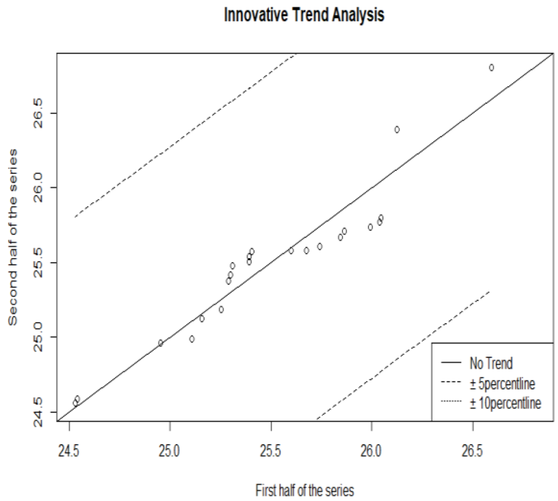

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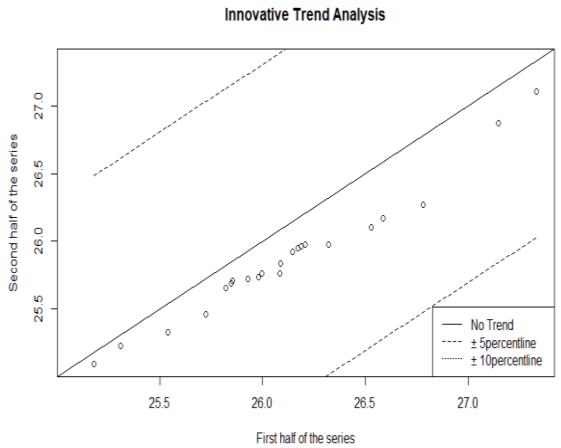

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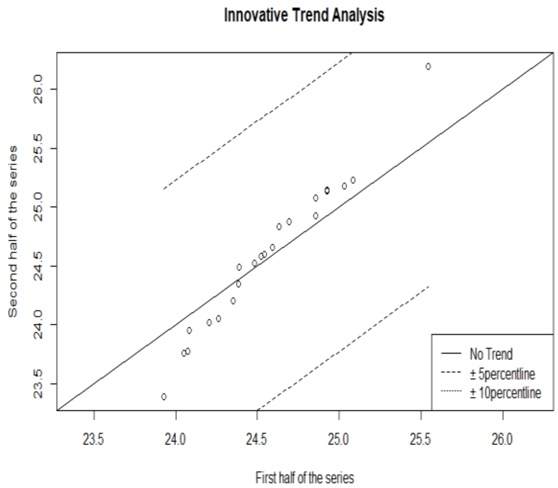

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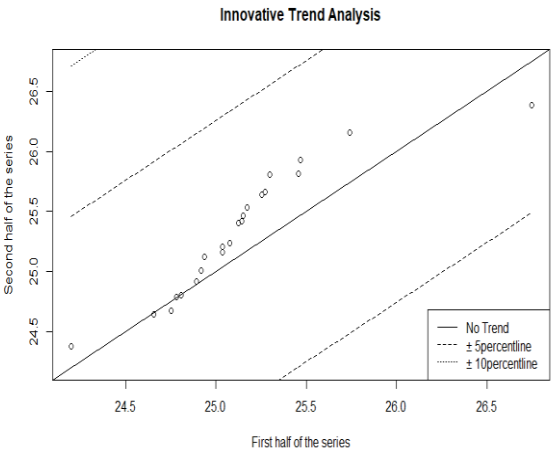

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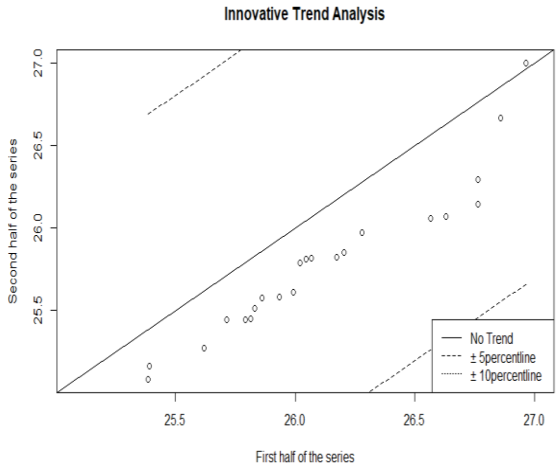

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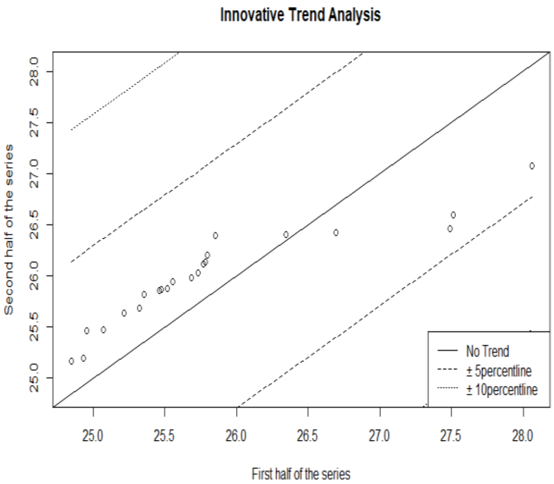

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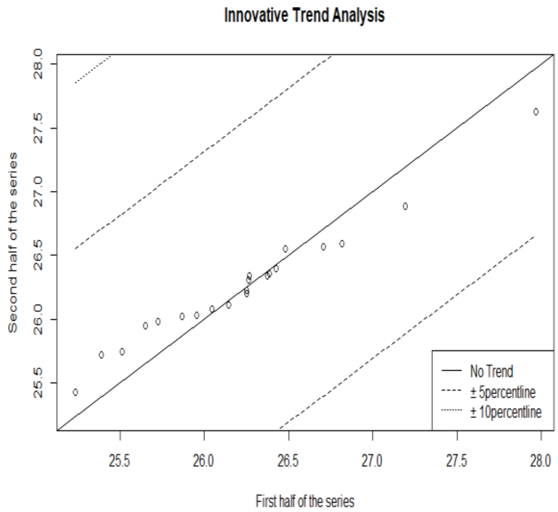

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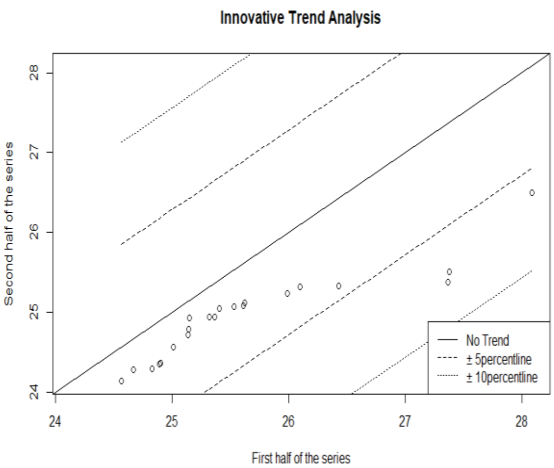

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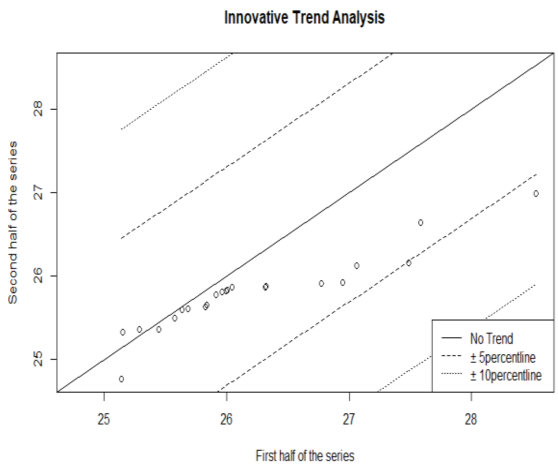

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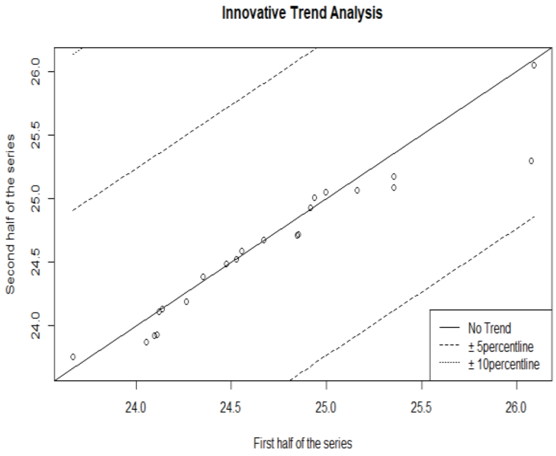

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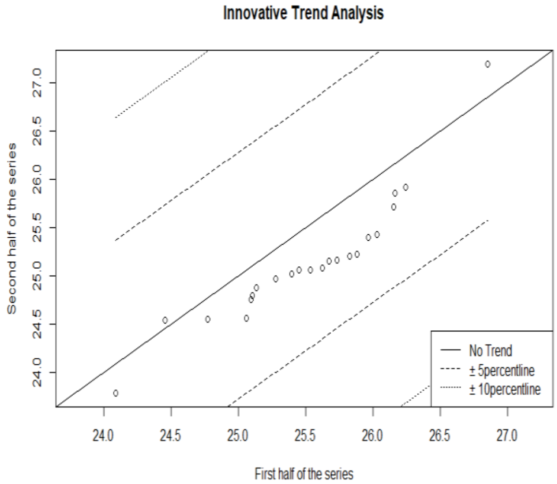

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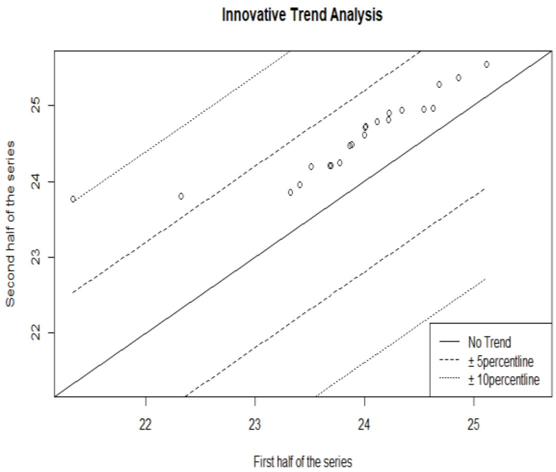

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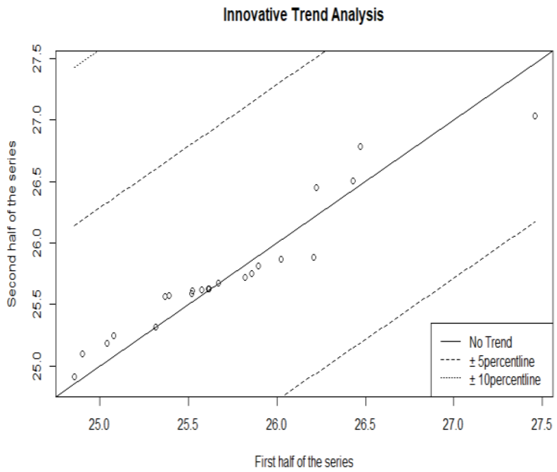

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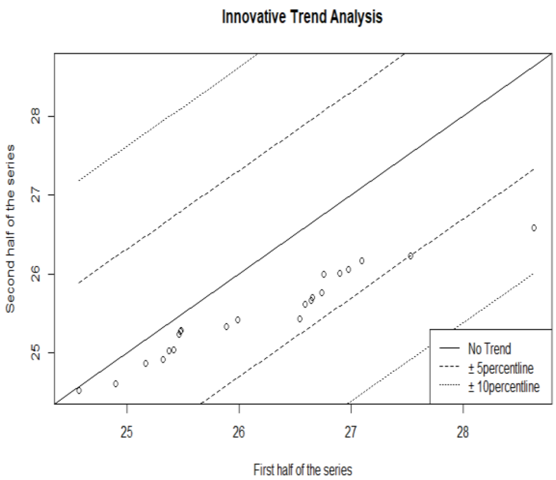

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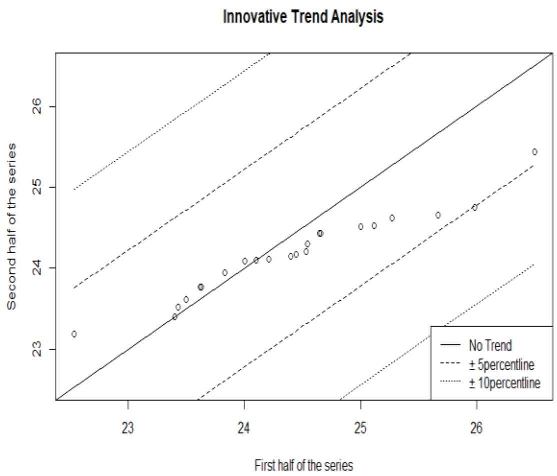

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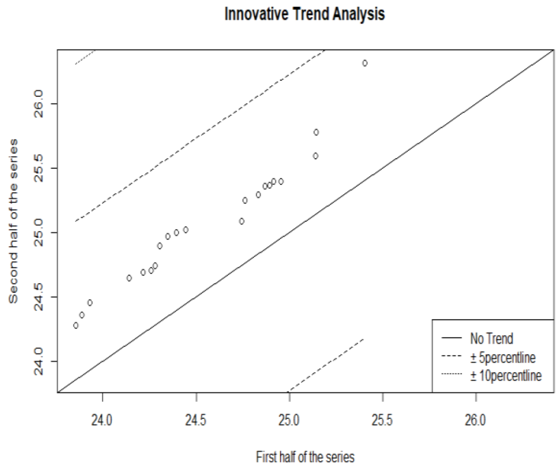

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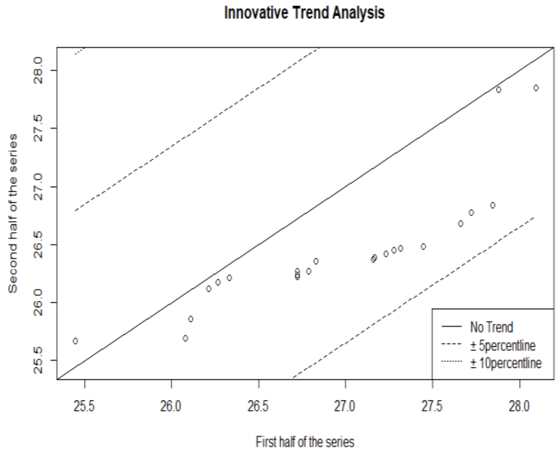

Teknaf

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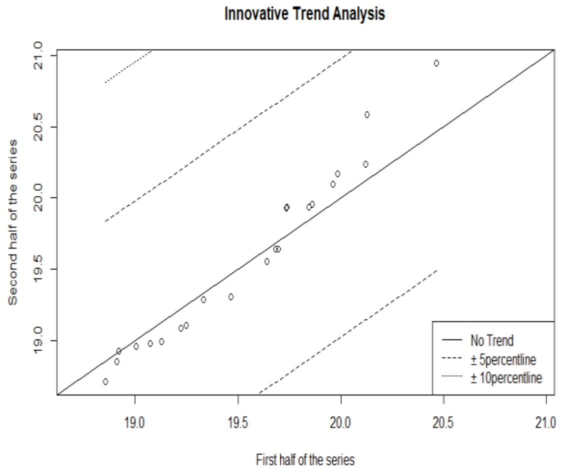

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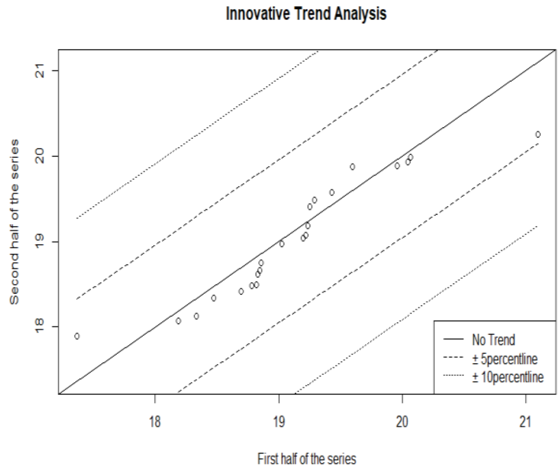

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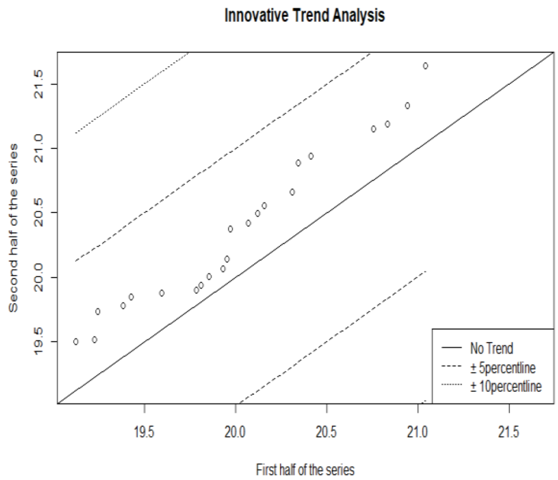

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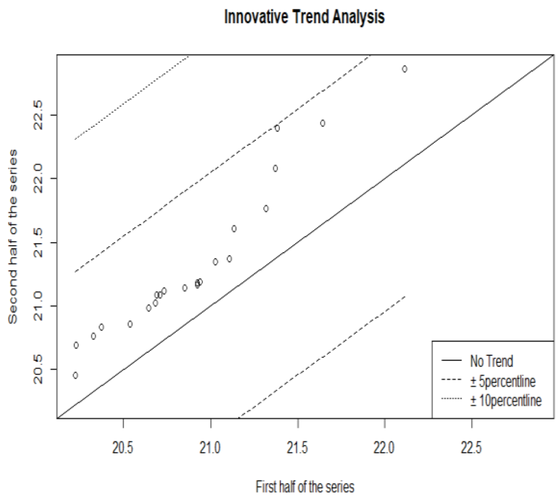

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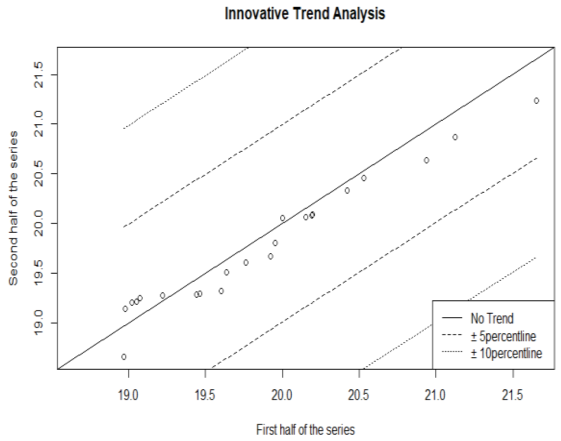

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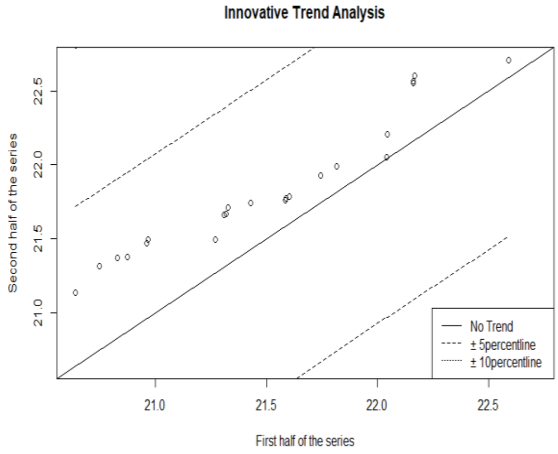

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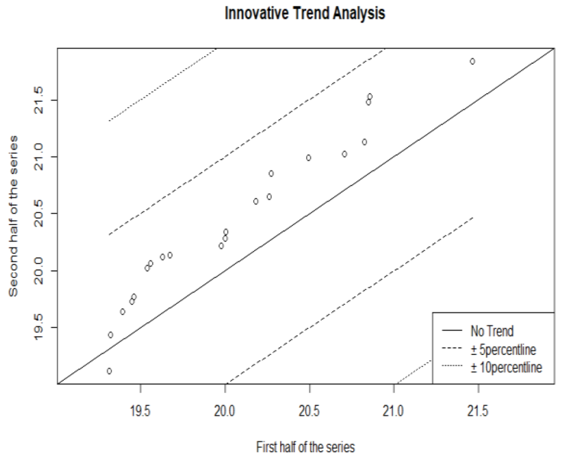

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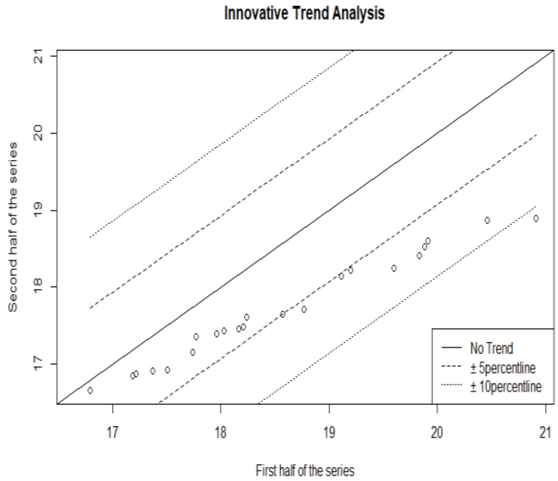

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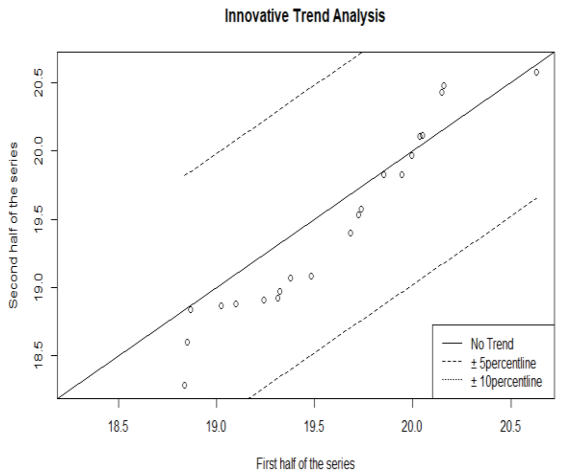

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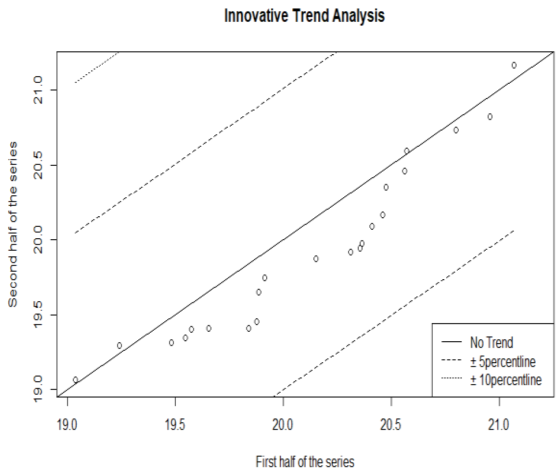

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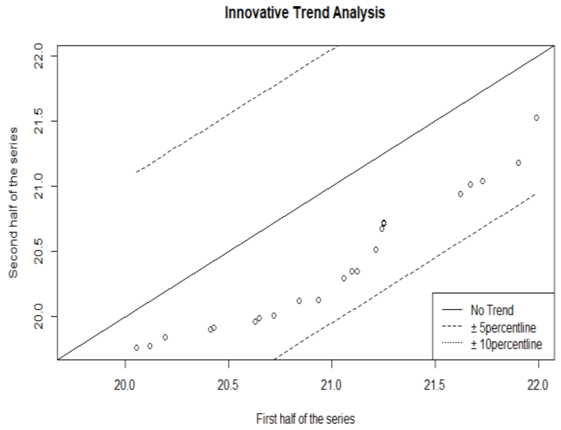

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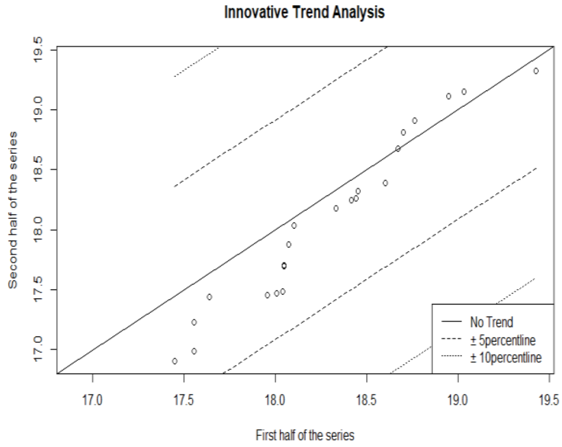

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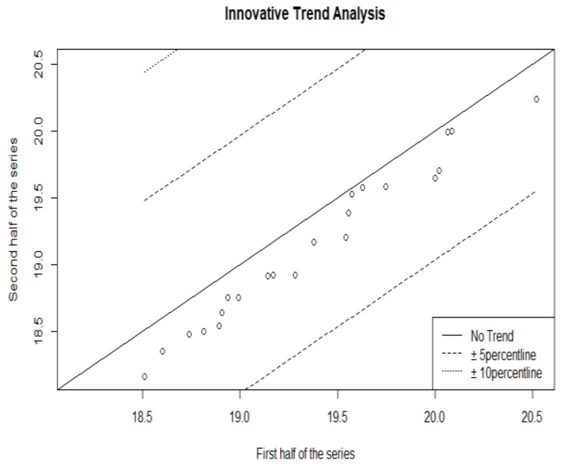

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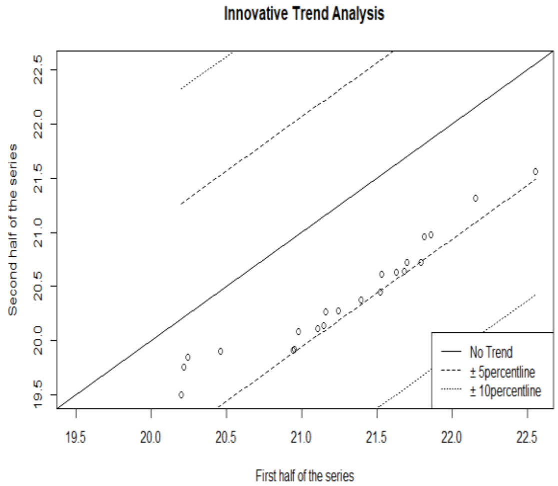

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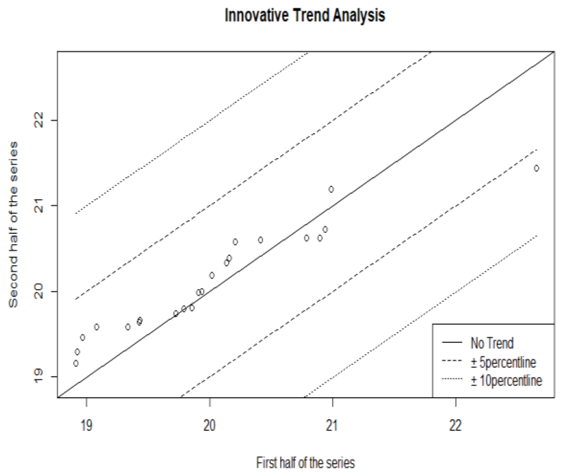

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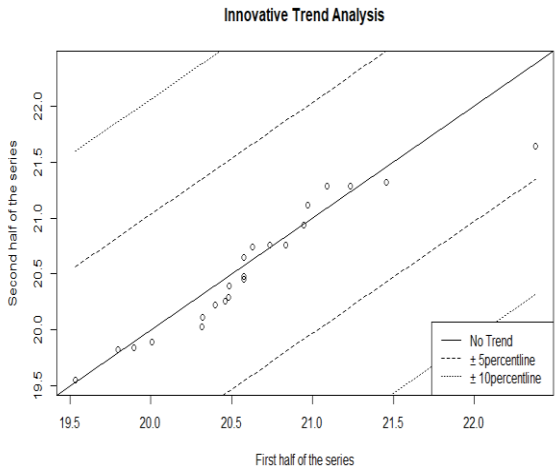

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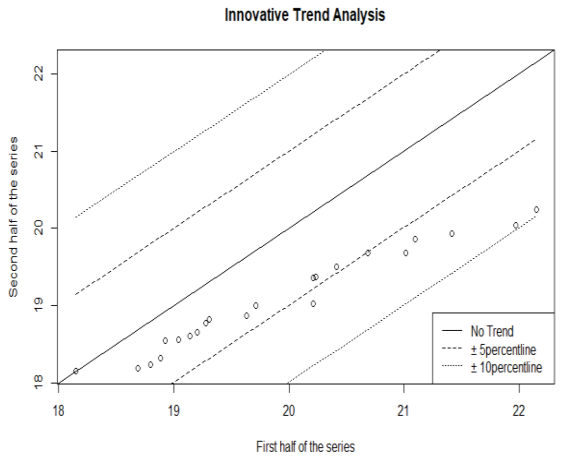

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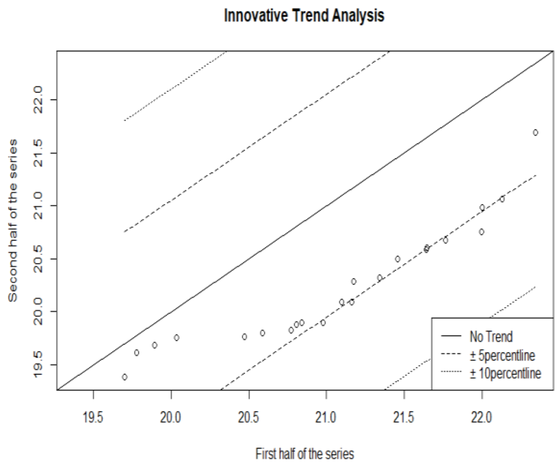

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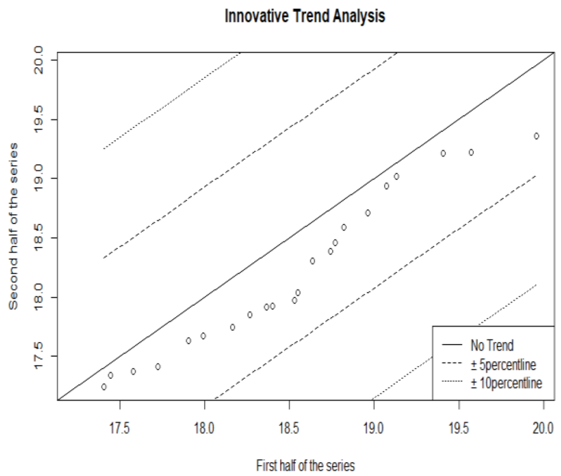

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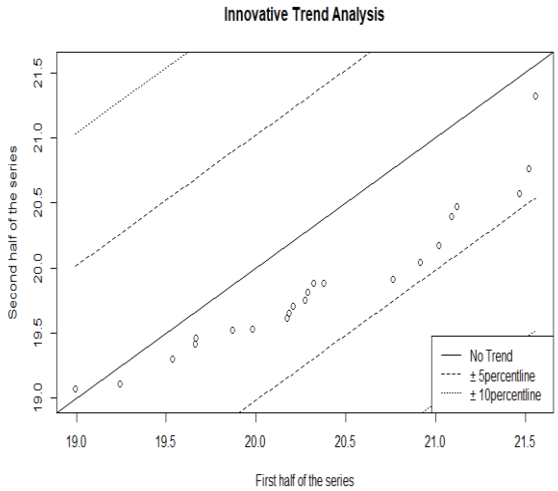

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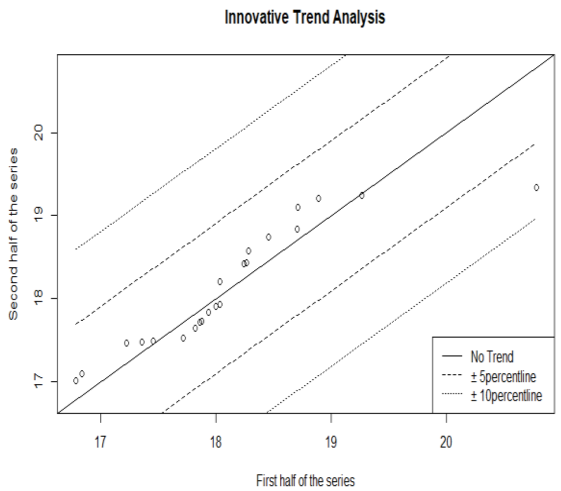

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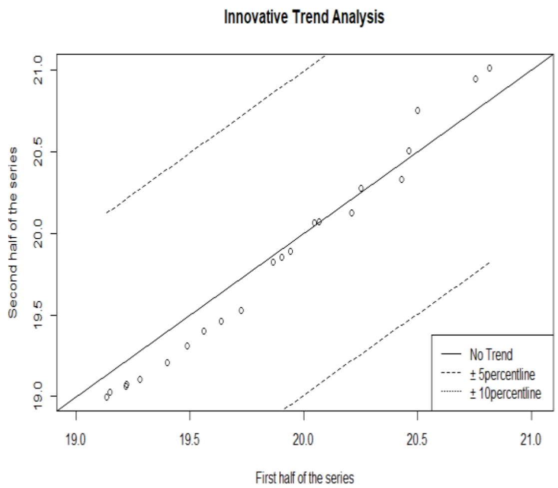

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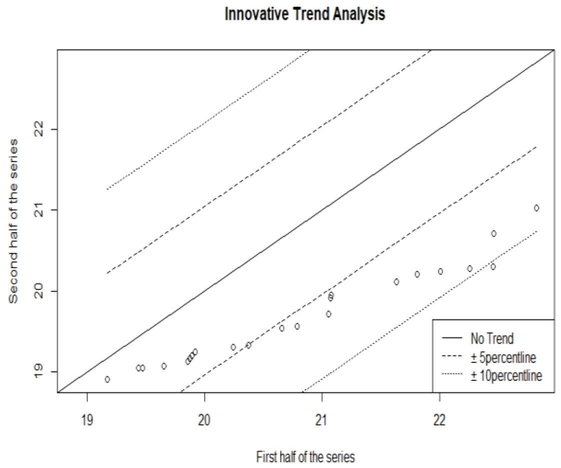

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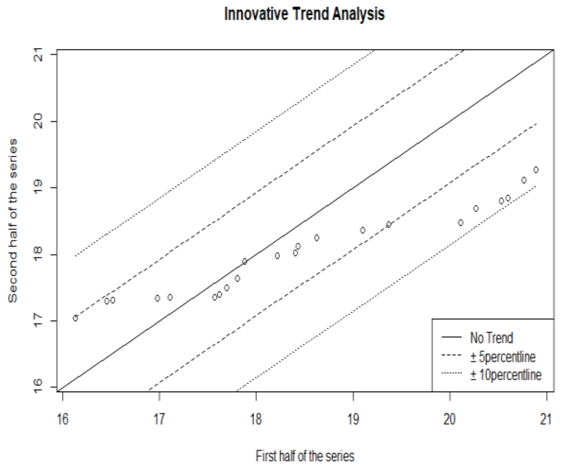

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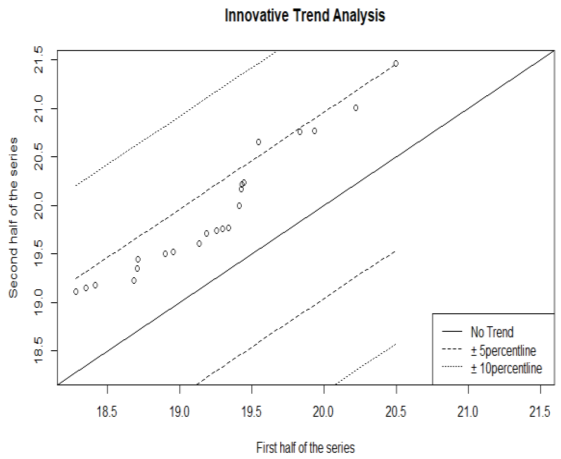

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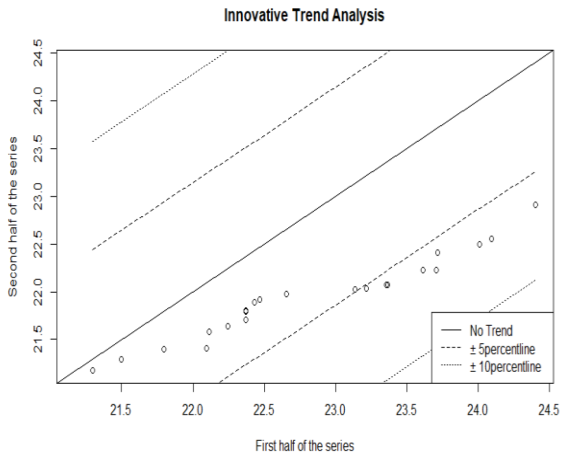
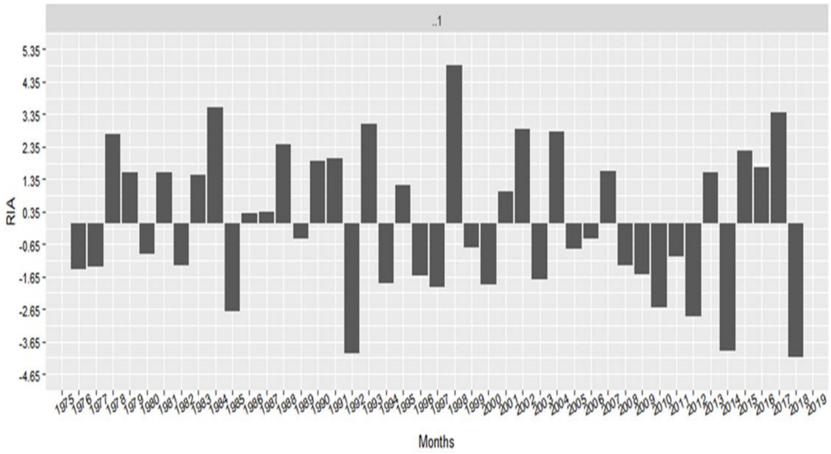


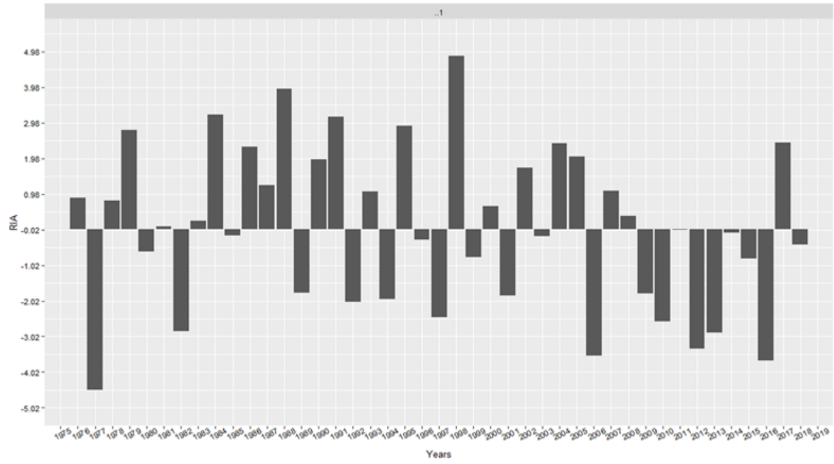
Teknaf

Dry

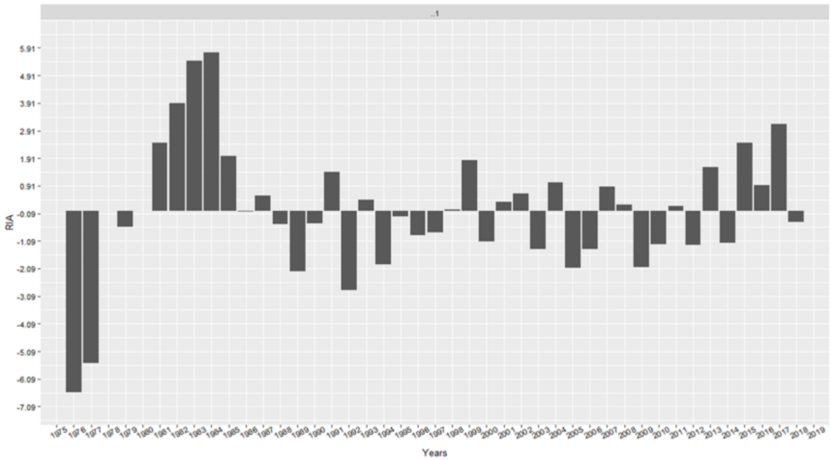
Figure A.4: Plot of innovative trends of annual average temperature series for the time period of 1975–2019



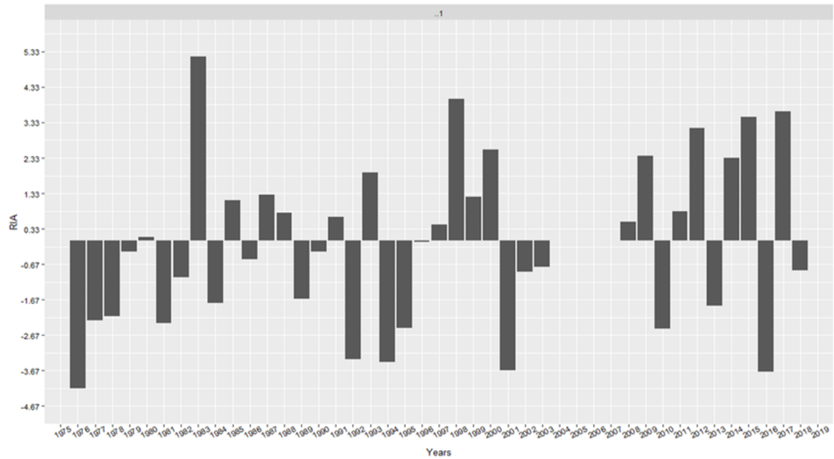
Barisal



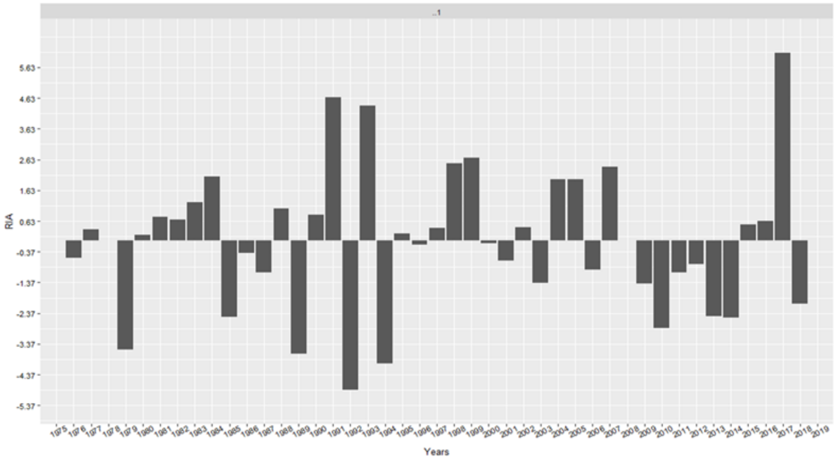
Bogra



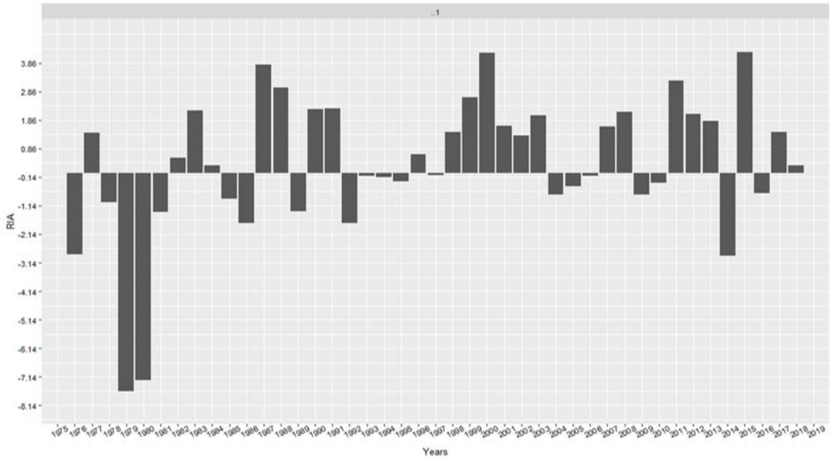
Chandpur



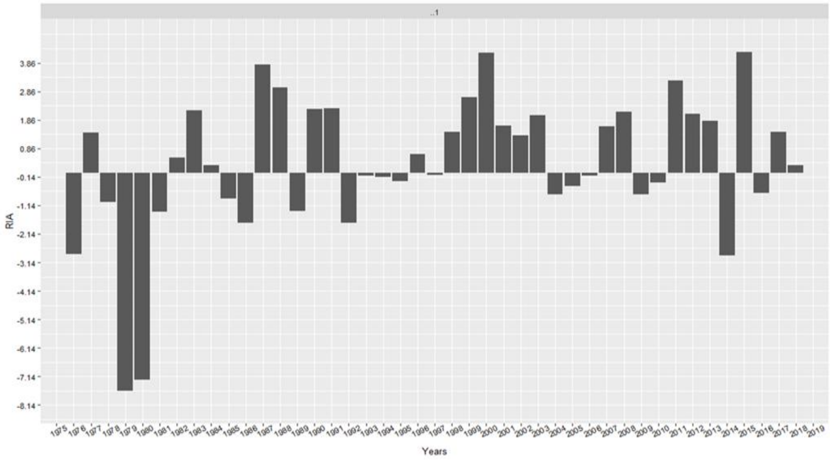
Chittagong



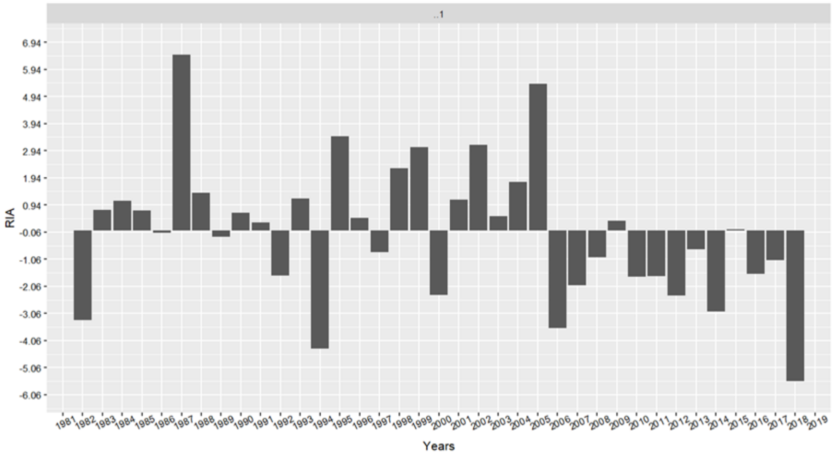
Comilla



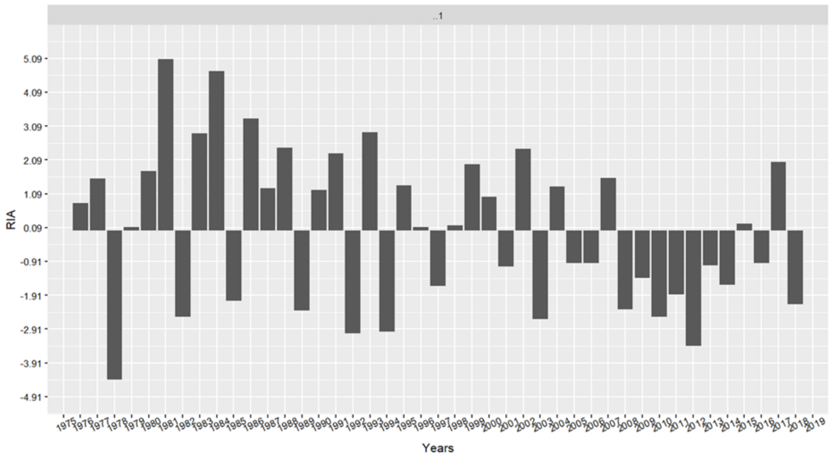
Cox’s Bazar



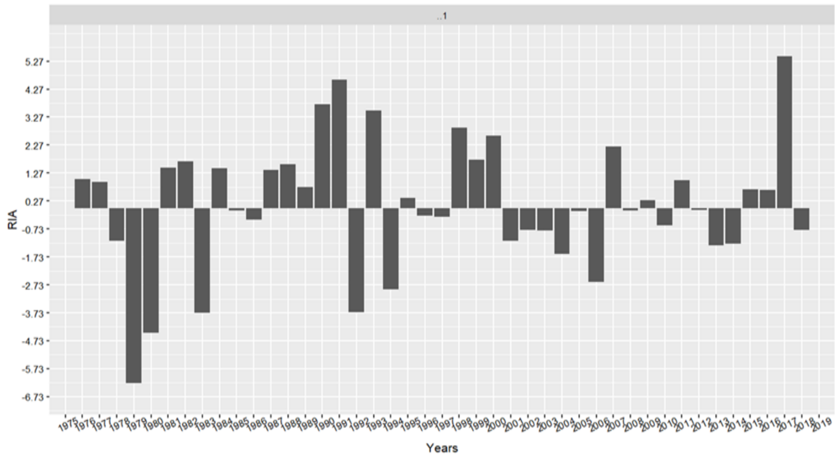
Dhaka



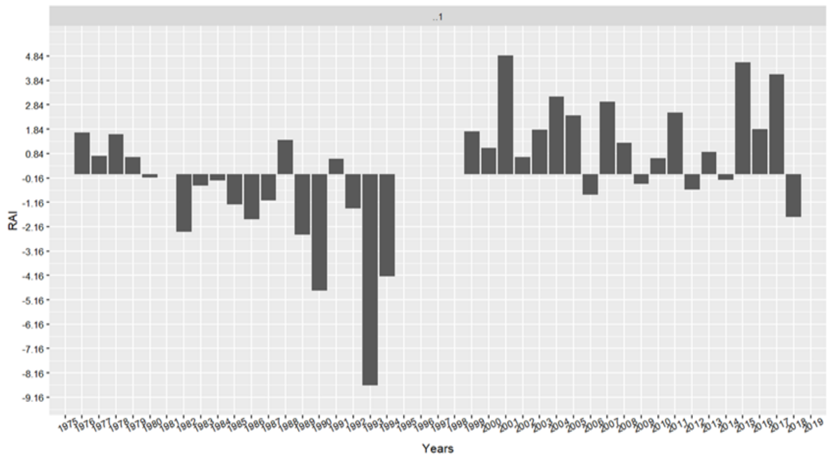
Dinajpur



Faridpur



Feni



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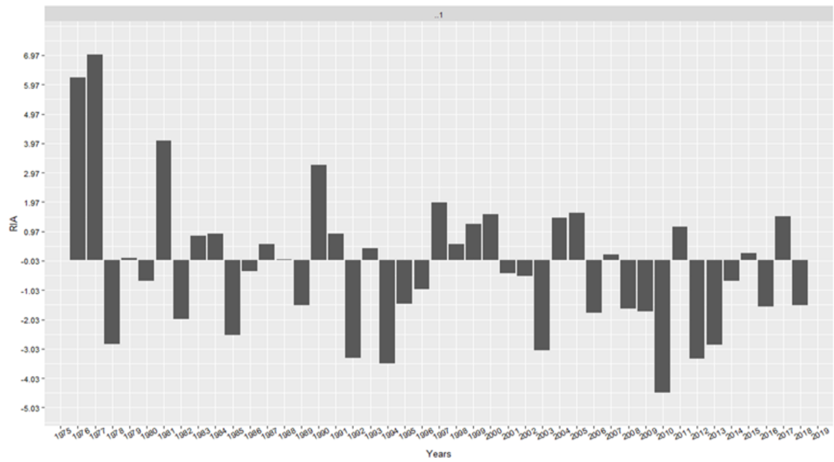
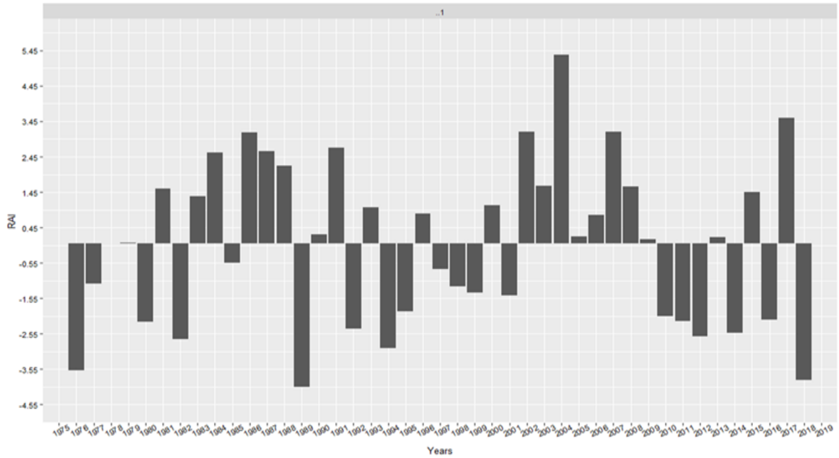
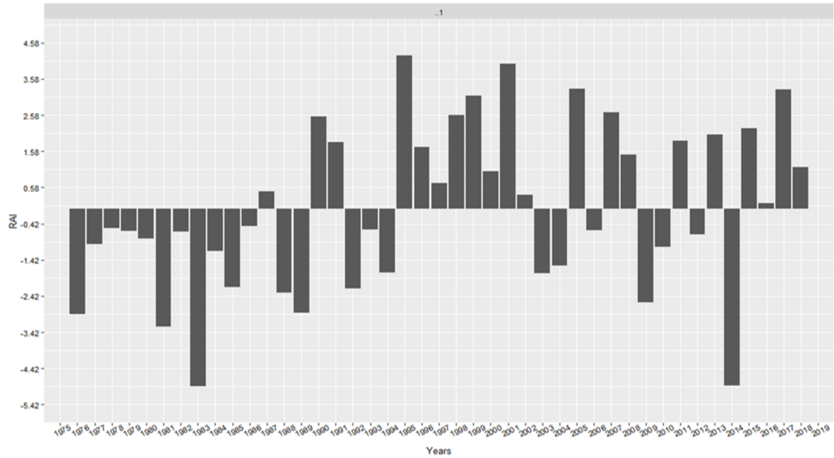


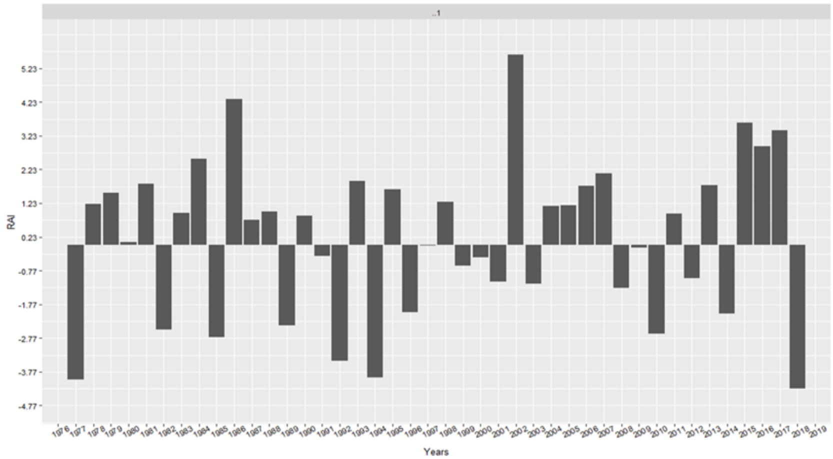
Ishurdi



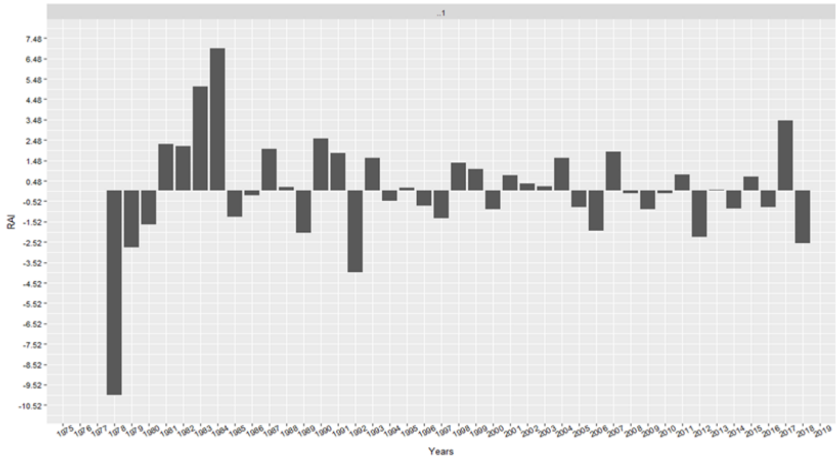
Jessore



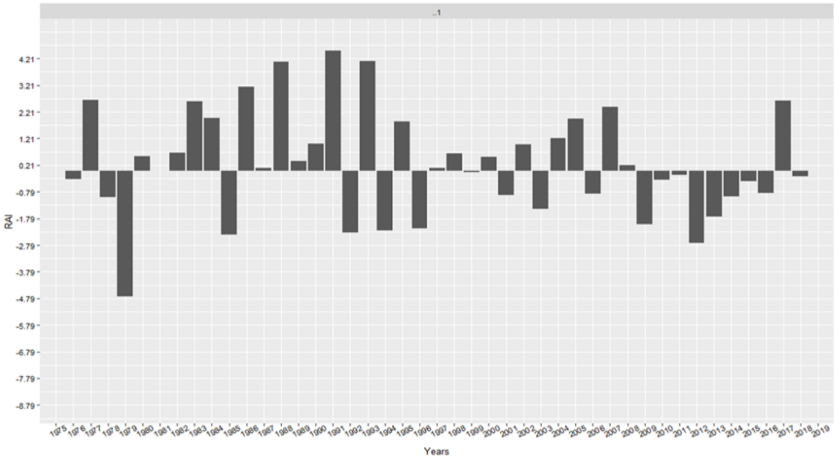
Khepupara



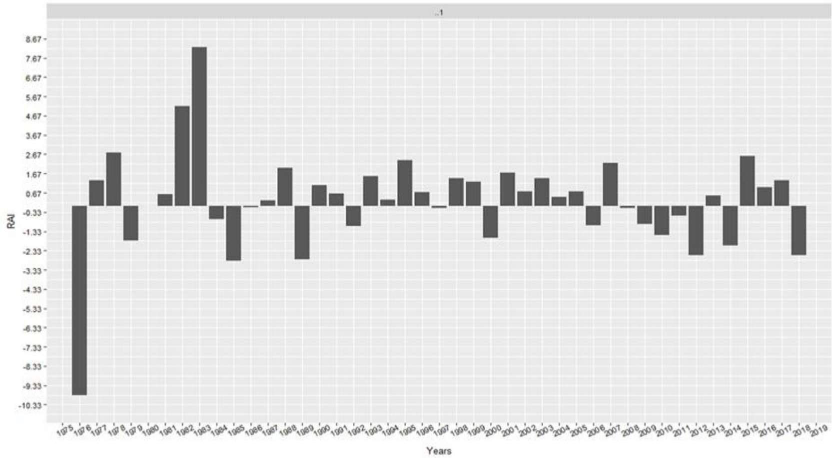
Khulna



M. Court



Mymensingh



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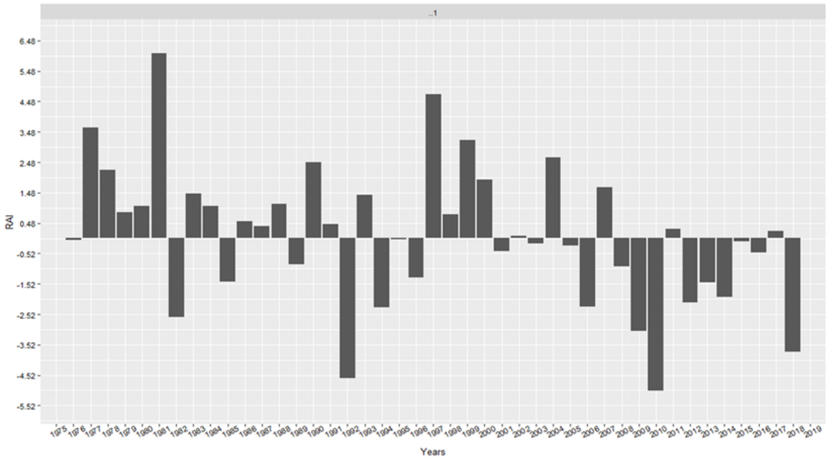

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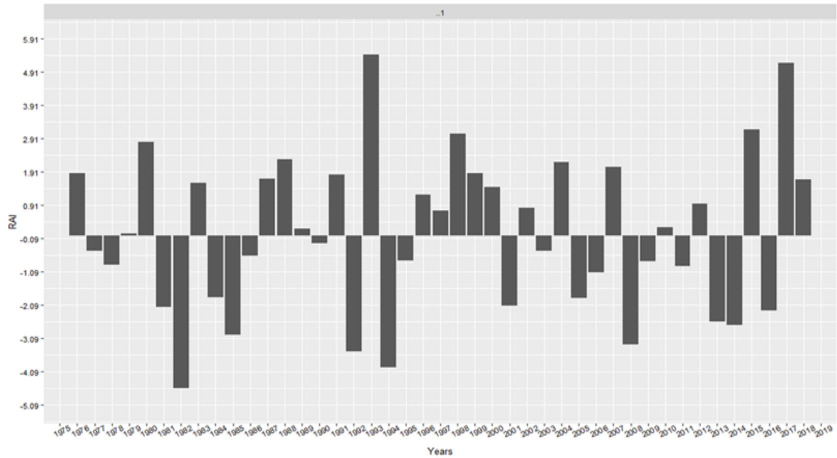
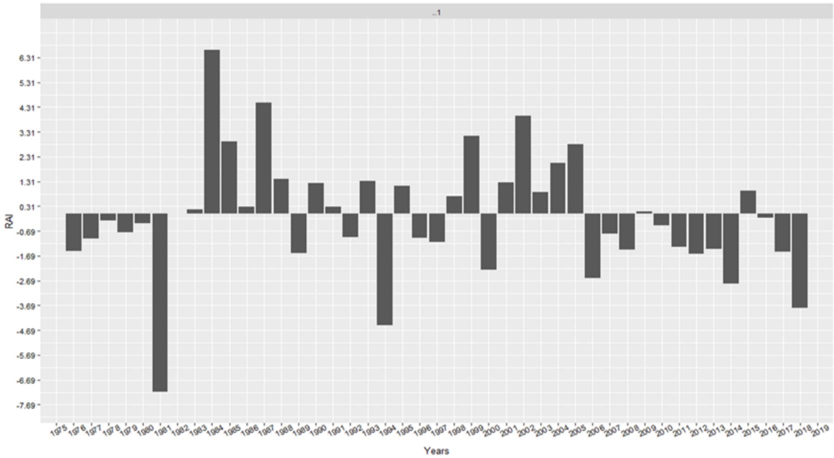
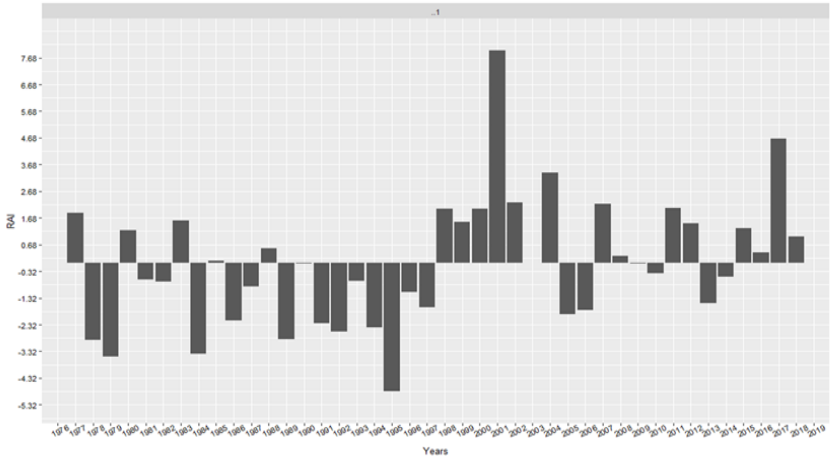


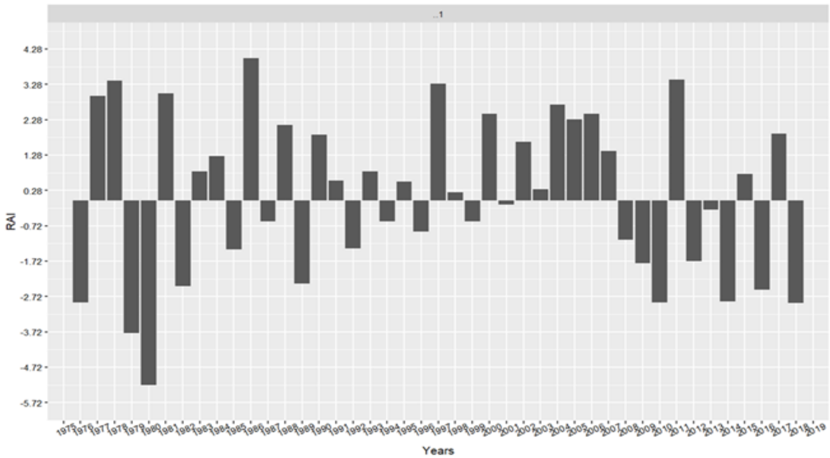
Rangamati



Rangpur



Sandwip



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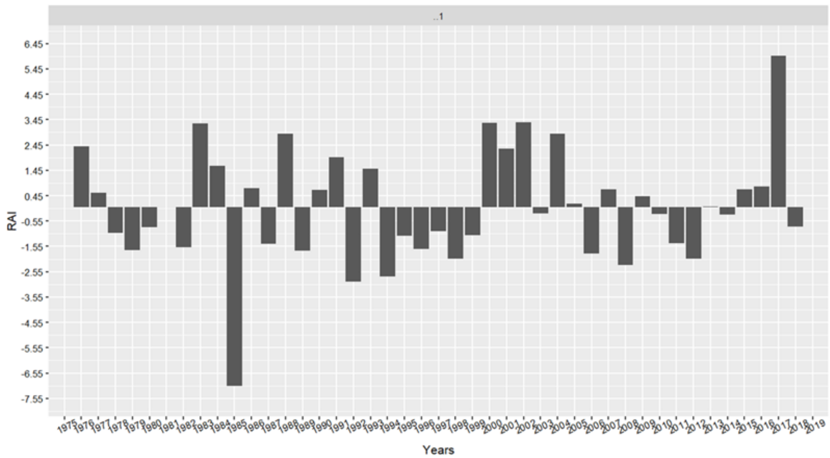
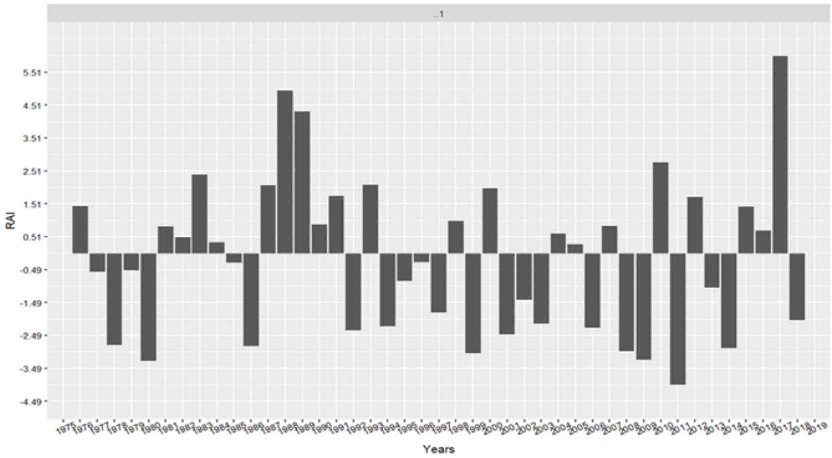


Srimangal



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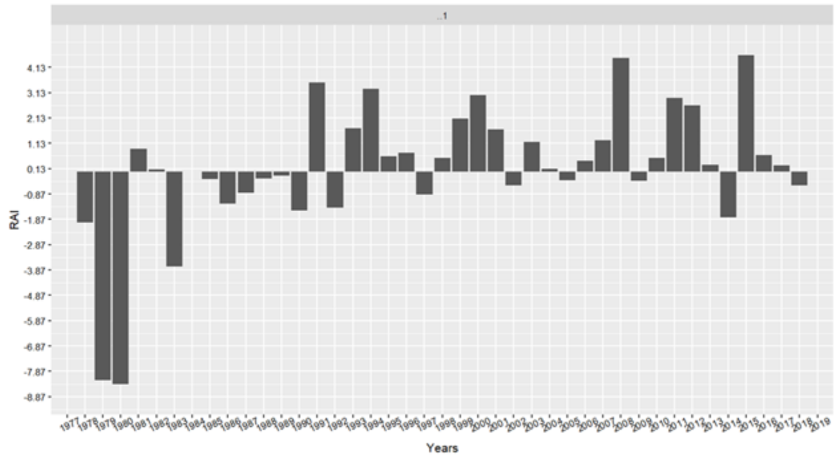
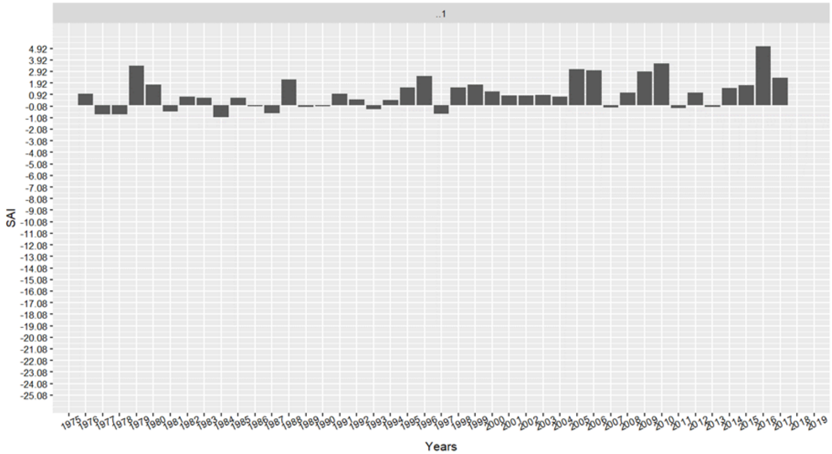


Teknaf

Figure A.5: Plot of standard anomaly index of annual average rainfall series for the time period of 1975–2019



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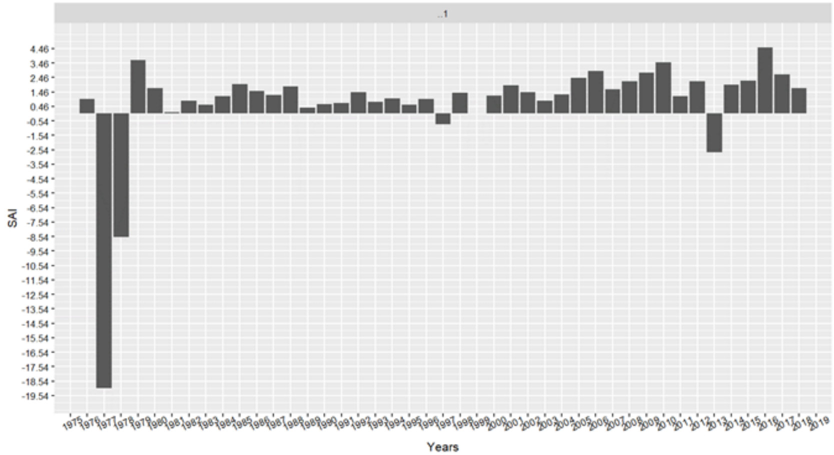
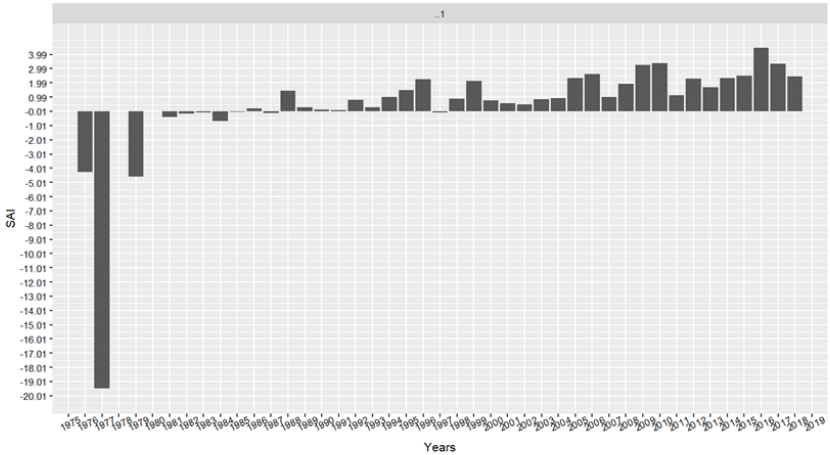
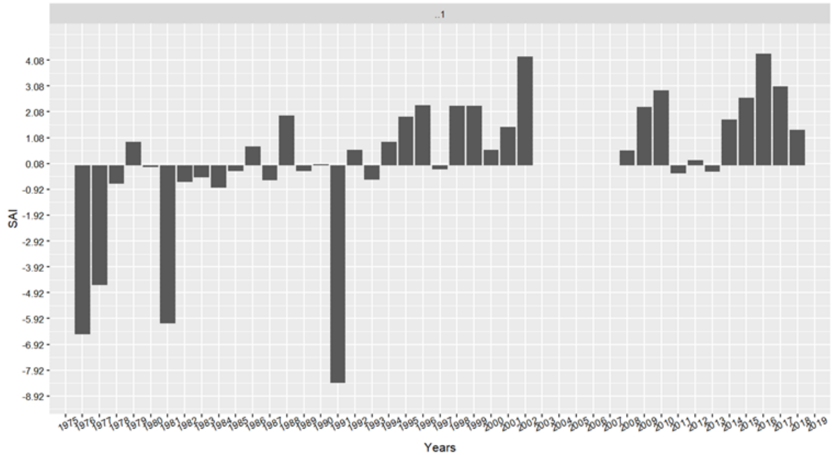


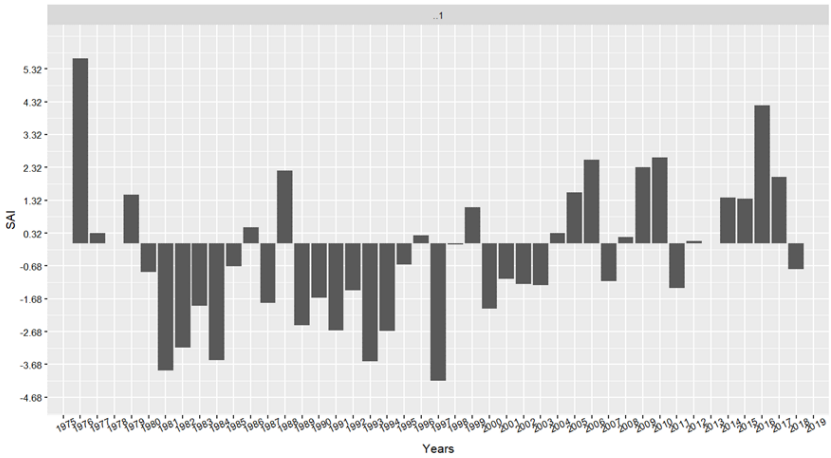
Bogra



Chandpur



Chittagong



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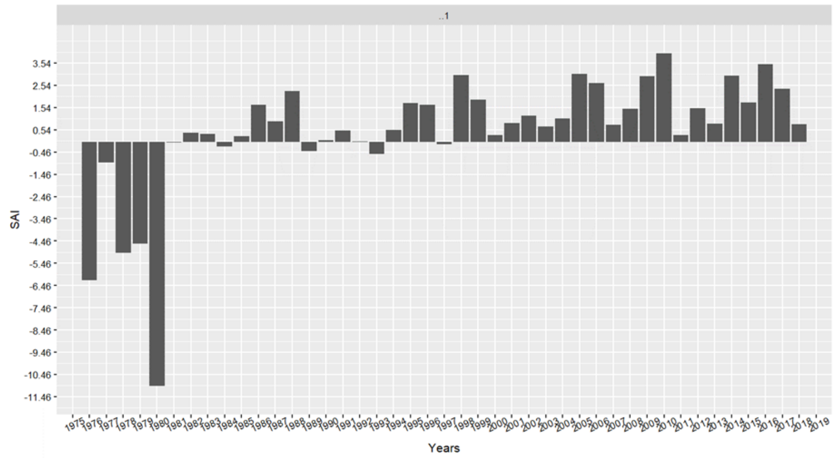
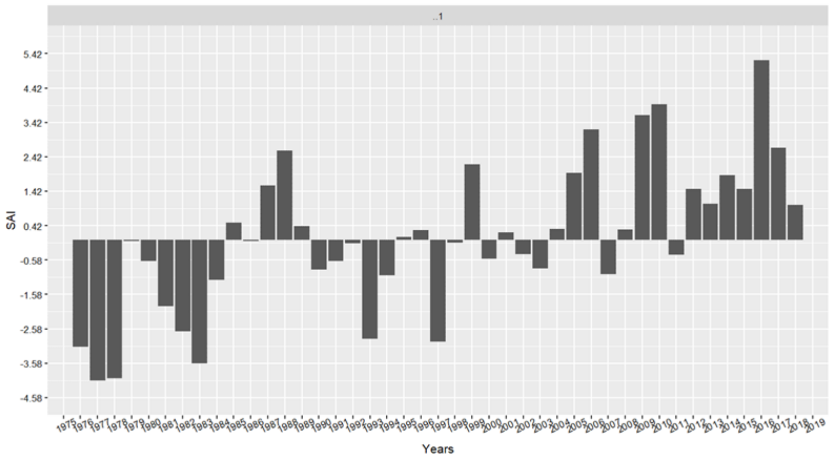
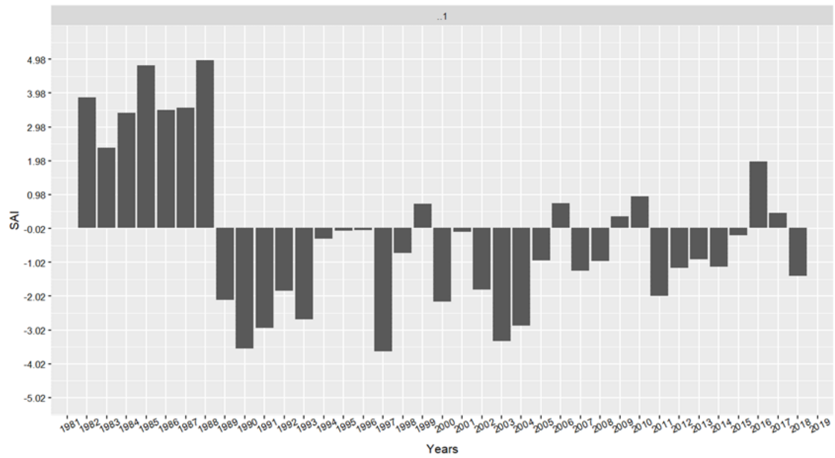


Cox's Bazar



Dhaka



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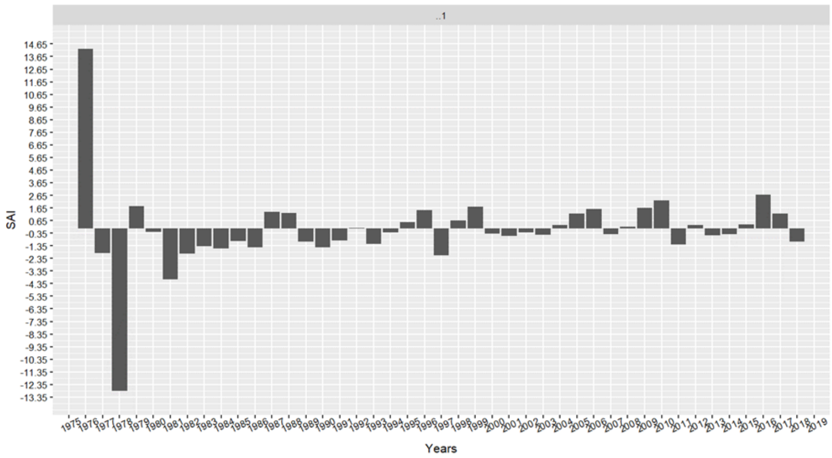
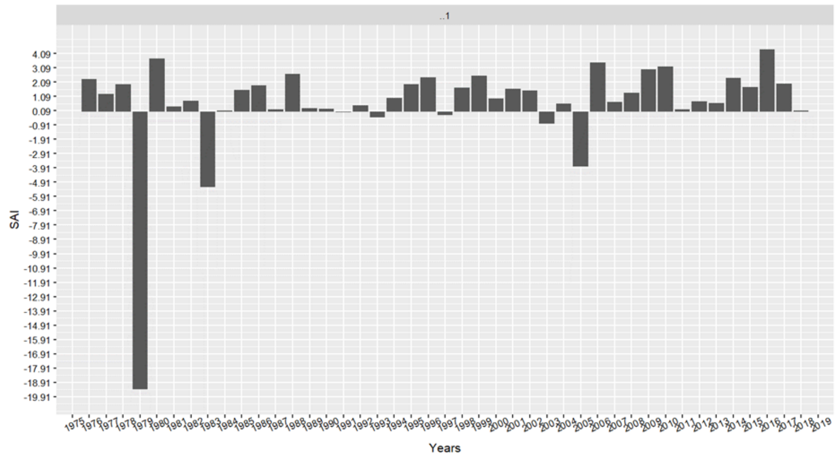


Faridpur



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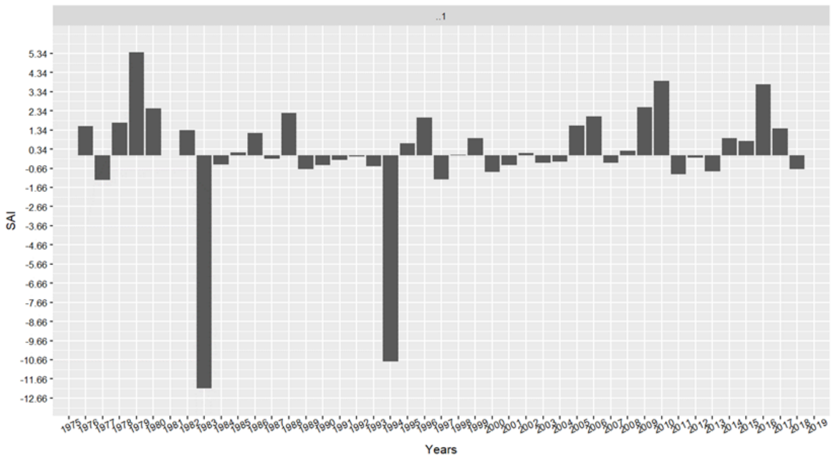
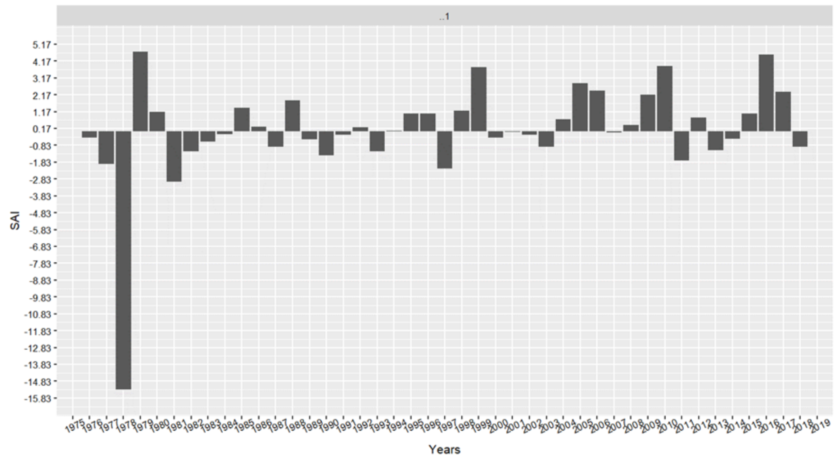
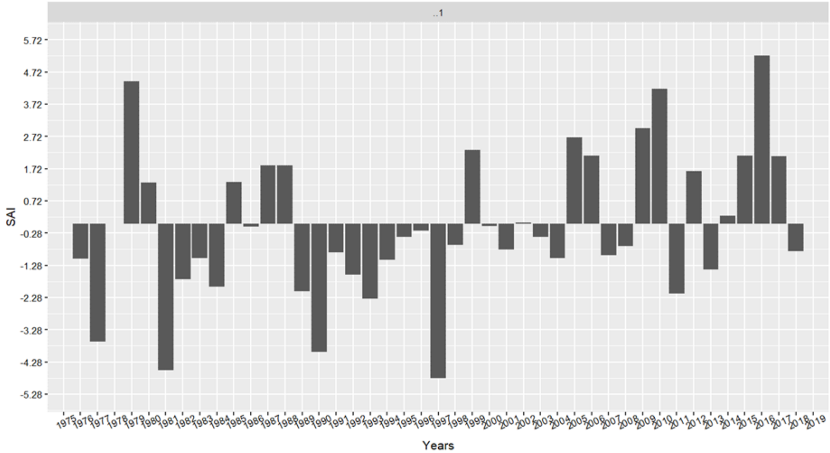


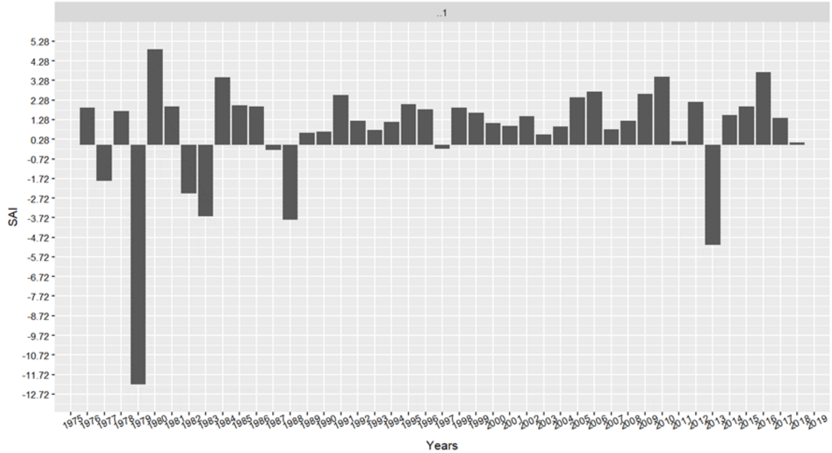
Hatiya



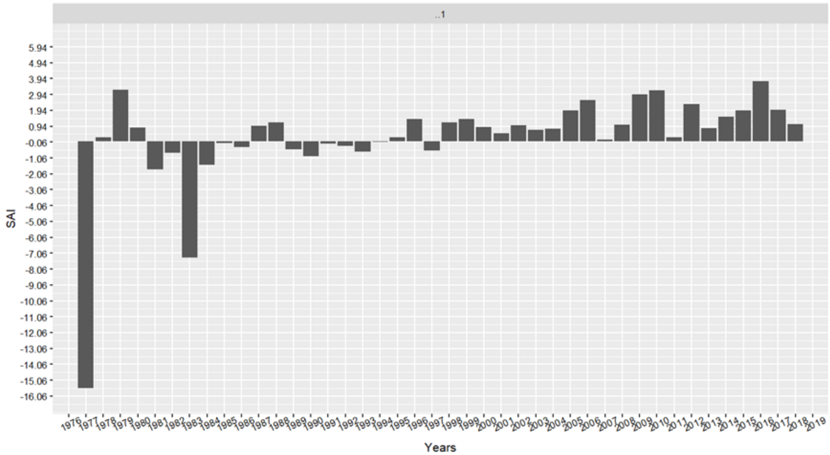
Ishurdi



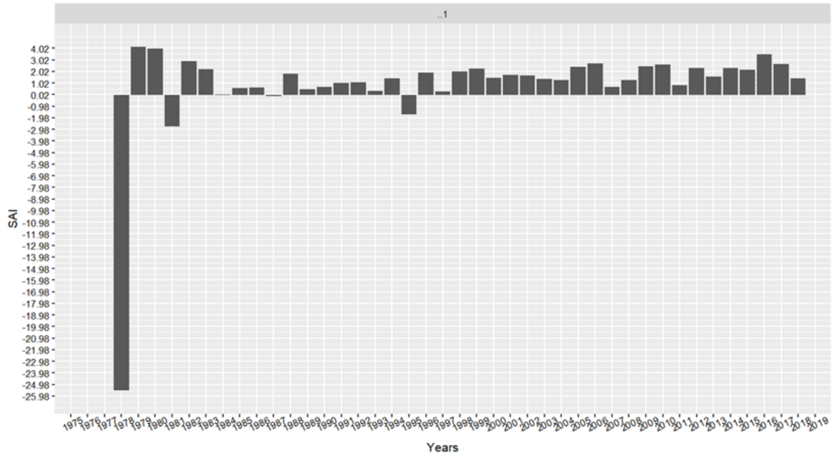
Jessore



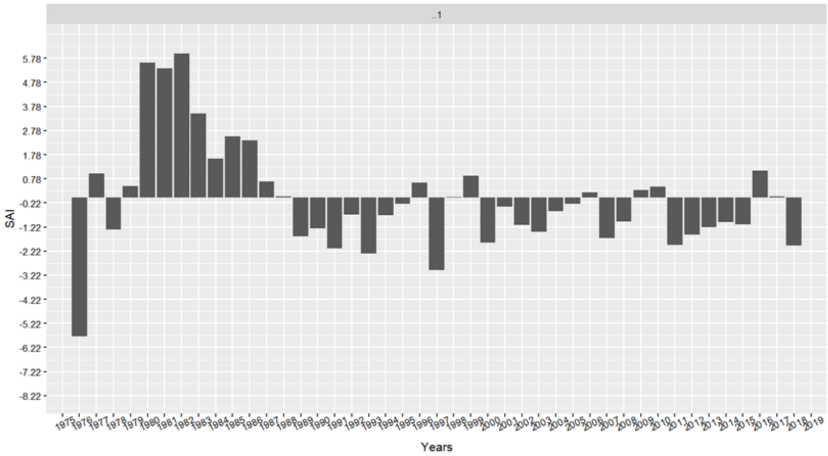
Khepupara



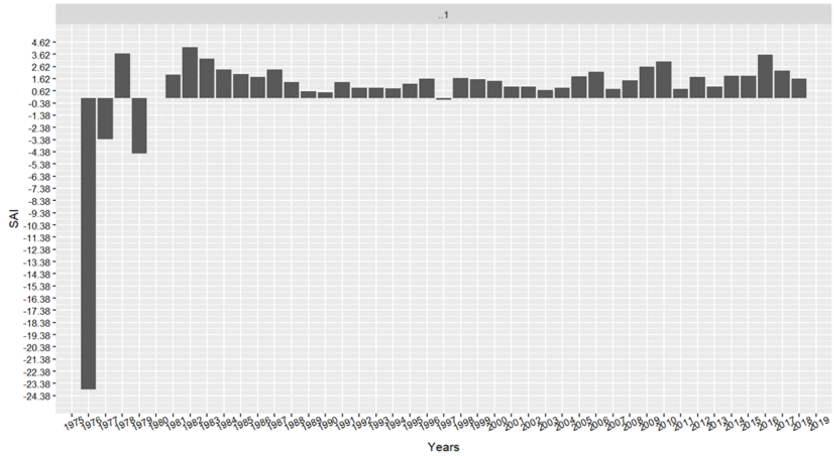
Khulna



M. Court



Mymensingh



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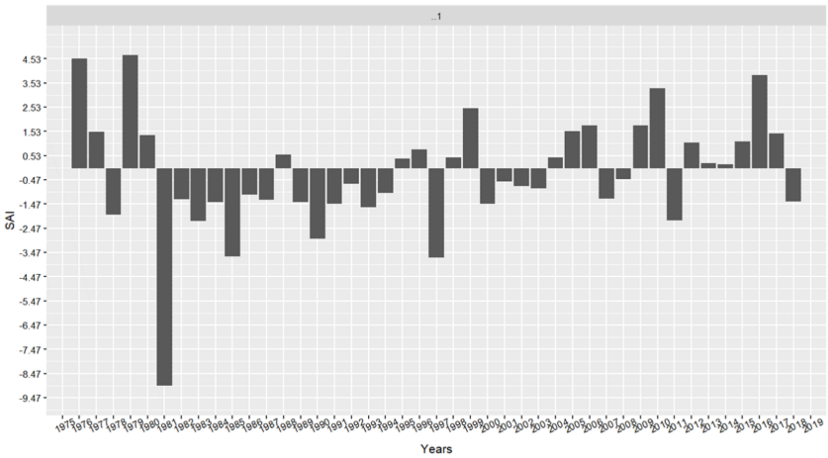
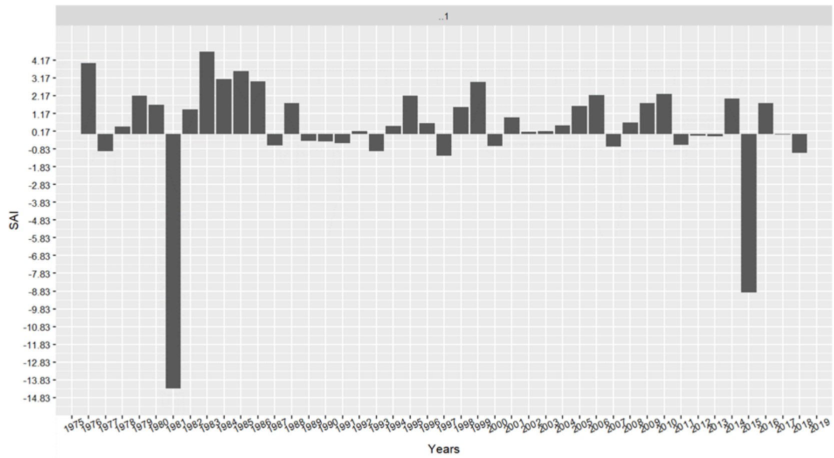
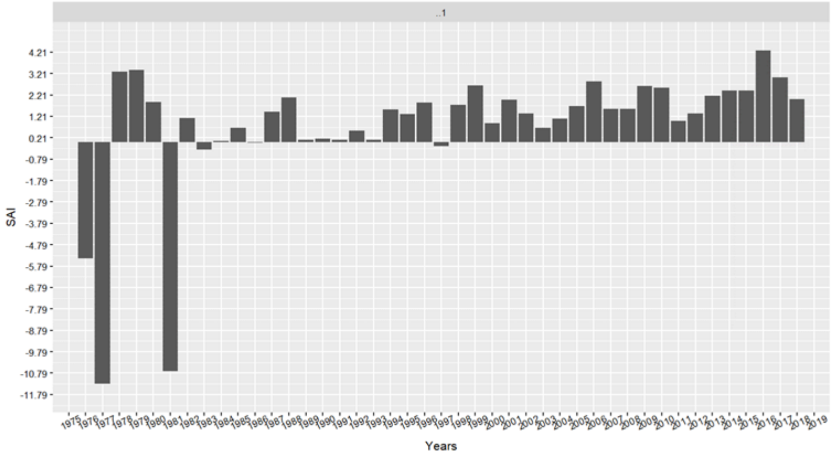


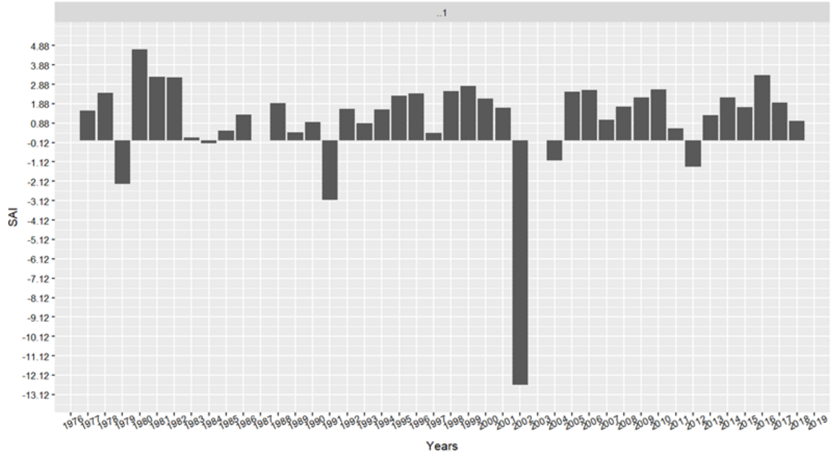
Rajshahi



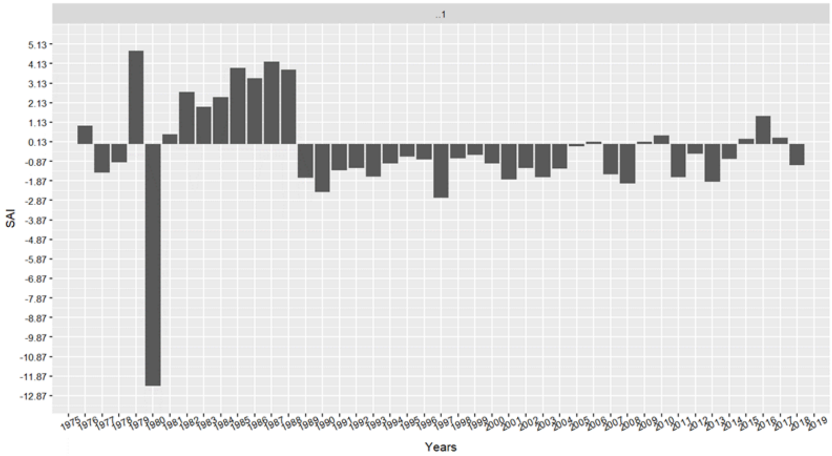
Rangamati



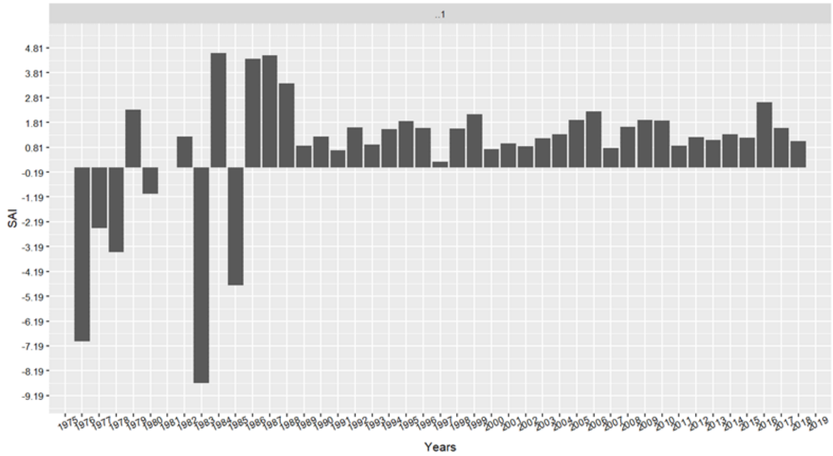
Rangpur



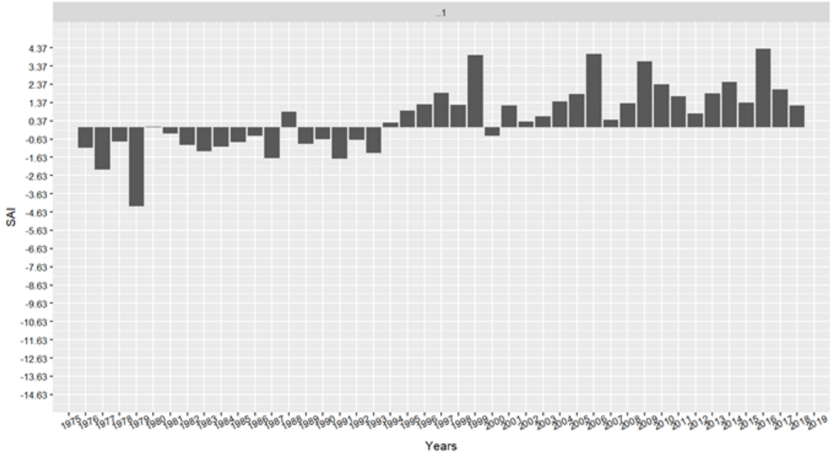
Sandwip



Satkhira



Srimangal



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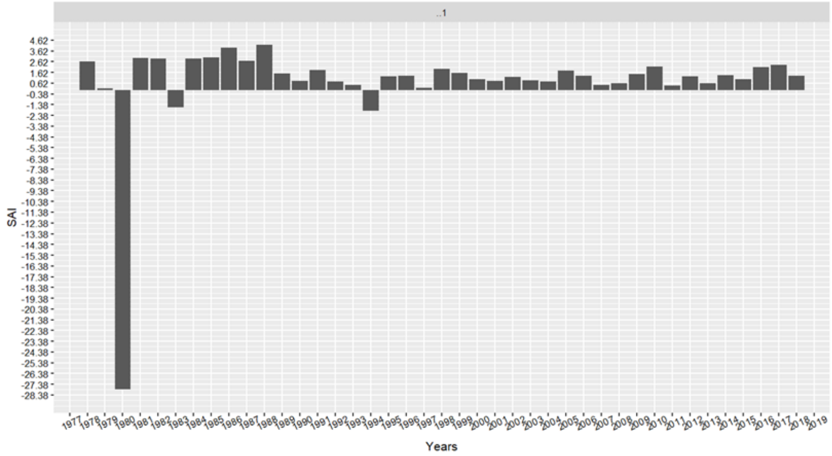
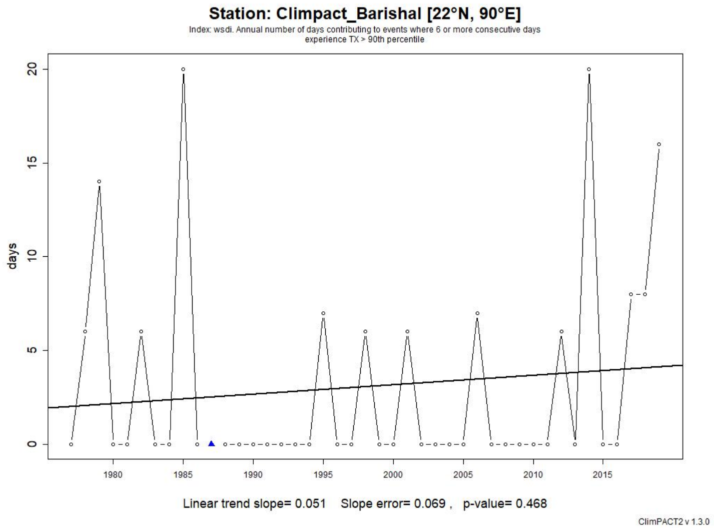
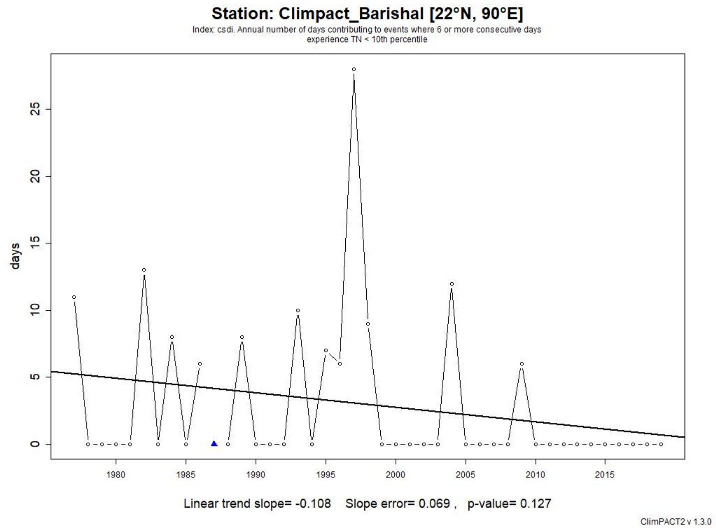


Teknaf

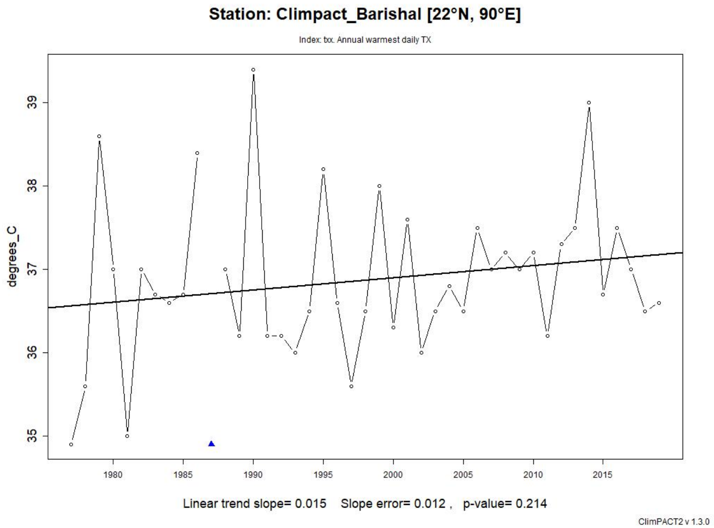
Figure A.6: Plot of standard anomaly index of annual average temperature series for the time period of 1975–2019



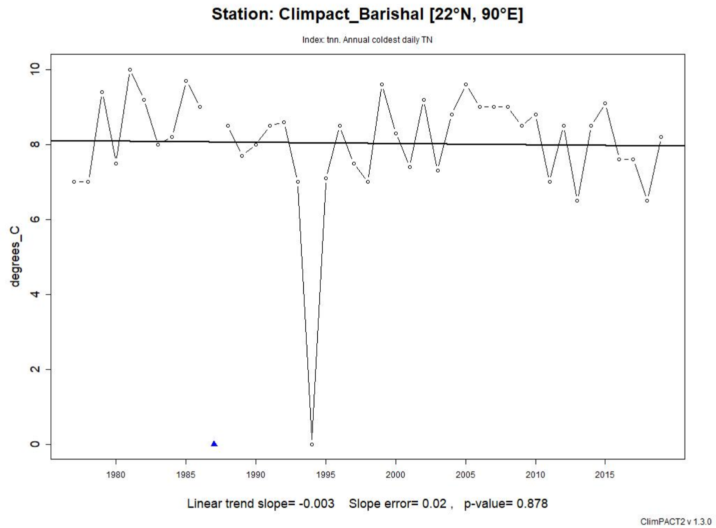
WSDI



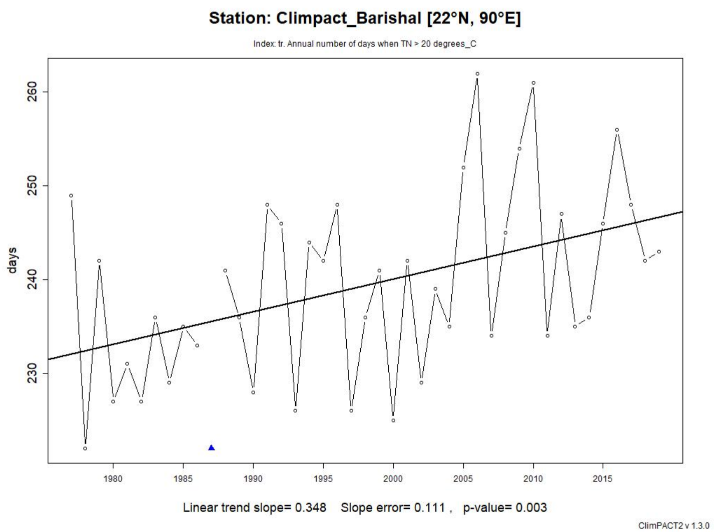
CSDI



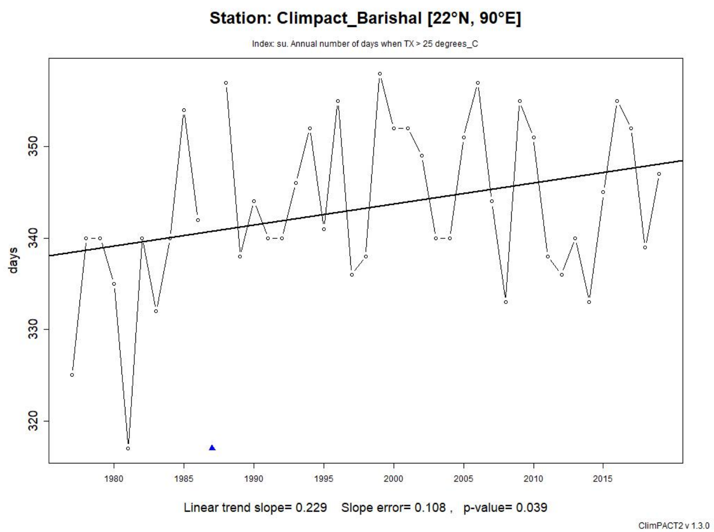
TXx



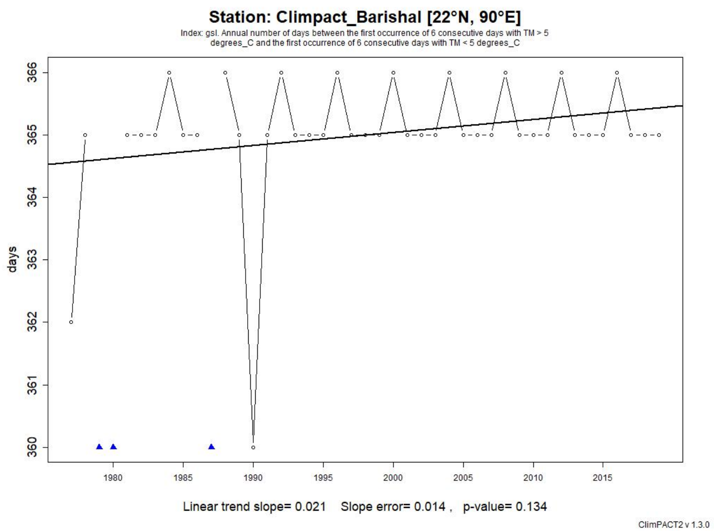
TNn



TR



SU25



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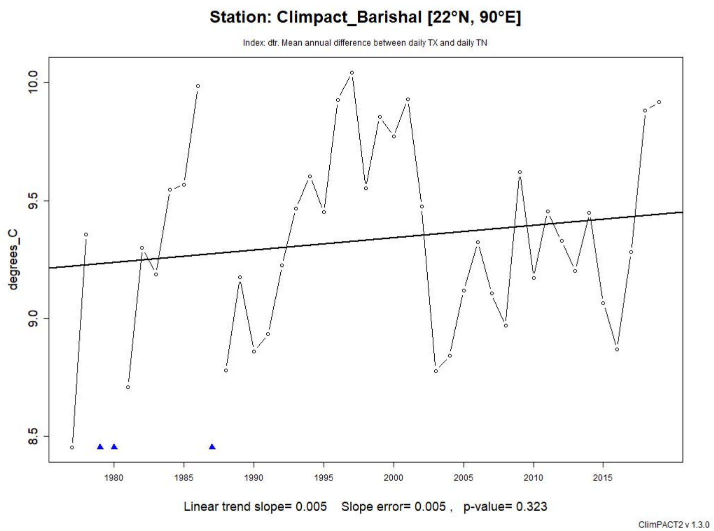

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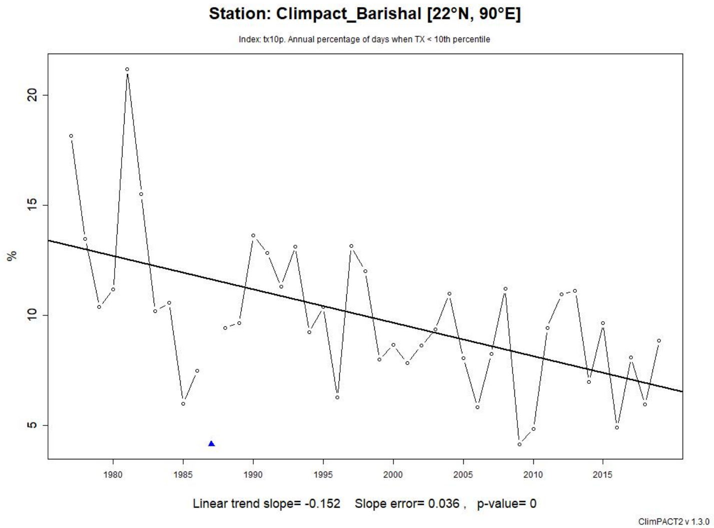
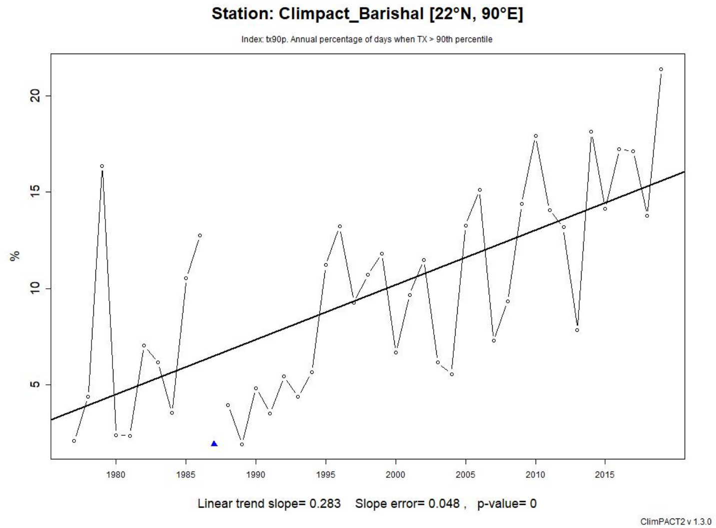
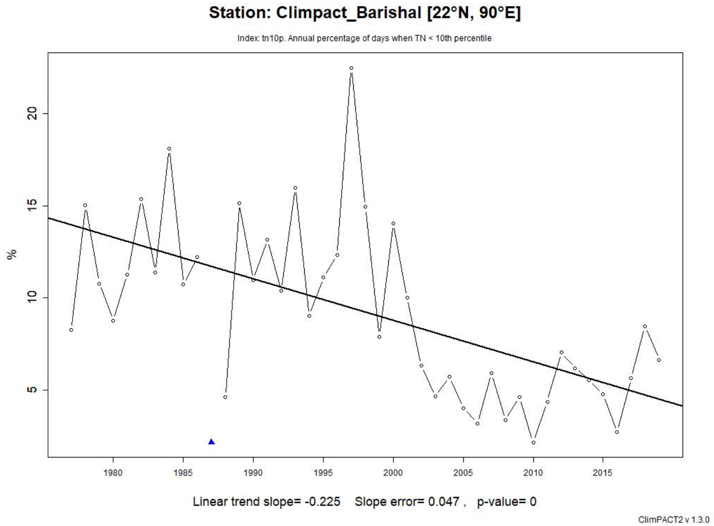


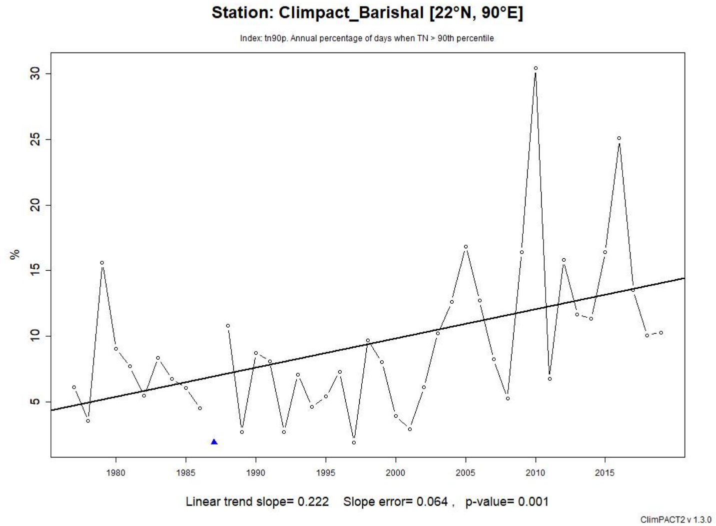
TX10p



TX90p



TN10p



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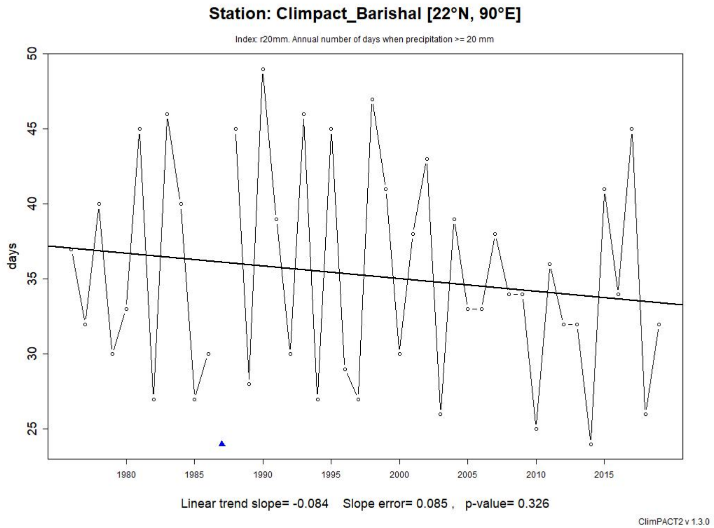

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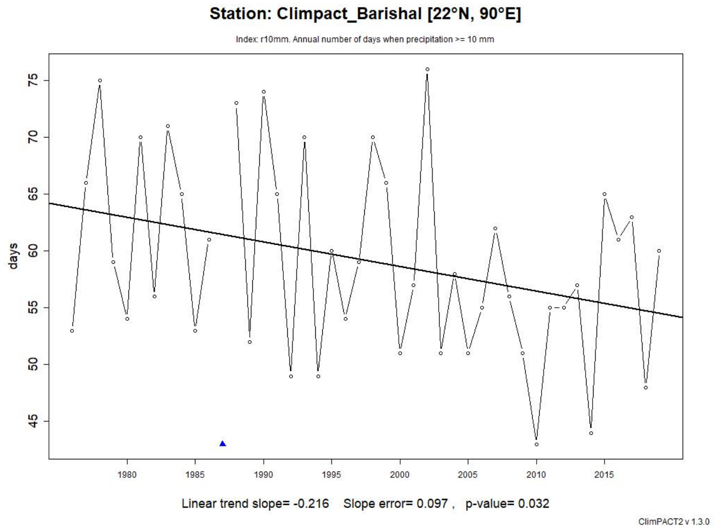
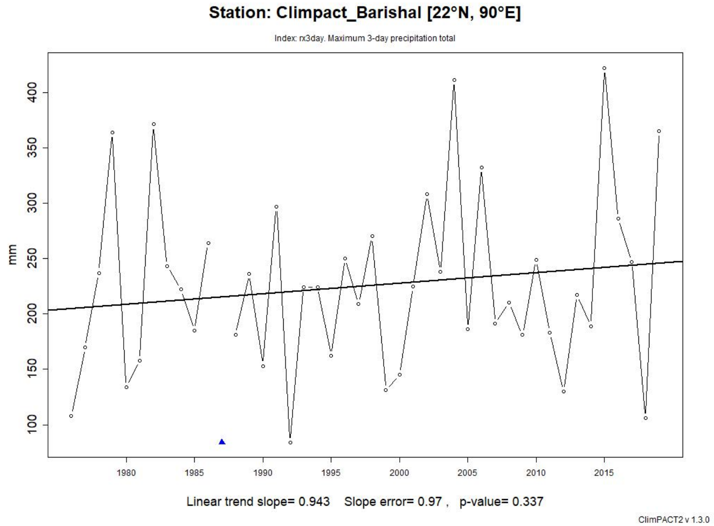
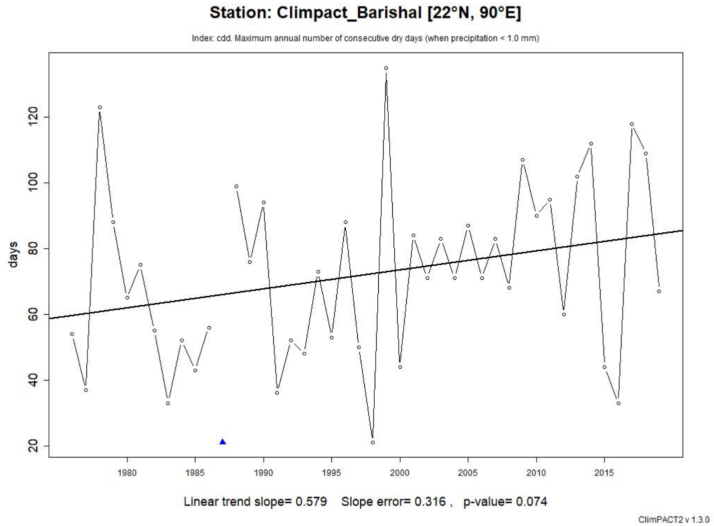


R10mm



RX3days



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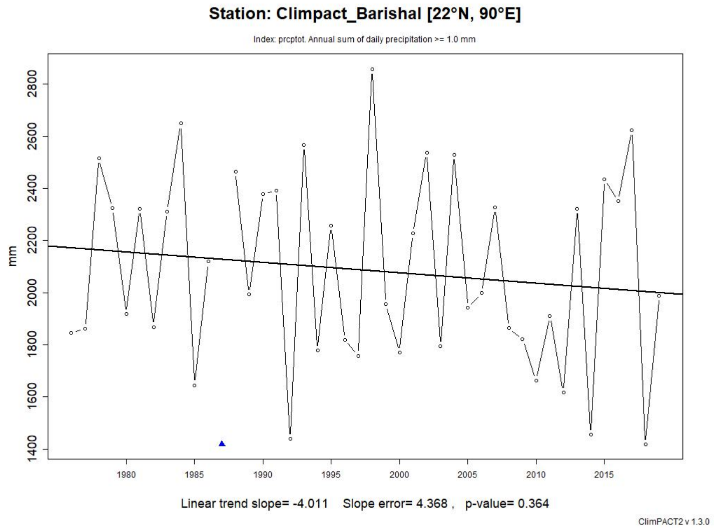
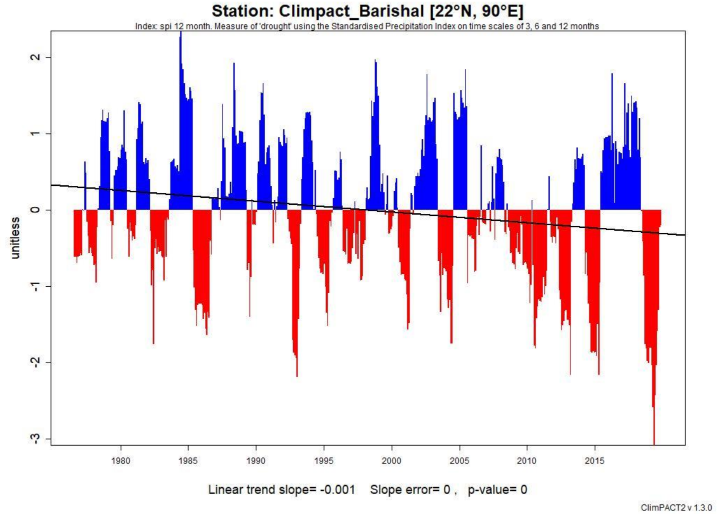
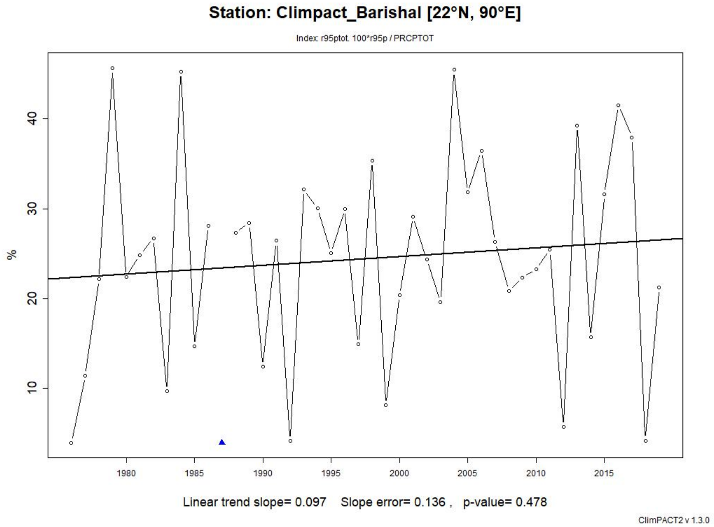


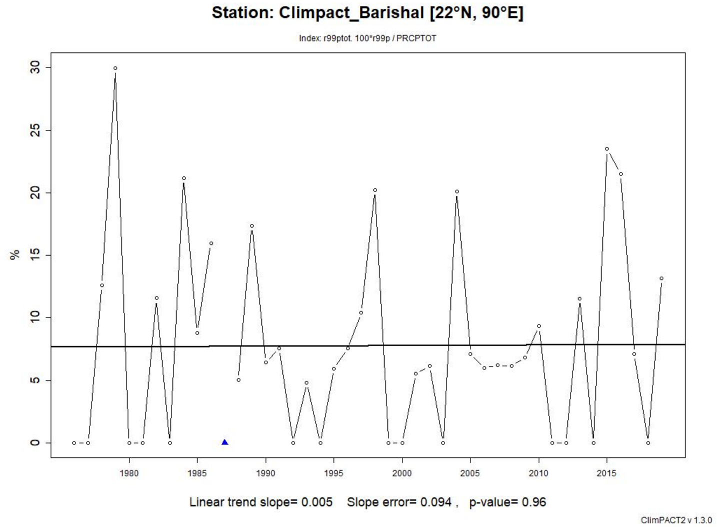
PRCPTOT



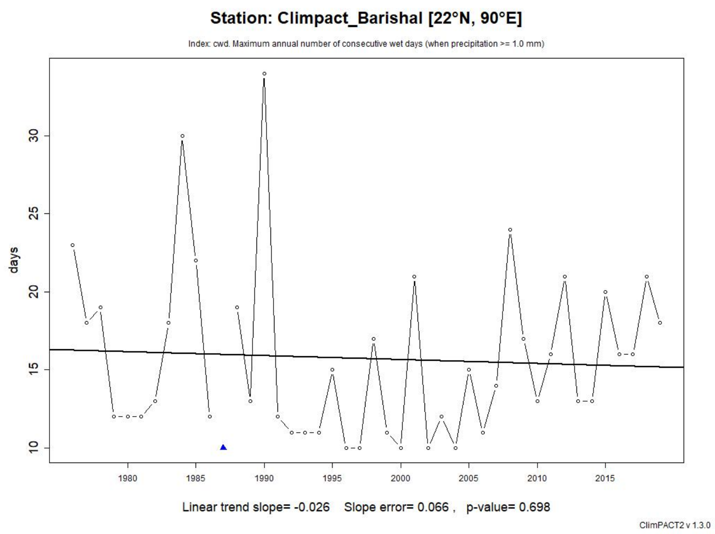
SPI



R95pTOT

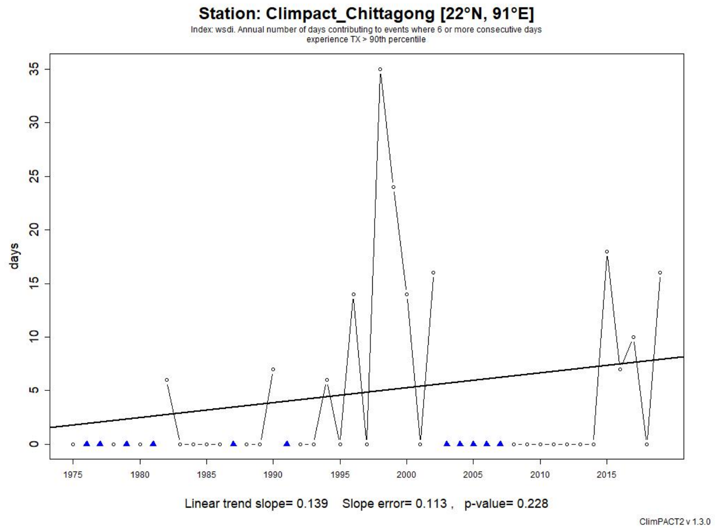


R99pTOT

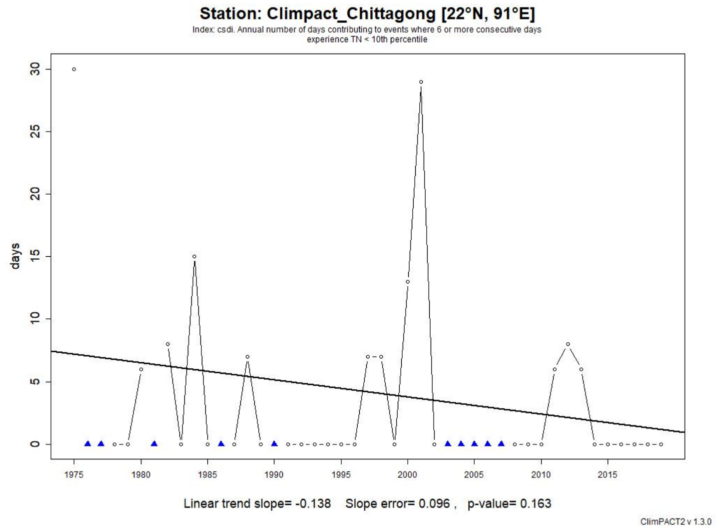


CWD

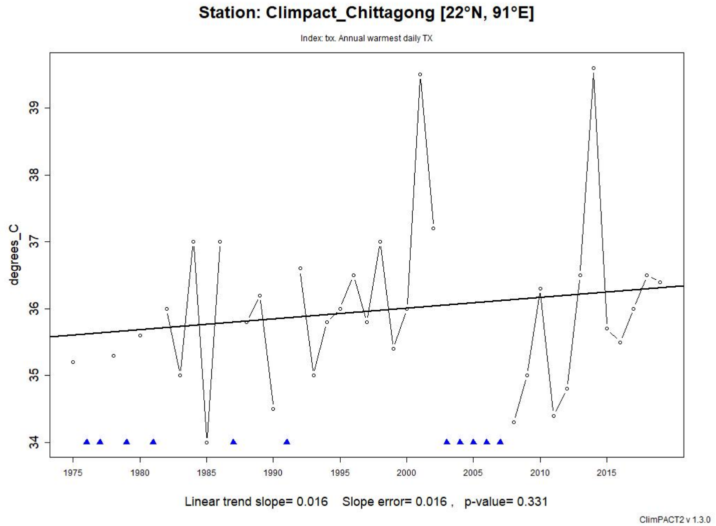
Figure A.7: Graphical representation of extreme indices analysis of Barisal



WSDI



CSDI



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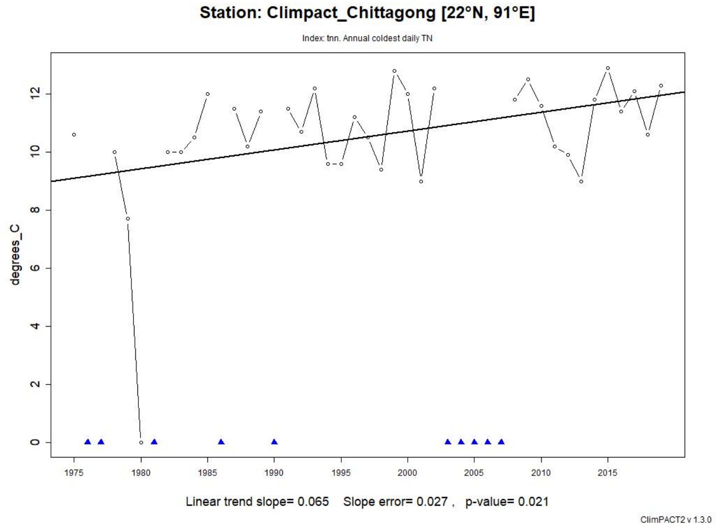

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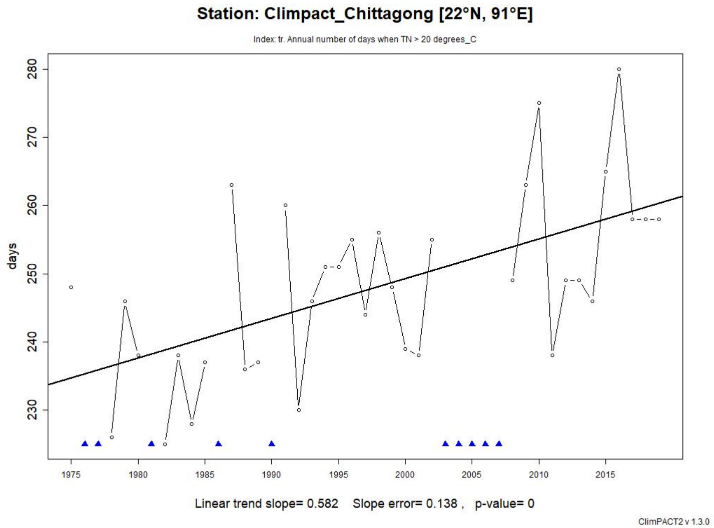

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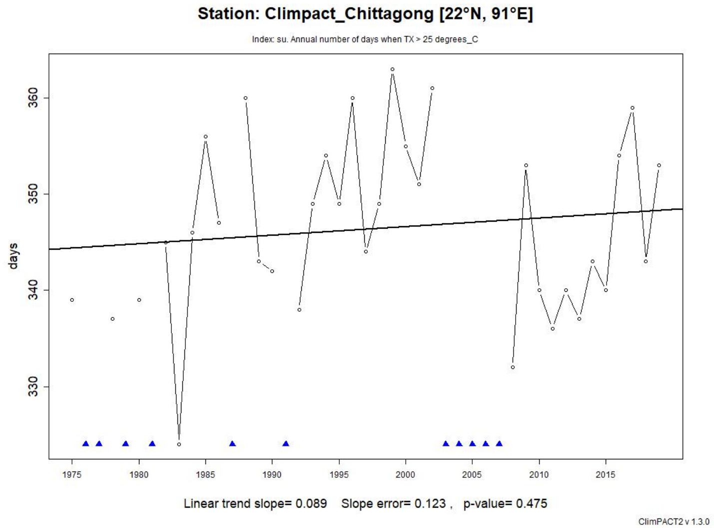

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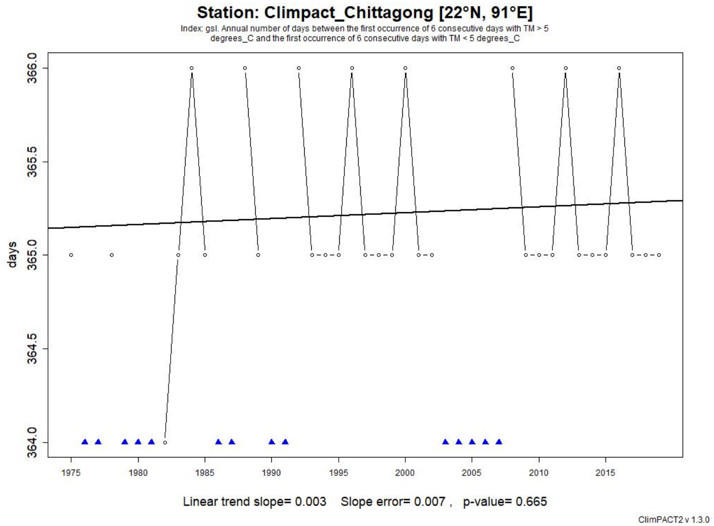

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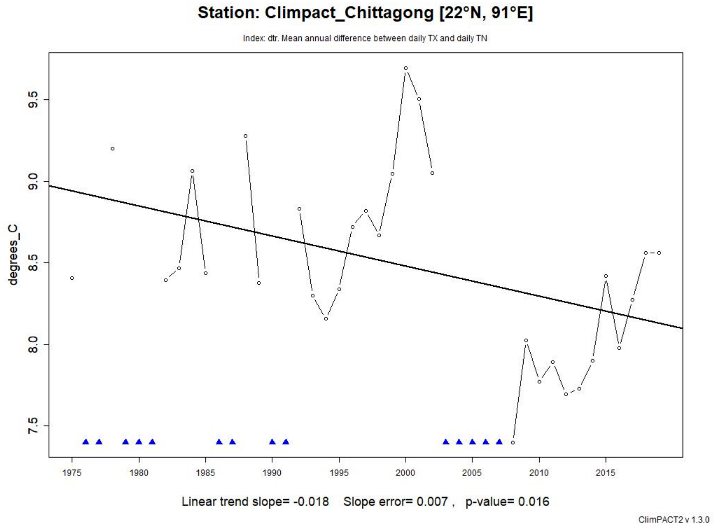

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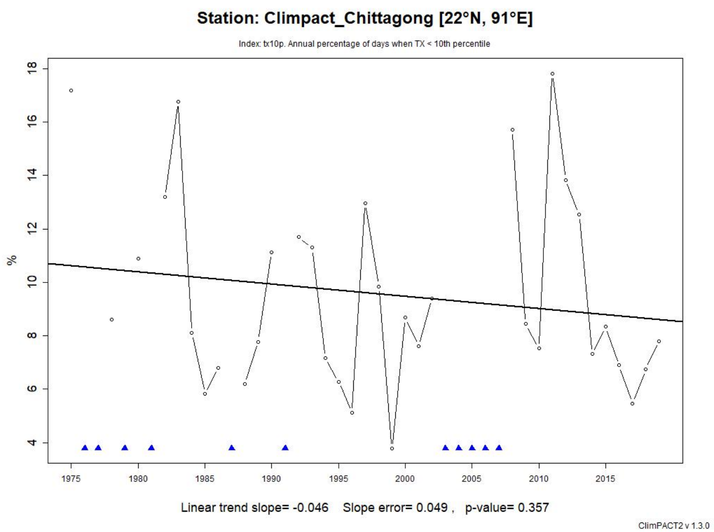

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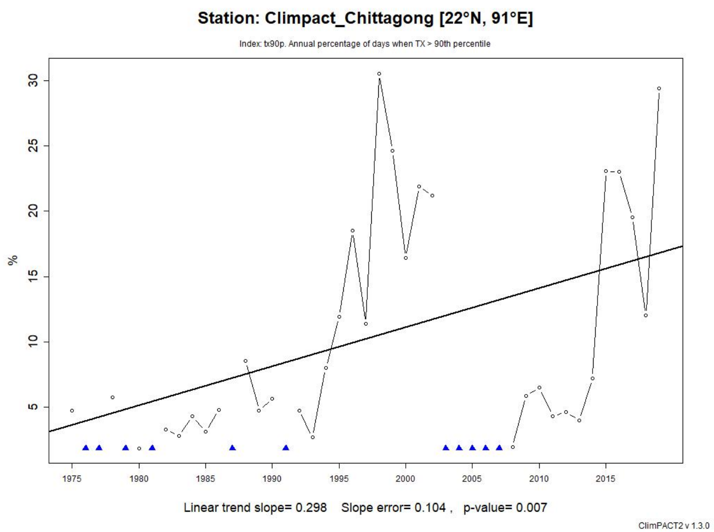

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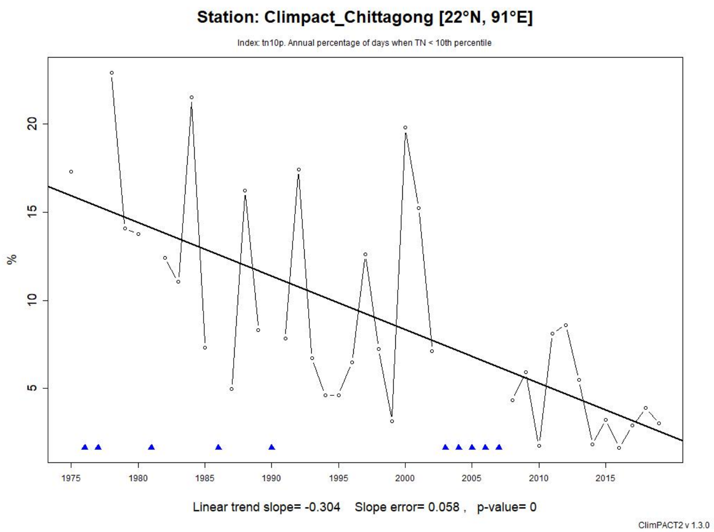

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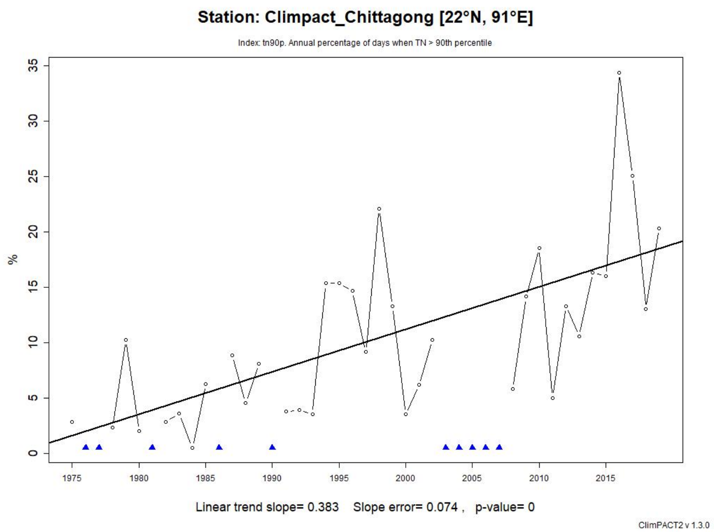

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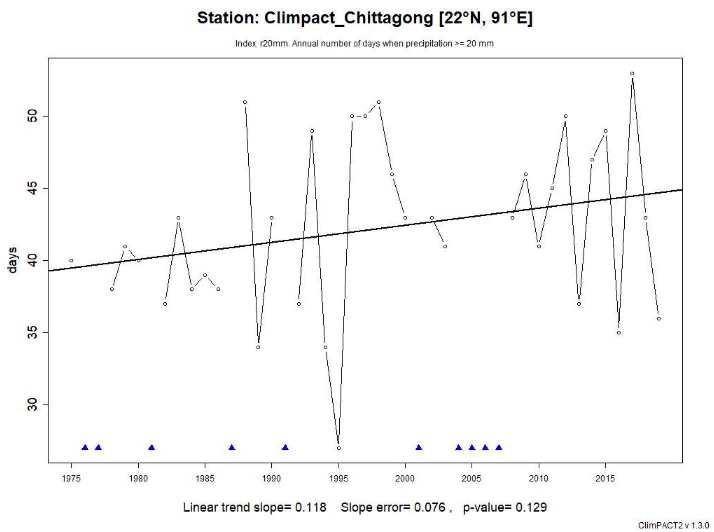
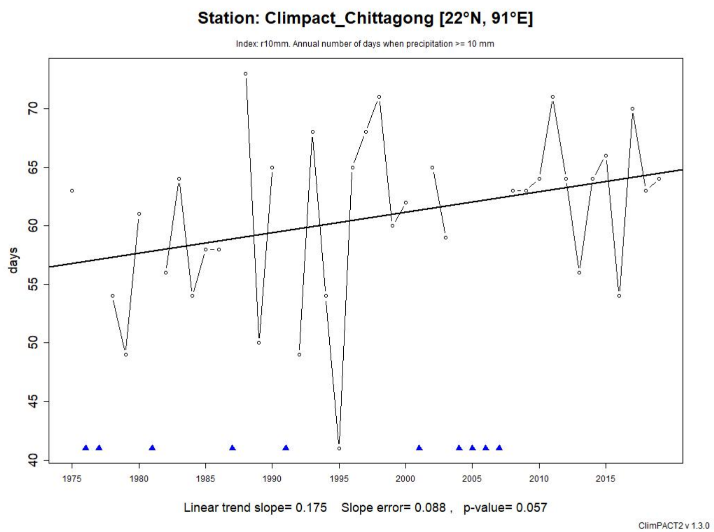
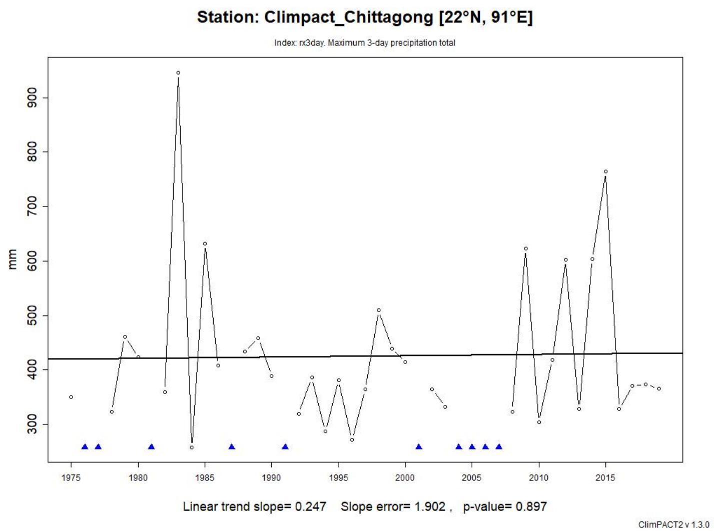


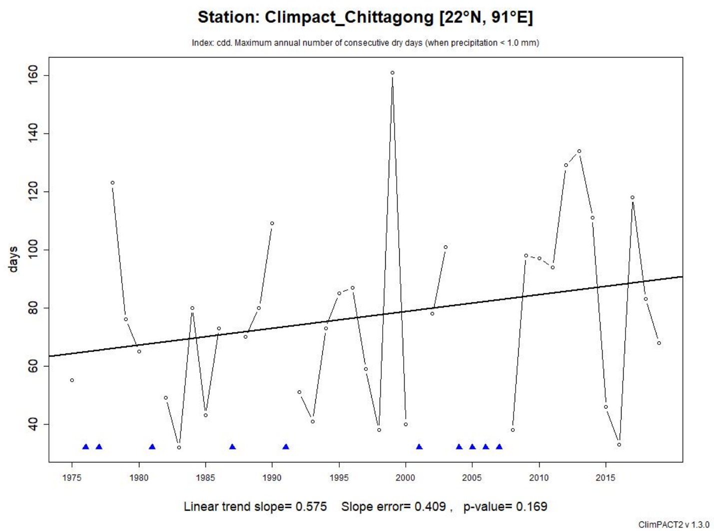
R20mm



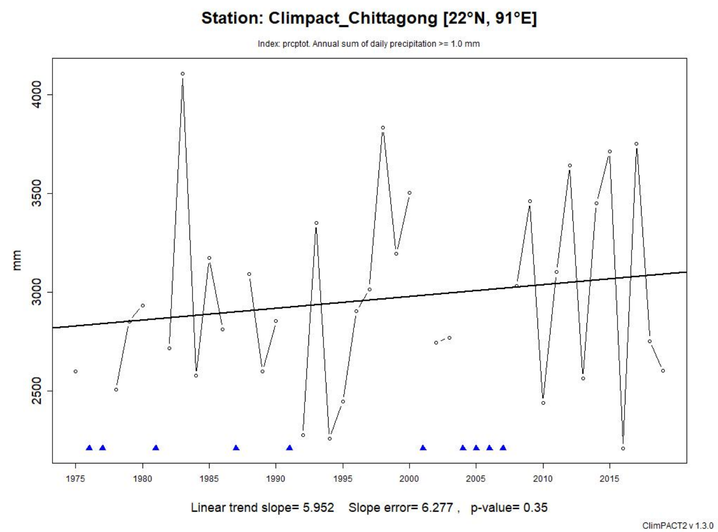
R10mm



RX3days



CDD



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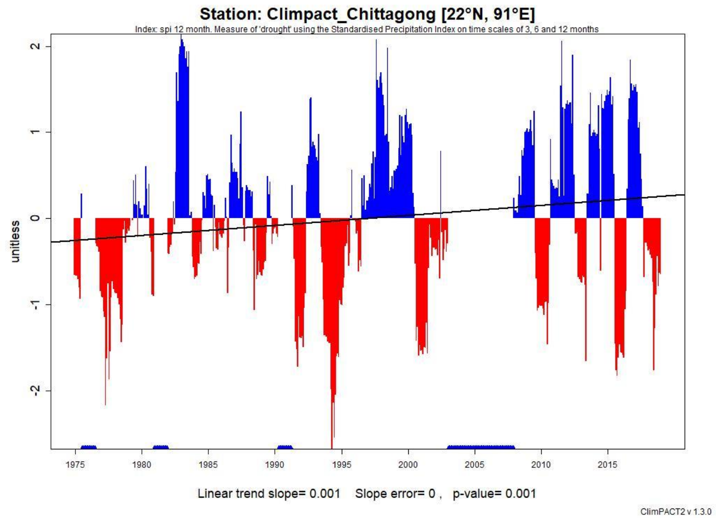
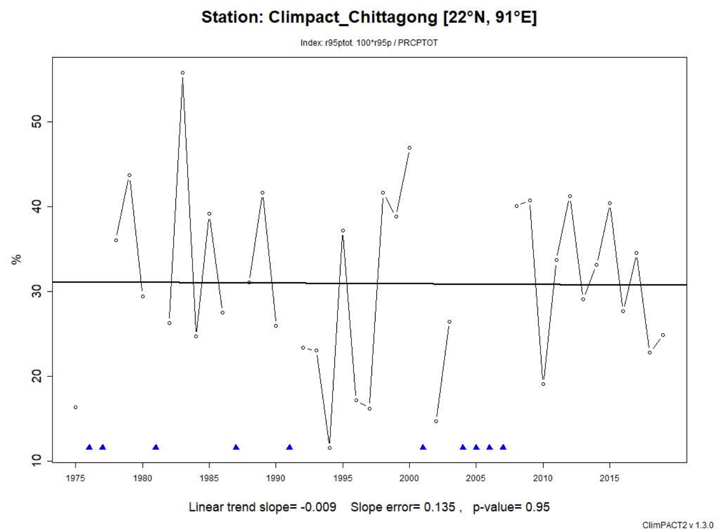
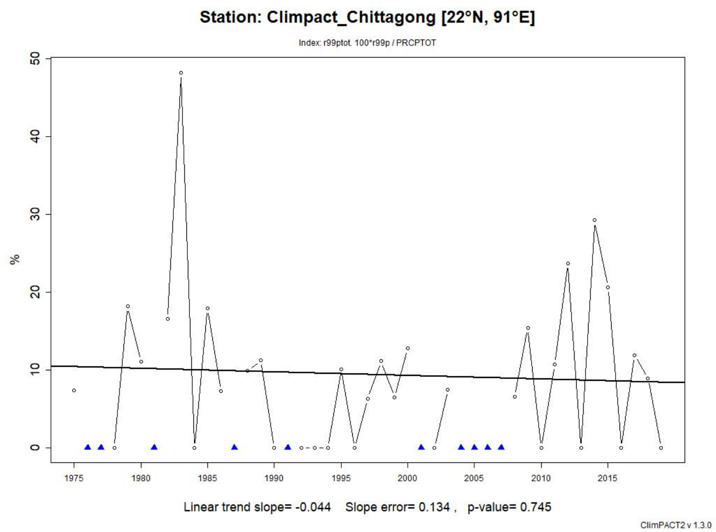


SPI



R95pTOT



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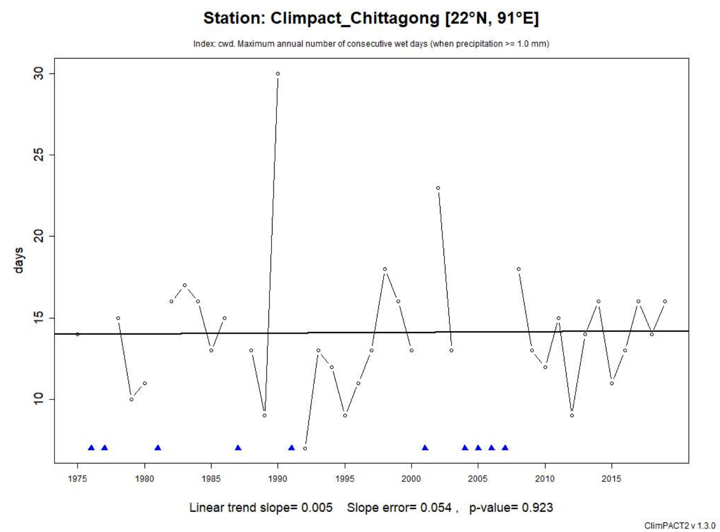
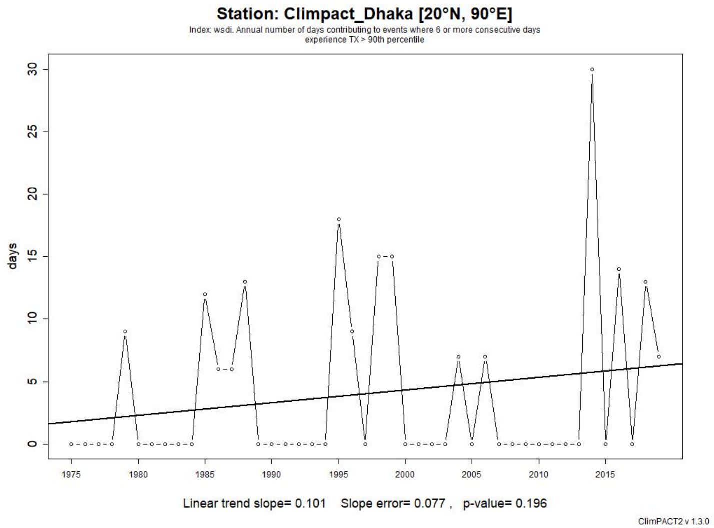


CWD

Figure A.8: Graphical representation of extreme indices analysis of Chittagong



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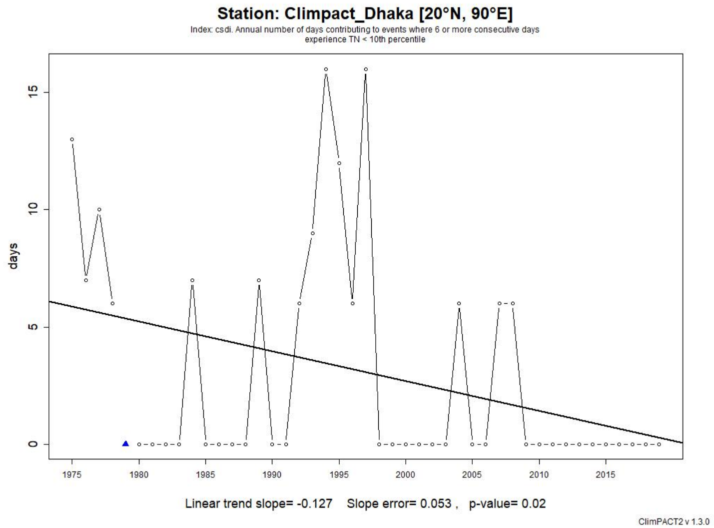

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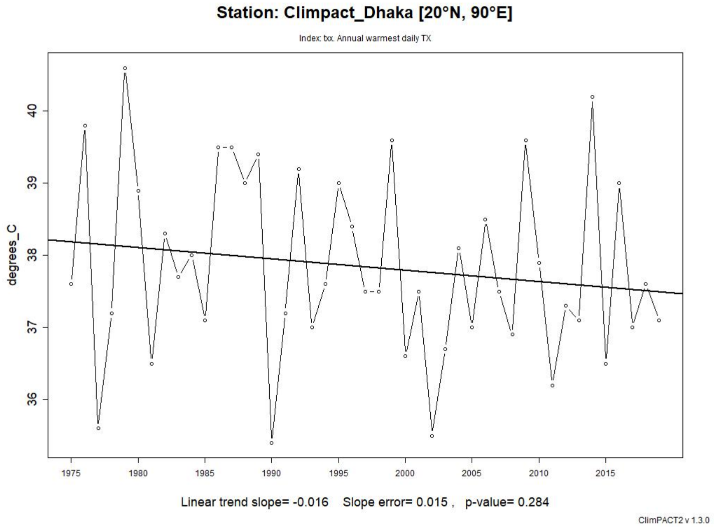
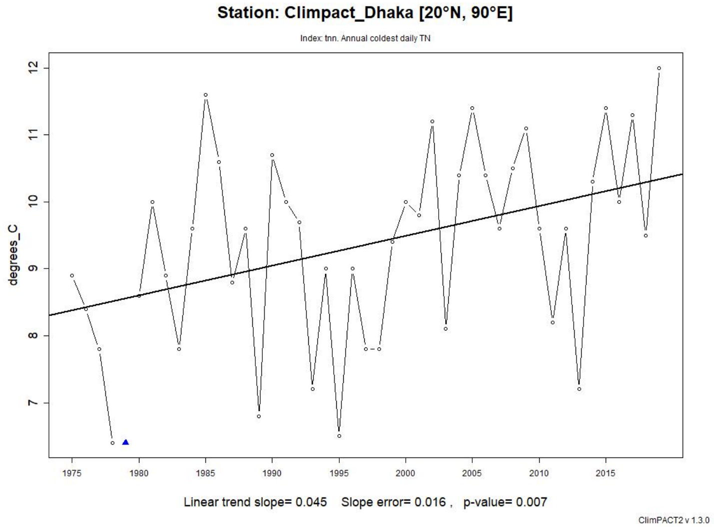
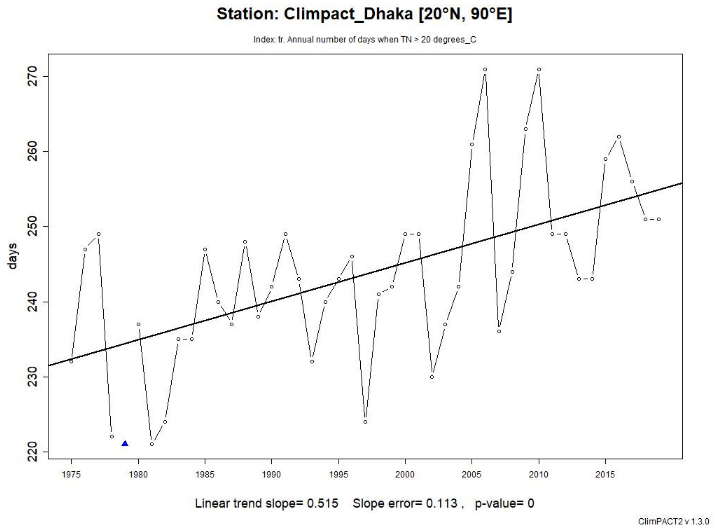


TXx



TNn



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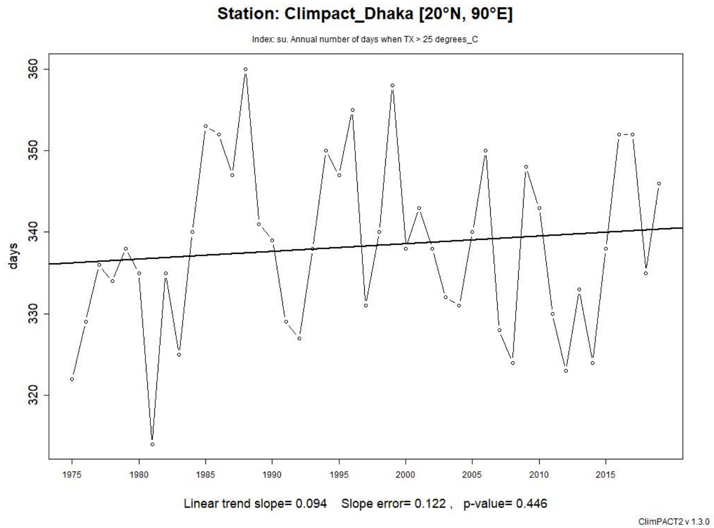

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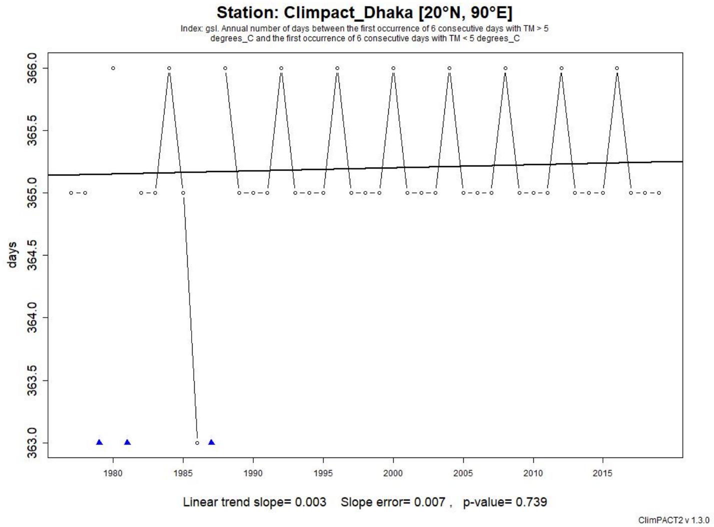

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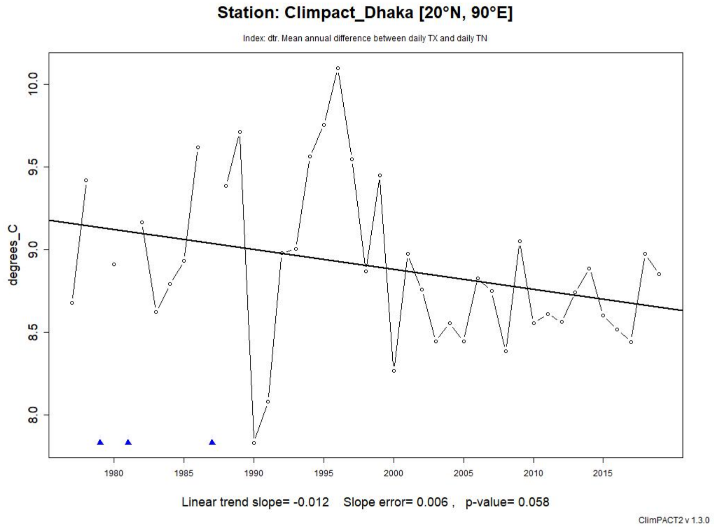

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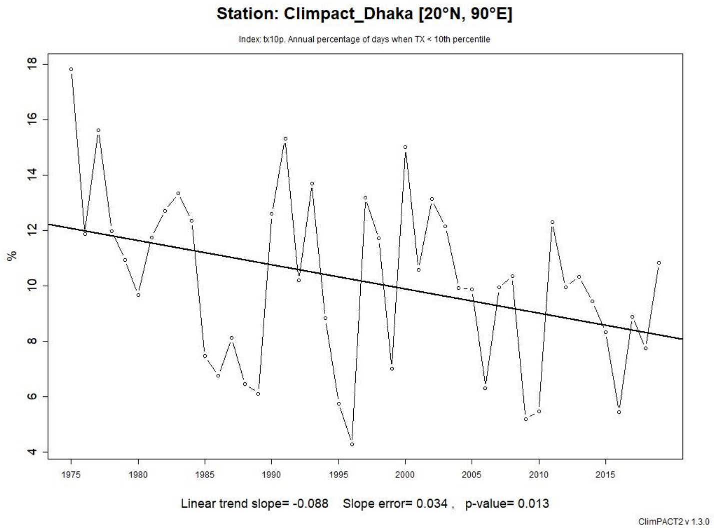

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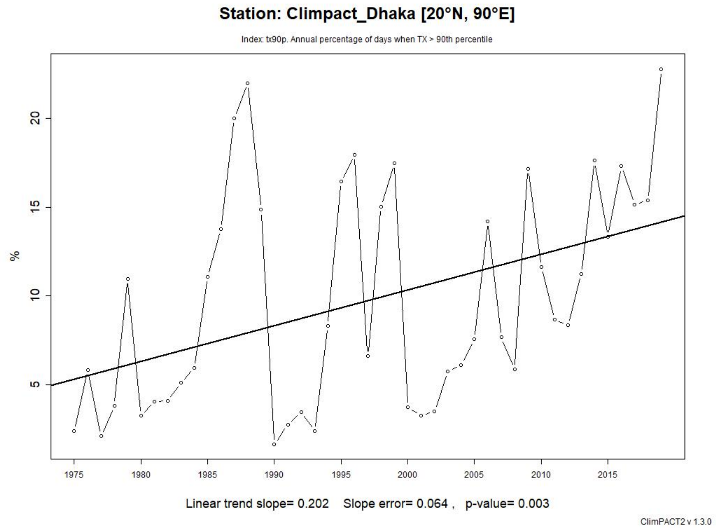

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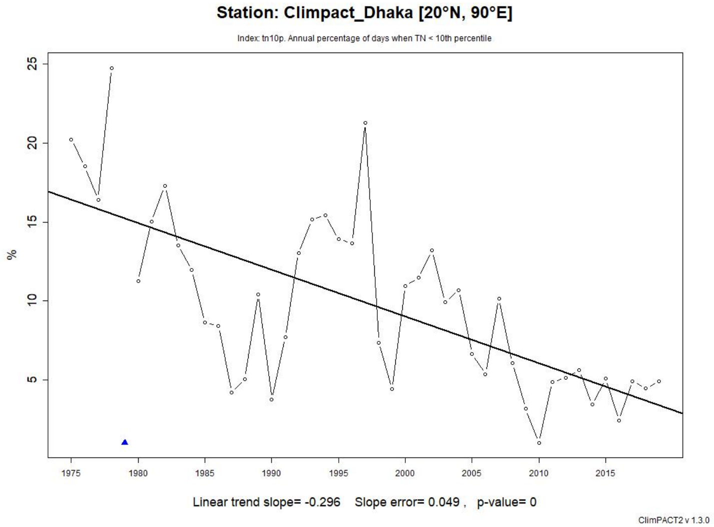

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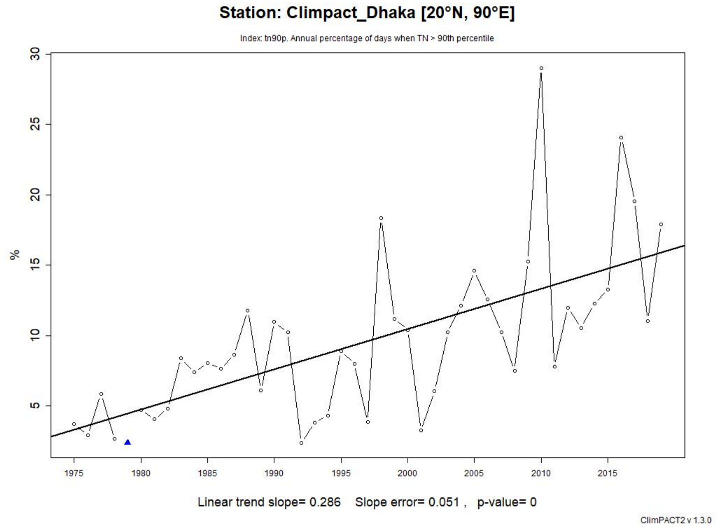

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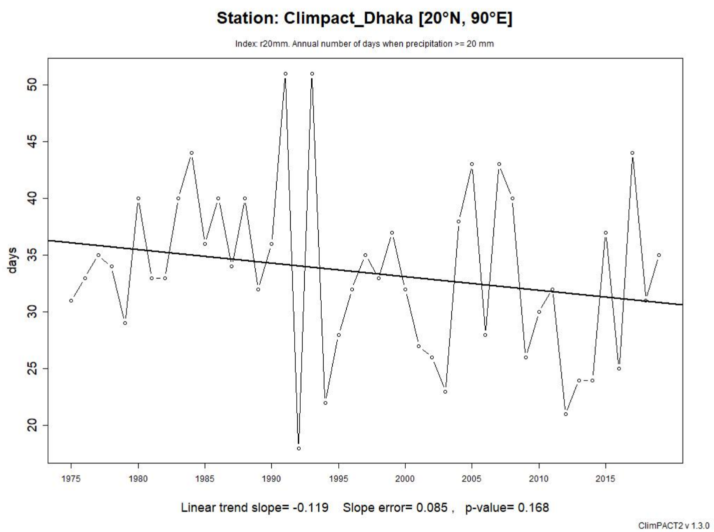
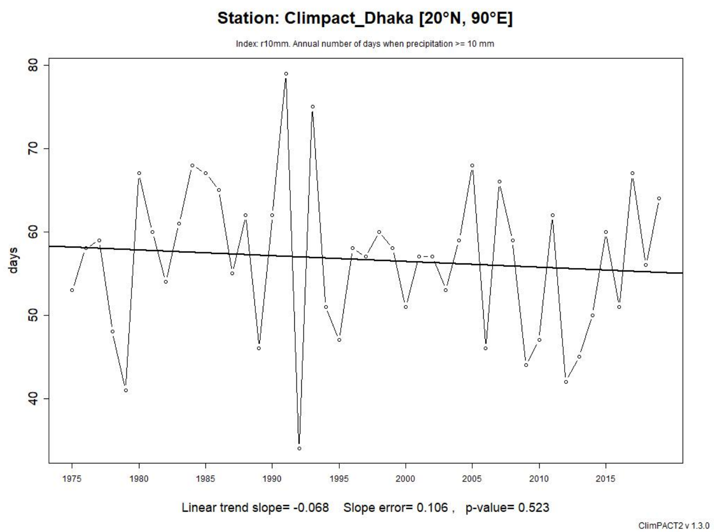
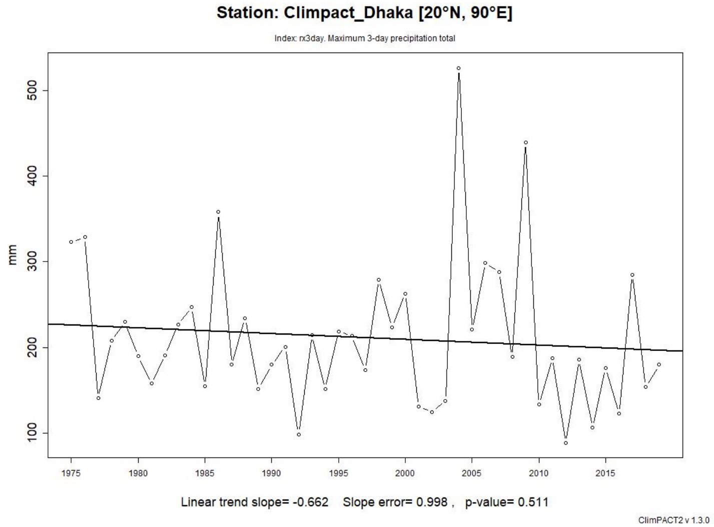


R20mm



R10mm



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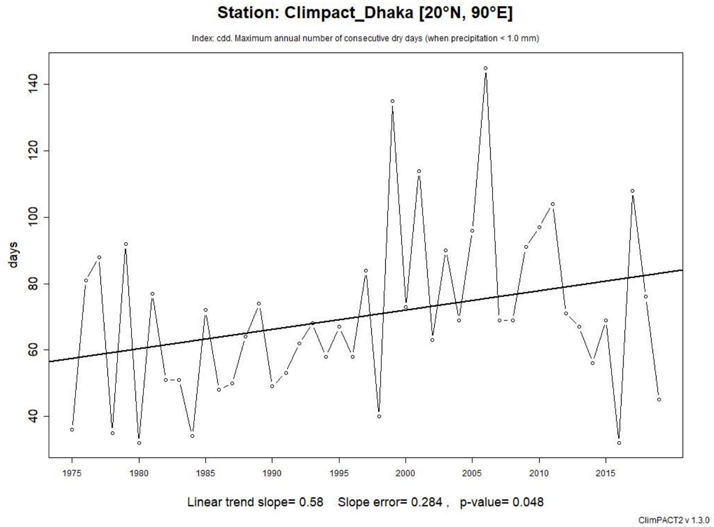
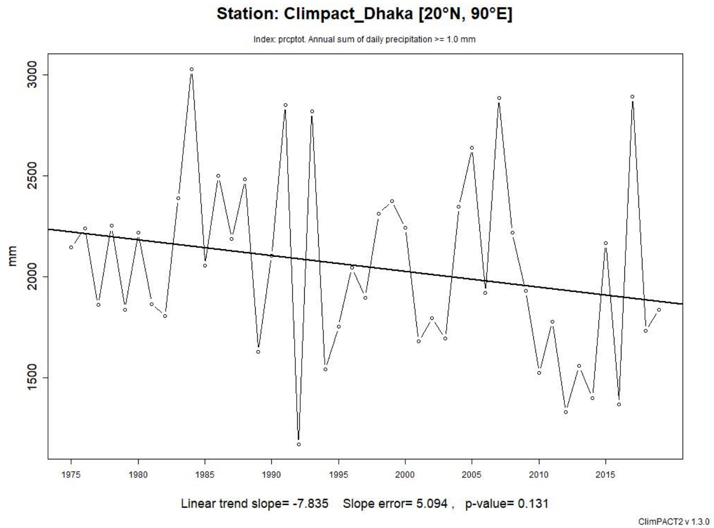
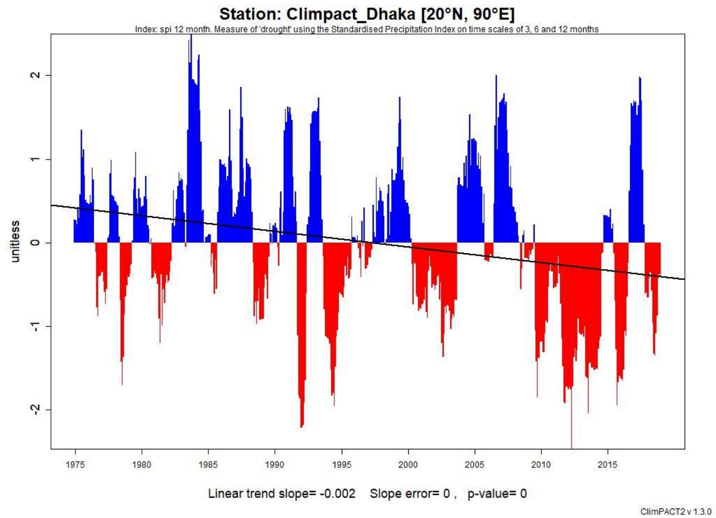


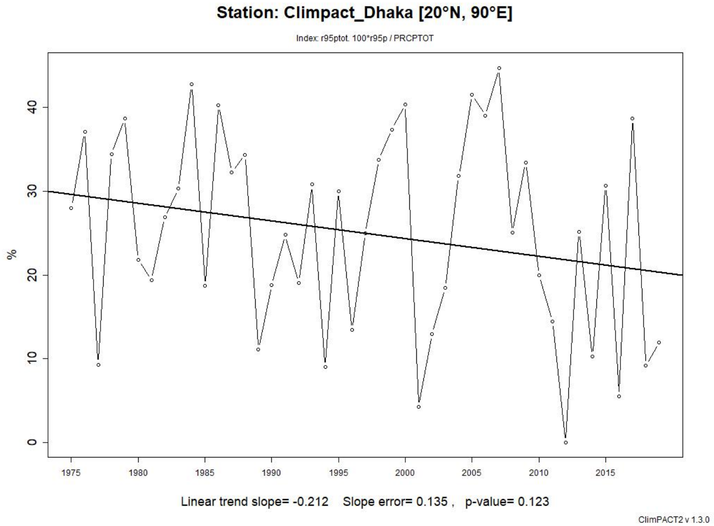
CDD



PRCPTOT



SPI



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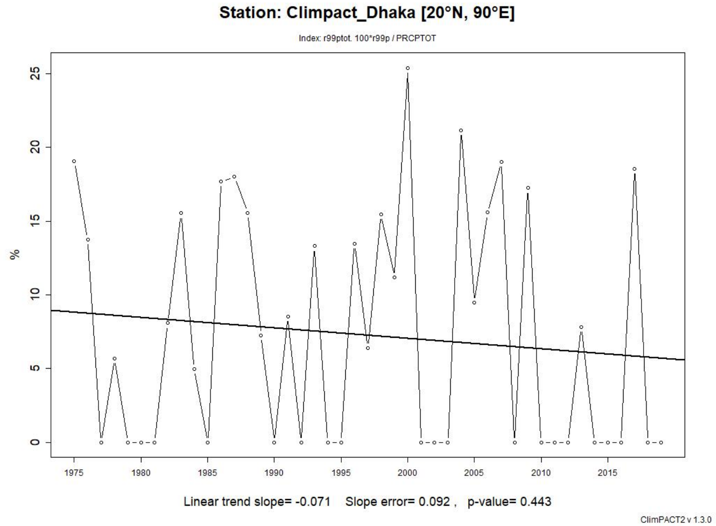

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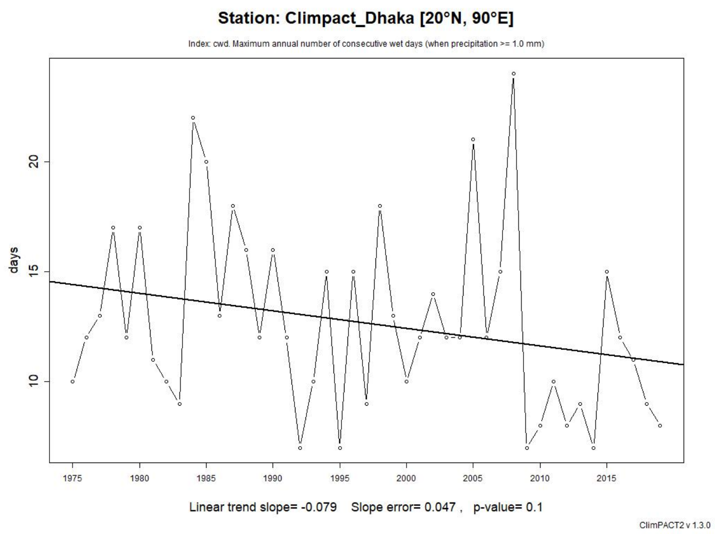
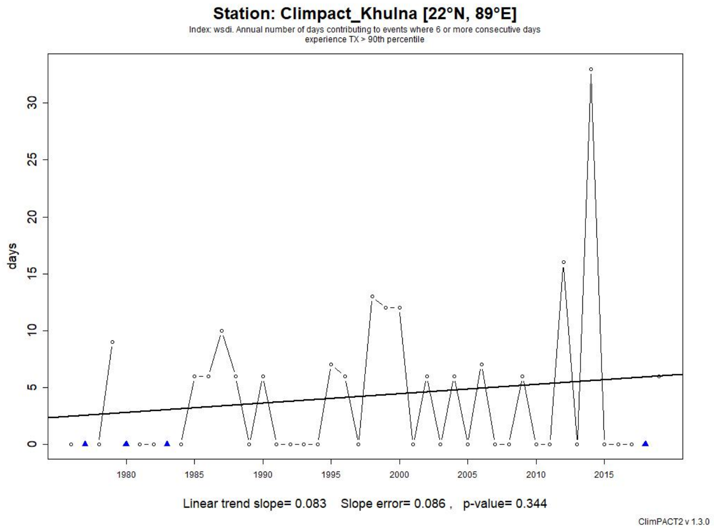


CWD

Figure A.9: Graphical representation of extreme indices analysis of Dhaka



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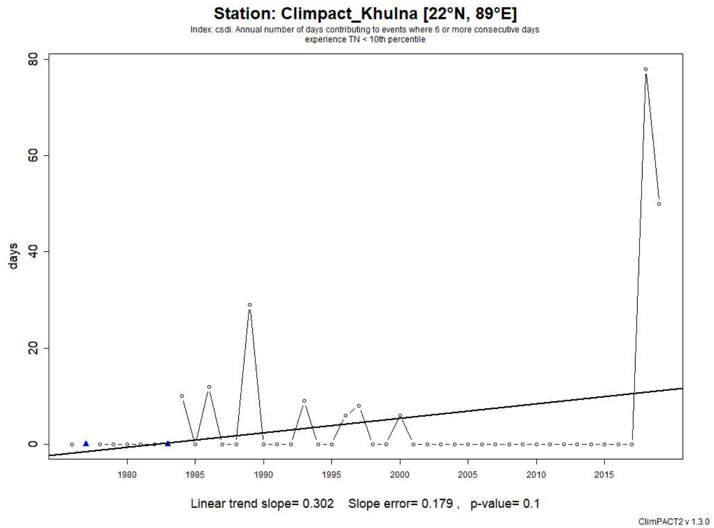

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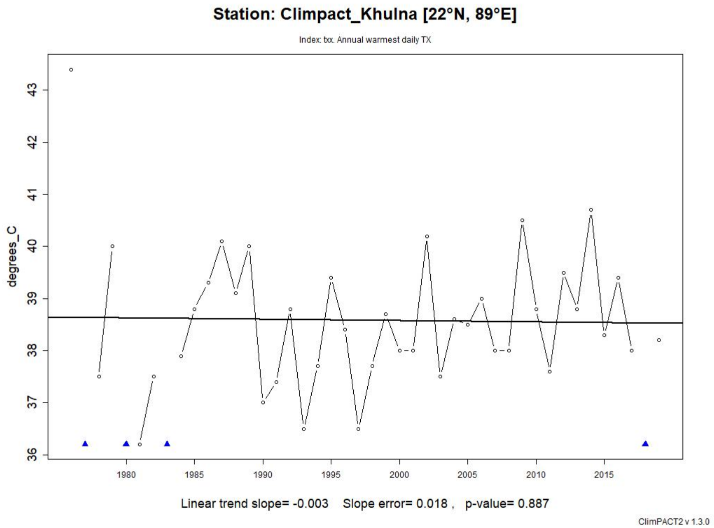

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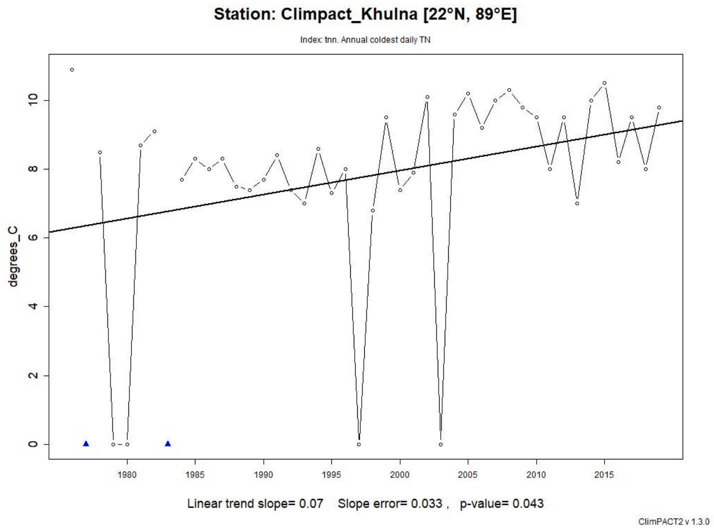
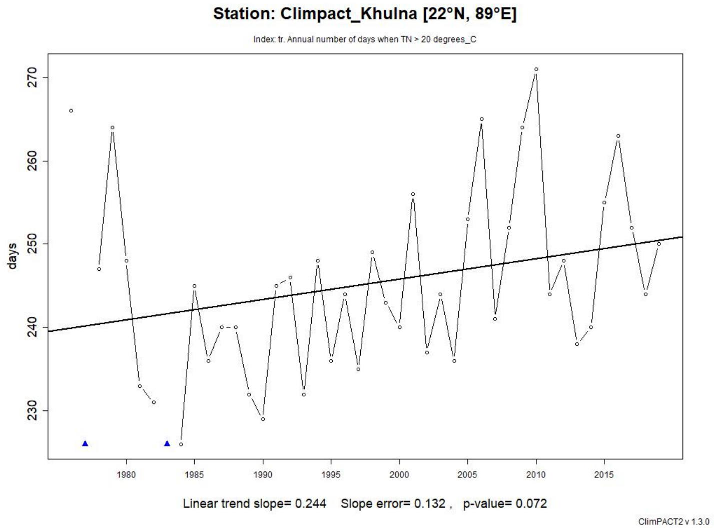


TNn



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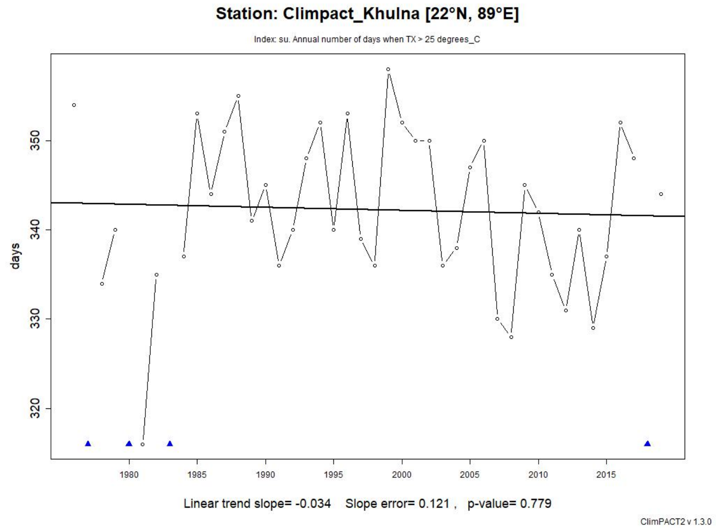

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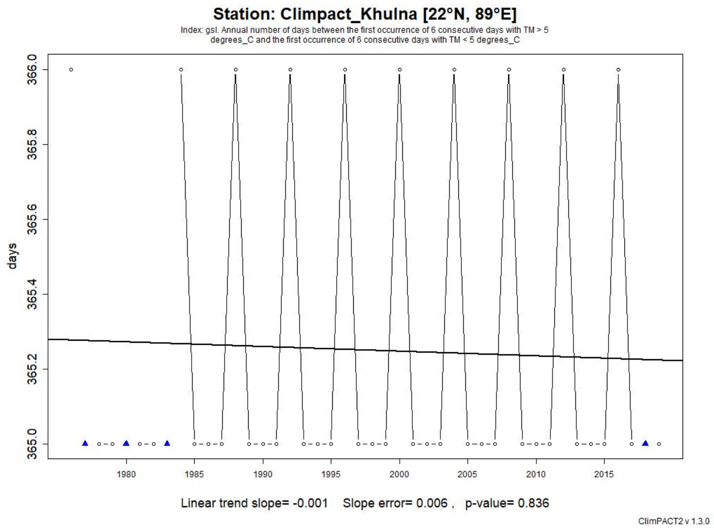
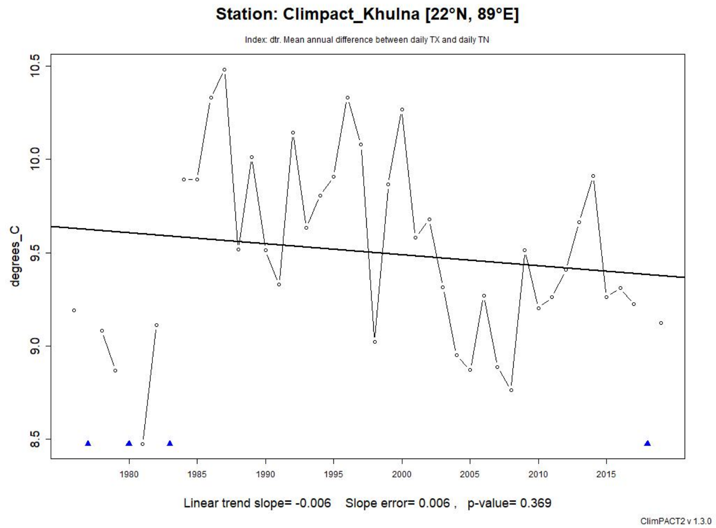


GSL



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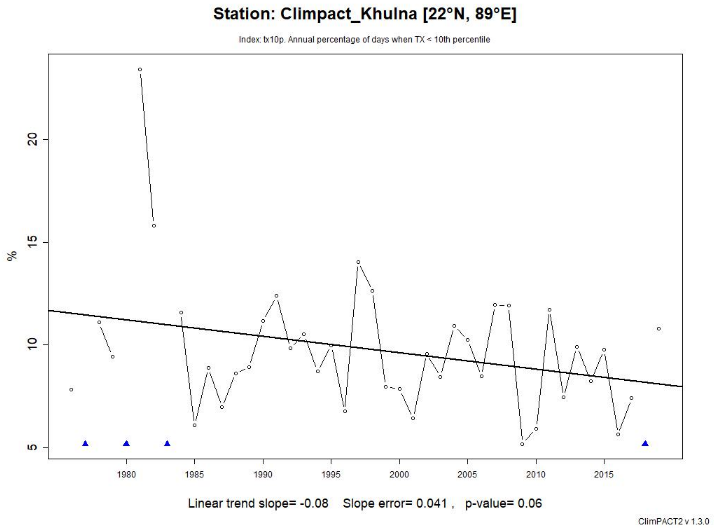
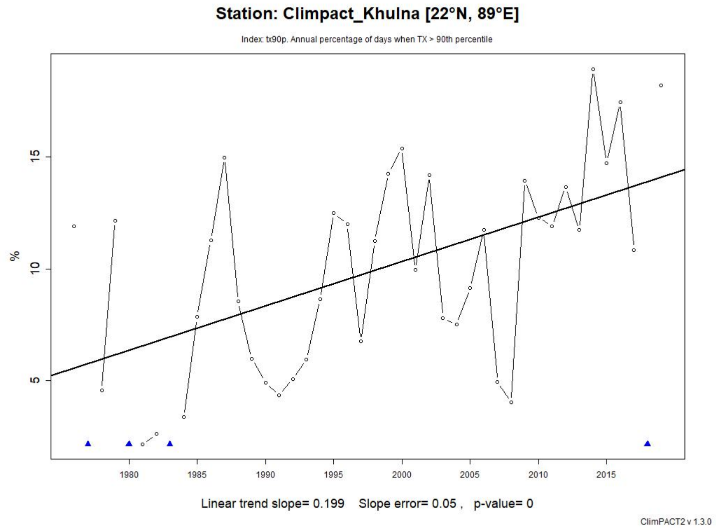


TX10p



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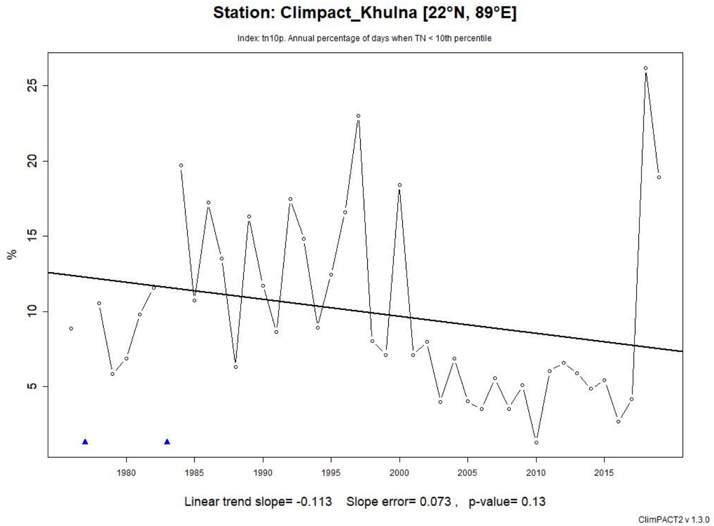
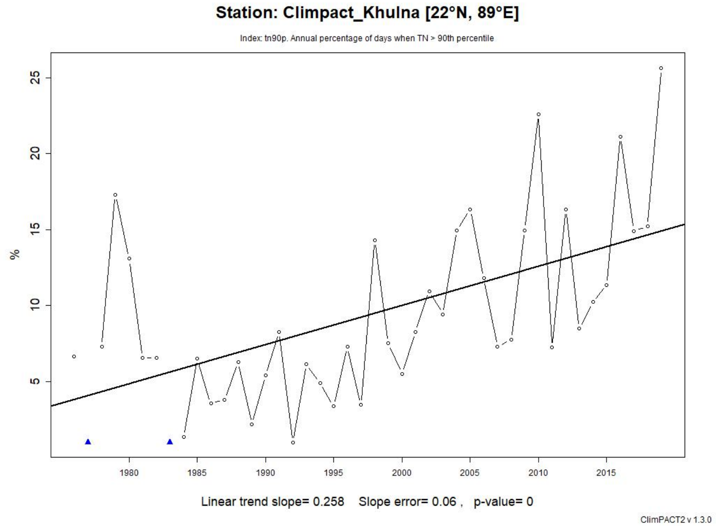


TN10p



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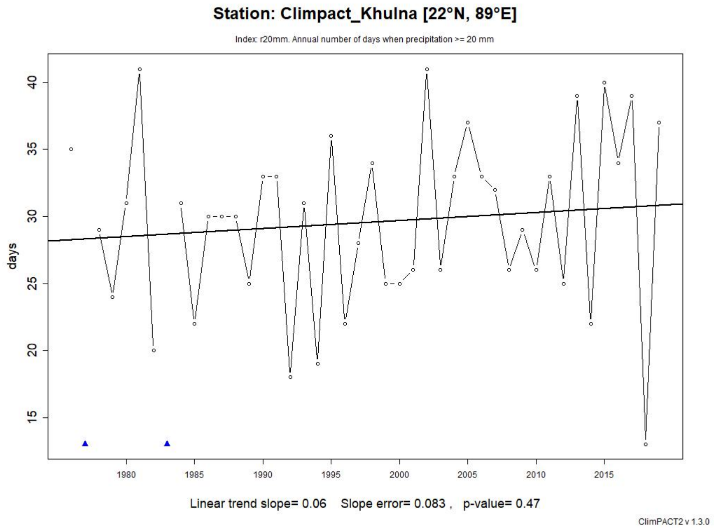
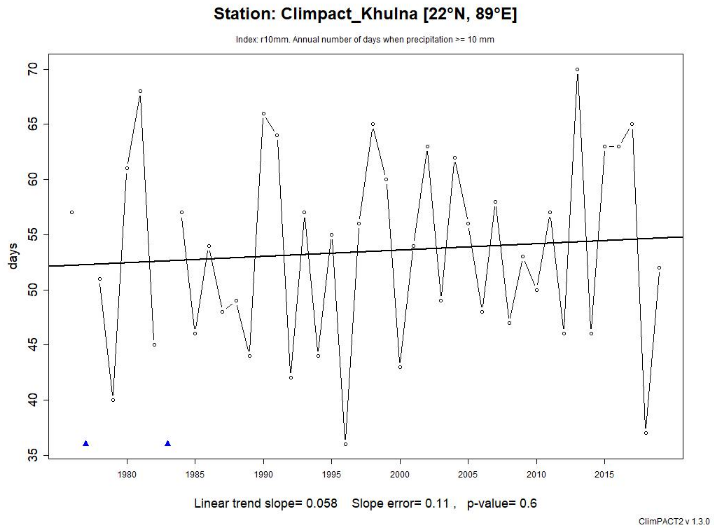
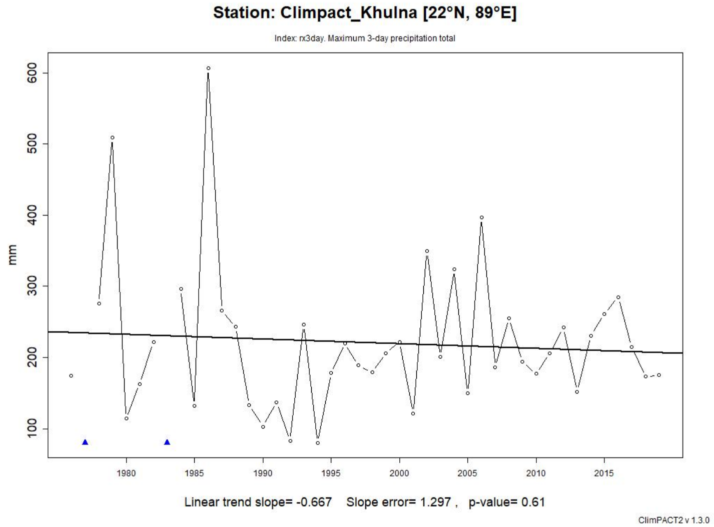


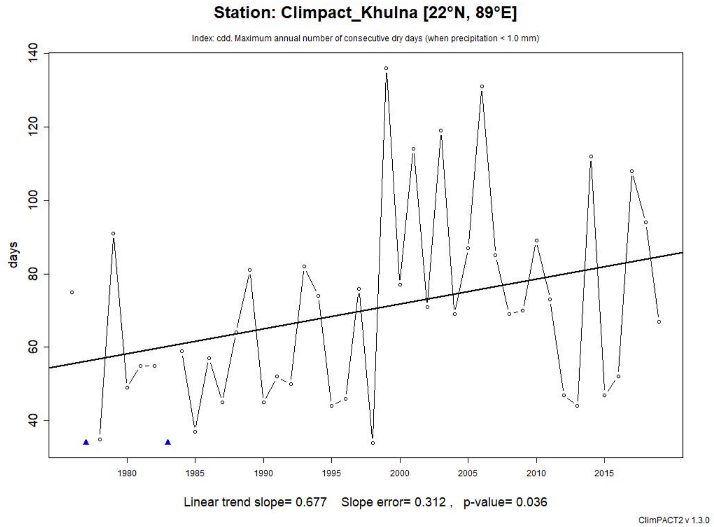
R20mm



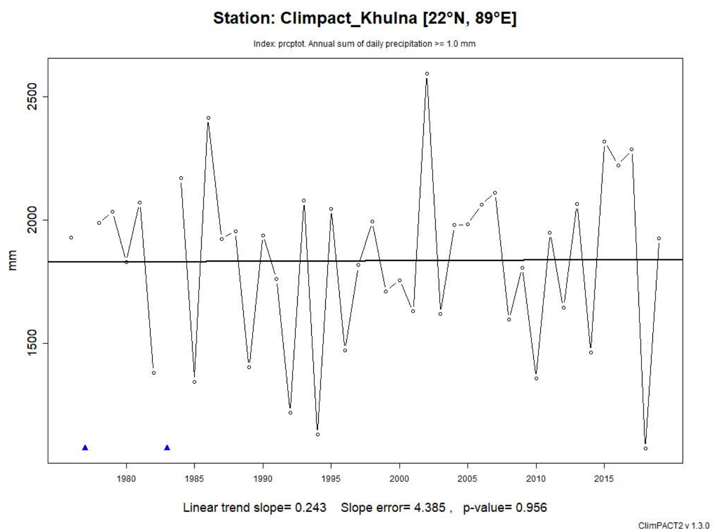
R10mm



RX3days



CDD



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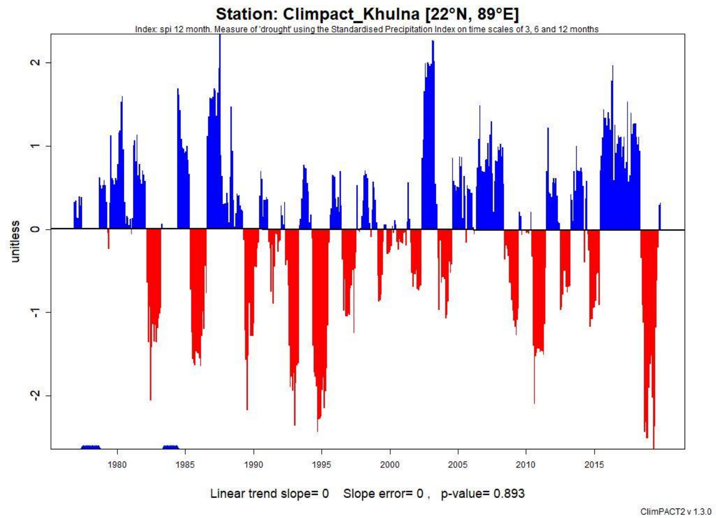

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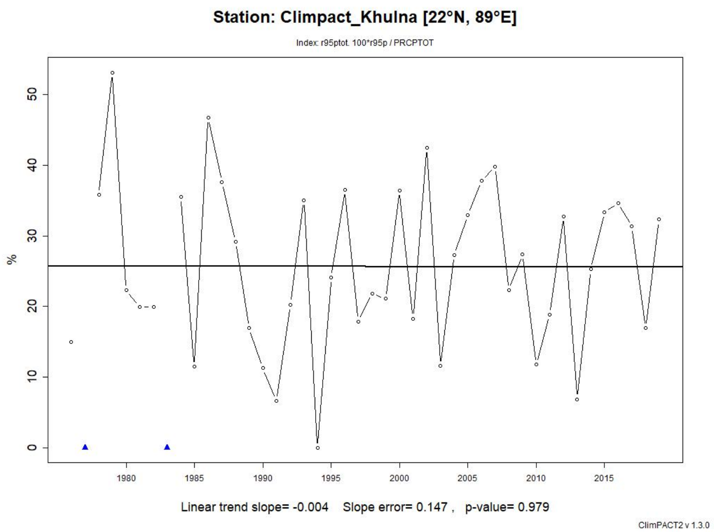

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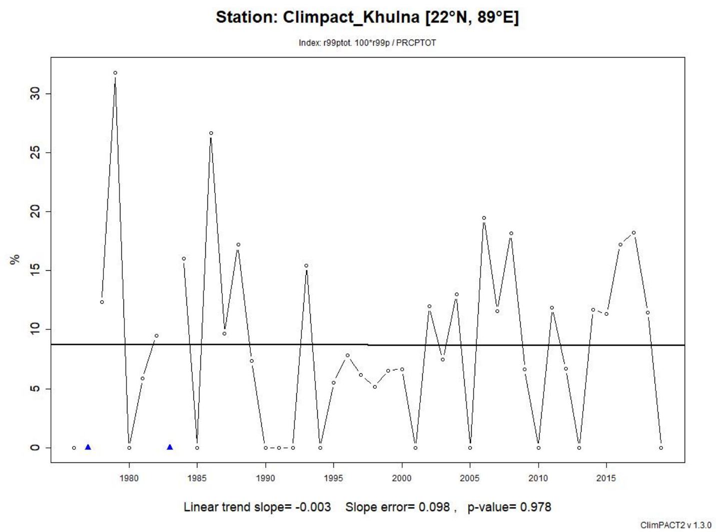

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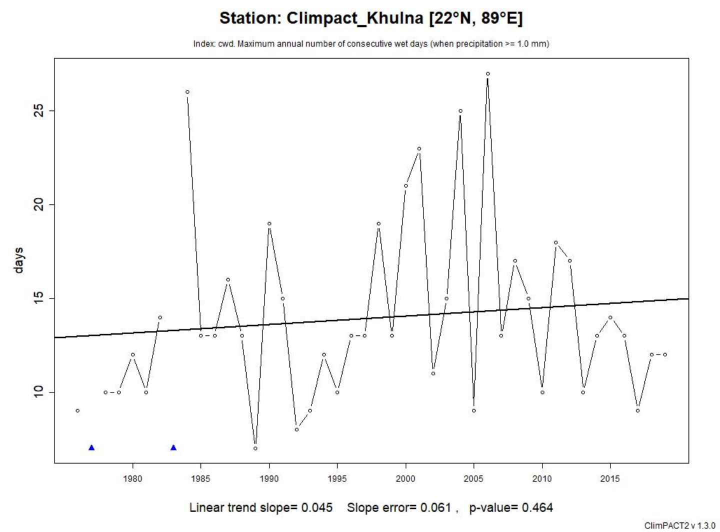
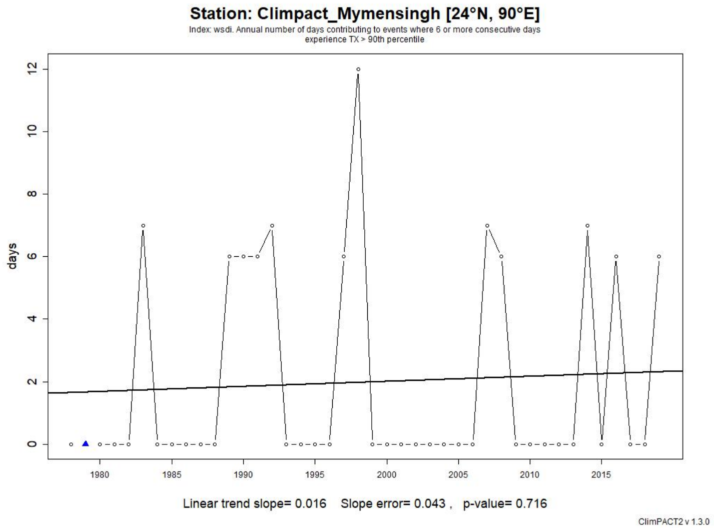


CWD

Figure A.10: Graphical representation of extreme indices analysis of Khulna



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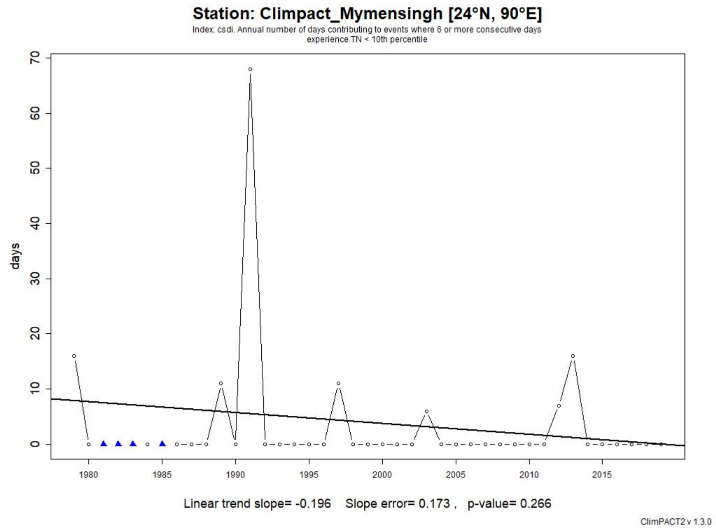
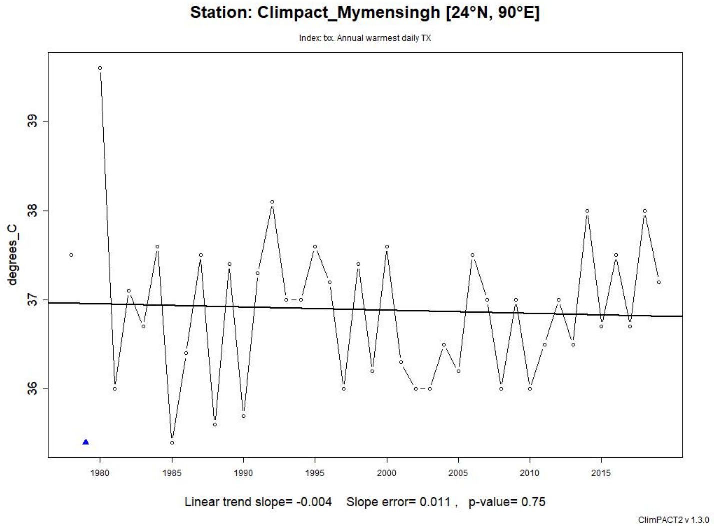
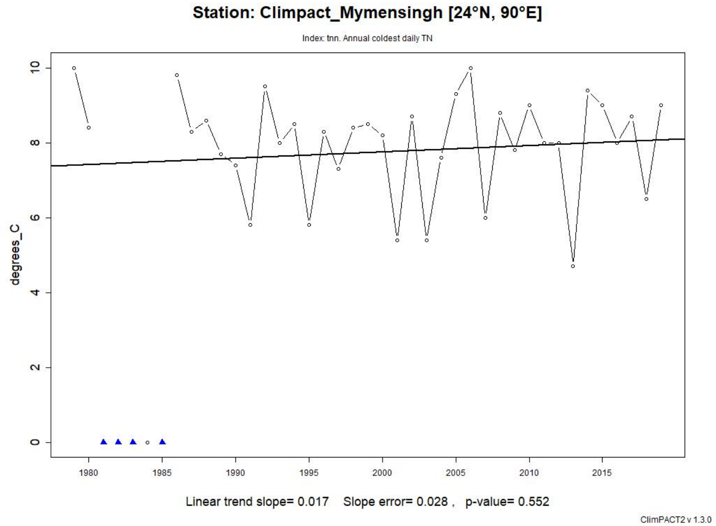


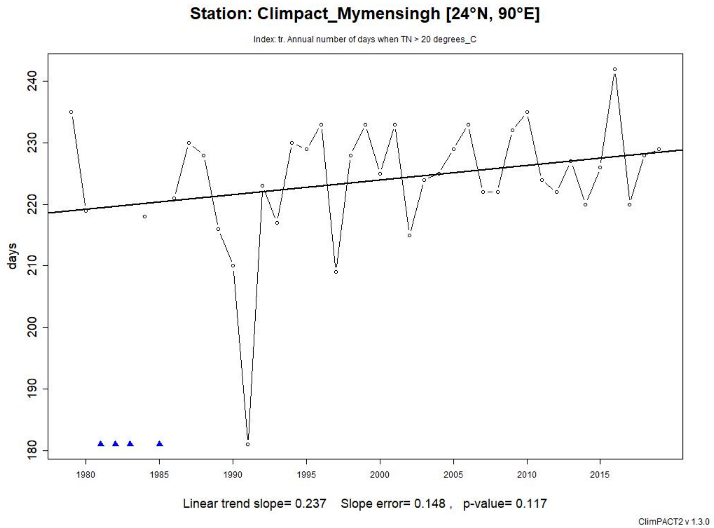
CSDI



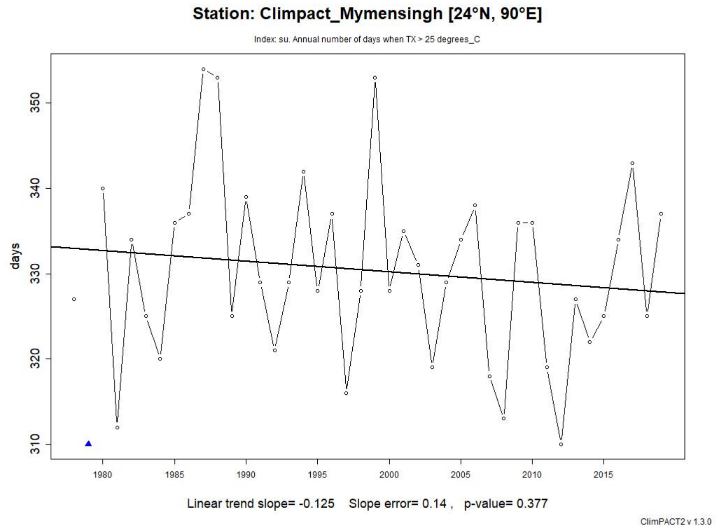
TXx



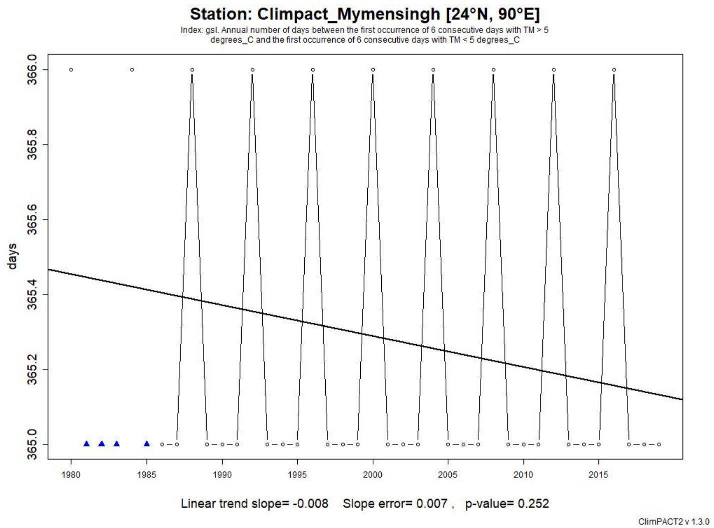
TNn



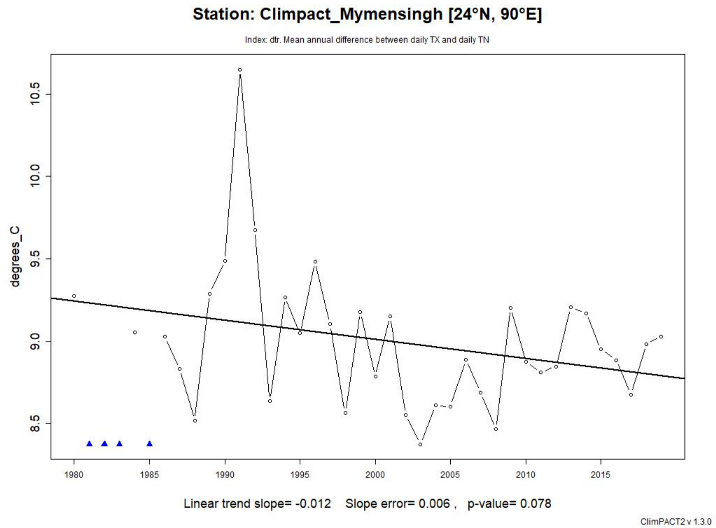
TR



SU25



GSL



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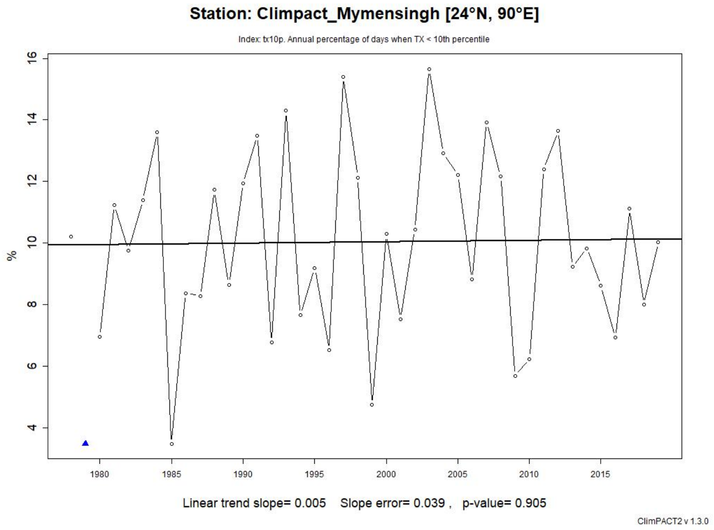
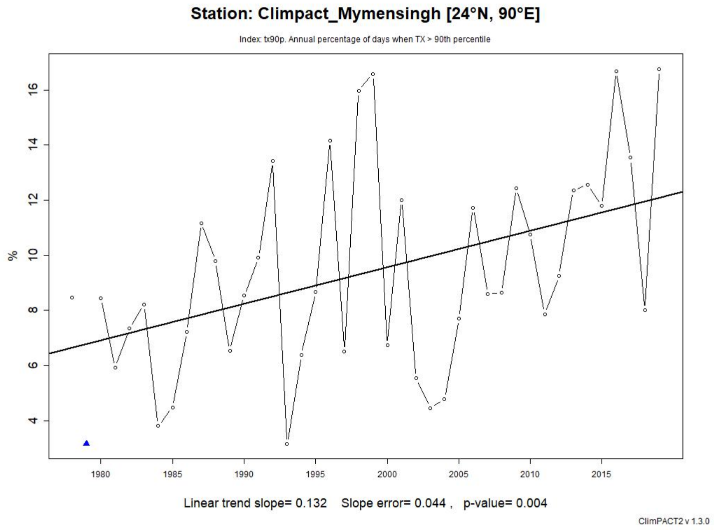
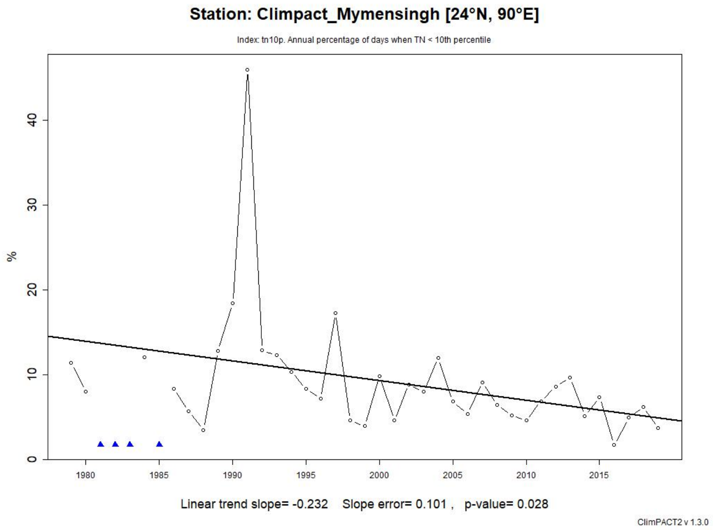


TX10p



TX90p



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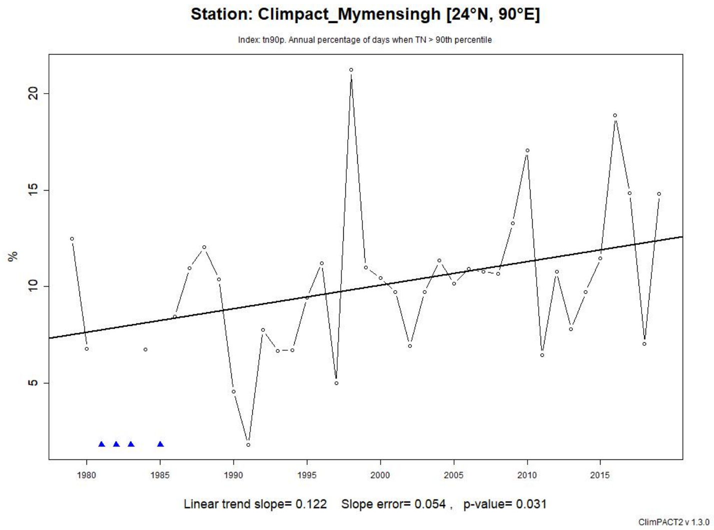
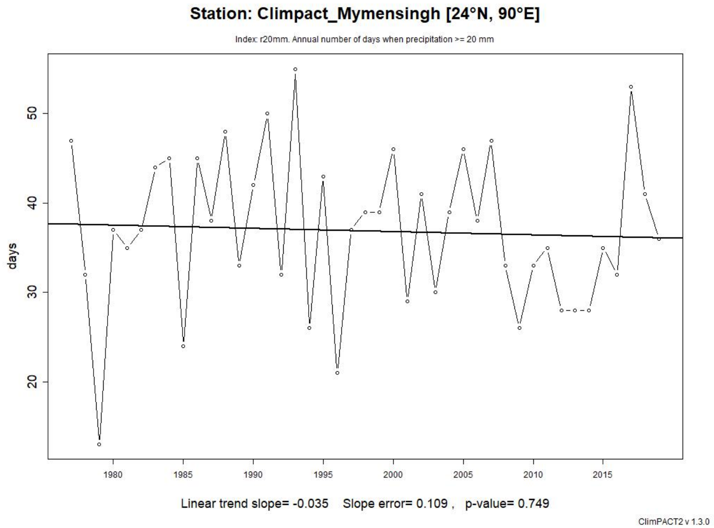
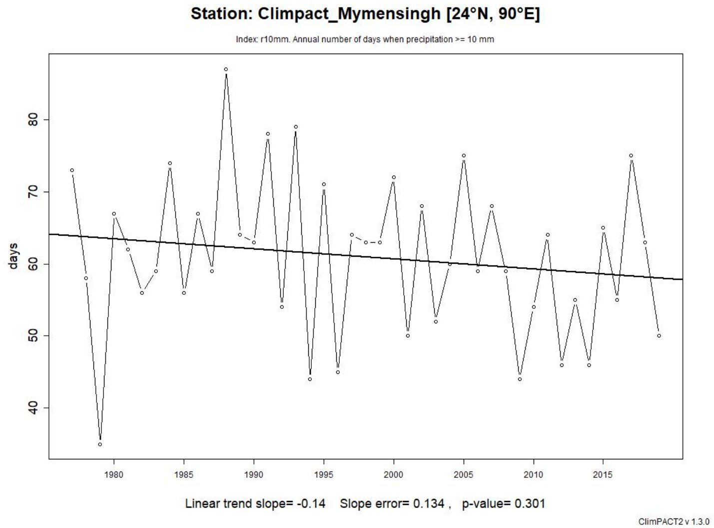


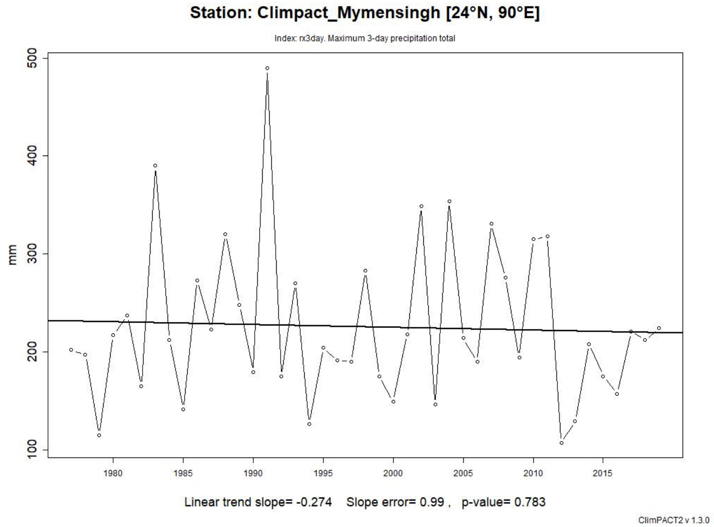
TN90p



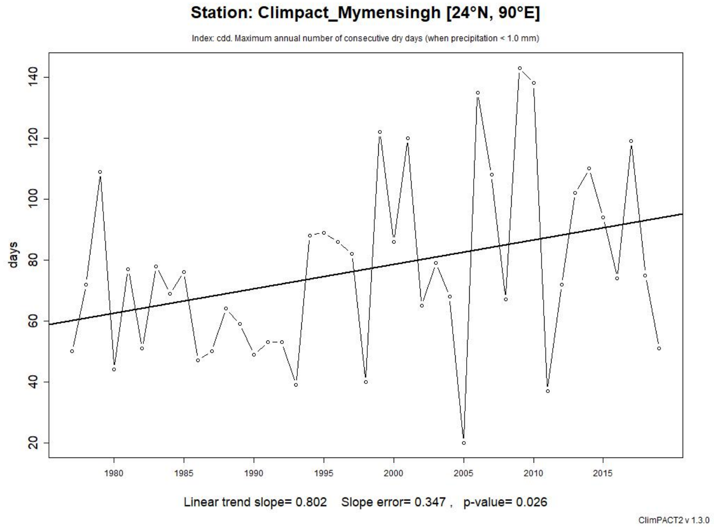
R20mm



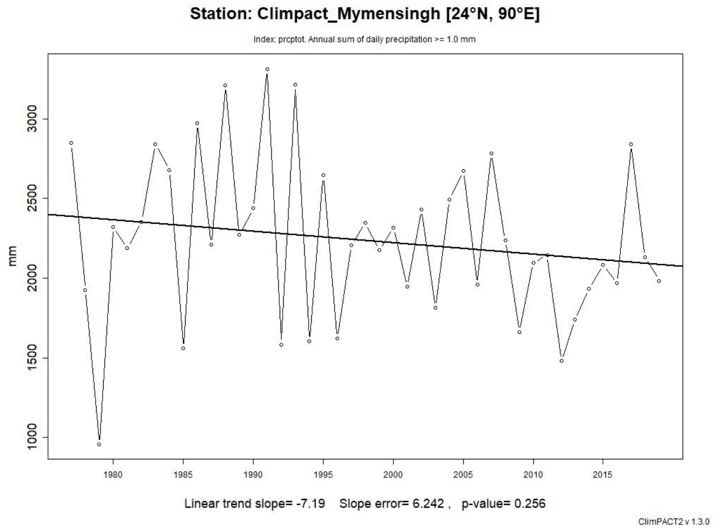
R10mm



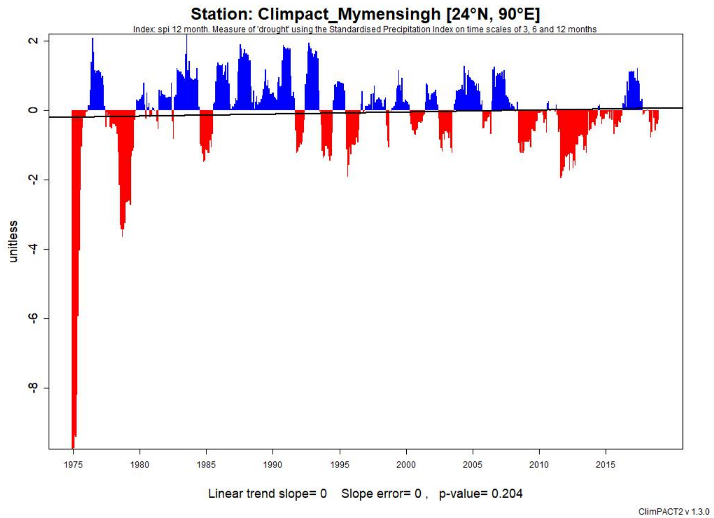
RX3days



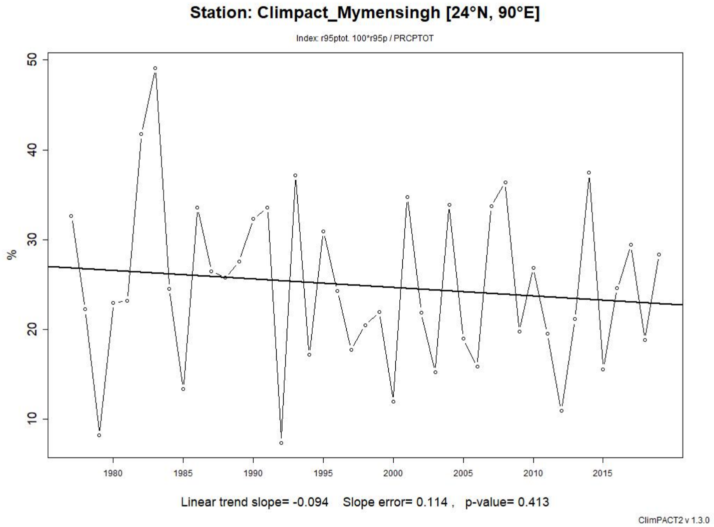
CDD



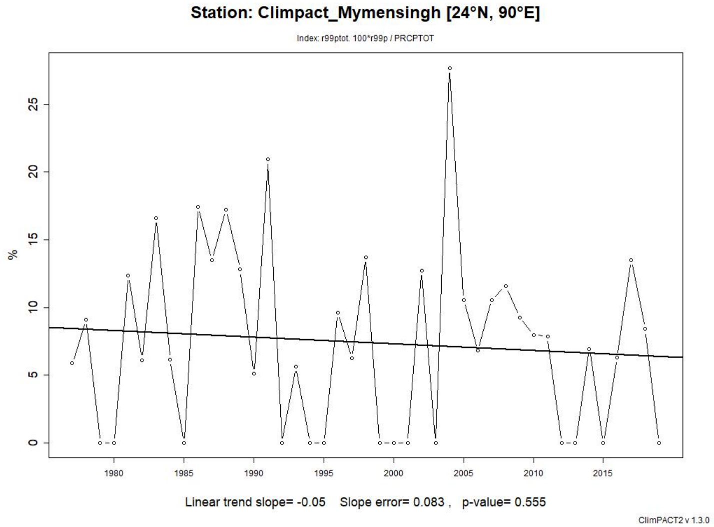
PRCPTOT



SPI



R95pTOT



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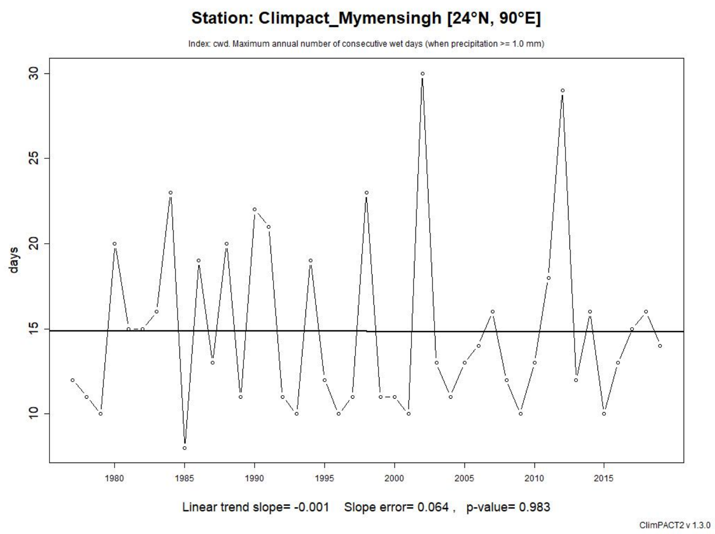
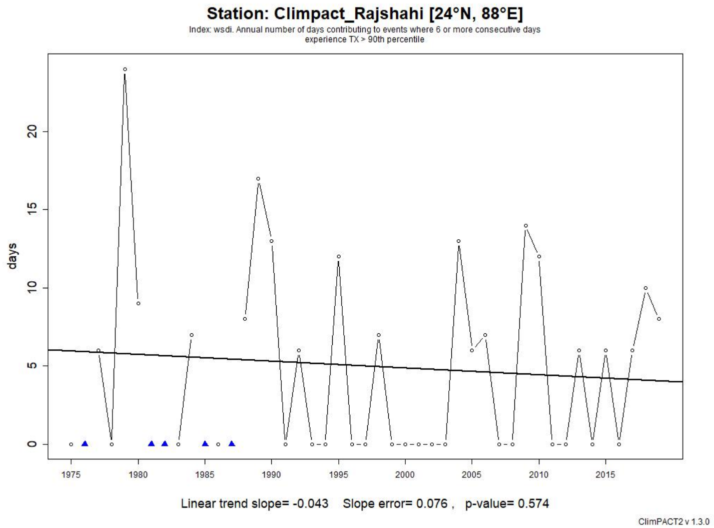
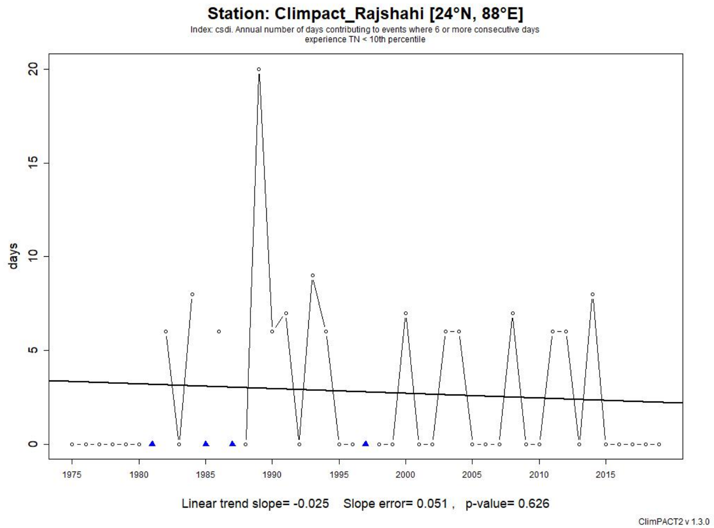


CWD

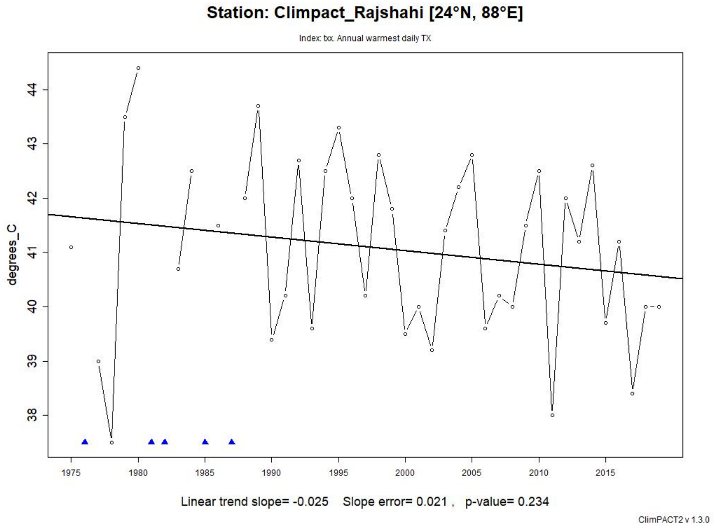
Figure A.11: Graphical representation of extreme indices analysis of Mymensingh



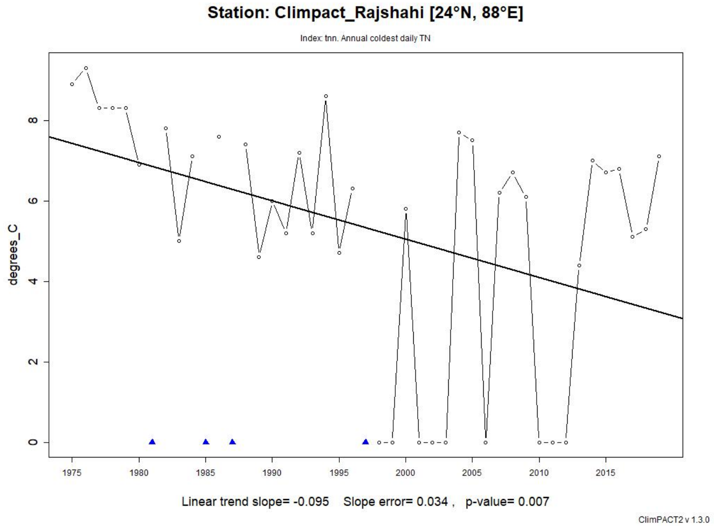
WSDI



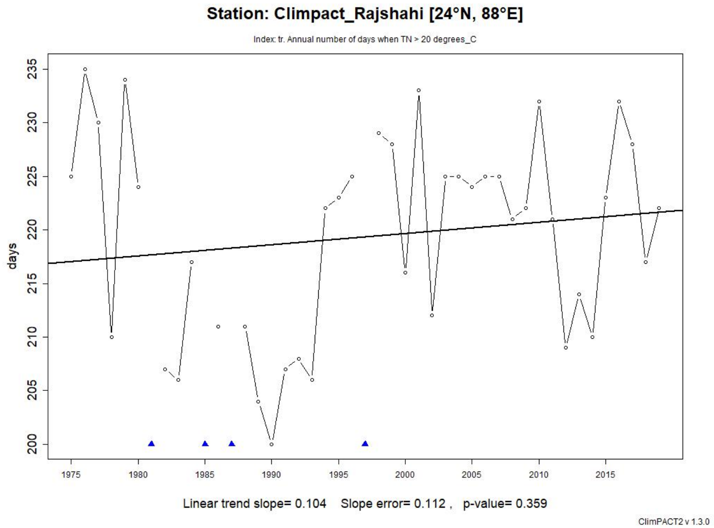
CSDI



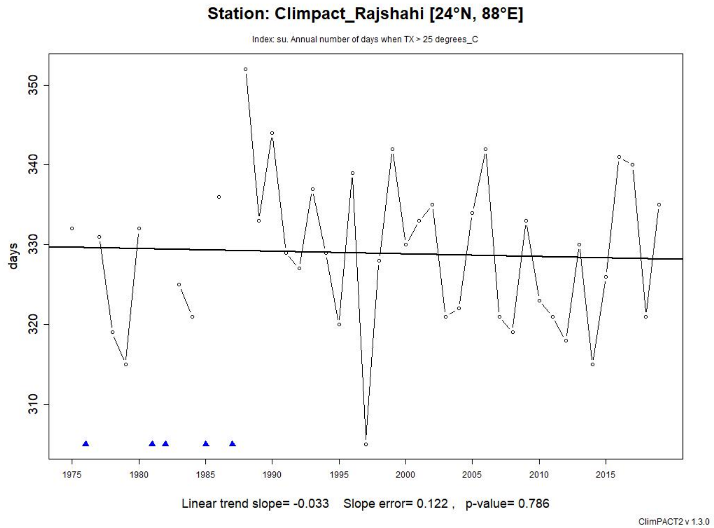
TXx



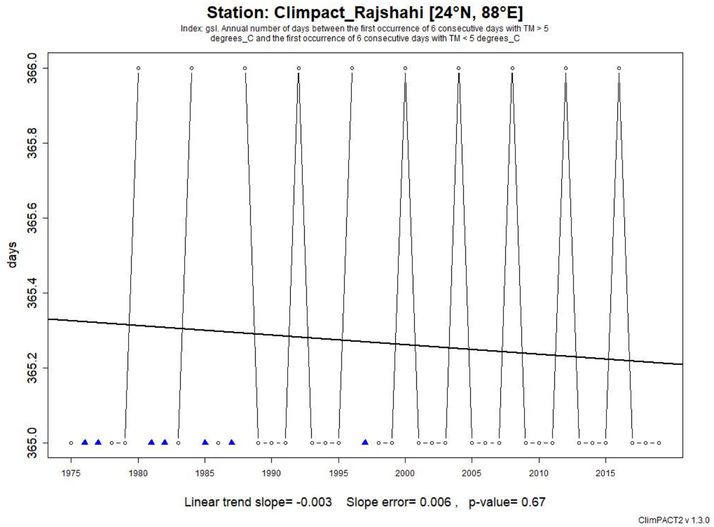
TNn



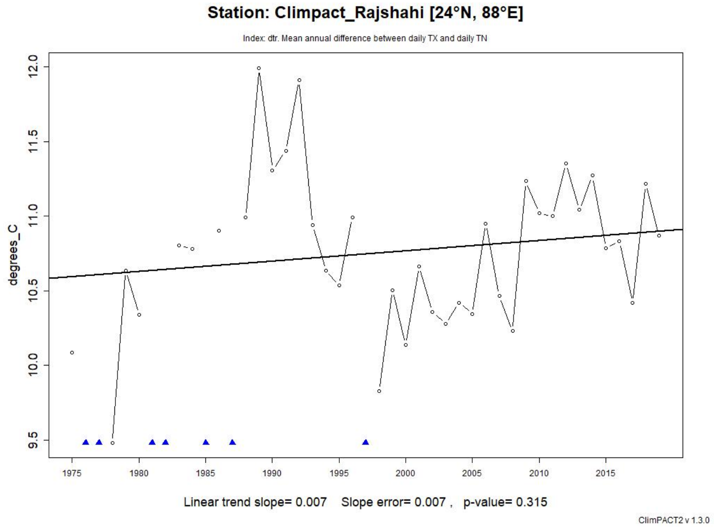
TR



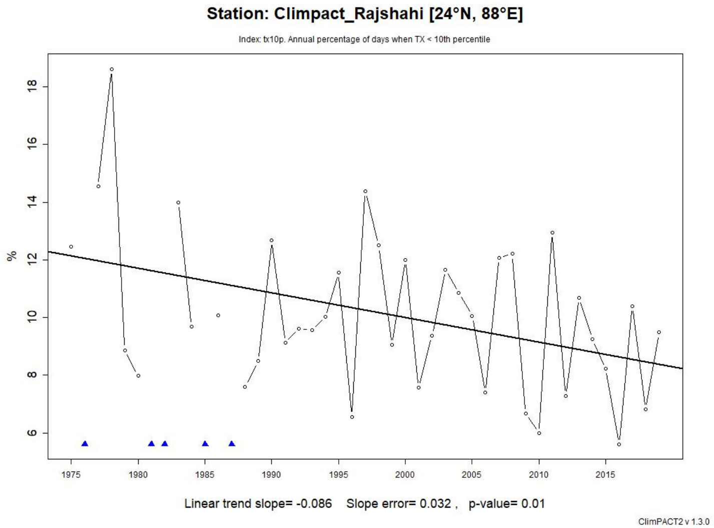
SU25



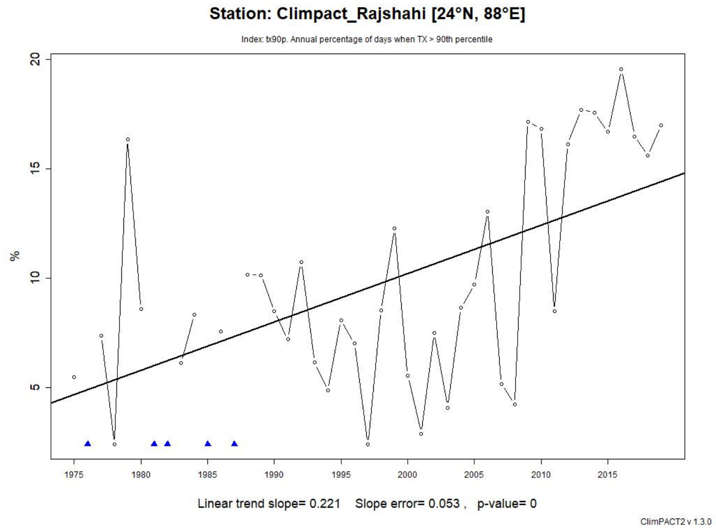
GSL



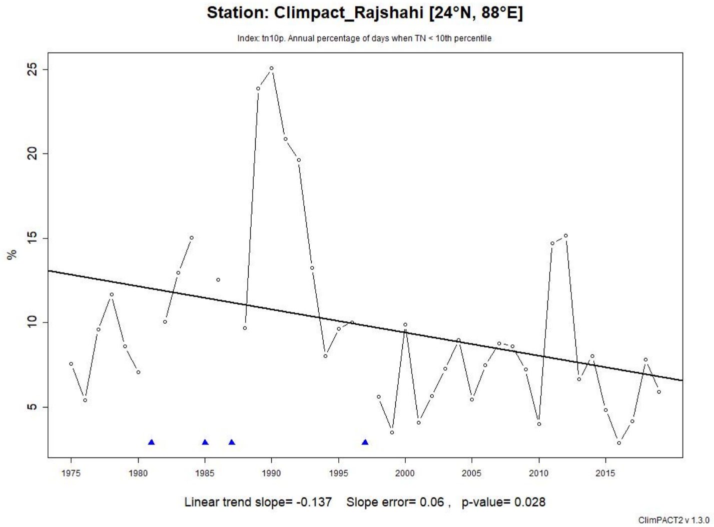
DTR



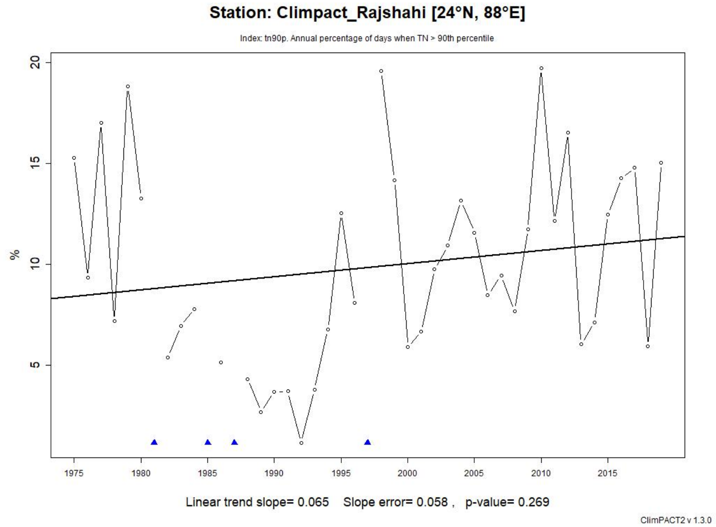
TX10p



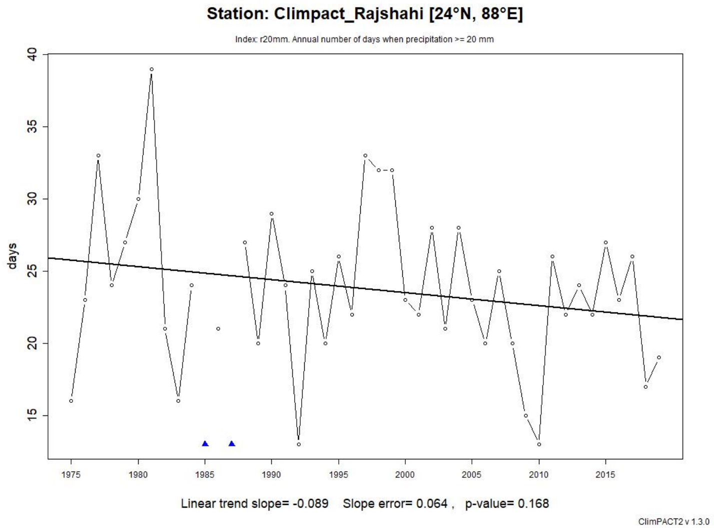
TX90p



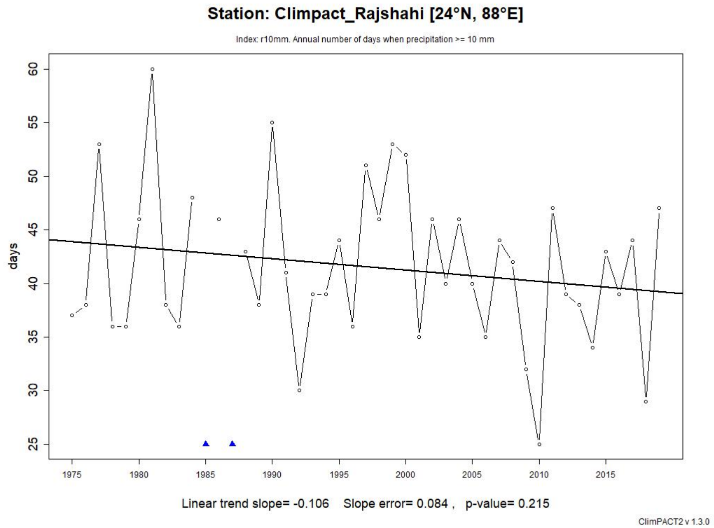
TN10p



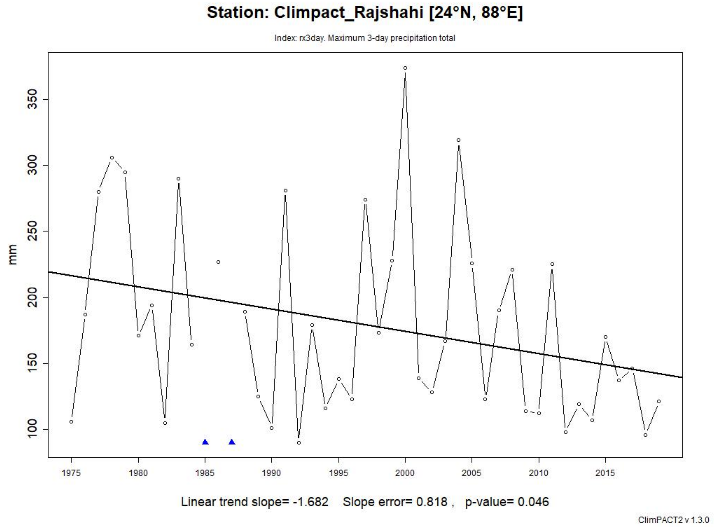
TN90p



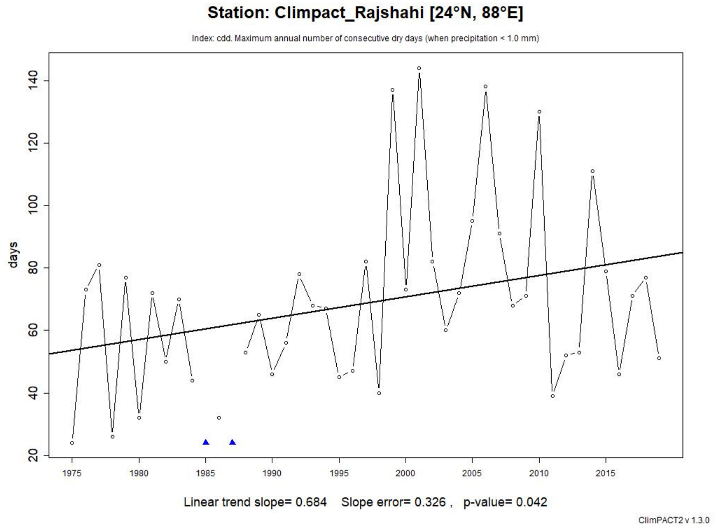
R20mm



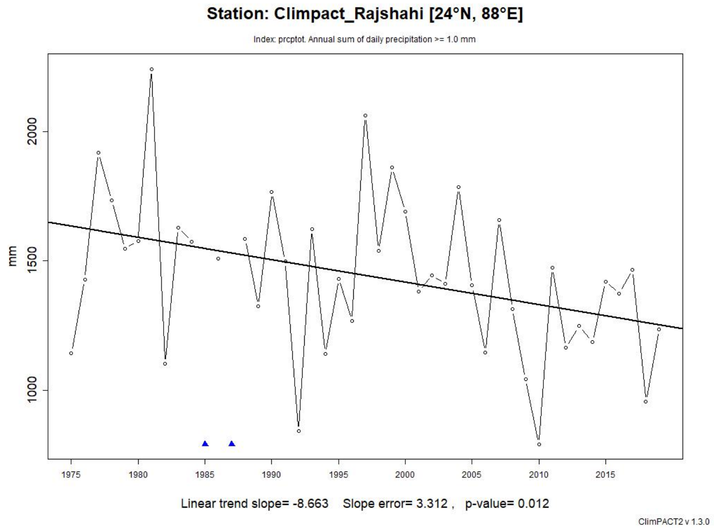
R10mm



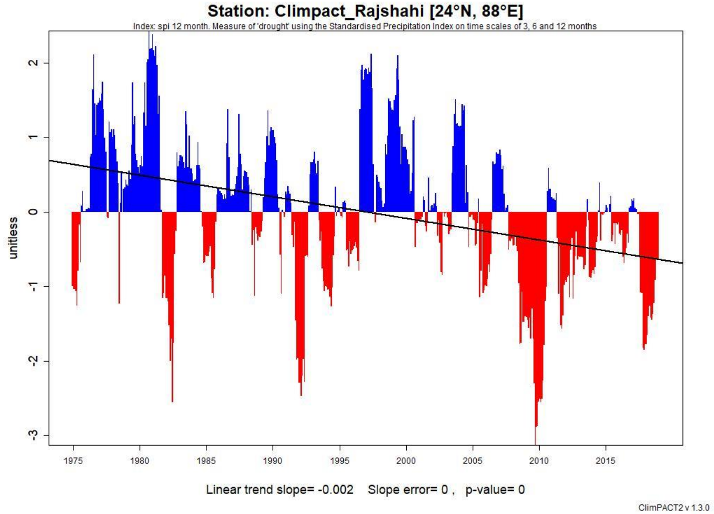
RX3days



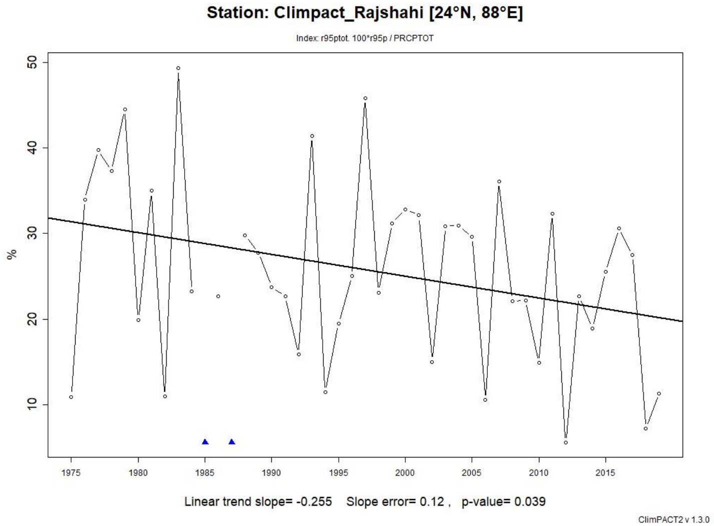
CDD



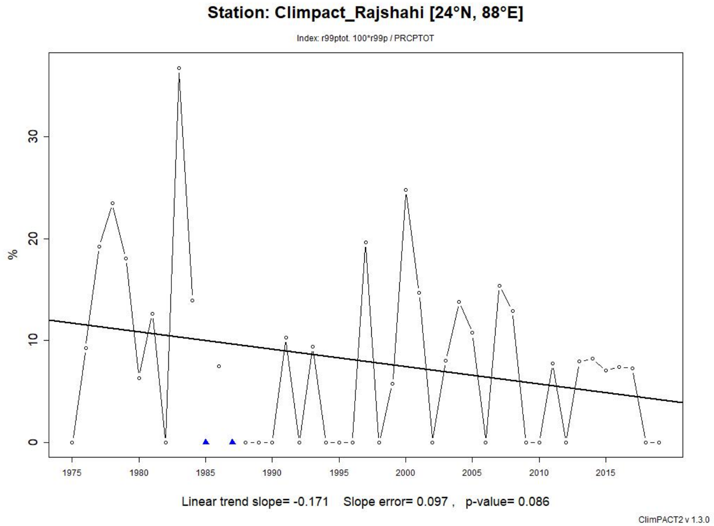
PRCPTOT



SPI



R95pTOT



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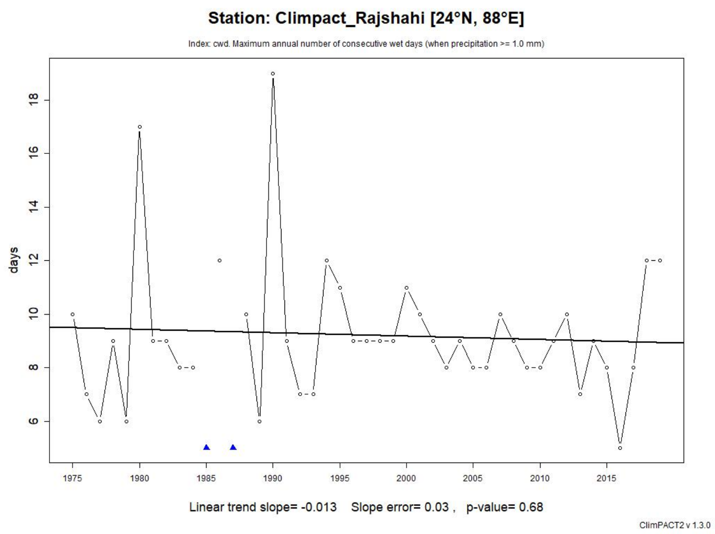
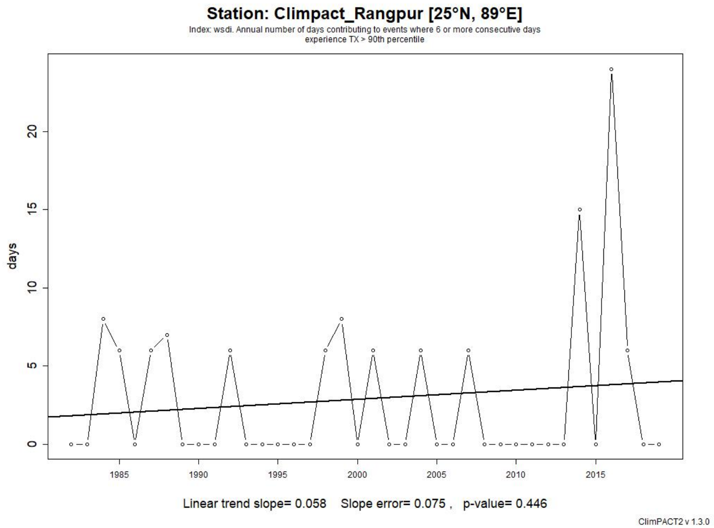
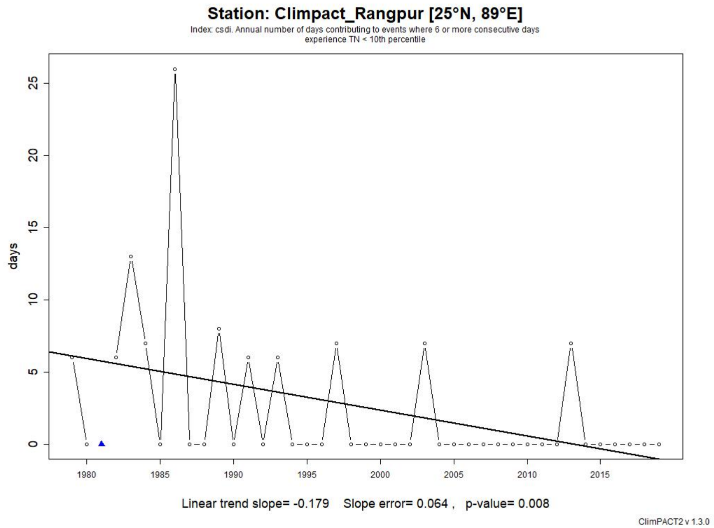


CWD

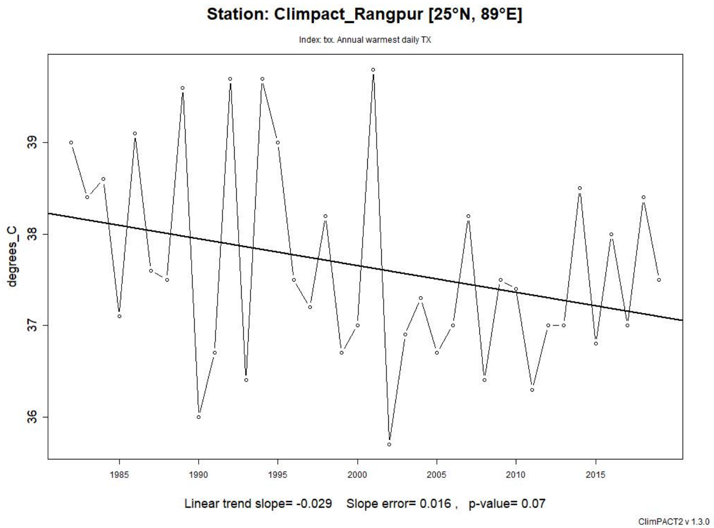
Figure A.12: Graphical representation of extreme indices analysis of Rajshahi



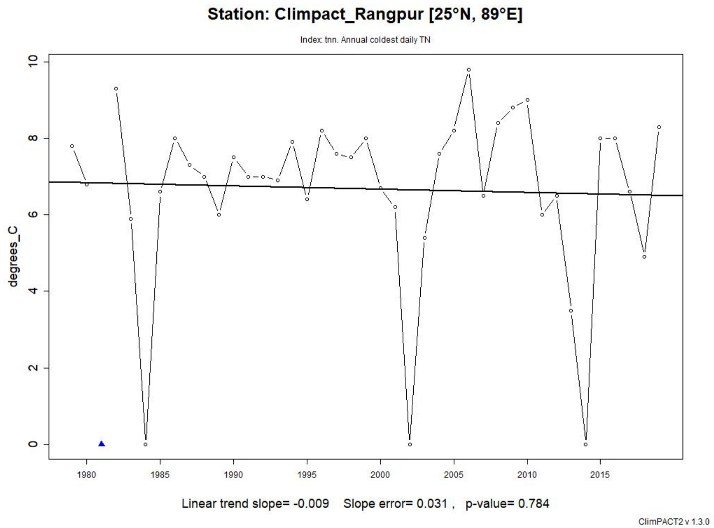
WSDI



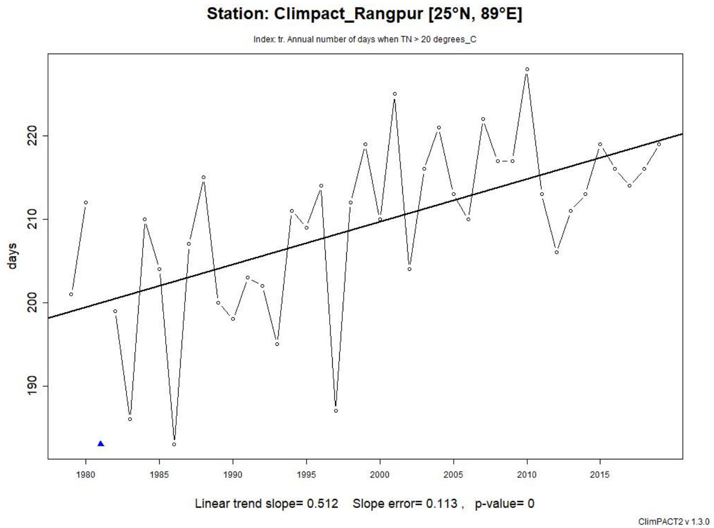
CSDI



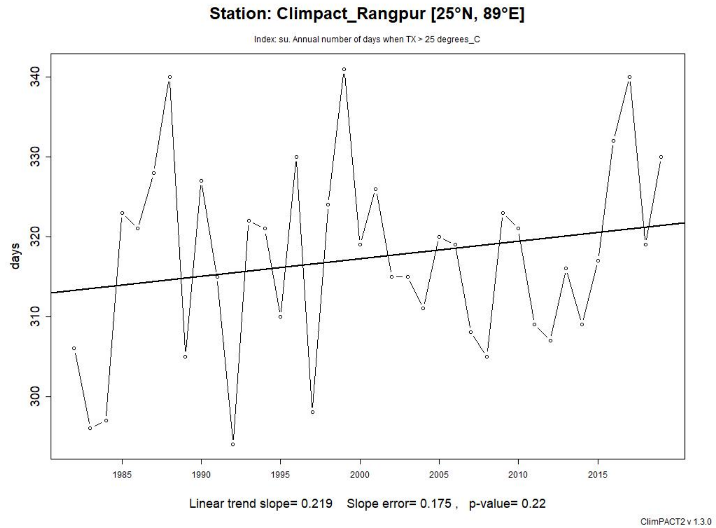
TXx



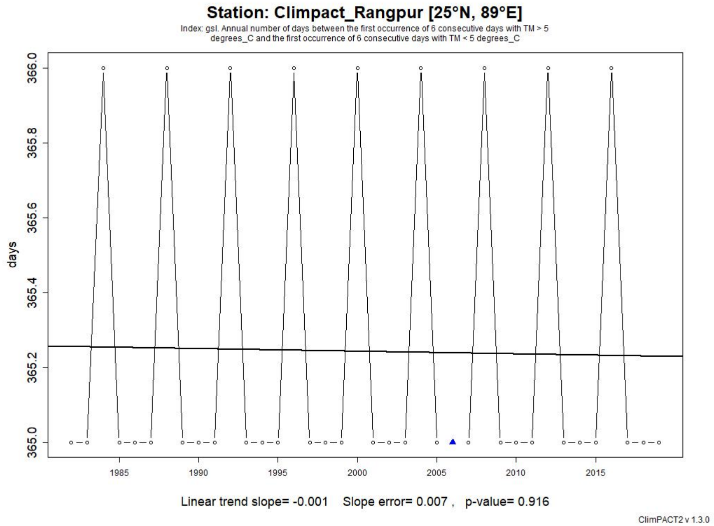
TNn



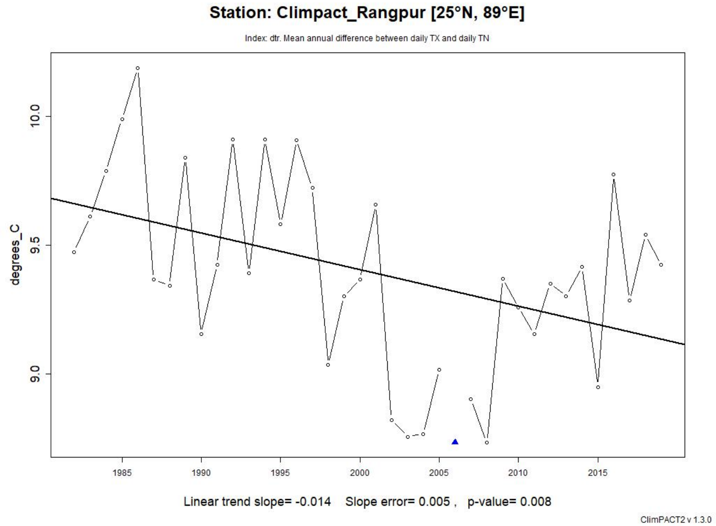
TR



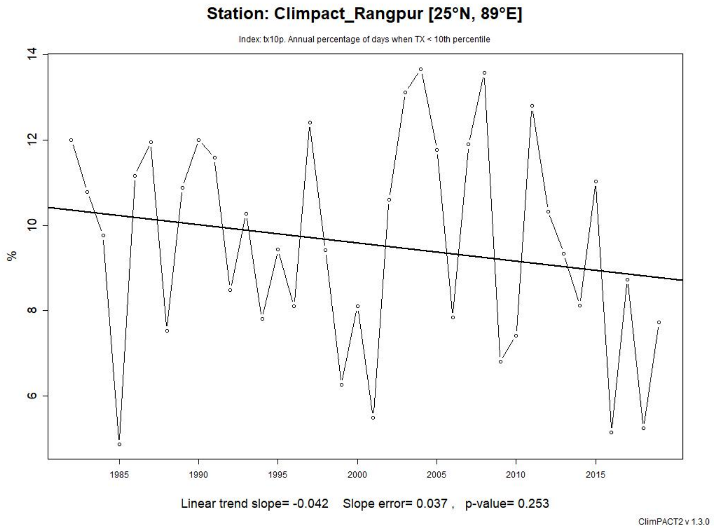
SU25



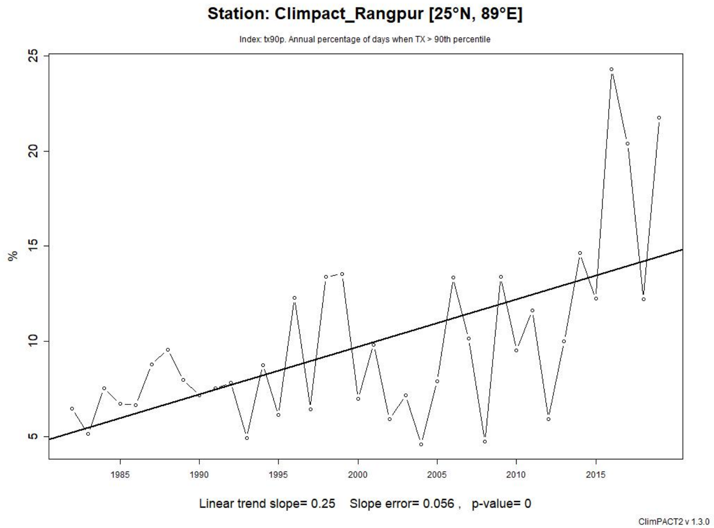
GSL



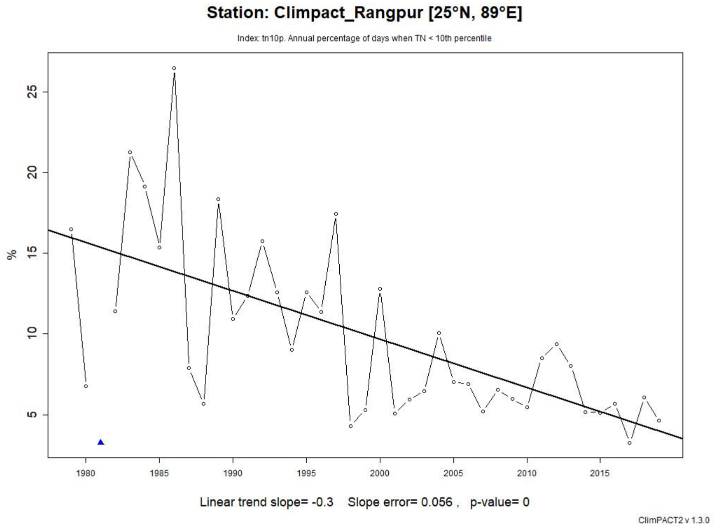
DTR



TX10p



TX90p



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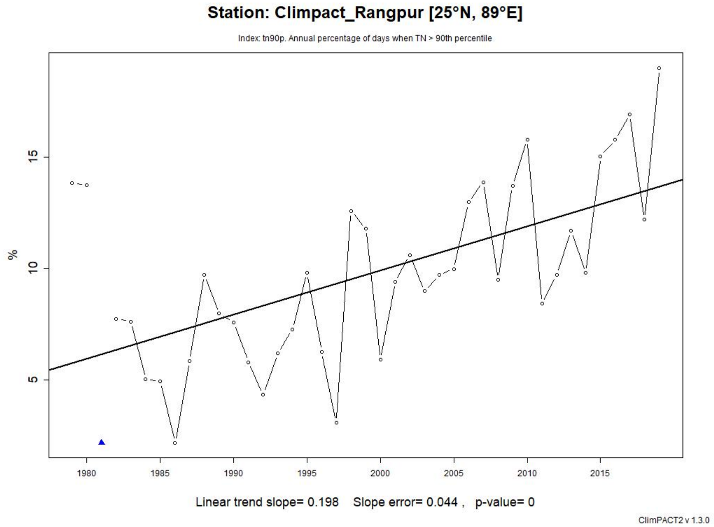
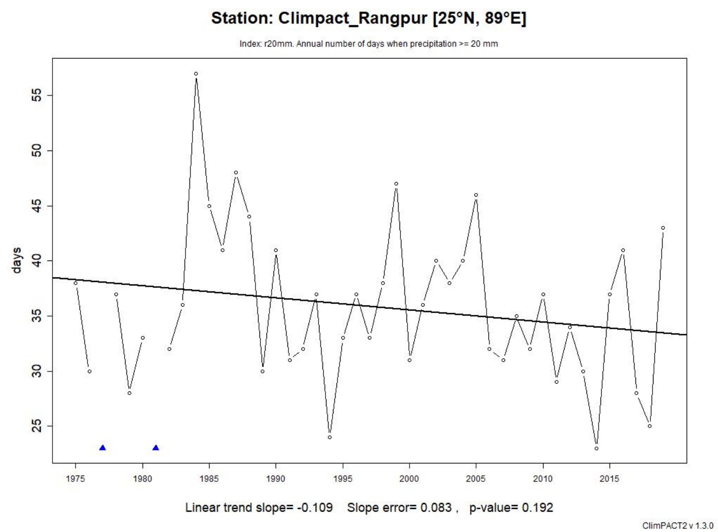
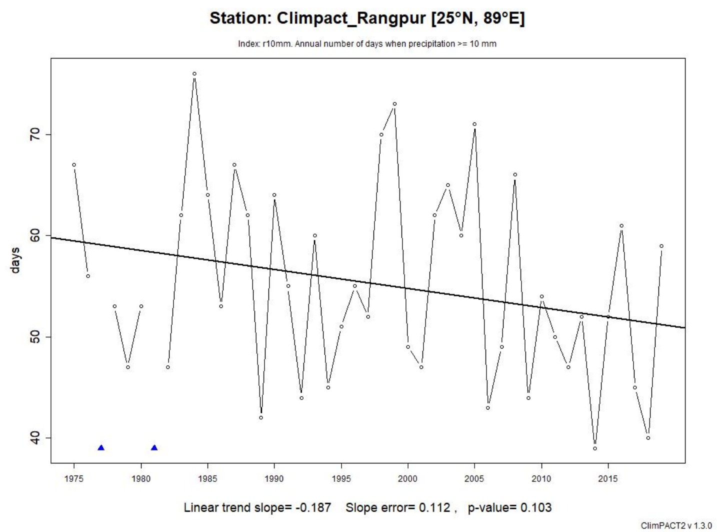


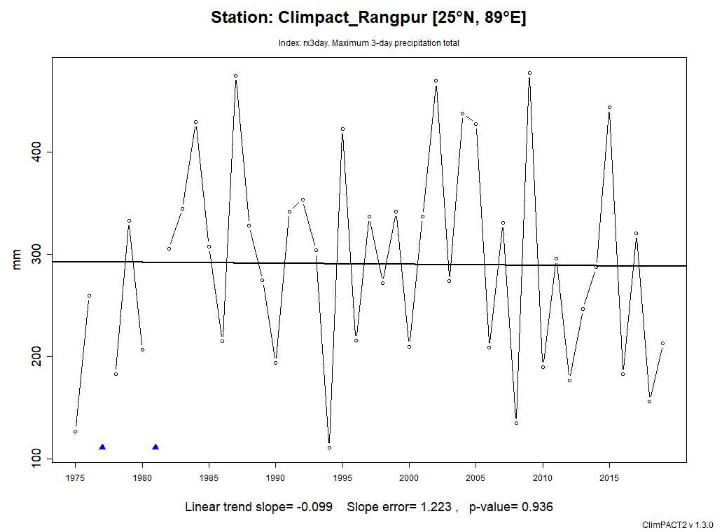
TN90p



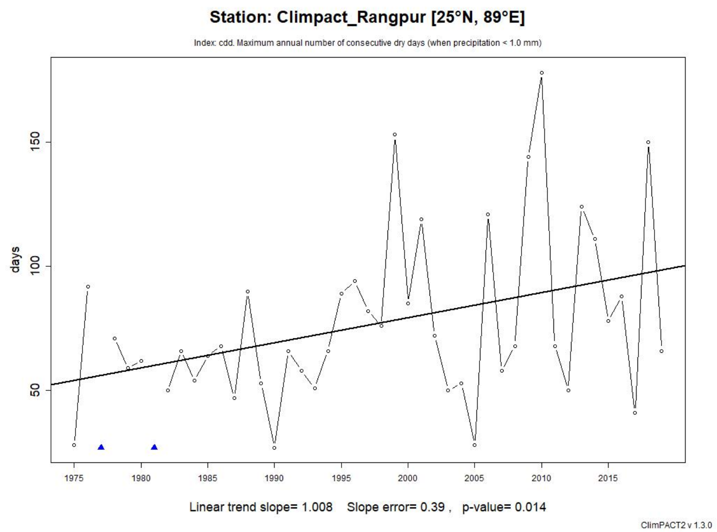
R20mm



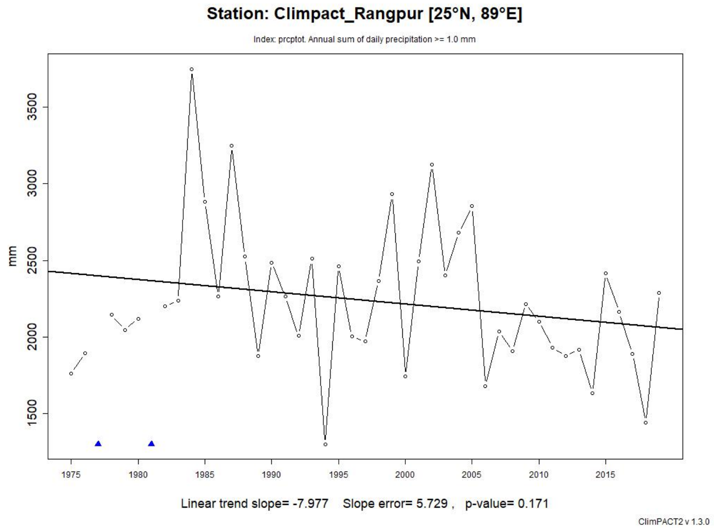
R10mm



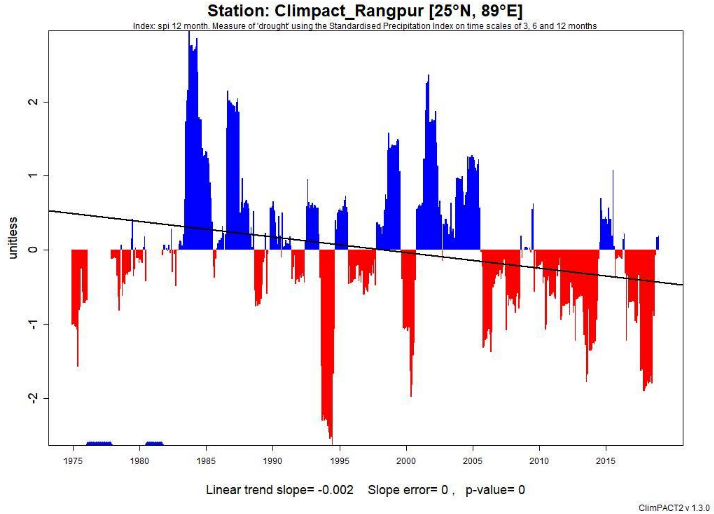
RX3days



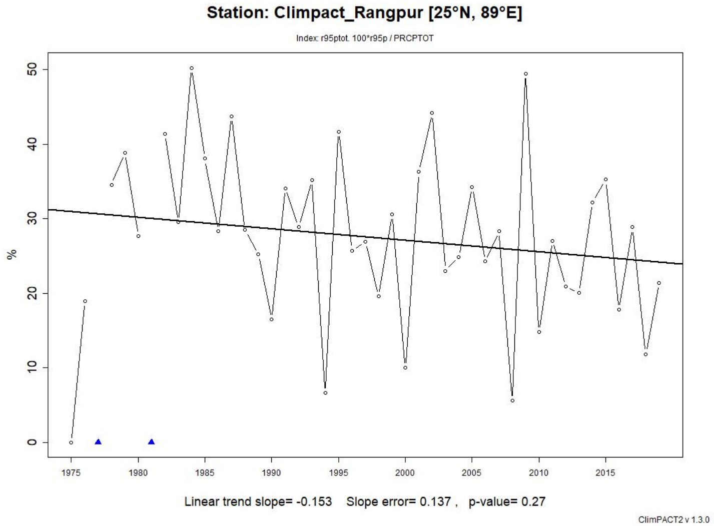
CDD



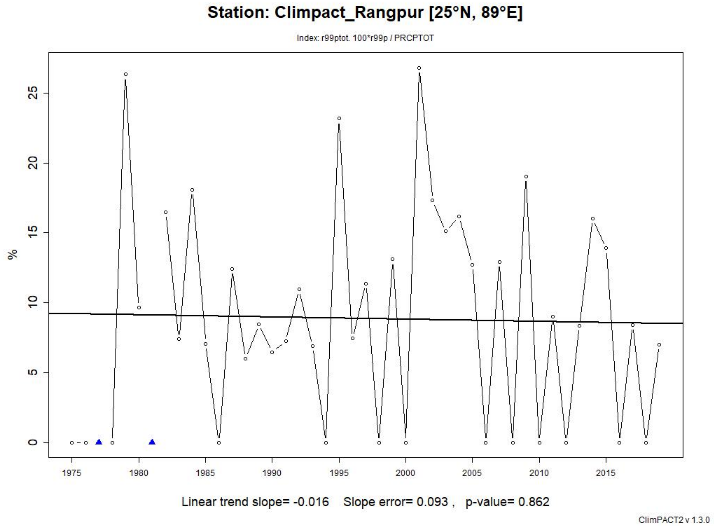
PRCPTOT



SPI



R95pTOT



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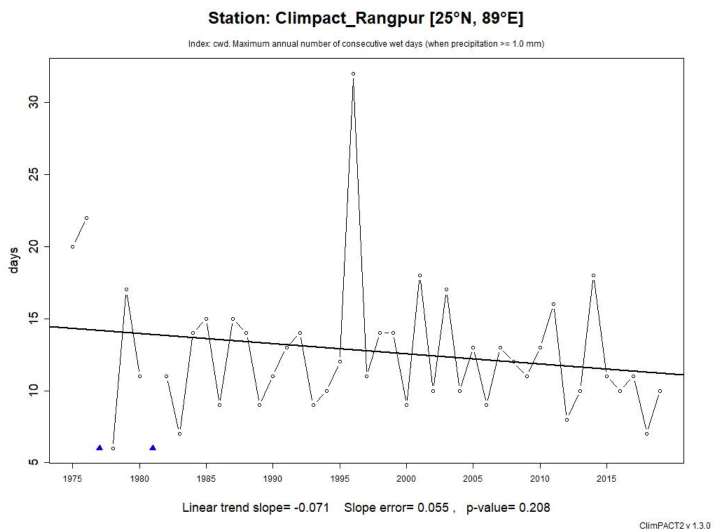
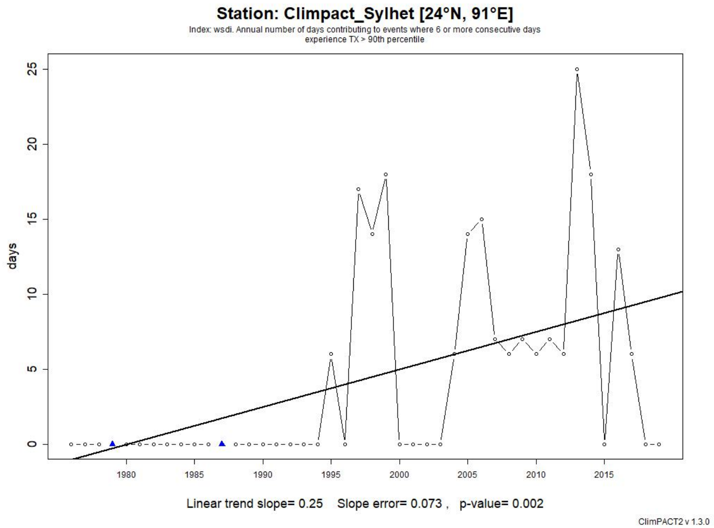


CWD

Figure A.13: Graphical representation of extreme indices analysis of Rangpur



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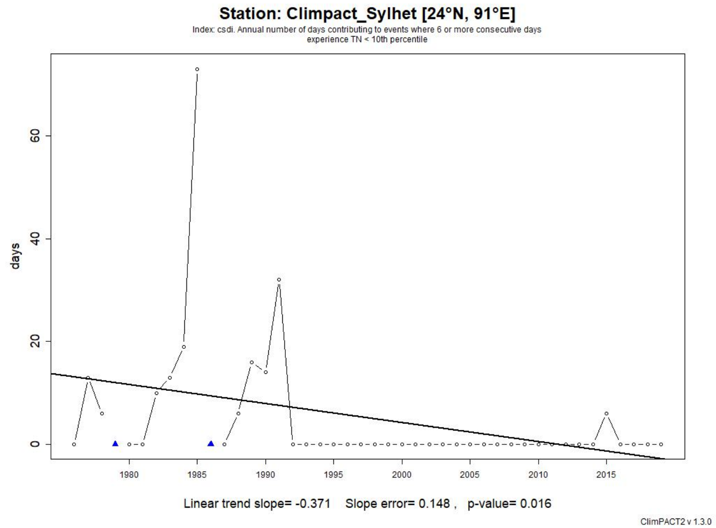
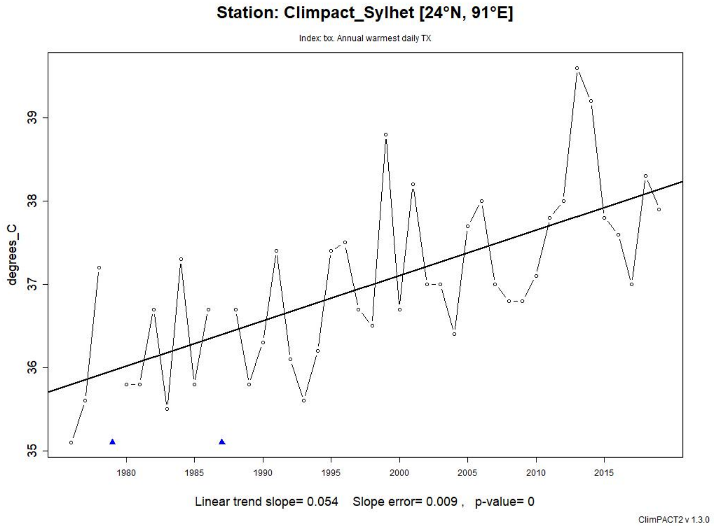
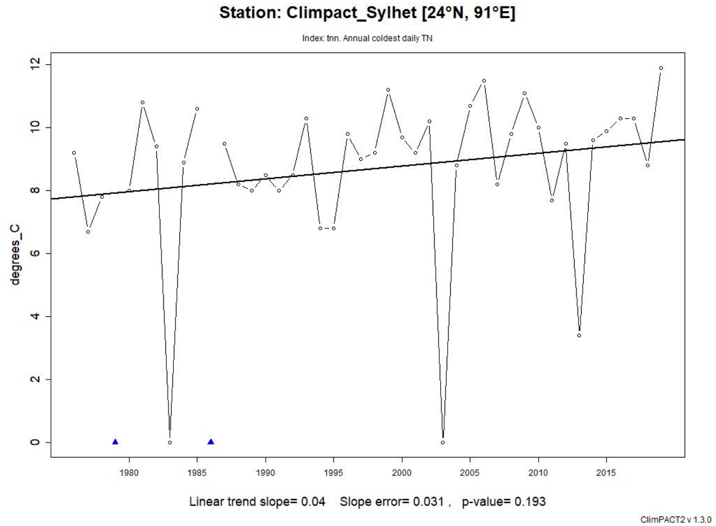


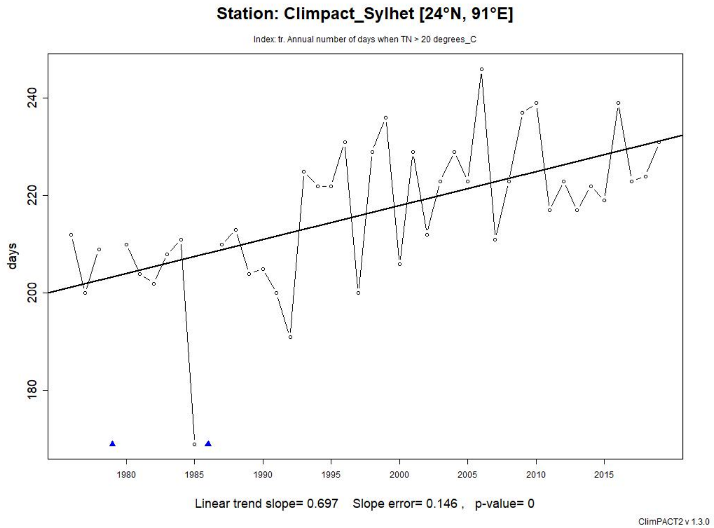
CSDI



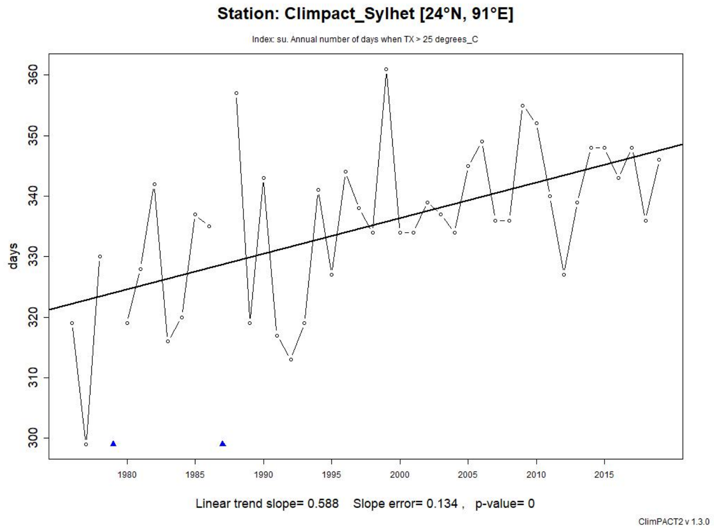
TXx



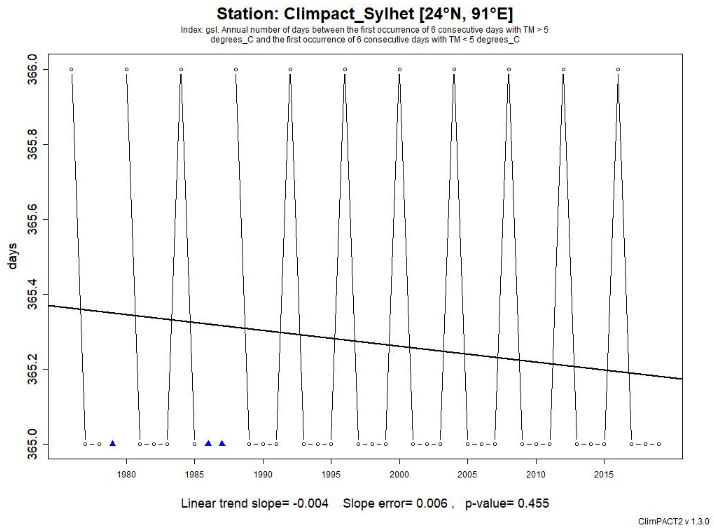
TNn



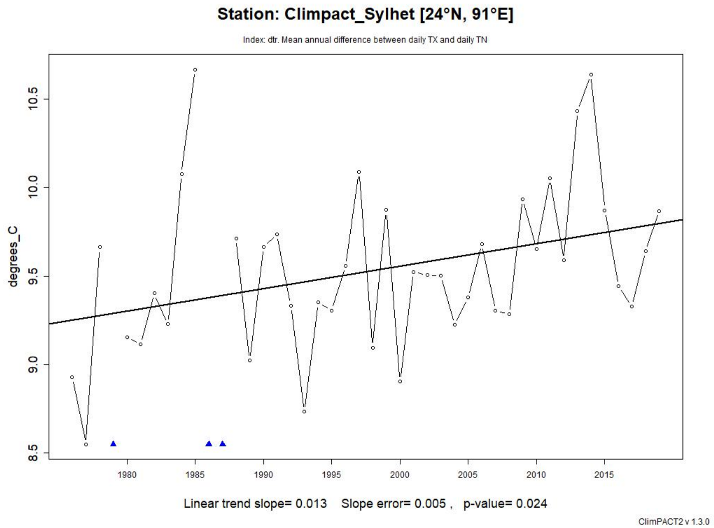
TR



SU25



GSL



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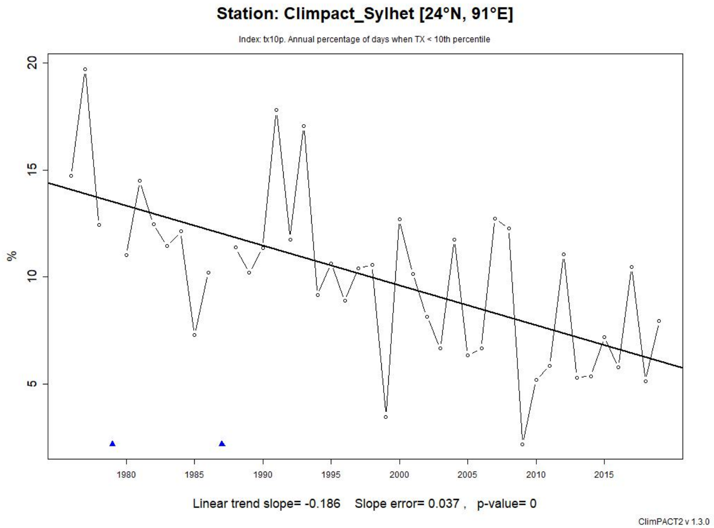

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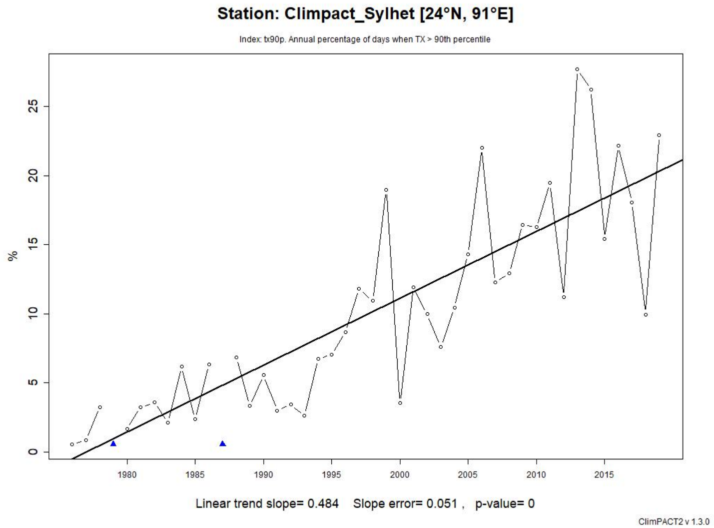
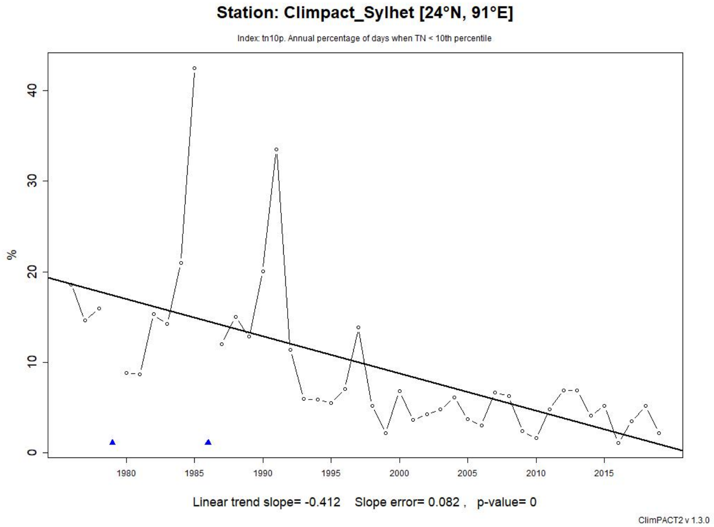


TX90p



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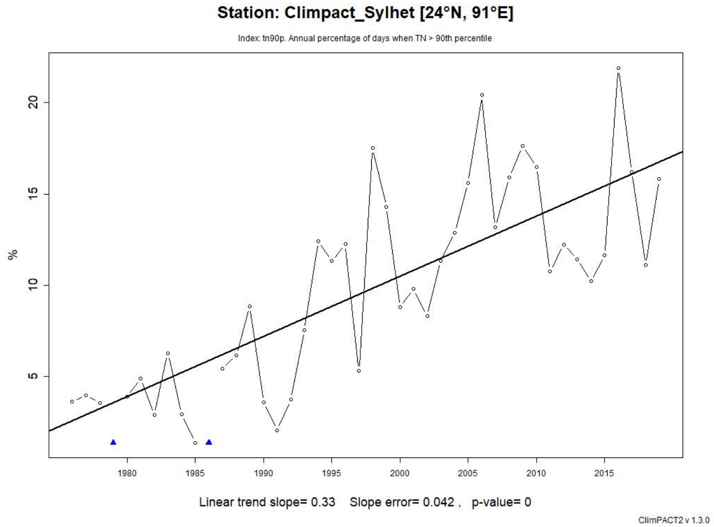

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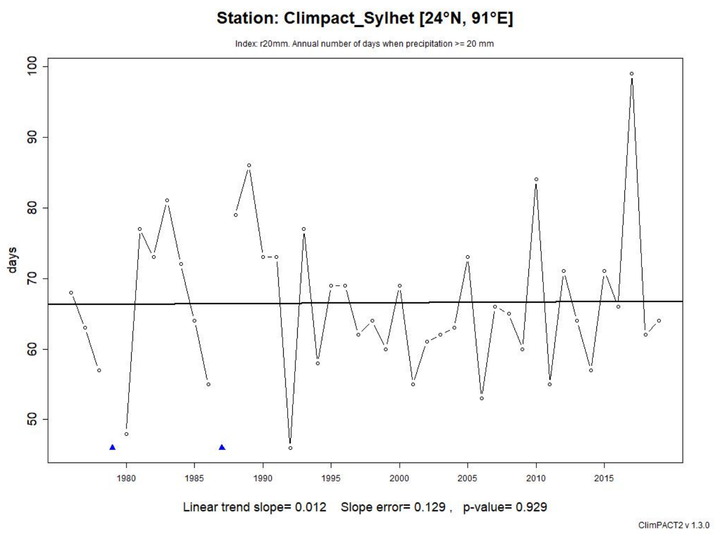
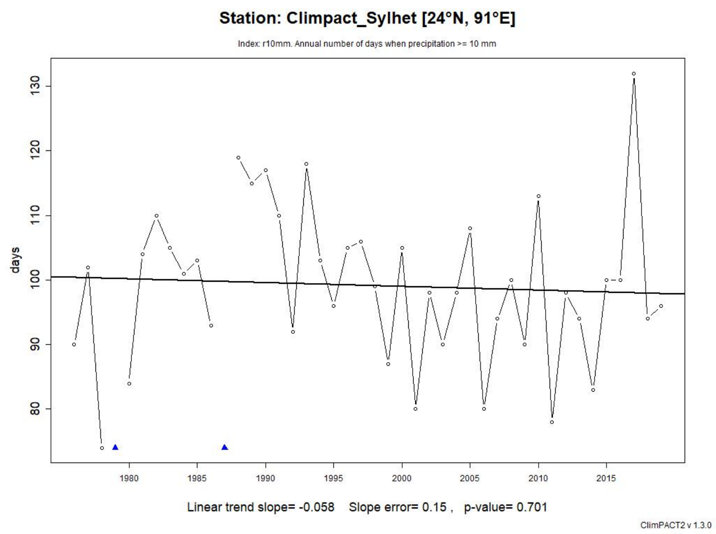
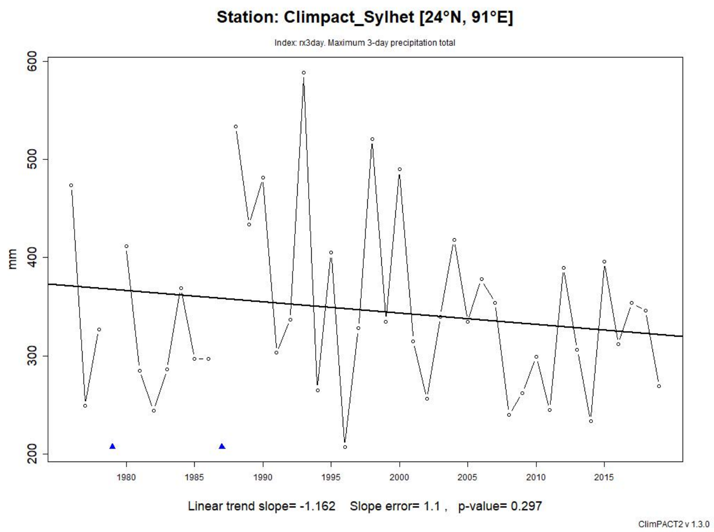


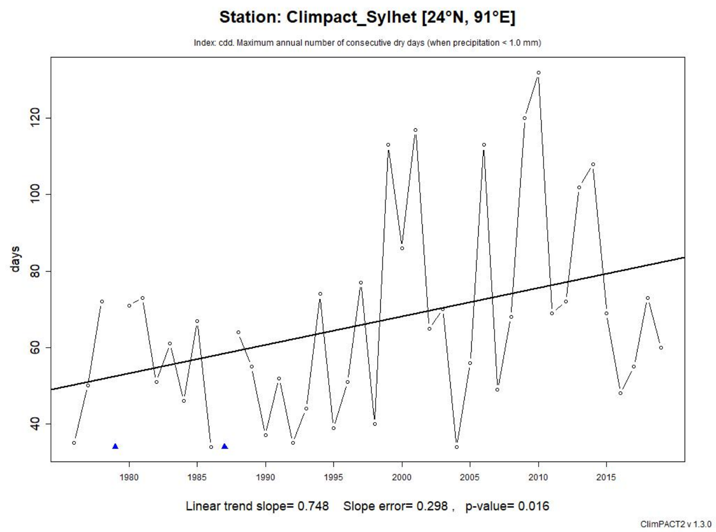
R20mm



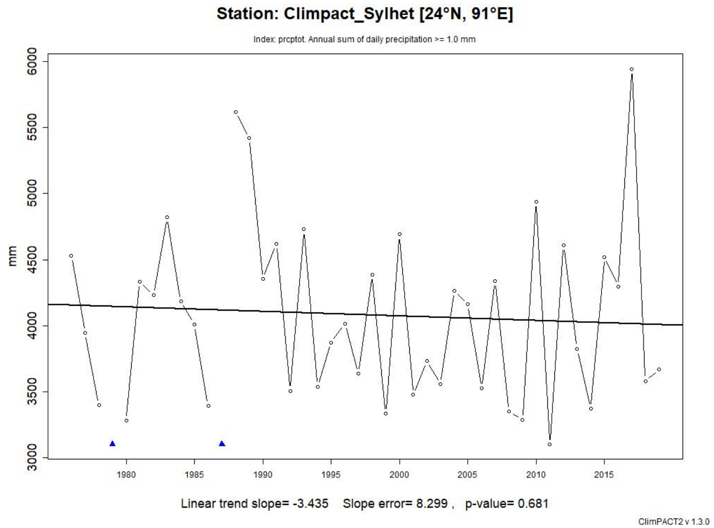
R10mm



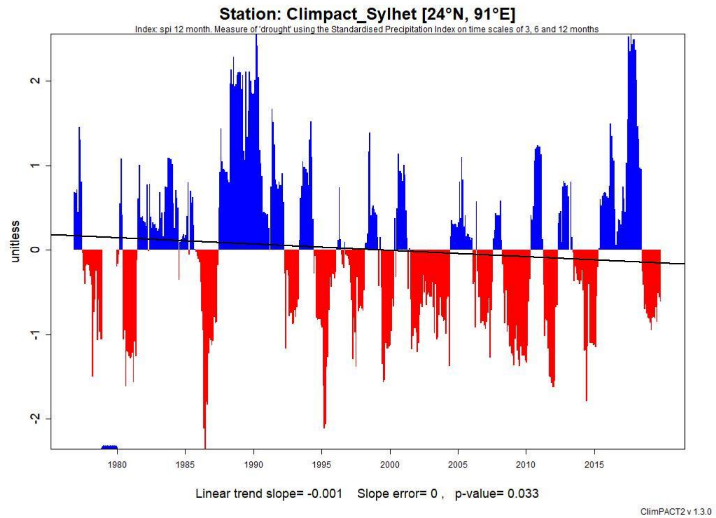
RX3days



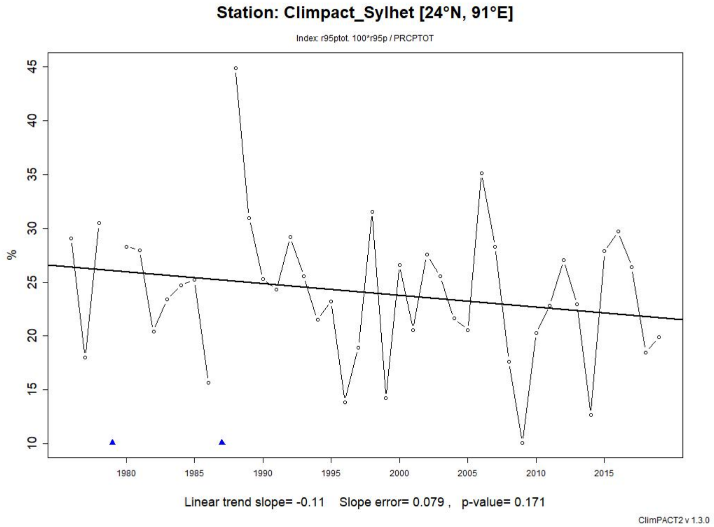
CDD



PRCPTOT



SPI



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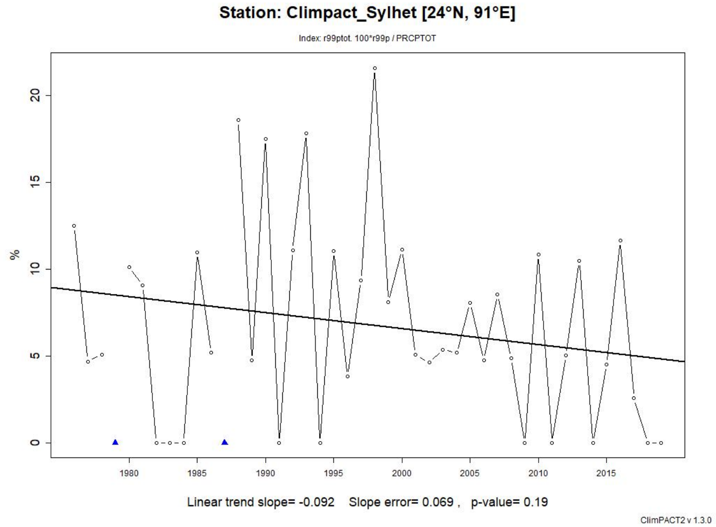

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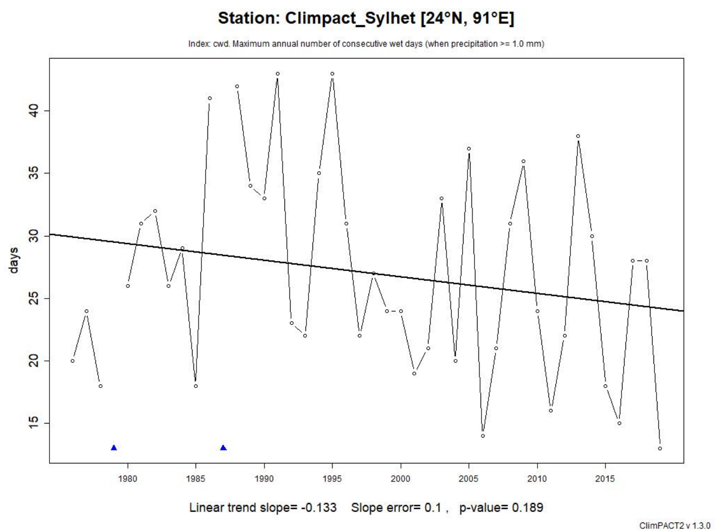

CWD

Figure A.14: Graphical representation of extreme indices analysis of Sylhet