MAXIMUM TEMPERATURE TREND ANALYSIS OF WEST BENGAL FROM 1951-2015

A thesis submitted towards partial fulfillment of the requirements for the degree of

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in

Water Resources and Hydraulic Engineering

Submitted by

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2022

Declaration of Originality and Compliance of Academic Ethics

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of my Master of Engineering degree in Water Resources & Hydraulic Engineering, in the Faculty of Engineering & Technology, Jadavpur University during the academic session 20219-22.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and referred all materials and results that are not original to this work.

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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled "***MAXIMUM TEMPERATURE TREND ANALYSIS OF WEST BENGAL FROM 1951-2015***" is Bona-fide work carried out by Satanik Mukherjee under our supervision and guidance of Dr.Rajib Das , Assistant Professor , School of Water Resources Engineering Jadavpur University for partial fulfillment of the requirements for the Post Graduate degree of Master of Engineering in Water Resources & Hydraulic Engineering during the academic session 2019-2022 in the department of School of Water Resources Engineering, Jadavpur University, Kolkata – 700032.

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This foregoing thesis is hereby approved as a credible study of an Engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed, or conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

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DEDICATION

This thesis is dedicated to my parents and my respected teachers, and my fellow colleagues who never stopped encouraging me throughout this Endeavour and constantly inspired me to keep working hard and encouraged me to never stop learning.

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Abstract

Right now Climate change is a global issue. Continuous rising of global temperatures has received a lot of attention from researchers as its directly impact on the Major Water resources sector, Minor Water Resources (Domestic & Industrial uses), agricultural sector. Trends in climate changing scenarios is very important. So, just to understand the trend of temperature or to find maximum temperature patterns, we use innovative trend analysis techniques (ITAM) for this study. Most trend analyzes are based on overall time periods, and recent temperature changes related to overall time periods have not been investigated. Current work shows that values from two different time zones give different results. For this work we are using gridded data acquired from the Indian Meteorological Department (IMD) over a period of 65 years (1951-2015) with a overlapping year of 1983 to find the graph of for 1st half and 2nd half, seasonal extreme temperature changes of 14 grid points covering thirteen district including part of Bay of Bengal (Sundarban region) in West Bengal were analyzed. After analyzing the entire period, we found that T_{max} showing negative downward pattern in winter and pre-monsoon seasons. The magnitude of slope of the gridded value is very high in winter and pre-monsoon seasons which indicates a negative pattern. After the analysis by using ITAM we found that the recent trends of Maximum temperature is more indicating with high magnitude of Slope.

Keywords :*Gridded; Maximum Temperature ; Innovative Trend Analysis*

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1. Chapter : 1

1.1. Introduction

One of the most important problems facing the world is global warming. This is due to increasing concentrations of greenhouse gases (GHG) in the atmosphere. Global warming is adversely affecting the water cycle, which is essential for life on Earth (Josh & Dwarakish, 2022) .Climate change phenomena are caused by uneven patterns of atmospheric warming around the world. So, spatio-temporal variations need to be studied. It is now generally accepted that the Earth's climate is changing at a greater rate than at any other time in recent history Intergovernmental Panel on Climate Change 2021 (IPCC 2021) . Significant variations in surface and air temperatures have been recorded since 1950, suggesting that the climate system is beginning to issue alarms (IPCC 2018). It is also worth noting that the intensity of temperature extremes is increasing faster than the intensity of average temperatures. Therefore, investigating the maximum temperature since 1950 is very important for understanding the global warming cycle .

As previous studies have not focused on this aspect of period analysis, the present study used the ITAM technique to assess extreme temperature patterns for different periods. Also note that none of the ITAM-related studies have been conducted in West Bengal, India. Therefore, the aim is to investigate extreme temperature patterns and their variability in 14 districts of West Bengal. Furthermore, it is important to mention that most trend analysis studies are conducted in large research areas. Consists of countries or states. Temperature trend analysis for different districts is necessary, as temperature is an important parameter for all kinds of hydrological studies, agricultural studies and some subsequent development projects. Also, the main purpose of this investigation is to confirm that the ITAM approach is applied at extreme temperatures without relying on restrictive assumptions such as serial correlation, non-normality and sample size.

2. Chapter : 2

2.1. Objective

The study has been carried out to find the rainfall trend over the districts of the West-Bengal over a duration of 65 years i.e., 1951-2015. The objective is to analyze the Temperature trend using one methods.

- Innovative trend analysis (ITAM)

Our prime objective is to find the Maximum temperature trend of West Bengal. For that reason the station point for T_{max} we have covering thirteen districts (Purba Medinipur, South 24 parganas -Bay of Bengal , Jhargram , Paschim Medinipur, South 24 parganas, Purulia , Paschim Bardhaman , Nadia , Birbhum , Mursidabad , Malda , Dakhsin Dinajpur , Jalpaiguri , Alipurduar) using ITAM seasonal basis.

A year of Indian Subcontinent can be divided into four different seasons

a) Winter – January, February
b) Pre-Monsoon or Summer -March, April, May
c) Monsoon- June, July, August, September
d) Post-Monsoon – October, November, December

3. Chapter : 3

3.1. Literature Review

Several studies have been conducted to examine variability in global maximum temperature and climate change. Changes in the risk of temperature extremes vary in severity across regions and are largely determined by how residents respond to several aspects of adaptation and mitigation strategies. Higher temperatures in metropolitan areas primarily affect people's health, economy, leisure activities, and general well-being . Trend identification approaches enable the detection and interpretation of climate change impacts and are of great need to detect temperature patterns at various spatial and temporal scales to better manage local water resources and vulnerabilities.

Sen Z., (2012 & 2014) Innovative Trend Analysis (ITAM) method have recently become important in different regions to assess trends in hydrological and meteorological variables. **Marak et al., (2020)** used the ITAM approach to analyze trends in low, medium and high rainfall in Meghalaya, India; Sen also developed a formula for calculating monotonic trend and a significance test for ITAM. This work resulted in easier data analysis **(Sen 2017)**.

Marak, J.D.K. et al., (2020) made studies on Innovative Trend Analysis of Spatial and temporal rainfall variations in Umiam and Umtru watersheds in Meghalaya, India.

Meghalaya is known to experience some of the heaviest rainfall in the world, but the region suffers from water shortages when the rains begin and the dry season begins. Studies of spatial and temporal variability in precipitation are of great importance, as changes in precipitation patterns and distribution can have significant impacts on water availability in watersheds. However, the long-term variability of precipitation in Meghalaya is not well understood. In this study, we document her two key watersheds in Meghalaya, namely the Umiam and Umtru watersheds, to study the spatial and temporal variability of rainfall. Using Indian Meteorological Department gridded precipitation data from 1901 to 2018, annual post-monsoon precipitation is increasing while winter, pre-monsoon and monsoon precipitation are decreasing. Indicates that the Identify trends in low-, medium-, and high-intensity precipitation using innovative trend analysis (ITA) methods. They found that low- and moderate-intensity precipitation decreased, while high-intensity precipitation increased on annual and seasonal timescales. Finally, trends identified by innovative trend analysis methods are cross-checked with the widely recognized Mann-Kendall (MK) test. They found broad agreement between the results obtained by the two methods. However, ITA can detect non-monotonic trends at different precipitation intensities and is more sensitive to hidden patterns than the MK test.

Singh, R.N. et al.,(2021) , made studies on Innovative trend analysis of spatio-temporal variations of rainfall in India during 1901–2019. Spatio-temporal precipitation trends over the last 119 years (1901-2019) in different climate zones in India were analyzed using gridded precipitation data. Innovative Trend Analysis (ITA) was performed to identify trends in seasonal and annual precipitation. Long-term trend and magnitude results obtained with the ITA method were compared with the traditional Mann-Kendall (M-K), modified Mann-Kendall (mM-K), and linear regression analysis (LRA) methods. . important Seasonal and annual rainfall trends are noted in almost all subdivisions of India. Monsoons and annual rainfall showed an increasing trend in most subdivisions of the peninsula and north-west India, while a decreasing trend was observed in the north-east central part of the country. Winter precipitation showed a decreasing trend in most subdivisions of the country. The M-K/mM-K and LRA results were consistent with the trend observed by ITA. However, ITA is more sensitive in detecting hidden trends missed by traditional M-K/mM-K and LRA tests. This study provides a scientific reference for assessing and actively mitigating climate change impacts on water resources in order to manage climate change risks.

Malik, A. et al., (2019) made studies on Spatial-temporal trend analysis of seasonal and annual rainfall (1966–2015) using innovative trend analysis method with significance test. This study presents spatial and temporal trends in seasonal (pre-monsoon, monsoon, post-monsoon, and winter) and annual (1966–2015) precipitation time series data at 13 stations in the Central Himalayan region of Uttarakhand, India. Look for patterns. Trends over time were significantly analyzed using a recently proposed innovative trend analysis method (ITA). test. The ITA method results were compared with the Mann-Kendall (MK) test at the 5% significance level. The Thiessen polygon (TP) method was used in an Arc-GIS 10.2 environment to interpolate the spatial variation of trends in seasonal and annual precipitation series. The comparative results show that the trends observed by the MK test (significantly positive for 3 time series, significantly negative for 6 time series) and ITA (significantly positive for 19 time series, significantly positive for 6 time series) were identified. was done 32 time series significantly negative). A developed map of spatial variability in precipitation trends will help stakeholders and/or water resource managers to understand the risks and vulnerabilities associated with climate change in the study area.

Malik, A. et al., (2020) made a study on Identification of EDI trend using Mann-Kendall and Şen-Innovative Trend methods (Uttarakhand, India). Identification of drought trends is essential in climate change scenarios, especially for efficient use of water resources. This article uses two methods, including traditional Mann-Kendall (MK) and graphical Şen-Innovative Trend (ŞIT), to measure the effective drought index (EDI) at 13 weather stations in Uttarakhand, India. detected a trend of The EDI was calculated using monthly precipitation data at survey stations for 54 years from 1962 to 2015. EDI magnitude (mm/year) was derived by Sen's Slope Estimator (SSE) method.

Dong, Z. et al., (2020) made the study on Innovative Trend Analysis of Air Temperature and Precipitation in the Jinsha River Basin, China. Trend recognition based on hydroclimatic time series is crucial to understanding. climate change. In this study, an innovative trend analysis (ITA) technique was used to investigate Temperature and precipitation trends in the Jinsha River basin (JRB) in China from 1961 to 1961 2016 based on 40 weather stations. A set of climatic factors was grouped into three categories Evaluate hidden trends separately in percentiles. ITA results show While annual and seasonal temperatures have increased significantly, the range of variation is The annual temperature tends to be narrower. Spatial pattern analysis of temperature shows High-altitude areas show a stronger upward trend than low-lying areas. moreover, ITA Shows Significant Increases in Annual Precipitation and Spring 'High' Category Precipitation amount.

4. Chapter :4

4.1. Study Area and Data

The northern middle & Southern part including Bay of Bengal of west Bengal covers 13 nos. districts. West Bengal lies roughly between 21°30’N and 27°11’N latitude and 85°49’30” E and 89°54’E longitude. Observed yearly maximum temperature data for 65 years (1951–2015) have been collected from the Indian Meteorological Department (IMD) for 14nos. stations of West Bengal. Historical monthly temperature data from1951 to 2015 have been chosen to perform the analysis.

The analysis was done on 14 nos. stations in West Bengal. Different seasons considered for this study are: winter (January-February) Pre-Monsoon (March-April-May), Monsoon (June – July – August - September) & post-monsoon (October – November - December). For all these analyses we have used the Yearly Average Temperature for T_{max} data for the period of 65 years (1951-2015) generated by the India Meteorological Department (IMD), Pune.

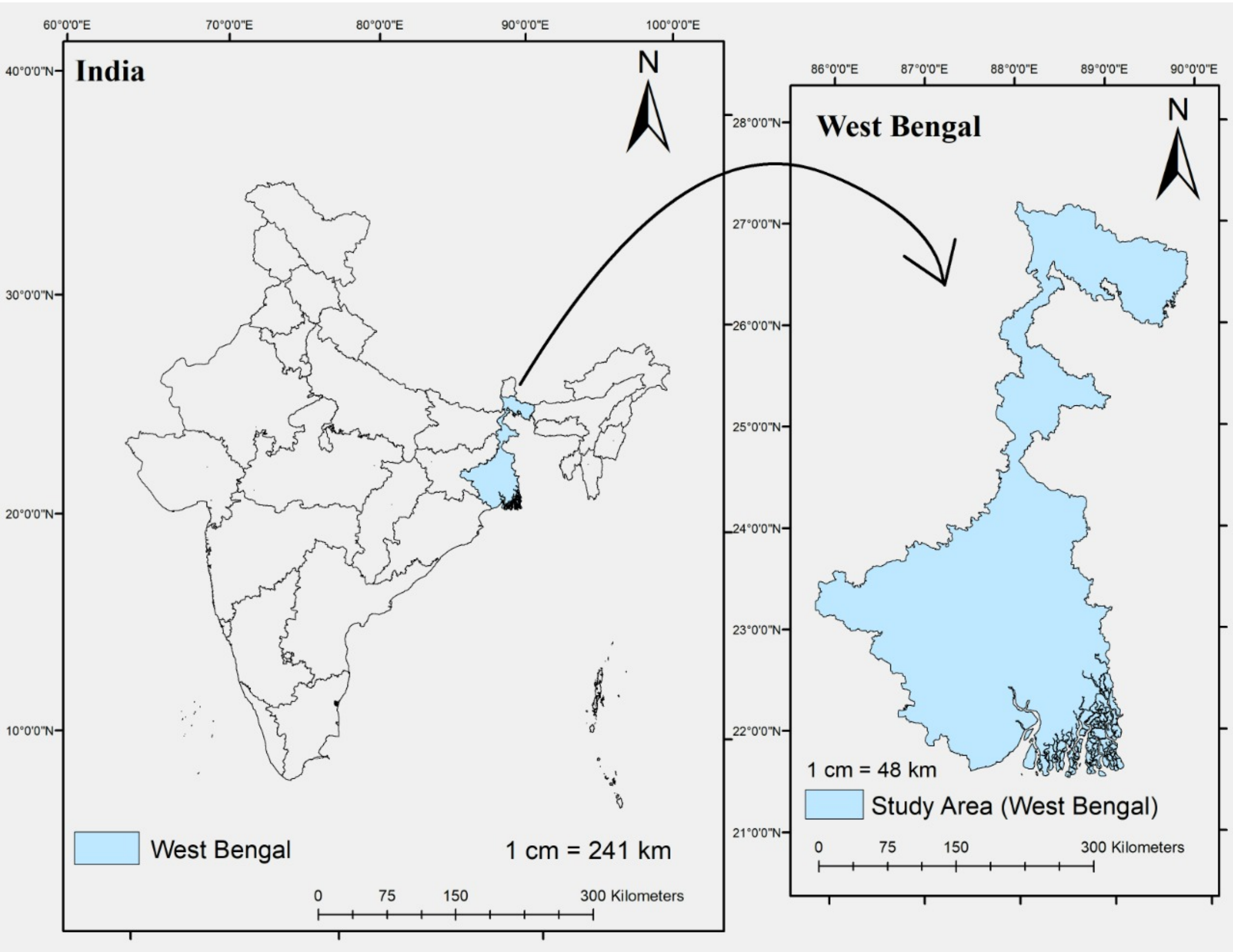

Figure 1(Study Area Map)

Figure 2 (Political Map of West Bengal)

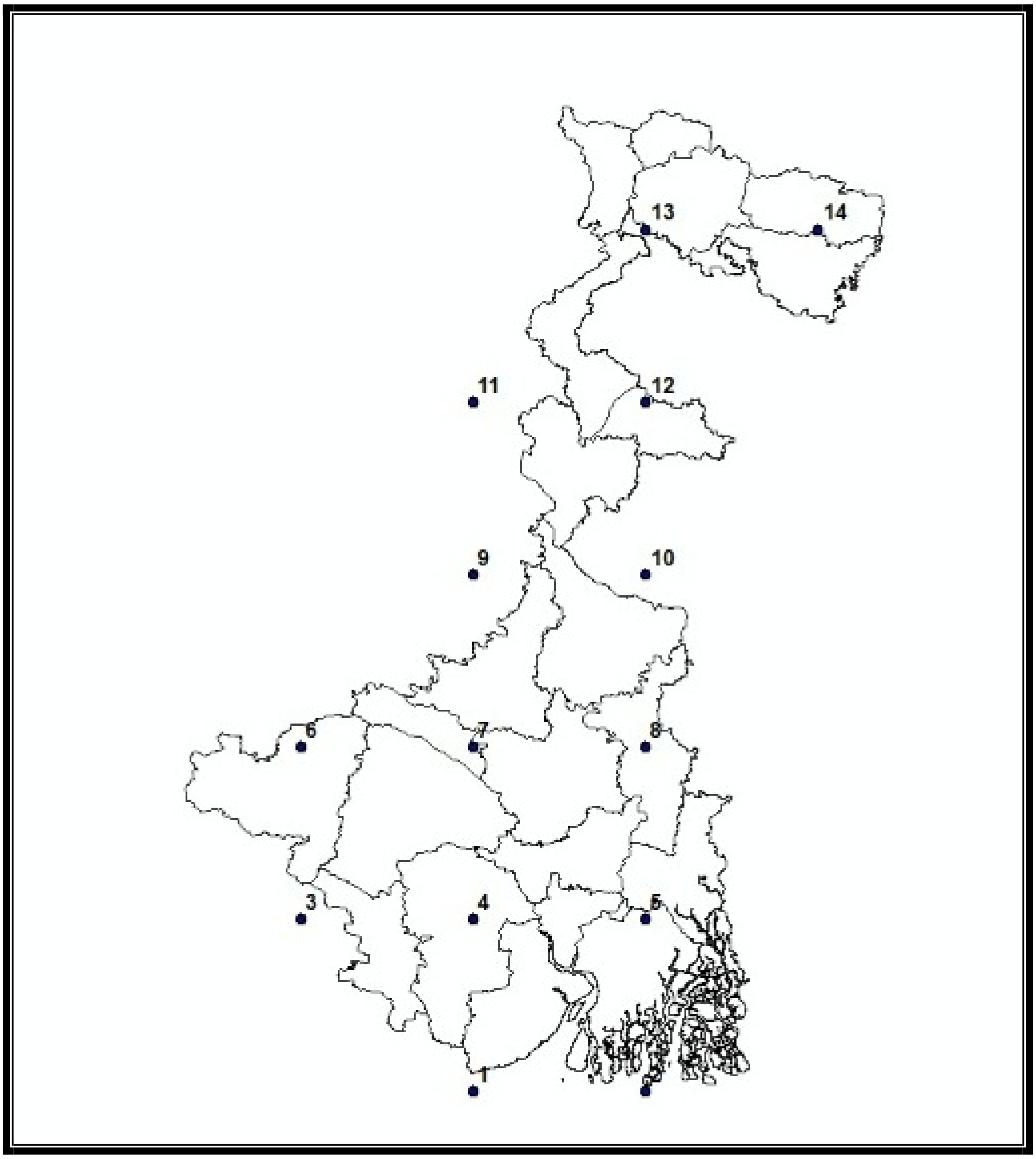

Figure 3 (Study Area Showing All Station Points)

5. Chapter : 5

5.1. Methodology

5.1.1. Steps followed

a) Collection of data from IMD Pune (IMD website)
b) Plotting the co-ordinates in Arc-GIS software and fixed the study area.
c) Extraction of DATA for the present study area (thirteen districts of the west Bengal which includes (Purba Medinipur, South 24 parganas -Bay of Bengal , Jhargram , Paschim Medinipur, South 24 parganas, Purulia , Paschim Bardhaman , Nadia , Birbhum , Mursidabad , Malda , Dakhsin Dinajpur , Jalpaiguri , Alipurduar)
d) Data is arranged seasonally.
e) Method use to analyze the temperature trend is ITAM.
f) Discussion of the result as per station point and district-wise.
g) Finally, we came on the result of trend in temperature of the given study area.

5.1.2. Innovative Trend Analysis Method (ITAM)

The trend in temperature time series was detected using a new approach of trend detection idea presented by (Sen 2012). The time series is split up into two equal halyes and sorted in ascending order using this procedure . The X-axis and Y-axis are used to plot the 1st half and 2nd half of the series respectively .The 1:1 slope determines the series trend ; if it lies on the line ,there is no trend ,it indicates a positive trend if it is above the line , and a negative trend if it is below the line .

For better understanding of trend analysis , the ITAM approach was also tested at various significance levels by Sen (2017). The slope of ITAM is defined by the following equation ;

$$\mathbf{S=2(X_j - X_i)/n}$$

[Where S is the Slope of ITAM , n number of sample data and X_i , X_j are the mean of 1st half and 2nd half respectively]

After calculation of the slope of the trend line ,the standard deviation of the slope is calculated as;

$$\sigma_s=[2\sqrt{2}x\sigma\sqrt{(1-\rho_{XiXj})}]/n\sqrt{n}$$

[Where $\boldsymbol{\sigma_s}$ is the standard slope ; $\boldsymbol{\sigma}$ is the standard deviation of the whole data series and ρ_{XiXj} is the cross correlation co-efficient between the 1st half & 2nd half.]

Finally the confidence limit (CL) of the trend at α level of significance are as follows;

$$CL_{(1-\alpha)}=0+-S_{cri}\,\sigma_s$$

[Where $CL_{(1-\alpha)}$ is the lower and upper confidence limit at the α level of significance . Here we used 5% level of significance for estimating significance.

If the Slope of ITA is greater than Confidence limit at 5% level of significance then it will consider Significant trend And if Slope of ITA is lesser than Confidence limit at 5% level of significance then it will consider Non-Significant trend ($S<CL_{(1-\alpha)}$).

Significant Trend = **($S>CL_{(1-\alpha)}$)**.

Non-Significant trend = **($S<CL_{(1-\alpha)}$)**

5.1.3. Co-ordinates of Different Points and Its Representation on The Map

Table 1(Co-Ordinates of Station Point)

Sl. No.	Co-Ordinates		Station Point
	Longitude	Latitude	
1	87.5	21.5	S1
2	88.5	21.5	S2
3	86.5	22.5	S3
4	87.5	22.5	S4
5	88.5	22.5	S5
6	86.5	23.5	S6
7	87.5	23.5	S7
8	88.5	23.5	S8
9	87.5	24.5	S9
10	88.5	24.5	S10
11	87.5	25.5	S11
12	88.5	25.5	S12
13	88.5	26.5	S13
14	89.5	26.5	S14

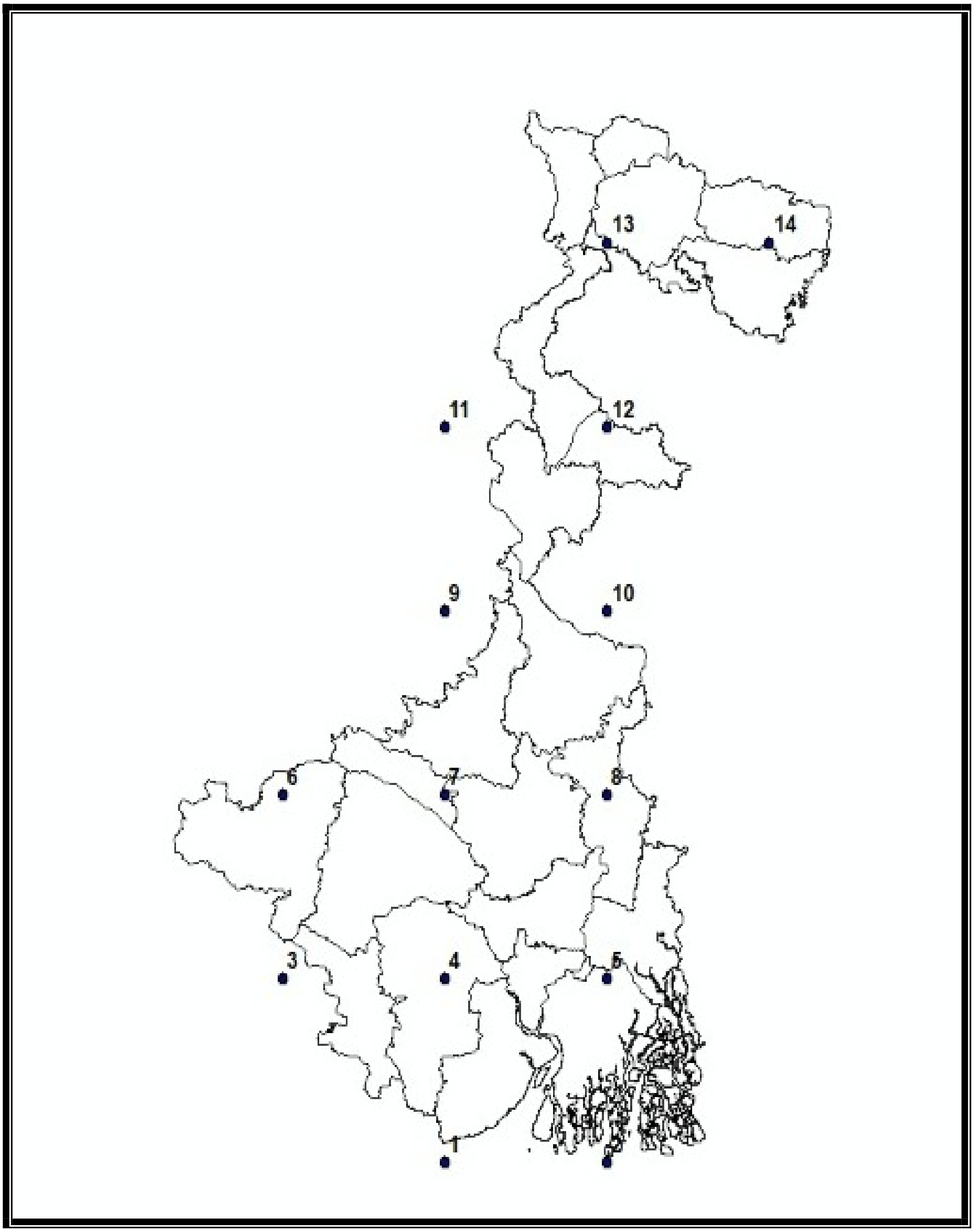

Figure 4 (Station Point of T_{max})

6. Chapter :6

6.1. Result and Discussion

In this study we have done analysis of the Temperature trend based on the 14 stations of the study area using the methods stated below;

- Innovative trend analysis

A year of Indian Subcontinent can be divided into four different seasons

e) Winter – January, February
f) Pre-Monsoon or Summer -March, April, May
g) Monsoon- June, July, August, September
h) Post-Monsoon – October, November, December

Seasonal Results are shown below in tabulated form.

Table 2 (ITA Test Results of Winter)

Station Point	Mean of 1st Half (X_i)	Mean of 2nd Half (X_j)	Standard Deviation (σ)	Slope $S=2(X_j - X_i)/n$	Correlation co-efficient (ρ_{XiXj})	Standard slope (σ_s)	$CL_{(1-\alpha)}$=0+- $S_{cri}\sigma_s$	Significant /Non Significant Trend	Trend
S1	27.480	27.326	0.727678	-0.004640	0.962725	0.000741	0.00145	S	Negative
S2	27.050	26.843	0.715915	-0.006276	0.961699	0.000739	0.00145	S	Negative
S3	27.815	27.548	0.846991	-0.008081	0.967067	0.000811	0.00159	S	Negative
S4	27.582	27.218	0.786704	-0.011024	0.971544	0.000700	0.00137	S	Negative
S5	27.386	27.051	0.758979	-0.010135	0.970673	0.000686	0.00134	S	Negative
S6	27.060	26.644	0.901294	-0.012621	0.977264	0.000717	0.00141	S	Negative
S7	27.453	26.972	0.853015	-0.014558	0.984363	0.000563	0.00110	S	Negative
S8	27.594	27.120	0.822902	-0.014381	0.977181	0.000656	0.00129	S	Negative
S9	26.534	26.079	0.889027	-0.013776	0.977924	0.000697	0.00137	S	Negative
S10	26.604	26.335	0.839149	-0.008170	0.967419	0.000799	0.00157	S	Negative
S11	25.691	25.532	0.940623	-0.004811	0.961625	0.000972	0.00191	S	Negative
S12	25.448	25.270	0.904826	-0.005408	0.962072	0.000930	0.00182	S	Negative
S13	21.839	21.769	0.904826	-0.002117	0.938240	0.001186	0.00232	NS	Negative
S14	22.063	22.077	0.884790	0.000447	0.936542	0.001176	0.00230	NS	Positive

*S = Significant , NS= Non-Significant

Table 3 (ITA Test Results of Pre-Monsoon)

Station Point	Mean of 1st Half (X_i)	Mean of 2nd Half (X_j)	Standard Deviation (σ)	Slope $S=2(X_j - X_i)/n$	Correlation co-efficient (ρ_{XiXj})	Standard slope (σ_s)	$CL_{(1-\alpha)}=0+-S_{cri}\sigma_s$	Significant /Non Significant Trend	Trend
S1	34.148	34.076	0.698973	-0.002186	0.975605	0.000576	0.00113	S	Negative
S2	33.584	33.423	0.732673	-0.004876	0.989049	0.000404	0.00079	S	Negative
S3	37.034	36.684	0.930879	-0.010588	0.980506	0.000686	0.00134	S	Negative
S4	35.159	34.950	1.337876	-0.006353	0.983208	0.000915	0.00179	S	Negative
S5	34.177	33.904	0.804340	-0.008252	0.983065	0.000552	0.00108	S	Negative
S6	36.890	36.409	1.041320	-0.014589	0.981548	0.000746	0.00146	S	Negative
S7	36.787	36.250	1.045638	-0.016283	0.984841	0.000679	0.00133	S	Negative
S8	35.981	35.498	0.956455	-0.014645	0.982772	0.000662	0.00130	S	Negative
S9	36.130	35.666	1.035171	-0.014057	0.974466	0.000873	0.00171	S	Negative
S10	35.675	35.353	0.961006	-0.009752	0.970045	0.000877	0.00172	S	Negative
S11	34.422	34.312	0.937138	-0.003320	0.969214	0.000867	0.00170	S	Negative
S12	33.813	33.644	0.870028	-0.005122	0.980665	0.000638	0.00125	S	Negative
S13	28.708	28.610	0.838789	-0.002964	0.986319	0.000518	0.00101	S	Negative
S14	28.635	28.612	0.789664	-0.000696	0.979960	0.000590	0.00116	NS	Negative

*S = Significant , NS= Non-Significant

Table 4 (ITA Test Results of Monsoon)

Station Point	Mean of 1st Half (X_i)	Mean of 2nd Half (X_j)	Standard Deviation (σ)	Slope $S=2(X_j - X_i)/n$	Correlation co-efficient (ρ_{XiXj})	Standard slope (σ_s)	$CL_{(1-\alpha)}=0+-S_{cri}\sigma_s$	Significant /Non Significant Trend	Trend
S1	32.007	32.189	0.492958	0.005507	0.953964	0.000558	0.00109	S	Positive
S2	31.929	32.087	0.500976	0.004775	0.955187	0.000559	0.00110	S	Positive
S3	32.909	32.898	0.593695	-0.000362	0.974046	0.000505	0.00099	NS	Negative
S4	32.610	32.708	0.530310	0.002964	0.950489	0.000622	0.00122	S	Positive
S5	32.292	32.473	0.502042	0.005486	0.959111	0.000536	0.00105	S	Positive
S6	32.956	32.911	0.614195	-0.001369	0.987481	0.000363	0.00071	S	Negative
S7	33.370	33.358	0.588702	-0.000375	0.983999	0.000393	0.00077	NS	Negative
S8	33.126	33.244	0.534319	0.003566	0.969355	0.000493	0.00097	S	Positive
S9	33.114	33.220	0.584622	0.003206	0.982448	0.000409	0.00080	S	Positive
S10	33.053	33.320	0.550284	0.008090	0.978902	0.000422	0.00083	S	Positive
S11	32.632	33.080	0.560995	0.013573	0.969214	0.000519	0.00102	S	Positive
S12	32.427	32.812	0.496916	0.011677	0.952888	0.000569	0.00112	S	Positive
S13	28.898	29.327	0.487114	0.012990	0.928643	0.000686	0.00135	S	Positive
S14	28.979	29.393	0.450981	0.012534	0.951545	0.000524	0.00103	S	Positive

*S = Significant , NS= Non-Significant

Table 5 (ITA Test Results of Post-Monsoon)

Station Point	Mean of 1st Half (X_i)	Mean of 2nd Half (X_j)	Standard Deviation (σ)	Slope $S=2(X_j - X_i)/n$	Correlation co-efficient (ρ_{XiXj})	Standard slope (σ_s)	$CL_{(1-\alpha)}=0+-S_{cri}\sigma_s$	Significant /Non Significant Trend	Trend
S1	29.163	29.255	0.565439	0.002799	0.969355	0.000522	0.00102	S	Positive
S2	29.022	29.112	0.574494	0.002718	0.969407	0.000530	0.00104	S	Positive
S3	29.129	29.026	0.625513	-0.003122	0.956162	0.000691	0.00135	S	Negative
S4	29.309	29.231	0.618916	-0.002368	0.939516	0.000803	0.00157	S	Negative
S5	29.350	29.392	0.582552	0.001279	0.959797	0.000616	0.00121	S	Positive
S6	28.852	28.701	0.618327	-0.004551	0.974445	0.000521	0.00102	S	Negative
S7	29.504	29.352	0.589507	-0.004585	0.984111	0.000392	0.00077	S	Negative
S8	29.597	29.539	0.561877	-0.001732	0.970709	0.000507	0.00099	S	Negative
S9	29.098	29.081	0.604709	-0.000530	0.989391	0.000329	0.00064	NS	Negative
S10	29.151	29.366	0.630566	0.006503	0.975089	0.000525	0.00103	S	Positive
S11	28.778	29.105	0.639201	0.009908	0.938823	0.000834	0.00163	S	Positive
S12	28.618	28.873	0.612479	0.007728	0.965586	0.000599	0.00117	S	Positive
S13	25.253	25.548	0.612967	0.008939	0.957084	0.000670	0.00131	S	Positive
S14	25.246	25.597	0.569155	0.010649	0.967655	0.000540	0.00106	S	Positive

*S = Significant , NS= Non-Significant

6.1.1. Here we are going to discuss each station season wise

6.1.1.1. Winter Season

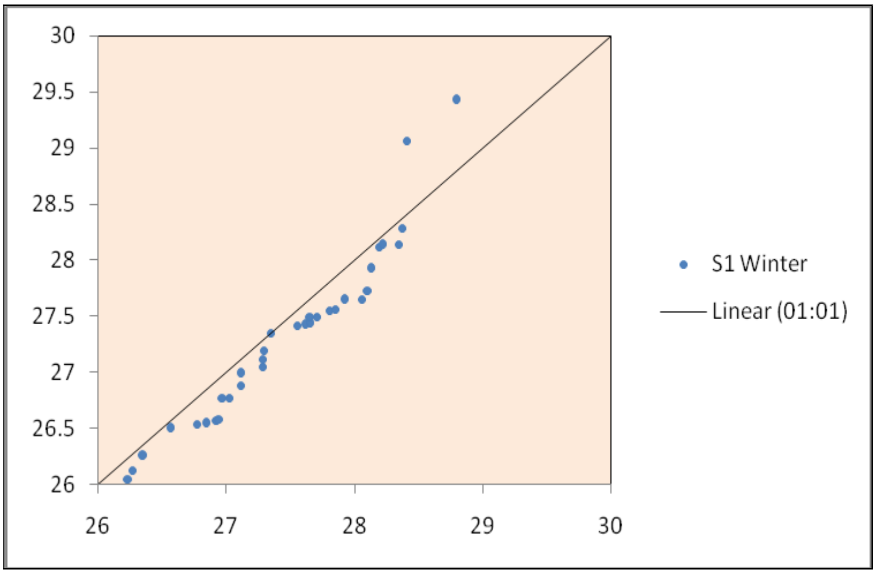

Figure 5 (S1 Winter)

Result : S1 Showing Significant Negative Trend

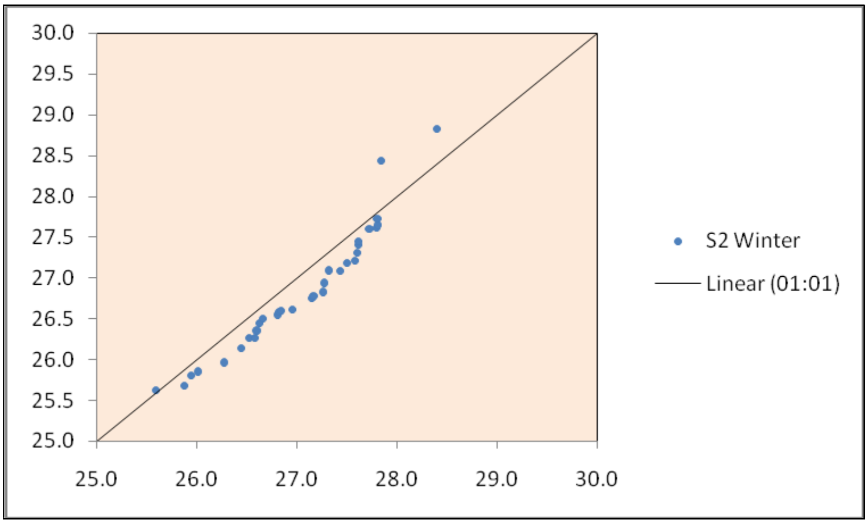

Figure 6 (S2 Winter)

<u>Result :</u> S2 Showing Significant Negative Trend

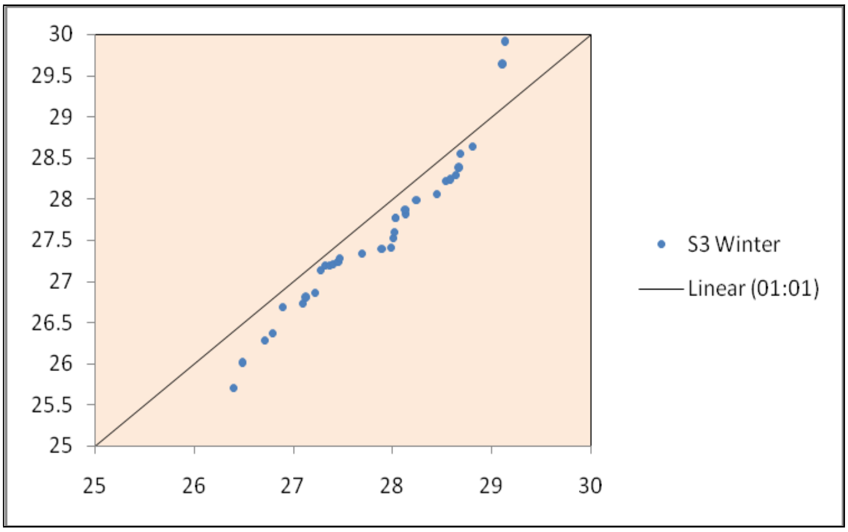

Figure 7 (S3 Winter)

<u>Result :</u> S3 Showing Significant Negative Trend

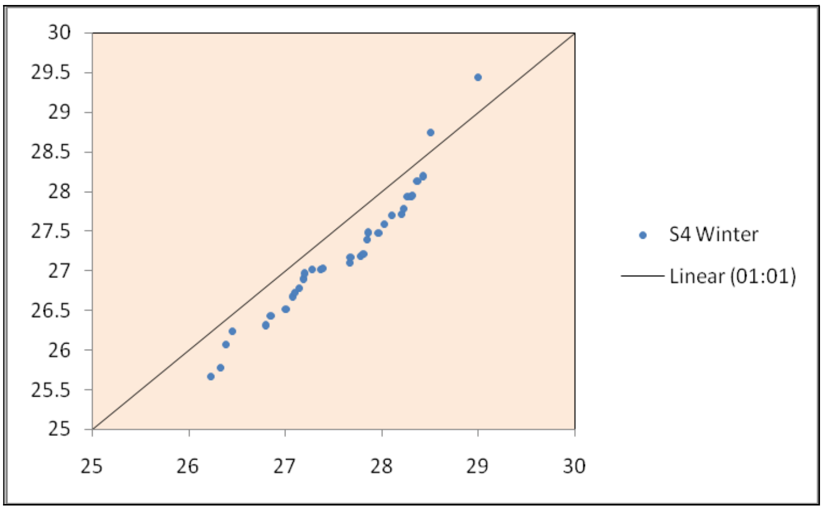

Figure 8 (S4 Winter)

Result : S4 Showing Significant Negative Trend

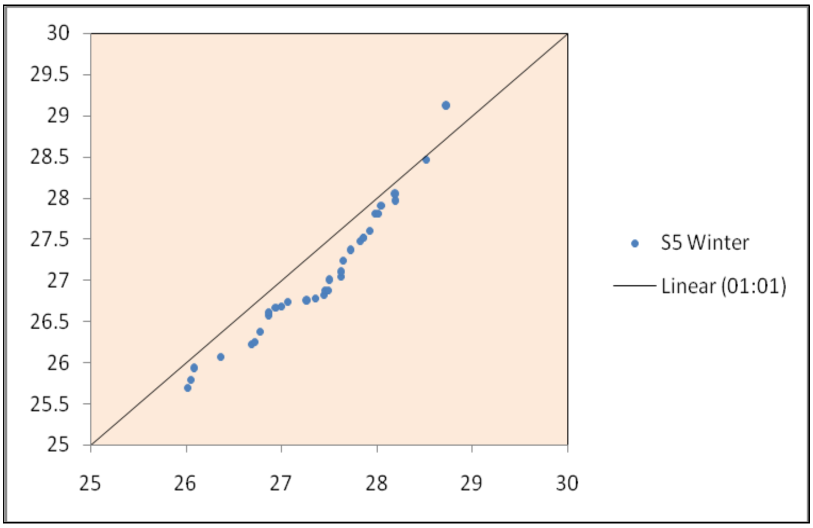

Figure 9 (S5 Winter)

Result : S5 Showing Significant Negative Trend

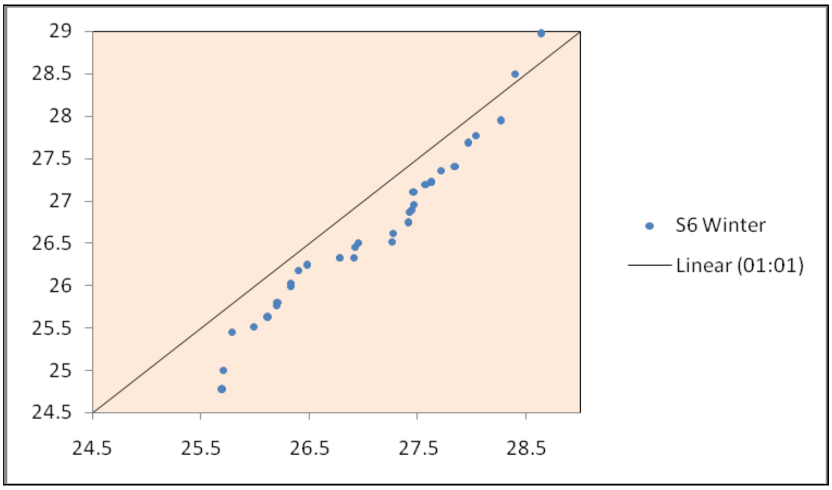

Figure 10 (S6 Winter)

Result : S6 Showing Significant Negative Trend

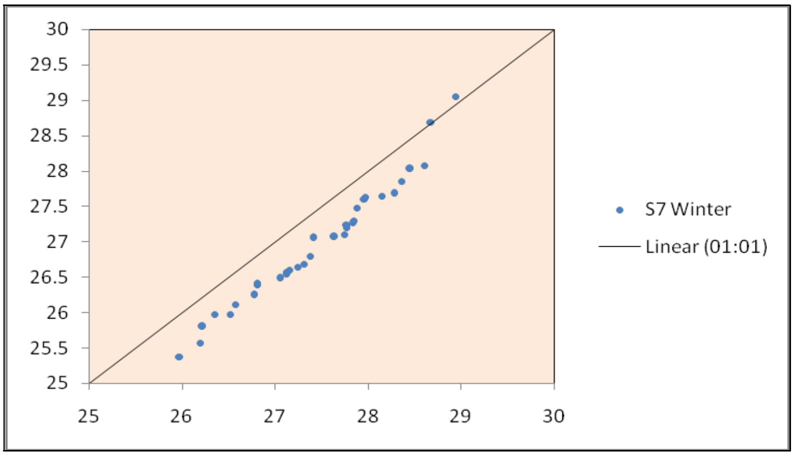

Figure 11 (S7 Winter))

Result : S7 Showing Significant Negative Trend

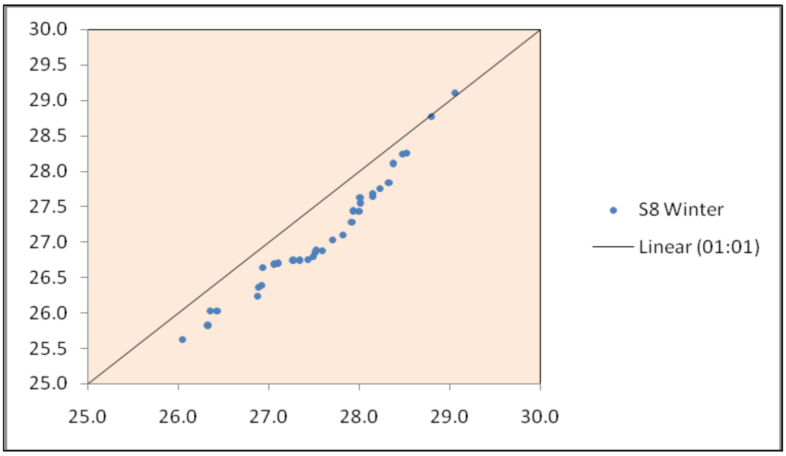

Figure 12 (S8 Winter)

<u>Result :</u> S8 Showing Significant Negative Trend

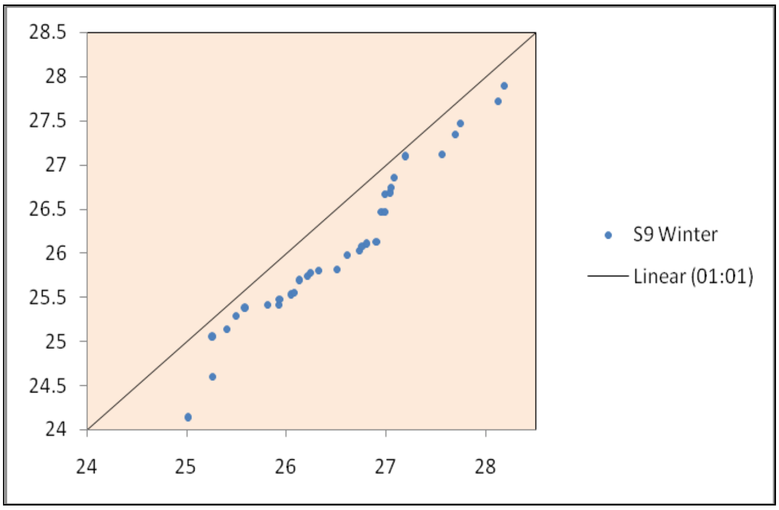

Figure 13 (S9 Winter)

<u>Result :</u> S9 Showing Significant Negative Trend

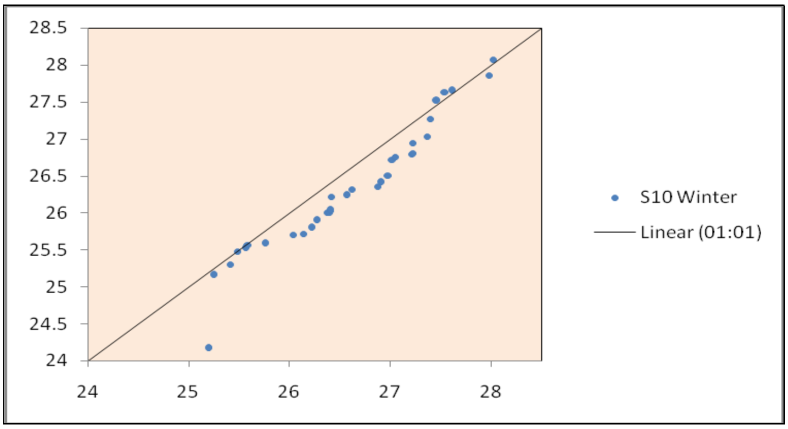

Figure 14 (S10 Winter)

Result : S10 Showing Significant Negative Trend

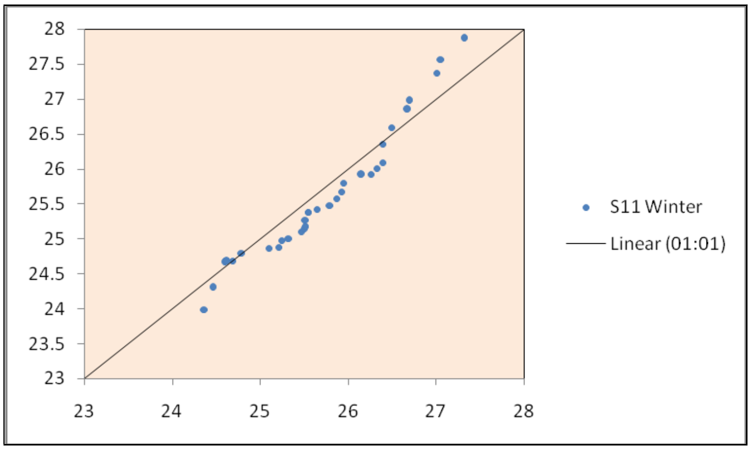

Figure 15 (S11 Winter)

Result : S11 Showing Significant Negative Trend

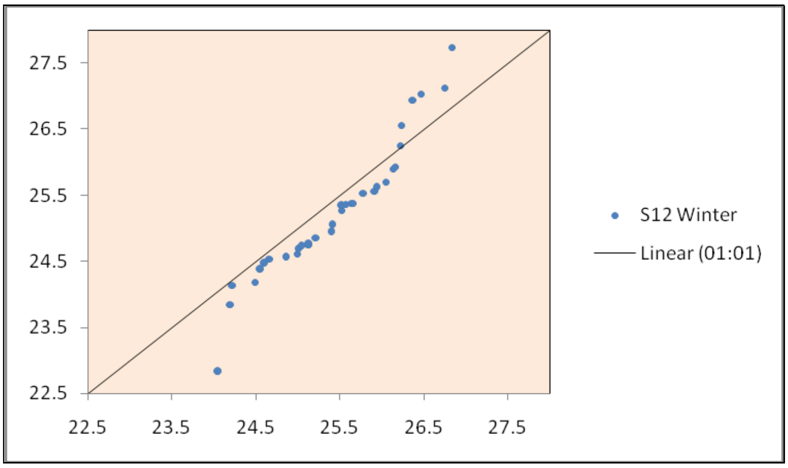

Figure 16 (S12 Winter)

Result : S12 Showing Significant Negative Trend

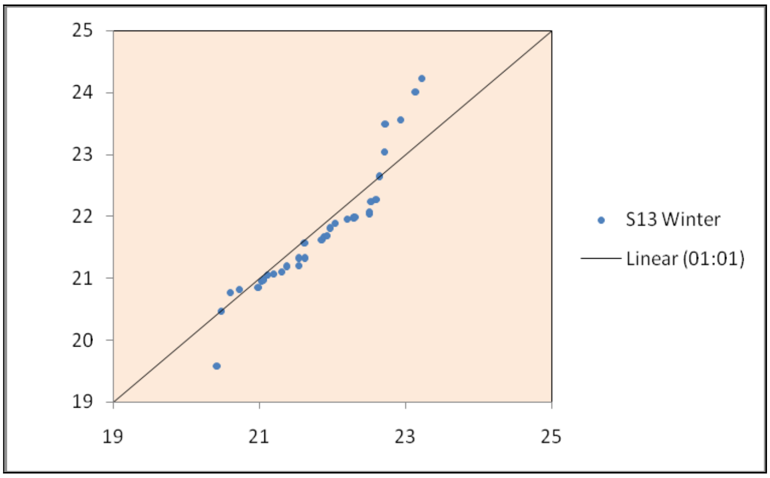

Figure 17 (S13 Winter)

Result : S13 Showing Non Significant Negative Trend

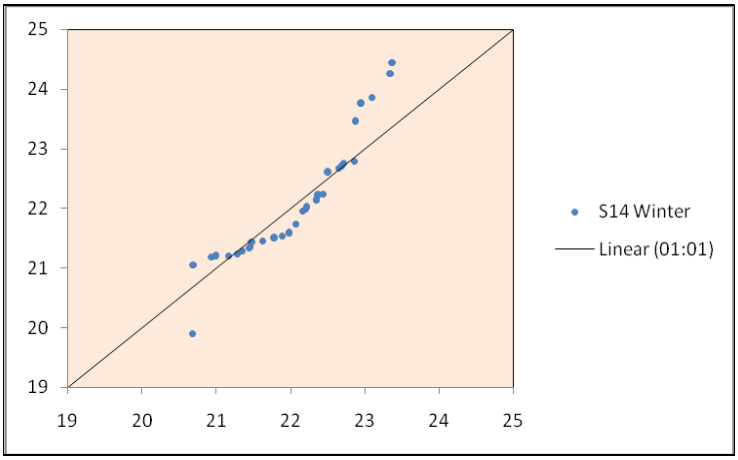

Figure 18 (S14 Winter)

Result : S14 Showing Non Significant Positive Trend

6.1.1.2. Pre-Monsoon Season

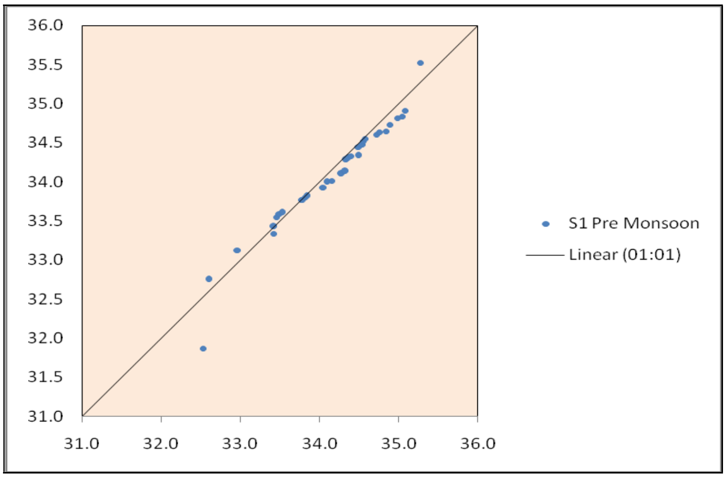

Figure 19 (S1 Pre-Monsoon)

<u>Result :</u> S1 Showing Significant Negative Trend

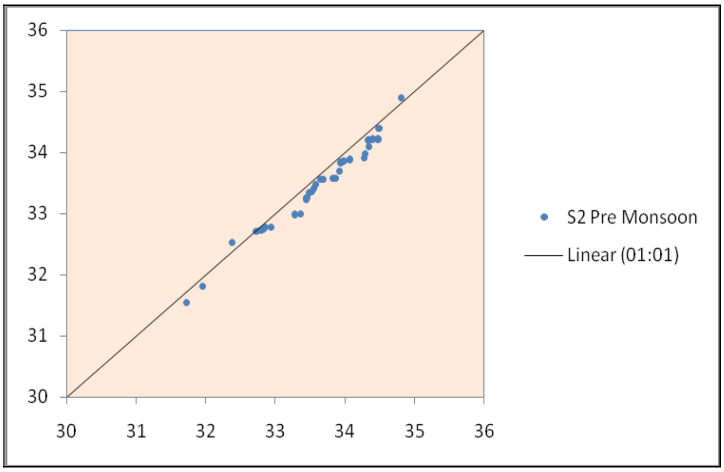

Figure 20 (S2 Pre-Monsoon)

<u>Result :</u> S2 Showing Significant Negative Trend

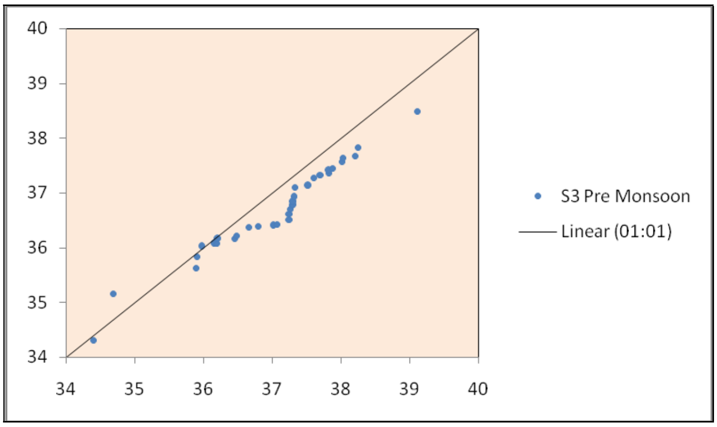

Figure 21(S3 Pre-Monsoon)

<u>Result :</u> S3 Showing Significant Negative Trend

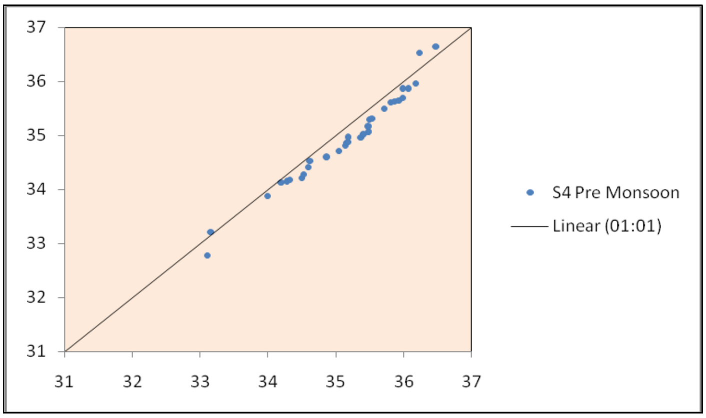

Figure 22 (S4 Pre-Monsoon)

<u>Result :</u> S4 Showing Significant Negative Trend

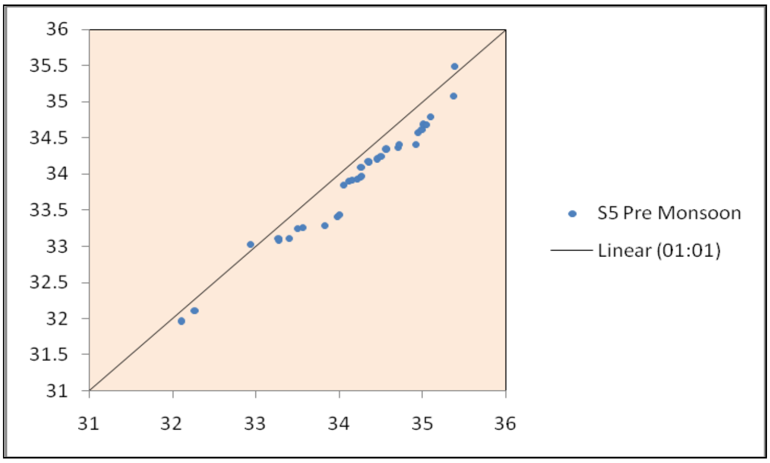

Figure 23 (S5 Pre-Monsoon)

Result : S5 Showing Significant Negative Trend

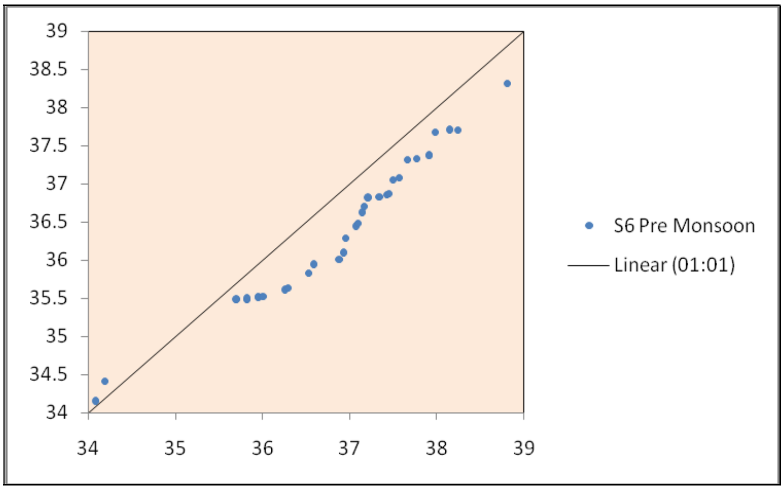

Figure 24 (S6 Pre-Monsoon)

Result : S6 Showing Significant Negative Trend

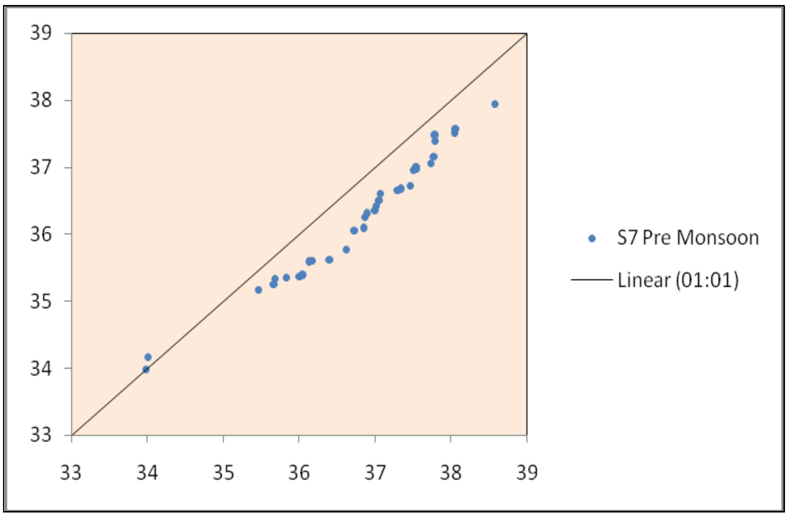

Figure 25(S7 Pre-Monsoon)

Result : S7 Showing Significant Negative Trend

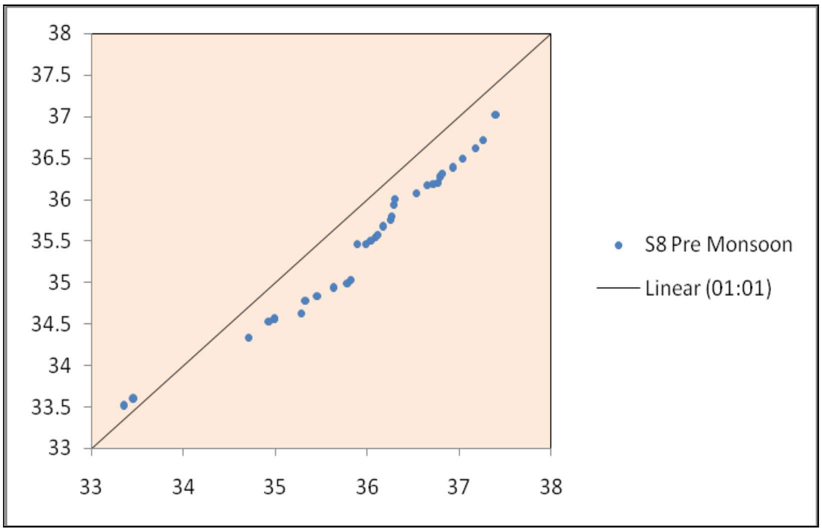

Figure 26(S8 Pre-Monsoon)

Result : S8 Showing Significant Negative Trend

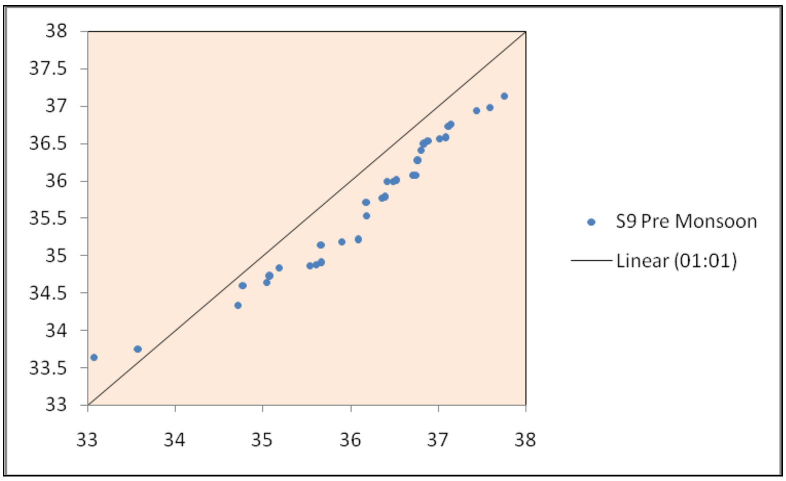

Figure 27 (S9 Pre-Monsoon)

<u>Result :</u> S9 Showing Significant Negative Trend

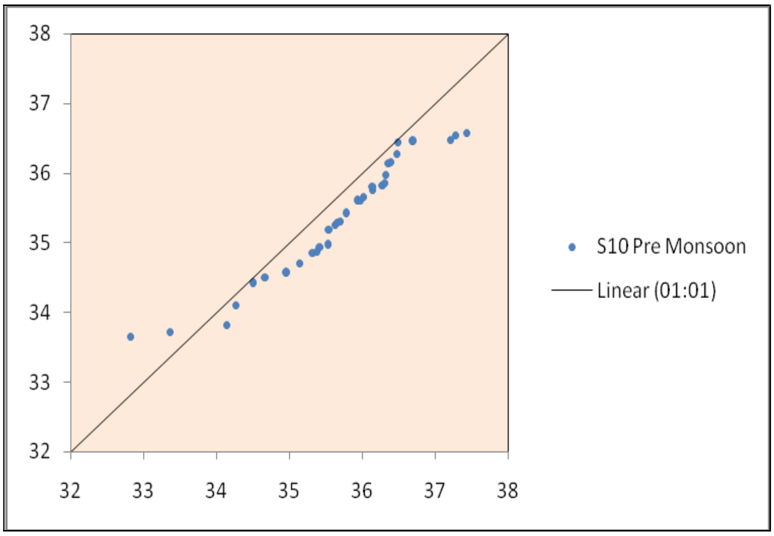

Figure 28 (S10 Pre-Monsoon)

Result : S10 Showing Significant Negative Trend

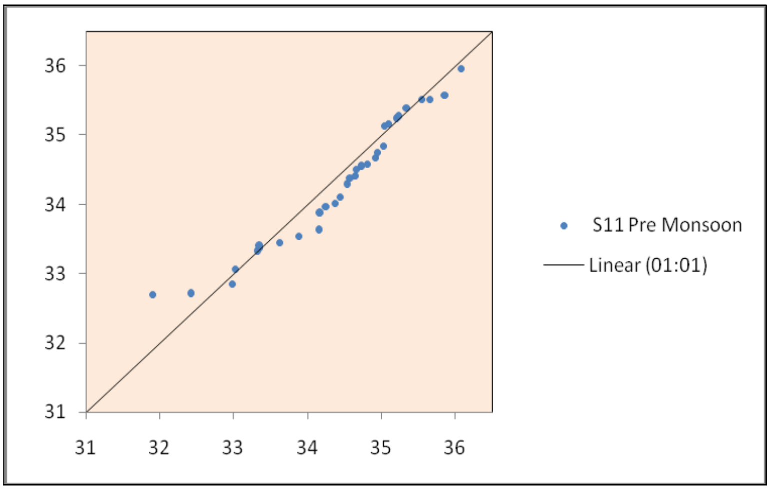

Figure 29 (S11 Pre-Monsoon)

Result : S11 Showing Significant Negative Trend

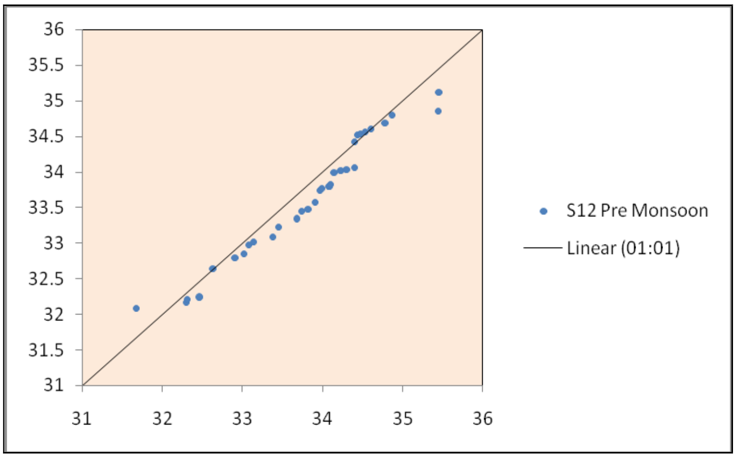

Figure 30 (S12 Pre-Monsoon)

Result : S12 Showing Significant Negative Trend

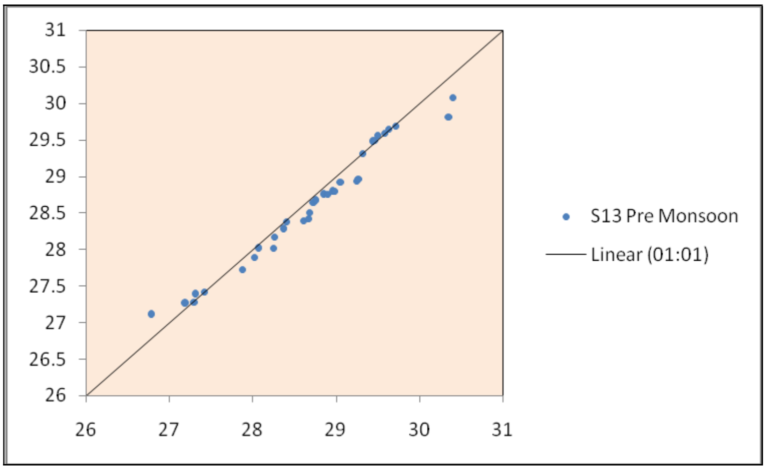

Figure 31 (S13 Pre-Monsoon)

Result : S13 Showing Significant Negative Trend

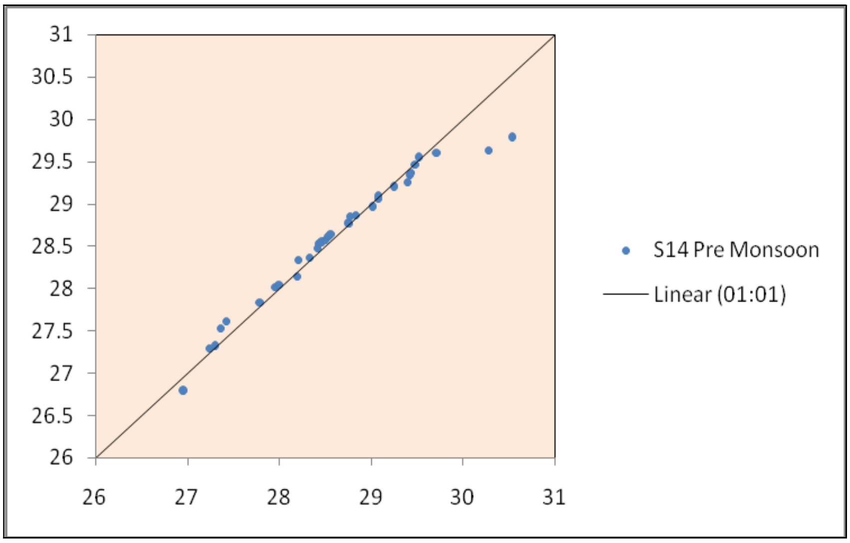

Figure 32 (S14 Pre-Monsoon)

Result : S14 Showing Non-Significant Negative Trend

6.1.1.3. Monsoon Season

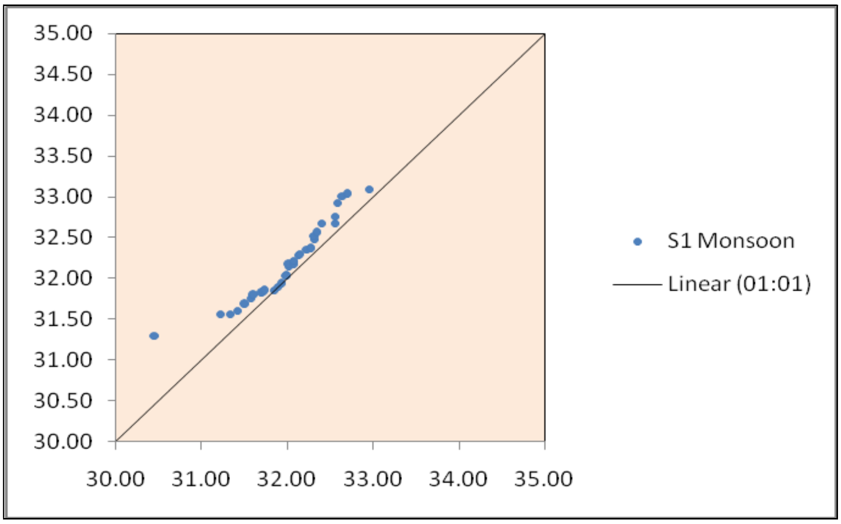

Figure 33 (S1 Monsoon)

Result : S1 Showing Significant Positive Trend

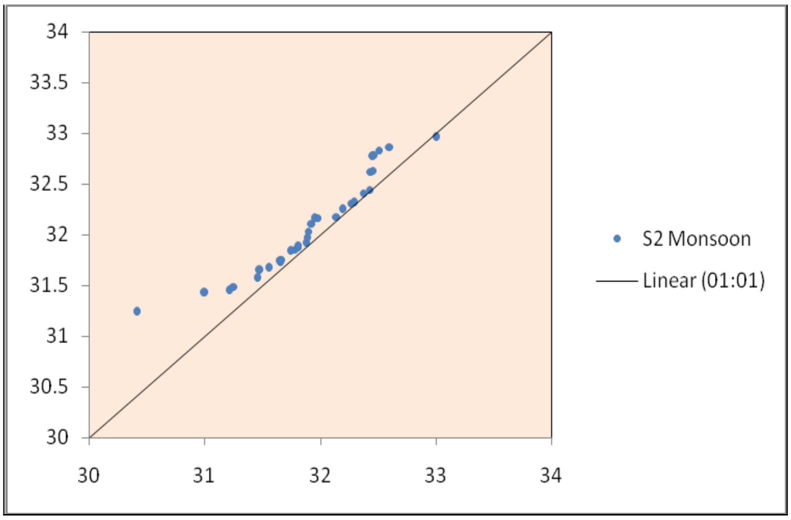

Figure 34 (S2 Monsoon)

Result : S2 Showing Significant Positive Trend

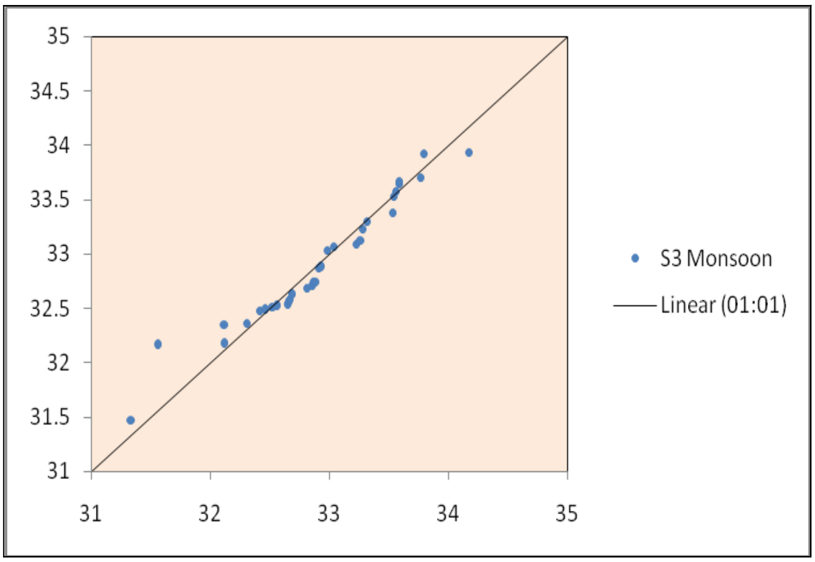

Figure 35 (S3 Monsoon)

Result : S3 Showing Non-Significant Negative Trend

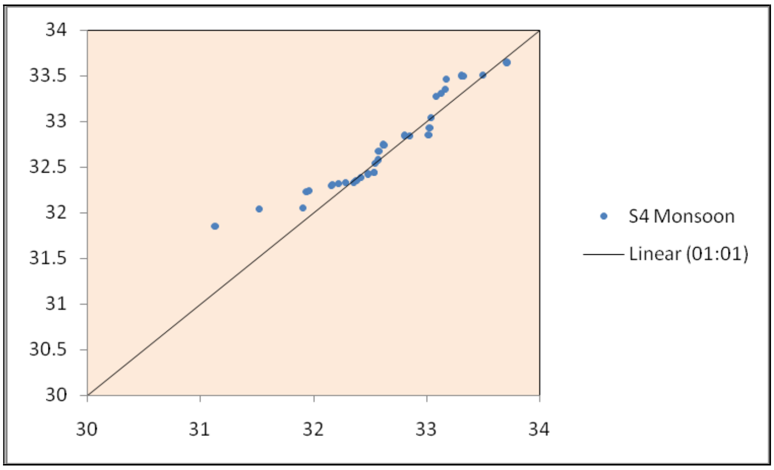

Figure 36 (S4 Monsoon)

Result : S4 Showing Significant Positive Trend

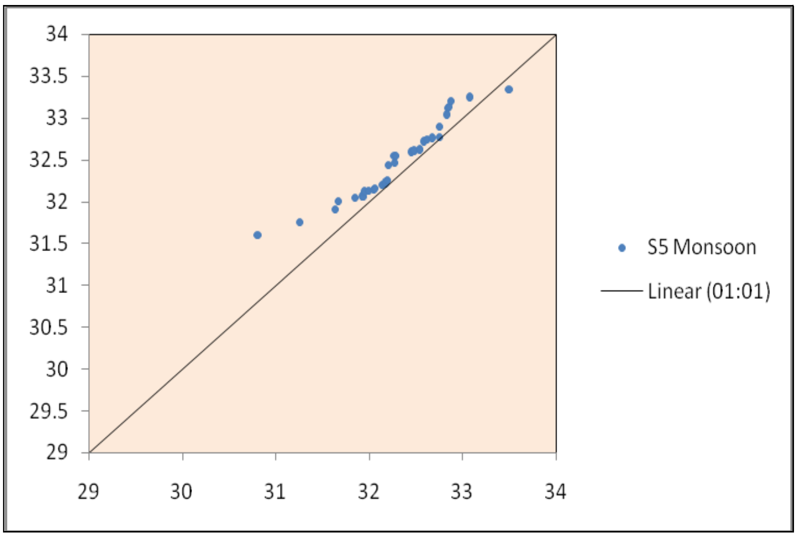

Figure 37 (S5 Monsoon)

Result : S5 Showing Significant Positive Trend

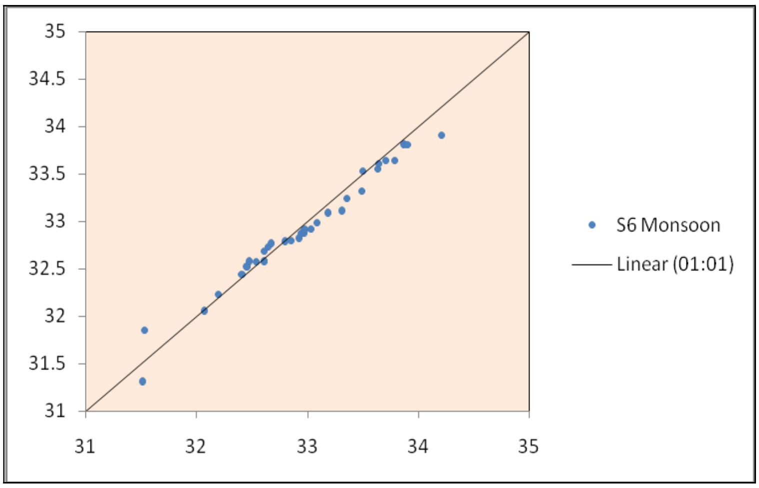

Figure 38 (S6 Monsoon)

Result : S6 Showing Significant Negative Trend

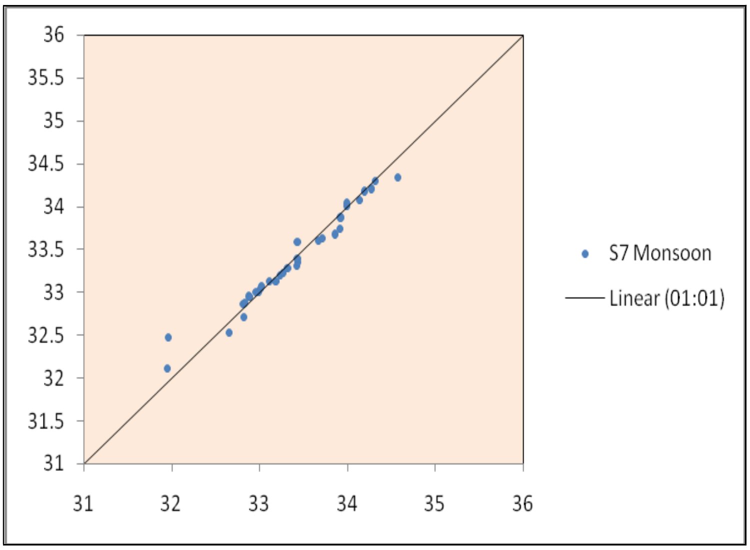

Figure 39 (S7 Monsoon)

Result : S7 Showing Non-Significant Negative Trend

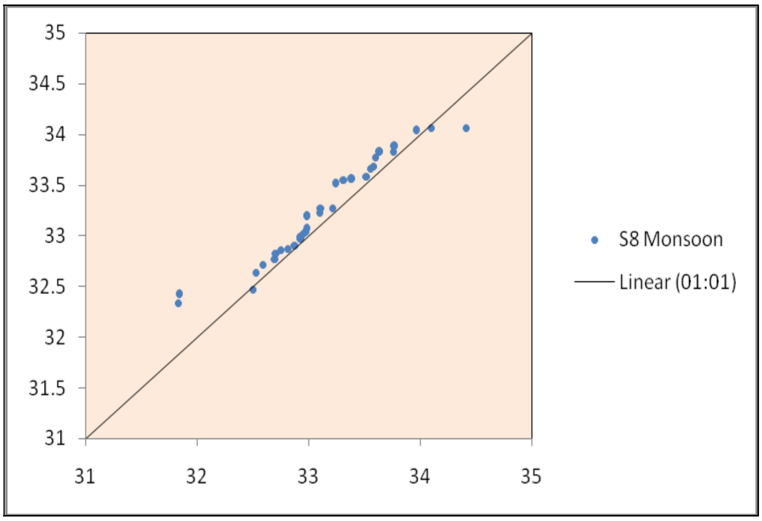

Figure 40 (S8 Monsoon)

Result : S8 Showing Significant Positive Trend

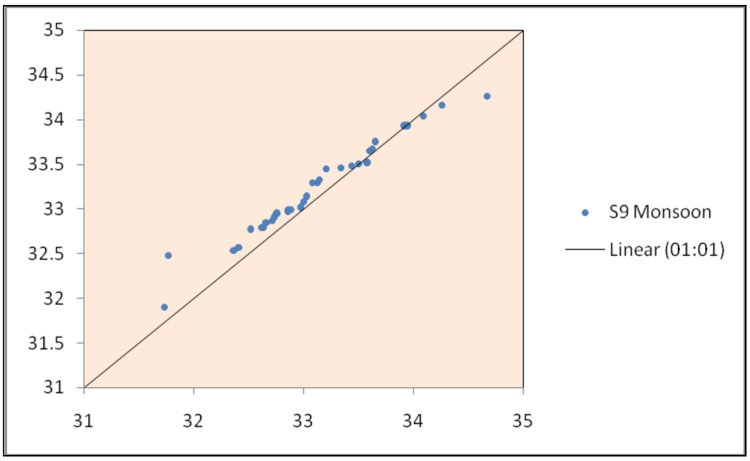

Figure 41 (S9 Monsoon)

Result : S9 Showing Significant Positive Trend

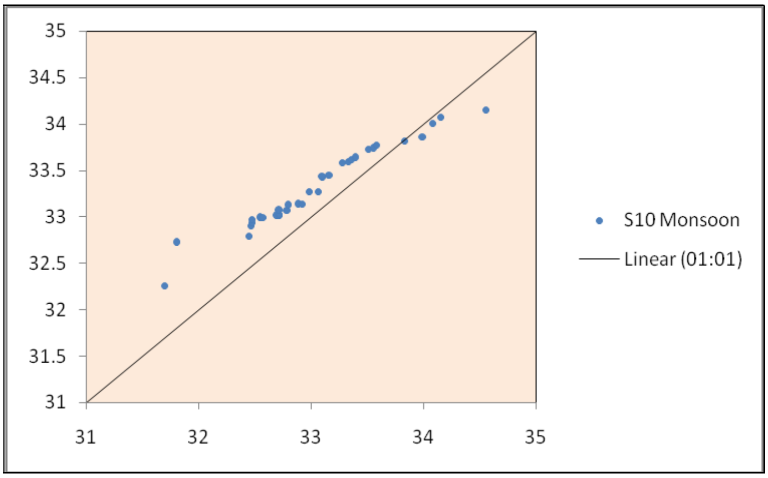

Figure 42 (S10 Monsoon)

Result : S10 Showing Significant Positive Trend

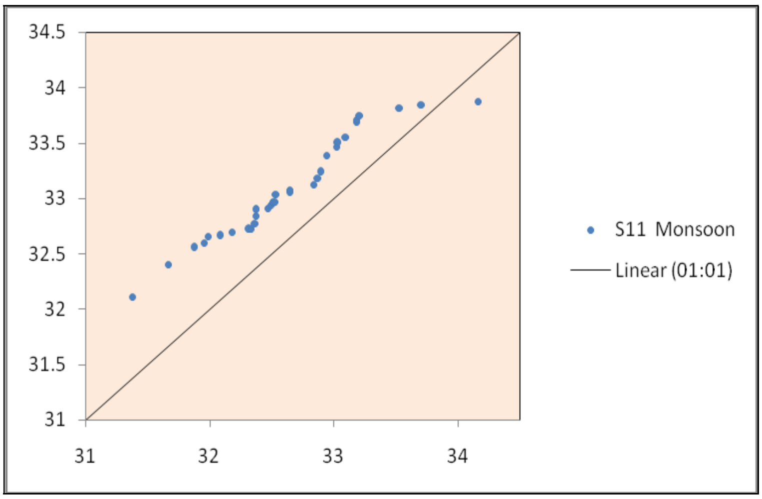

Figure 43 (S11 Monsoon)

Result : S11 Showing Significant Positive Trend

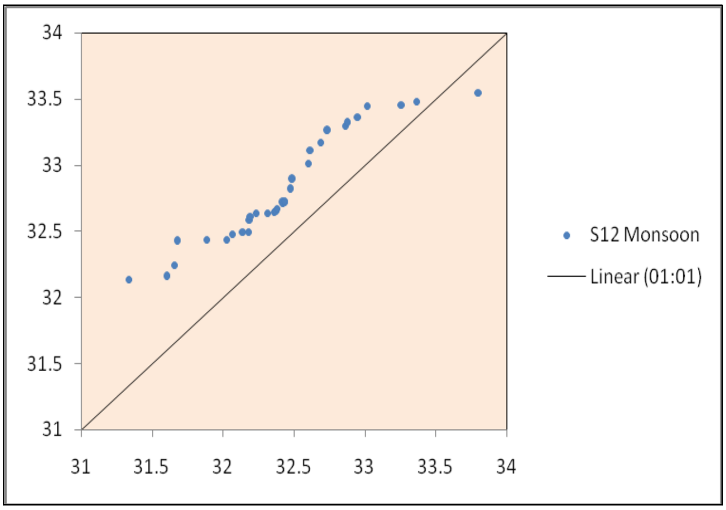

Figure 44 (S12 Monsoon)

Result : S12 Showing Significant Positive Trend

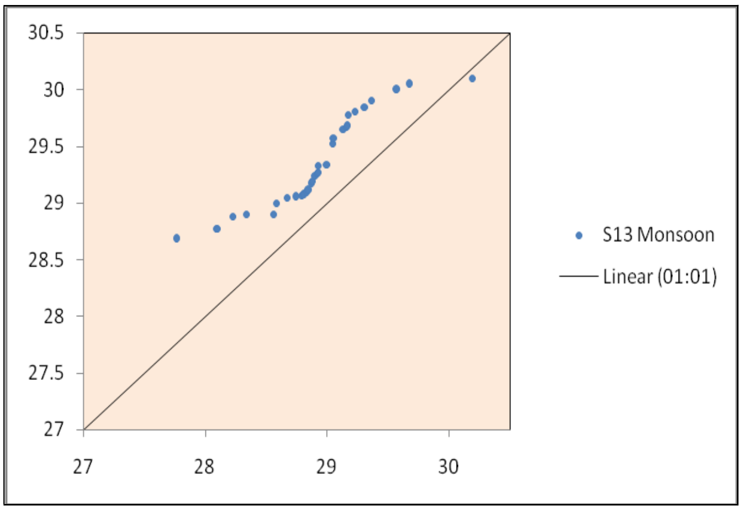

Figure 45 (S13 Monsoon)

Result : S13 Showing Significant Positive Trend

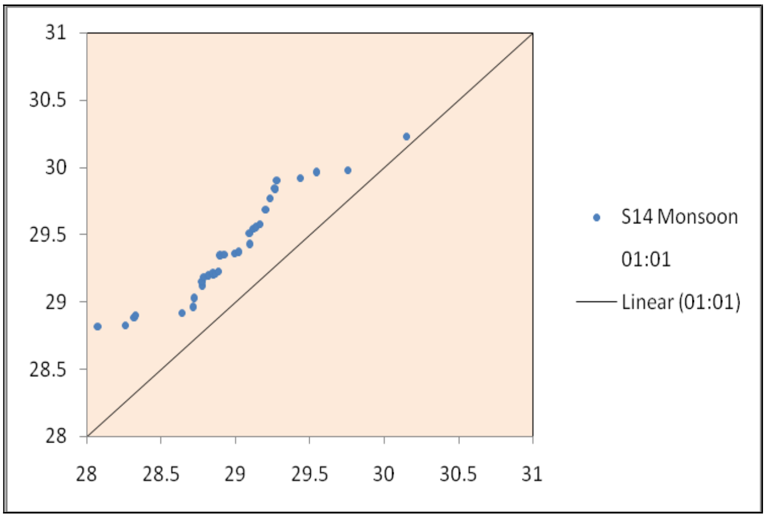

Figure 46 (S14 Monsoon)

Result : S14 Showing Significant Positive Trend

6.1.1.4. Post Monsoon Season

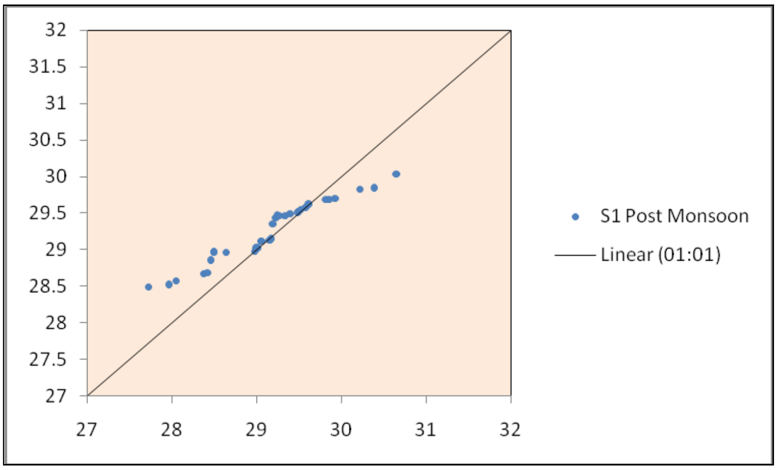

Figure 47 (S1 Post Monsoon)

Result : S1 Showing Significant Positive Trend

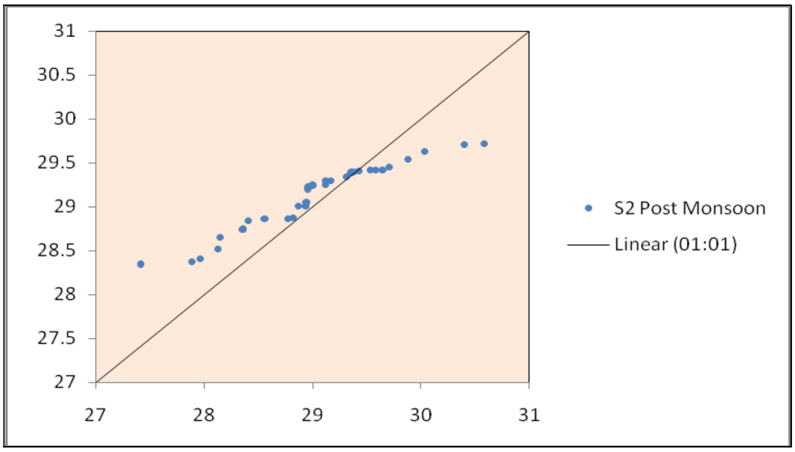

Figure 48 (S2 Post Monsoon)

Result : S2 Showing Significant Positive Trend

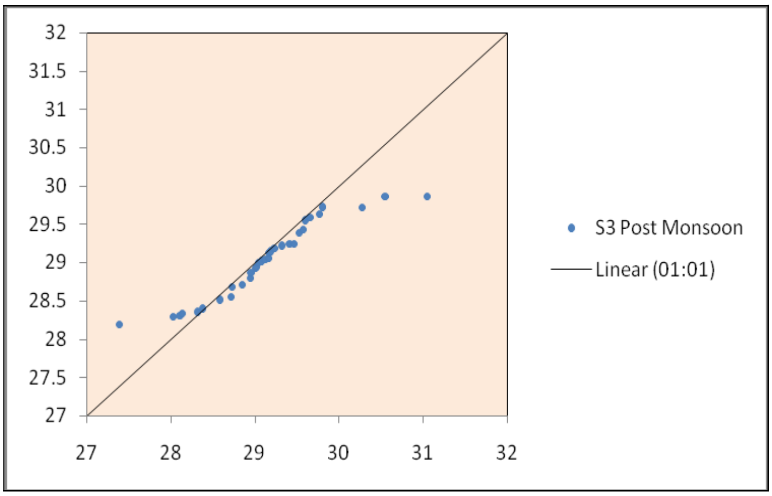

Figure 49 (S3 Post Monsoon)

Result : S3 Showing Significant Negative Trend

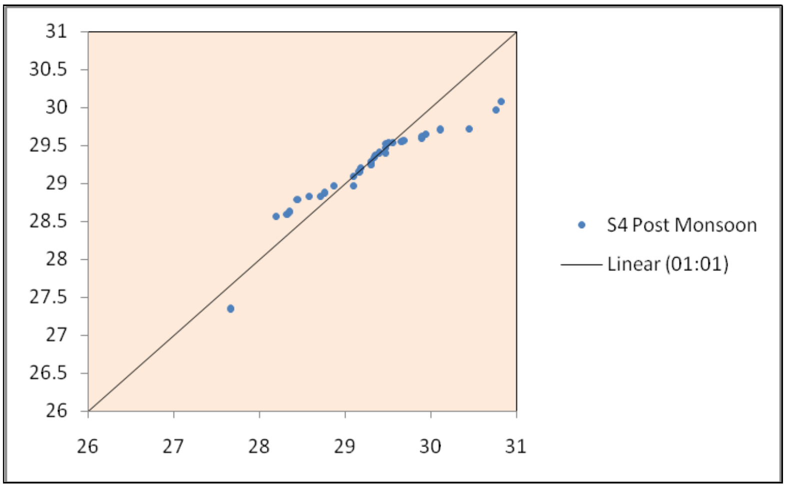

Figure 50 (S4 Post Monsoon)

Result : S4 Showing Significant Negative Trend

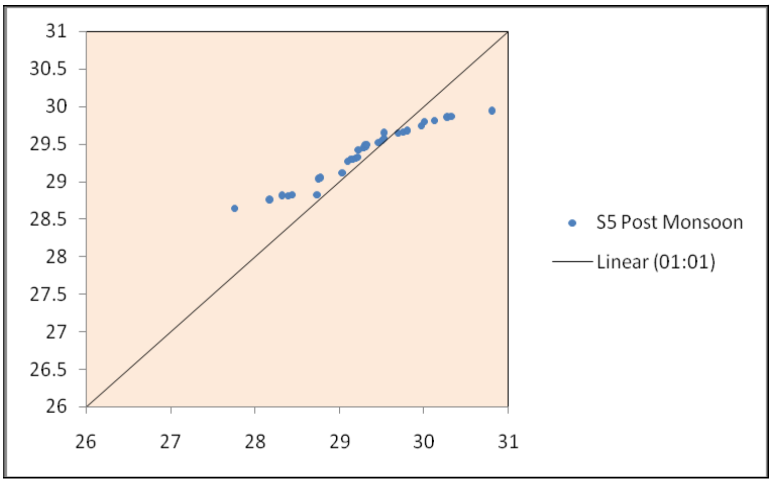

Figure 51 (S5 Post Monsoon)

Result : S5 Showing Significant Positive Trend

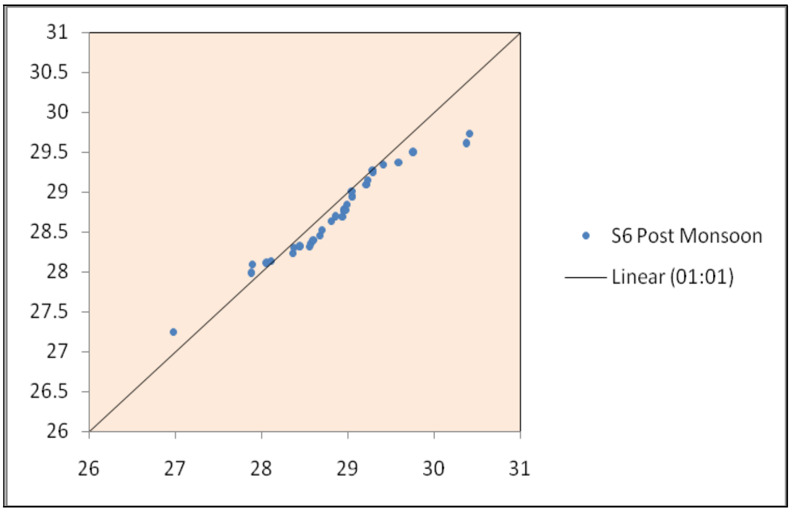

Figure 52 (S6 Post Monsoon)

Result : S6 Showing Significant Negative Trend

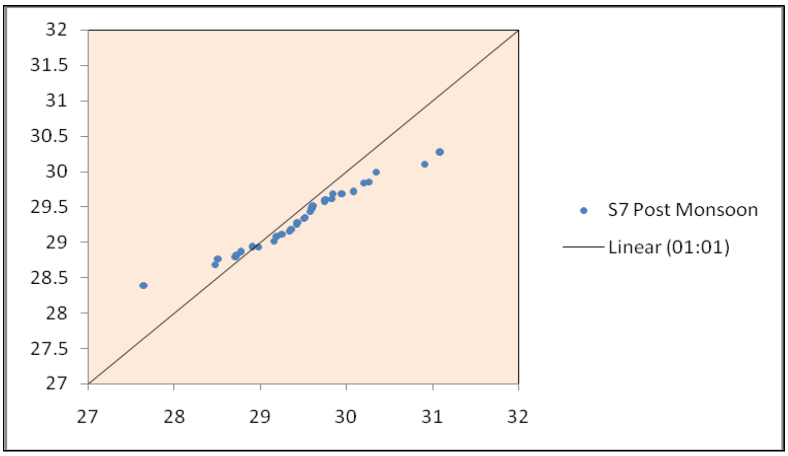

Figure 53 (S7 Post Monsoon)

Result : S7 Showing Significant Negative Trend

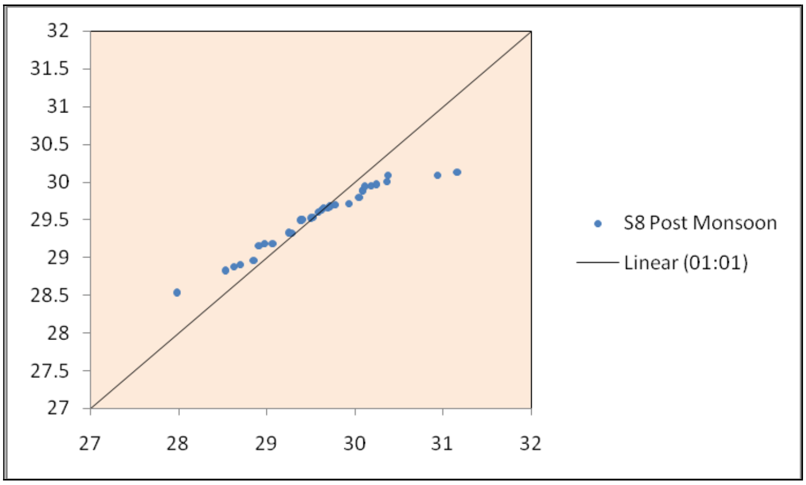

Figure 54 (S8 Post Monsoon)

Result : S8 Showing Significant Negative Trend

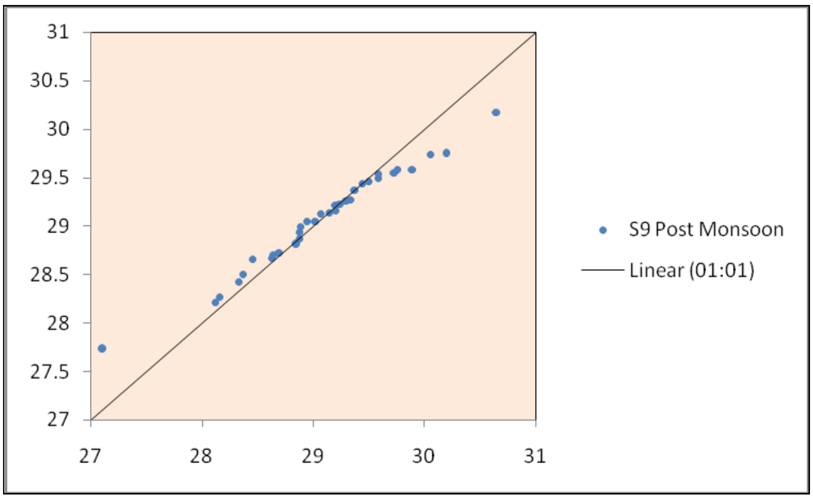

Figure 55 (S9 Post Monsoon)

Result : S9 Showing Non-Significant Negative Trend

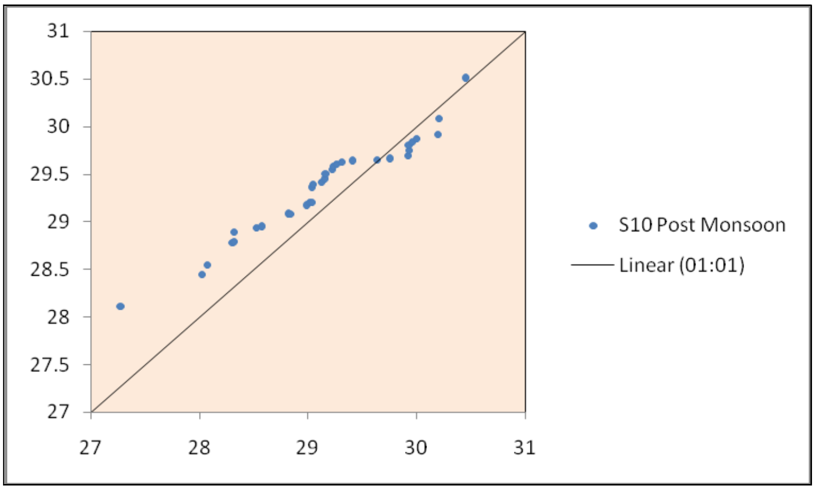

Figure 56 (S10 Post-Monsoon)

Result : S10 Showing Significant Positive Trend

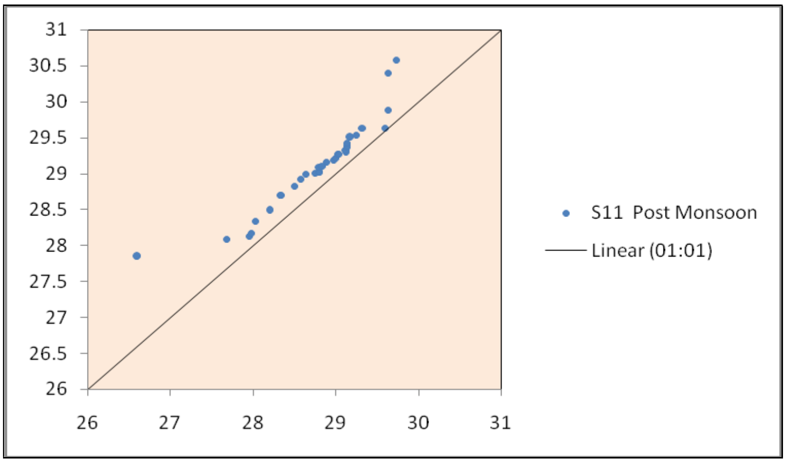

Figure 57 (S11 Post Monsoon)

Result : S11 Showing Significant Positive Trend

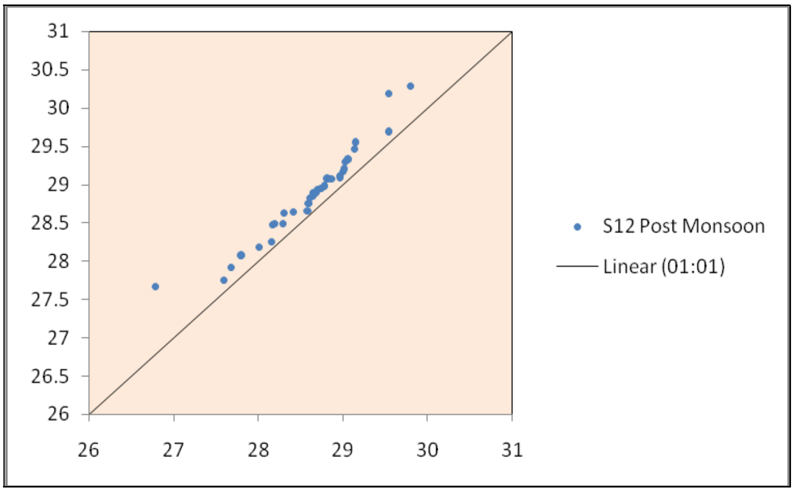

Figure 58 (S12 Post Monsoon)

Result : S12 Showing Significant Positive Trend

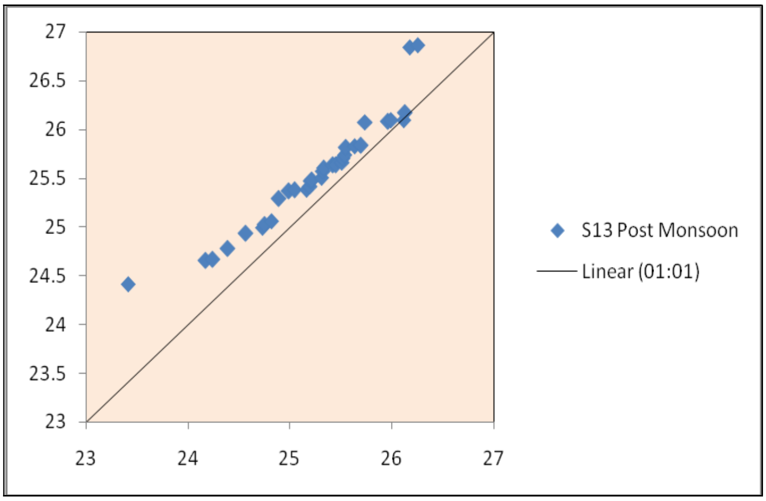

Figure 59 (S13 Post Monsoon)

Result : S13 Showing Significant Positive Trend

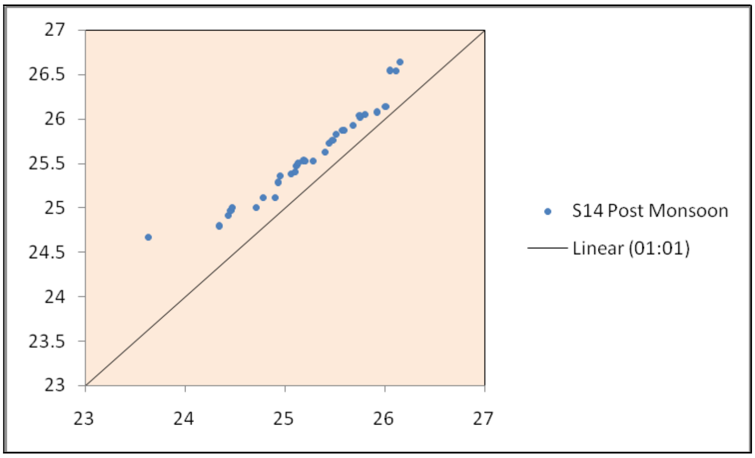

Figure 60 (S14 Post Monsoon)

Result : S14 Showing Significant Positive Trend

6.1.2. Spatial variation of ITA Slope(S) as per season wise

Spatial variation of ITA Slope (S) is represented below Season wise for Winter, Pre-Monsoon , Monsoon & Post –Monsoon respectively.

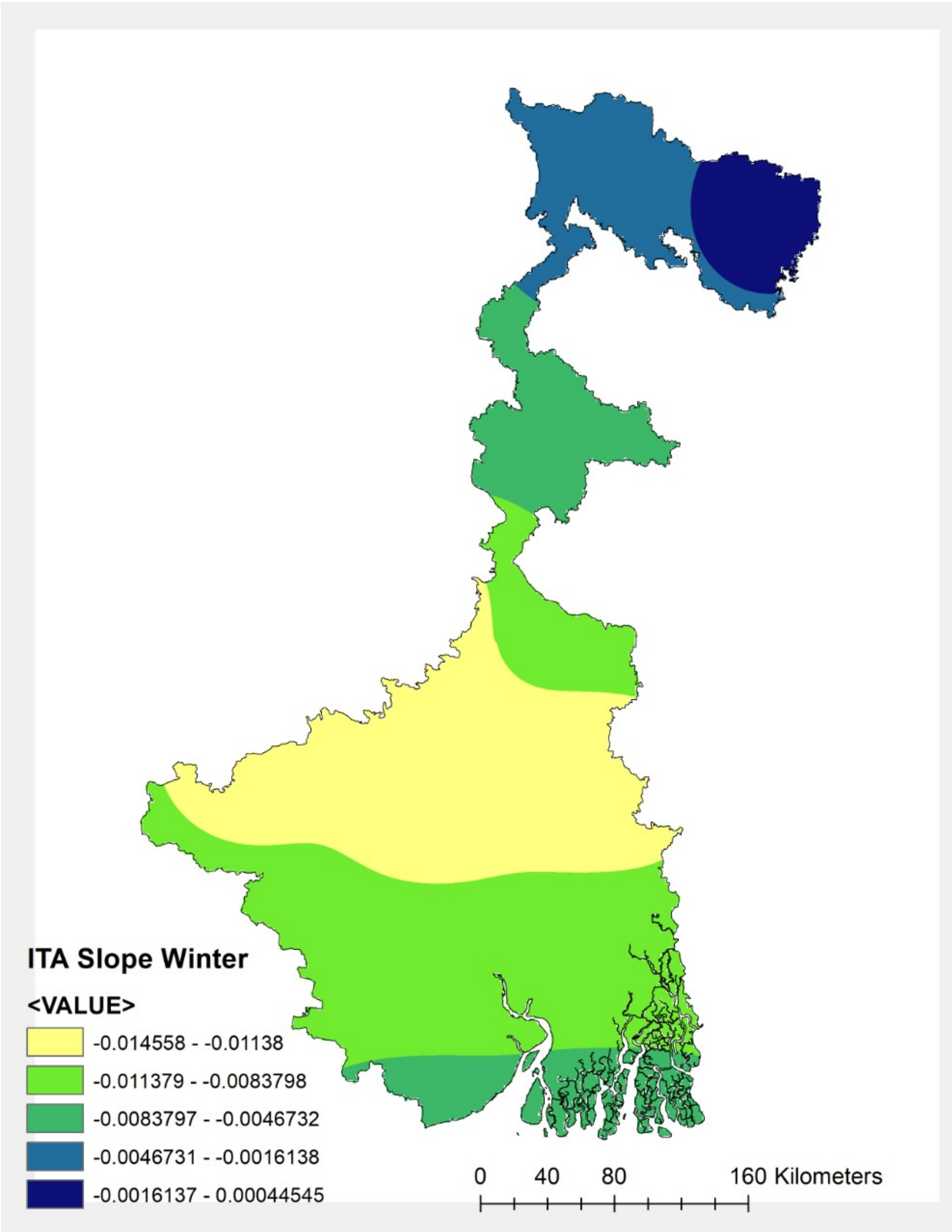

Figure 61 (ITA Slope Winter)

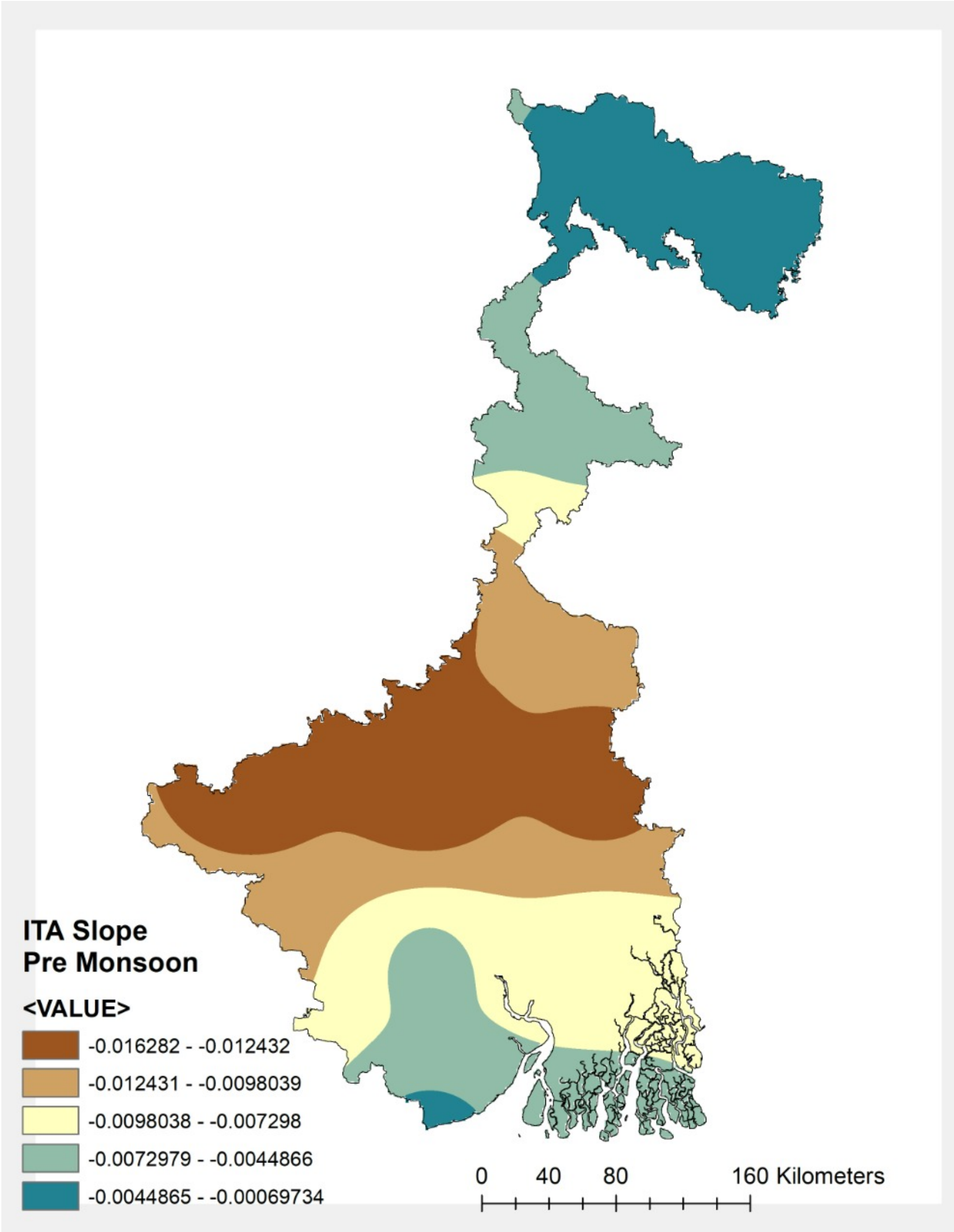

Figure 62 (ITA Slope Pre-Monsoon)

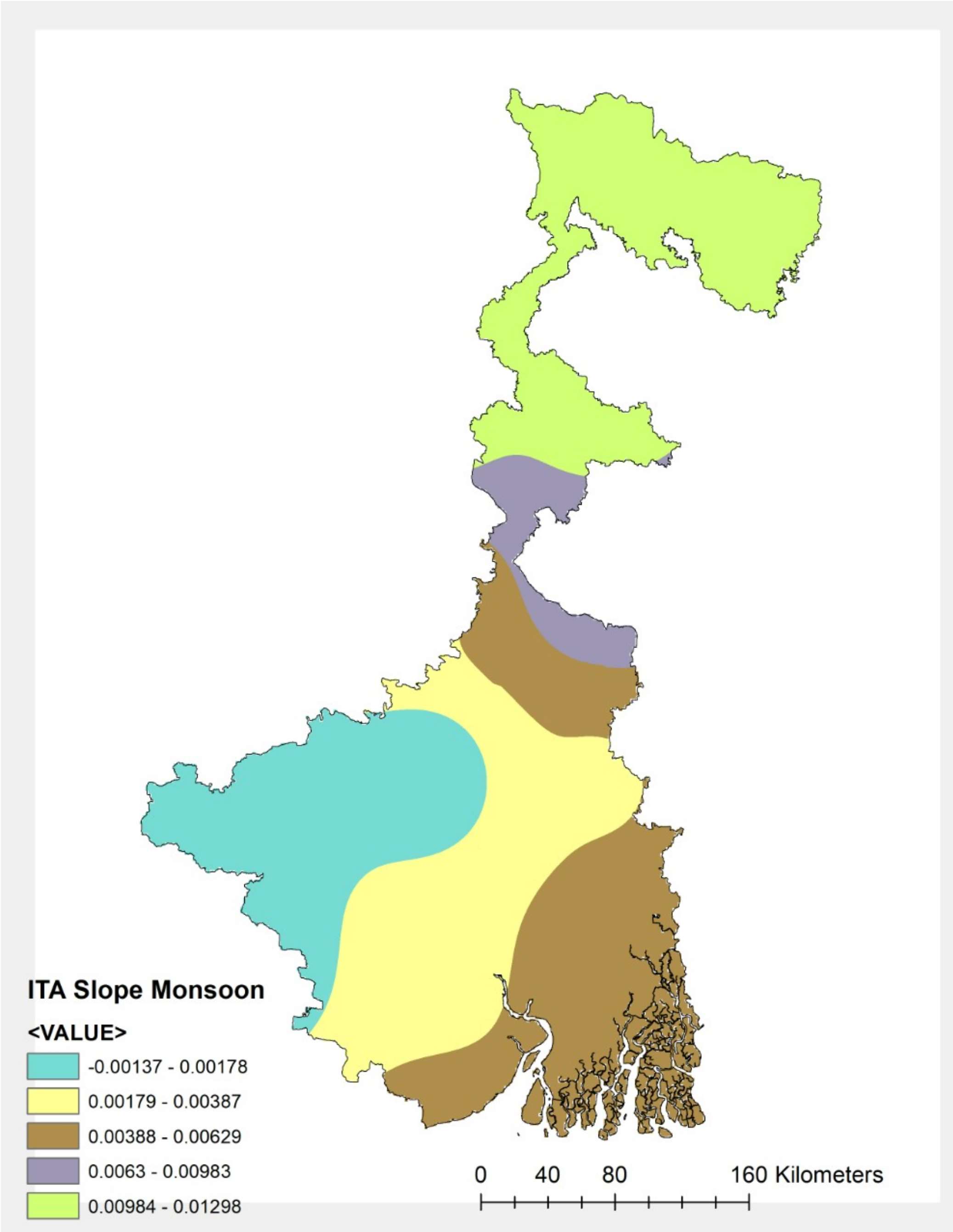

Figure 63 (ITA Slope Monsoon)

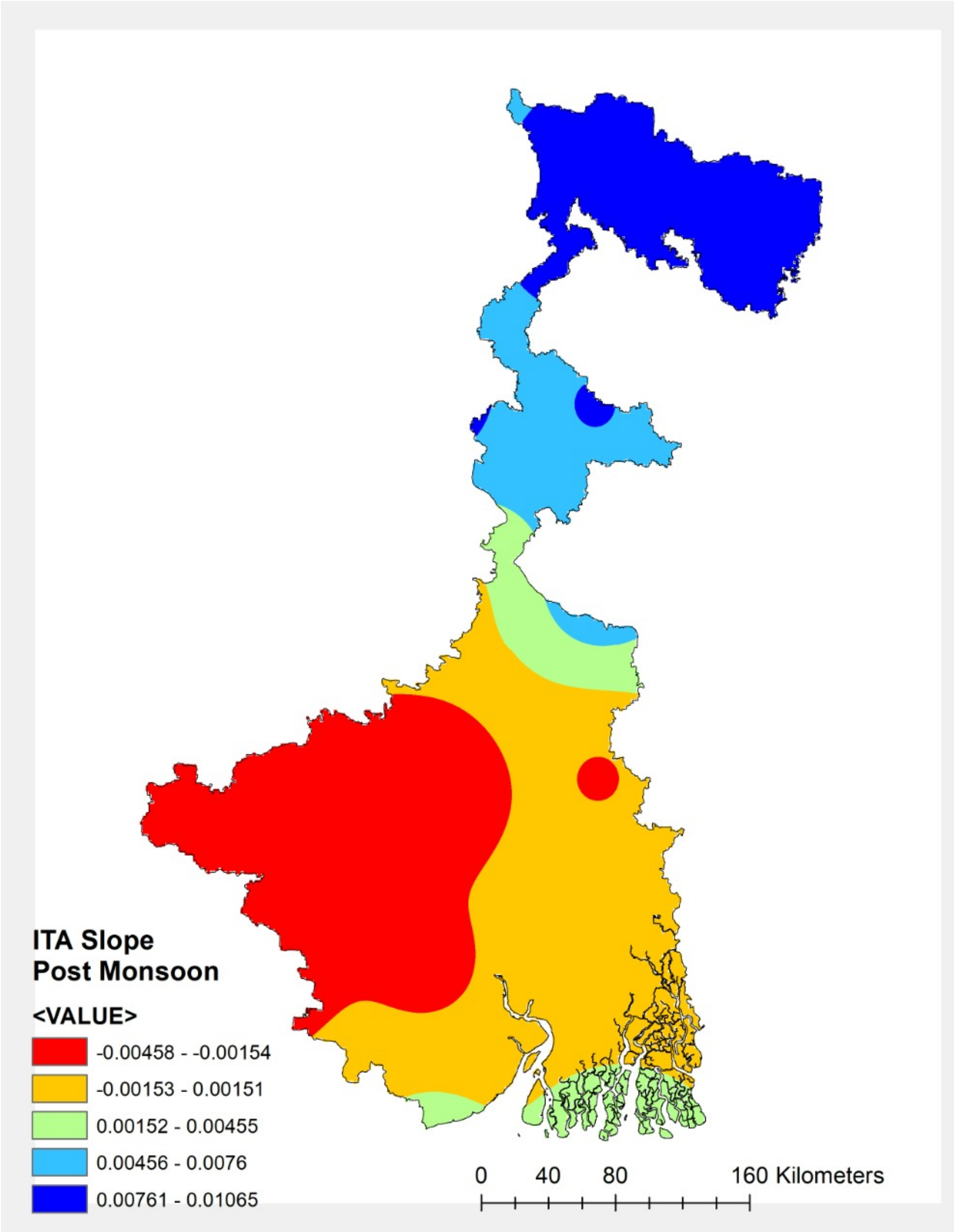

Figure 64 (ITA Slope Post-Monsoon)

6.1.3. Significant/Non-Significant Representation

Level of Significance at α=0.05 is represented below for Winter , Pre-Monsoon , Monsoon & Post-Monsoon

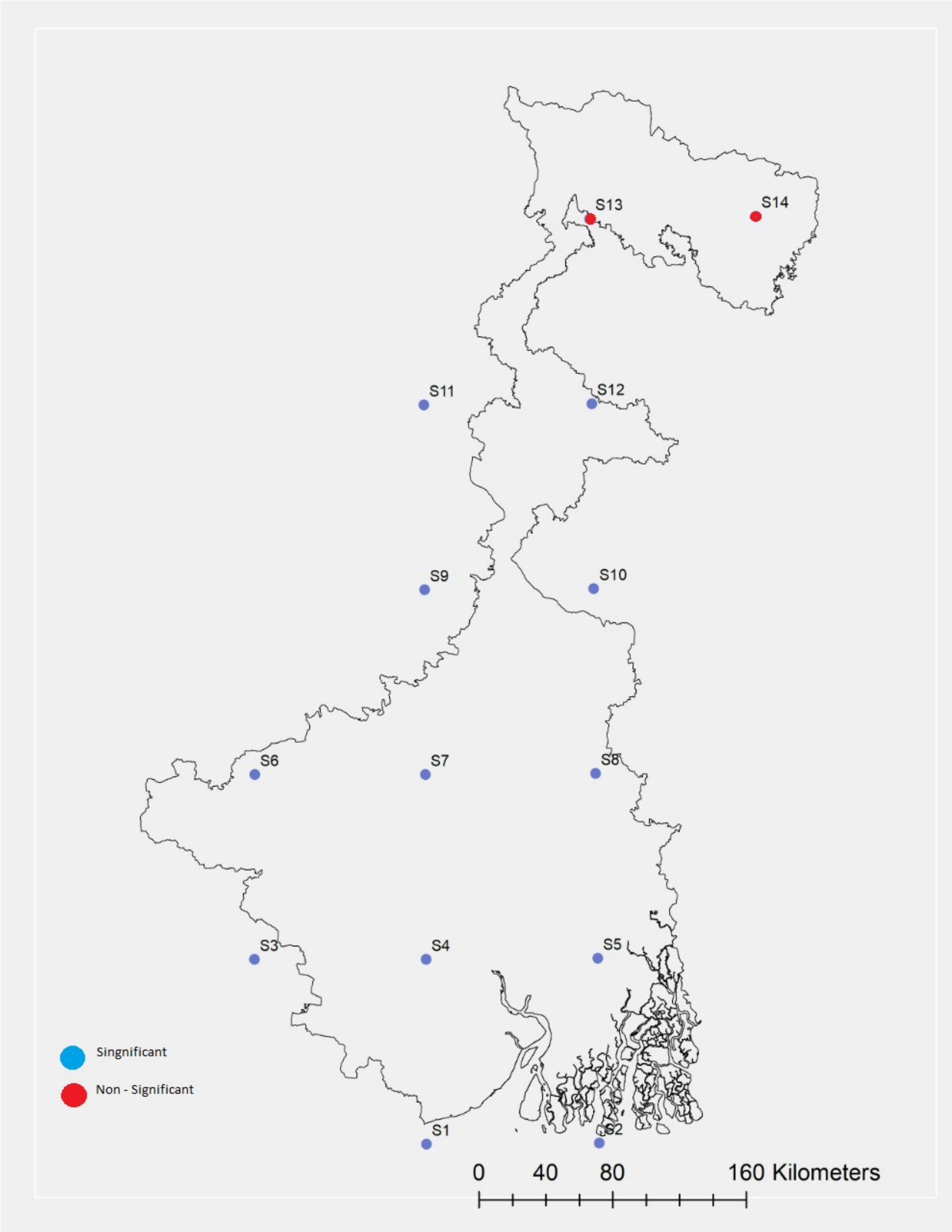

Figure 65 (Winter)

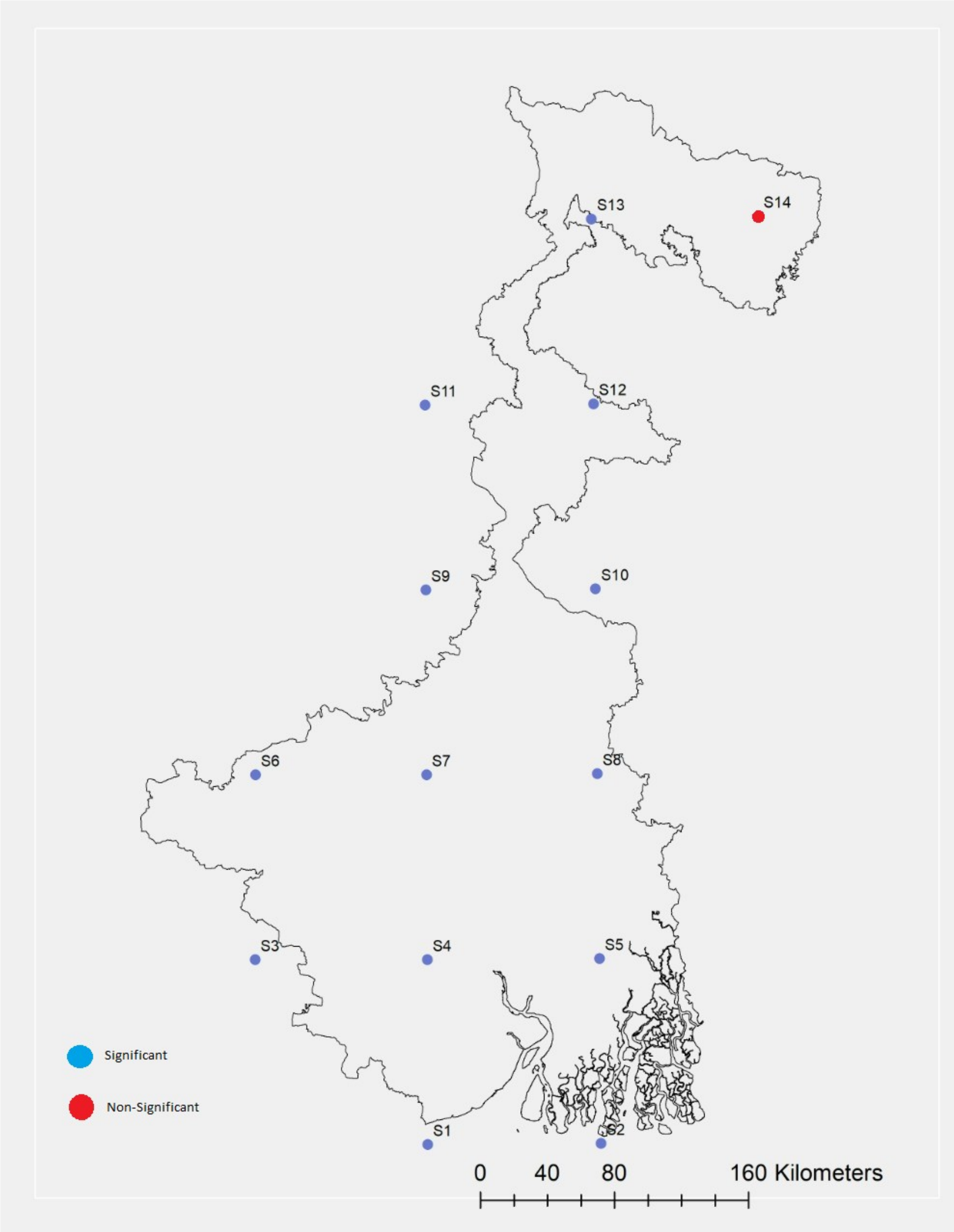

Figure 66 (Pre-Monsoon)

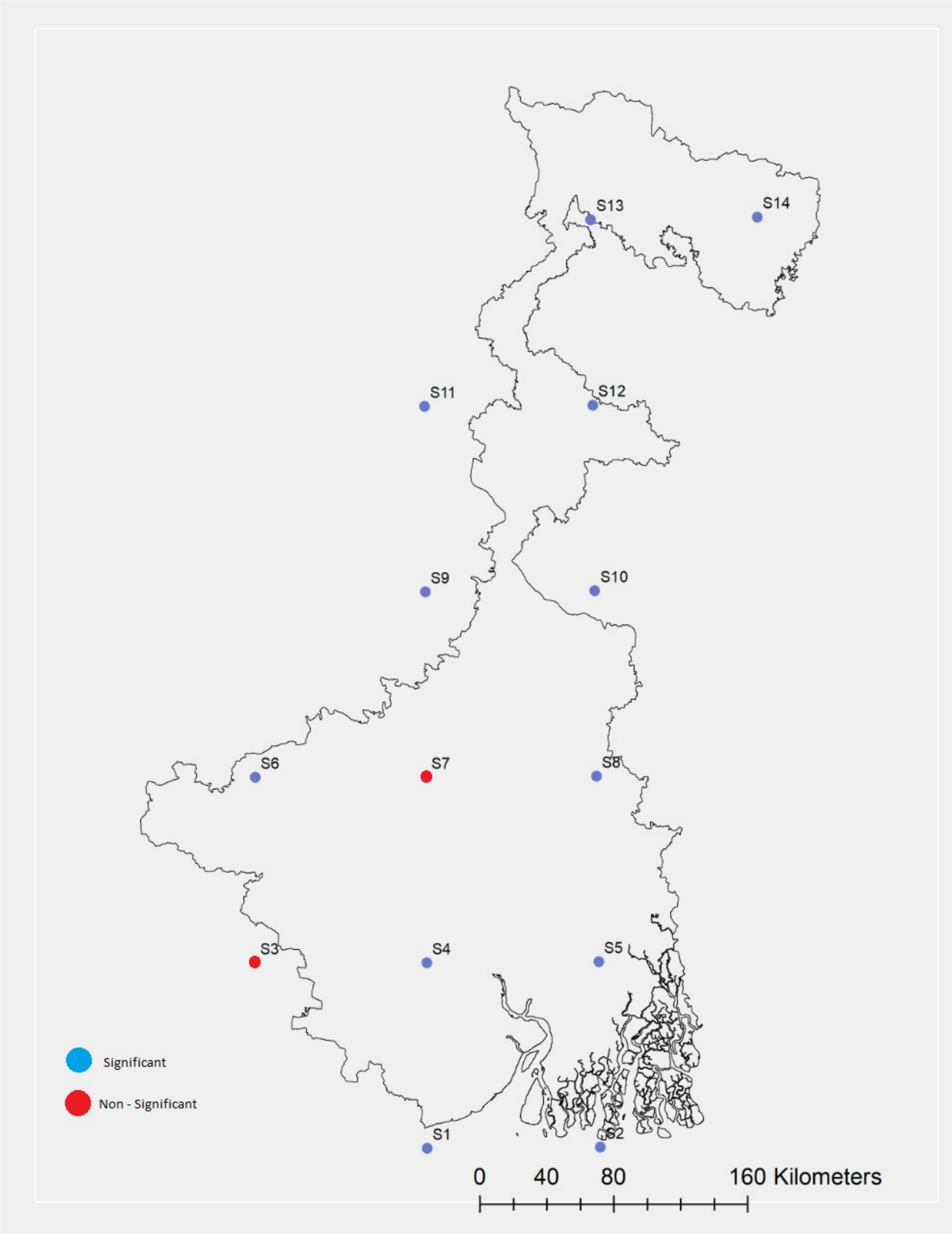

Figure 67 (Monsoon)

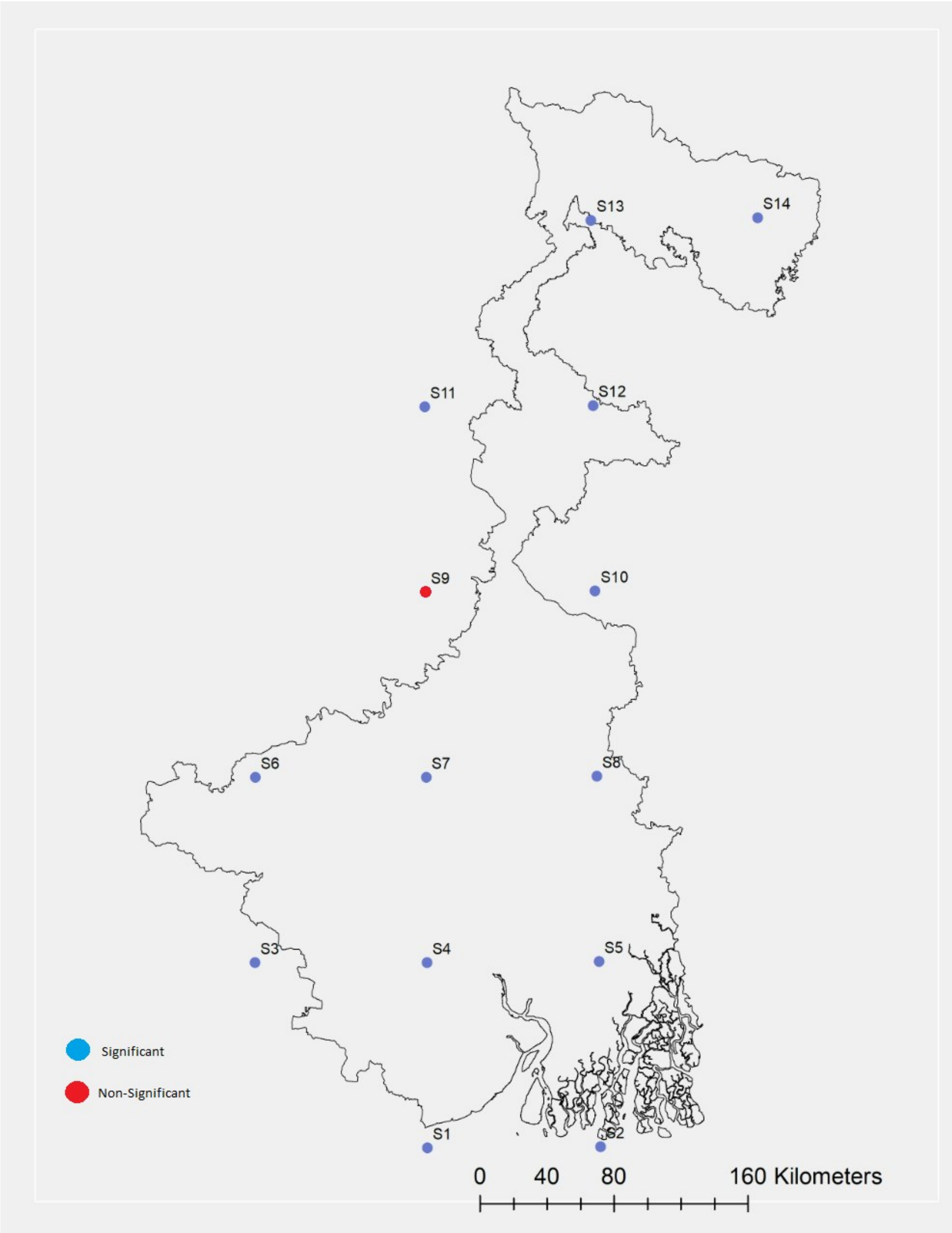

Figure 68 (Post-Monsoon)

7. Chapter :7

7.1. Conclusion

During this study the variety of Seasonal Maximum Temperature all over west Bengal was analysed using Innovative Trend Analysis Method(ITAM) during the period of 1951-2015.The Entire Time period was divided in two time period. 1st half is considered from 1951-1983 & 2nd half is considered from 1983 -2015.

The obtained results are compared each other seasonally for the trend Analysis. Furthermore, the impact of the spatial patterns of the trend are mainly analysed. The Spatial variation of the ITA Slope for the entire study are season wise shown in figure no.60,61,62 & 63 And the level of Significance at 5% shown in the figure nos. – 64,65,66 & 67 The Main Conclusion are as follows

- T_{max} for the entire time period for winter shows 92.31 % Negative Trend where as 7.69 % of Positive Trend.
- T_{max} for the entire time period for Pre-Monsoon shows 100% Negative Trend
- T_{max} for the entire time period for Monsoon shows Positive Trend with 78.57% grid with very high magnitude.
- T_{max} for the entire time period for Post Monsoon shows positive Trend 57.14% of Grid with very High Magnitude.

The percentage changes in the in slope of ITAM for these entire time period reflects the remarkable changes in Maximum temperature in different seasons which indicates the climate changing pattern in current days and future days.

7.2. Future Scope

The results of this analysis may help to ecological protection, social development, future water resources design, and future climate prediction in the study area. As well as can help to take mitigation plan to handle extreme weather condition in recent as well as future time.

8. Chapter :8

8.1. Reference

Şen, Z. (2012). Innovative trend analysis methodology. *Journal of Hydrologic Engineering*, *17*(9), 1042-1046. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000556

Şen, Z. (2014). Trend identification simulation and application. *Journal of Hydrologic Engineering, 19*(3), 635-642. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000811

Şen, Z. (2017). Innovative trend significance test and applications. *Theoretical and applied climatology, 127*(3), 939-947. https://doi.org/10.1007/s00704-015-1681-x

Marak, J.D.K., Sarma, A.K. & Bhattacharjya, R.K (2020). Innovative trend analysis of spatial and temporal rainfall variations in Umiam and Umtru watersheds in Meghalaya, India. *Theor Appl Climatol 142, 1397–1412*. https://doi.org/10.1007/s00704-020-03383-1

Singh, R., Sah, S., Das, B., Potekar S., Chaudhury, A., Pathak H. (2021) . Innovative trend analysis of spatio-temporal variations of rainfall in India during 1901–2019. *Theor Appl Climatol 145*, 821–838. https://doi.org/10.1007/s00704-021-03657-2

Malik, A., Kumar, A., Guhathakurta, P., Kisi, O. (2019). Spatial-temporal trend analysis of seasonal and annual rainfall (1966–2015) using innovative trend analysis method with significance test. *Arab J Geosci 12*, 328. https://doi.org/10.1007/s12517-019-4454-5

Malik, A., Kumar, A., Pham, Q.B., Zhu, S., Linh, N.T.T., Tri, D.Q.(2020). Identification of EDI trend using Mann-Kendall and Şen-Innovative Trend methods (Uttarakhand, India). *Arab J Geosci 13*, 951. https://doi.org/10.1007/s12517-020-05926-2

Dong, Z., Jia, W., Sarukkalige, R., Fu, G., Meng, Q., & Wang, Q. (2020). Innovative Trend Analysis of Air Temperature and Precipitation in the Jinsha River Basin, China. *Water, 12*(11), 3293. https://doi.org/10.3390/w12113293

IPCC. (2018). Global Warming of 1.5°C.An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change. In *Press.*

IPCC. (2021). Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. In *Cambridge University Press.*

Jose, D. M., & Dwarakish, G. S. (2022). Bias Correction and trend analysis of temperature data by a high-resolution CMIP6 Model over a Tropical River Basin. *Asia-Pacific Journal of Atmospheric Sciences*, *58*(1), 97-115. https://doi.org/10.1007/s13143-021-00240-7